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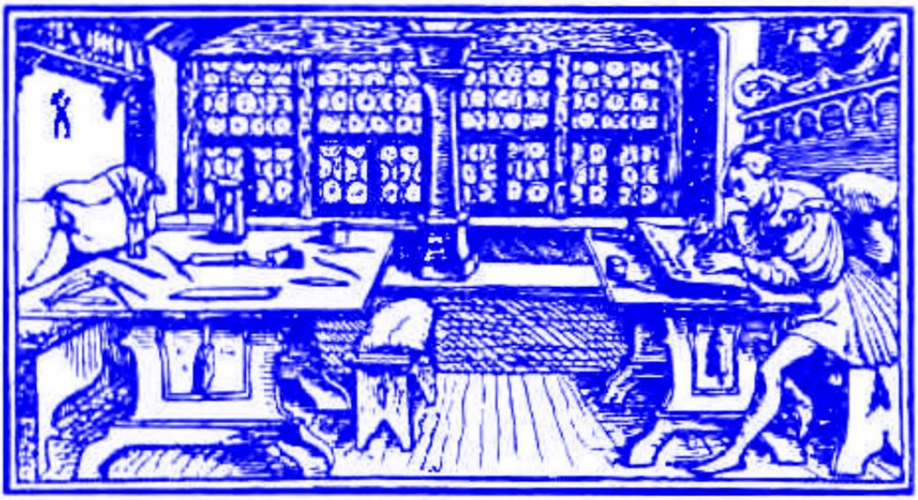

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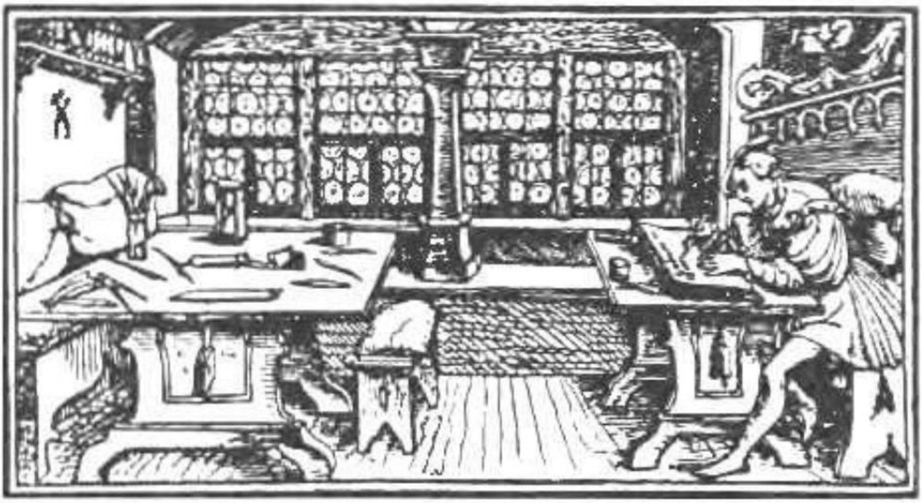

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Contents

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MODELING THE SPATIAL VARIABILITY OF THE ELECTRICAL CONDUCTIVITY OF THE SOIL USING DIFFERENT SPATIAL INTERPOLATION METHODS: CASE OF THE DAWLING NATIONAL PARK IN MAURITANIA

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ABSTRACT:
One of the most important indicators for land degradation is the progressive salinization of soils. This work, conducted at the Dawling National Park (southern Mauritania), assess the effects of salinity on soil quality. Analyzes of spatial variation in salinity were performed using interpolation and spatial analysis (GIS) methods. Thus, maps of electrical conductivity have been developed using several methods of interpolation and spatial analysis: Inverse Weighting (IDW), Local Polynomial Interpolation (LPI), Radial Base Function (RBF) and Ordinary Kriging (OK). The obtained results showed that the best estimator is IDW method, which provides a good ability to predict electrical conductivity, with a mean squared error (RMSE) of 0.34 mS/cm and a correlation coefficient (R) of 0.99.

Key-words: *Electrical Conductivity, Salinity, Soil, GIS, Interpolation, Diawling National Park, Mauritania.*

1. INTRODUCTION

The lower delta of the Senegal River is characterized by the interface between continental and coastal waters. However, these ecosystems are considered the most important in West Africa (Hamerlynck & Cazottes, 1998). This area is home to many unique wetland ecosystems that have been severely disrupted by the droughts of the 1970s and the construction of the anti-salt dam since the 1980s. In addition to the construction of the Diama anti-salt dam in 1986, a formation of many clay dunes with a high salt concentration was observed (Barbiéro et *al.*, 2004; Barbiéro & Caruba, 1998; Hamerlynck, 2000; Ngom et *al.*, 2016). The Diawling National Park (PND) located in the lower delta of the Senegal River was created in 1991 to restore the old flood plains and to preserve the ecosystem values and compensate the negative effects of the Diama dam.

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In addition, soil salinization present a common problem in the Senegal River delta (Ngom et *al.*, 2016). It affects plant growth, agricultural productivity, soil and water quality, and increases soil erosion, especially in semi-arid and arid regions(Asfaw et *al.* 2018; Elgettafi et *al.* 2011; Elhag, 2016; Yao & Yang, 2010). According to several studies, the phenomenon of salinization can lead to a loss of arable land with soil degradation(Gorji et *al.* 2017; Seyedmohammadi et *al.* 2016; Tripathi et *al.* 2015). The detection, monitoring and mapping of soils affected by salinities have major challenges because of the involvement of certain dynamic processes. Indeed, the spatial variability of electrical conductivity (EC) is an important indicator of soil salinity (Marko et al., 2014; Seyedmohammadi et al., 2016; Tripathi et al., 2015). The interpolation techniques proposed by some geographic information analysis tools are used to model results on a given surface. The accuracy of spatial modeling methods of soil properties has been analyzed in several studies (Saito et al., 2005; Seyedmohammadi et al., 2016; Tripathi et al., 2015; Varouchakis & Hristopulos, 2013). Geostatistical methods have been used in several studies, to estimate electrical conductivity (Bhunia et al., 2018; Friedel, 2006; Khosravi et al., 2016; Seyedmohammadi et al., 2016; Tripathi et al., 2015; Zehtabian et al., 2012). However, it is appropriate to adopt an effective technique to predict the spatial distribution of certain soil characteristics (Emadi & Baghernejad, 2014; Seyedmohammadi et al., 2016; Tripathi et al., 2015; Zarco-Perello & Simões, 2017). The objective of this work is to study the interpolation of the flood basins of the PND in order to evaluate the spatial extent of the zones degraded by soil salinity. Indeed, four interpolation methods will be tested for spatial analysis: IDW, LPI, RBF and OK. In addition, about 100 soil samples were taken from the surface of the PND. A global portable positioning system (GPS) was used to record the coordinates of each sampling point.

2. MATERIALS AND METHODS

2.1. Study zone

This study was conducted in the Dawling National Park in southwestern Mauritania. This zone is extended between 16° 35'00"N, 16° 20'00"W and 16° 05'00 N and 16° 30'00"W. It covers an area of 353 km^2. It is a sub-Sahelian zone with low rainfall (170 mm / year)(Mohamedou et al., 1998) . The park consists of several basins that develop from north to south: Diawling, Bell, Gambar and N'Tiallakh. These basins are surrounded by a coastal dune to the northwest, the dunes Birette and Ziré and the right bank of the Senegal River to the east (**Fig. 1**). The flora of this area is conditioned by the presence of salt and the nature of the soil. The plant cover is marked by species like *Indigofera ablongifolia*, *Iponea*, *Acacia nilotica*, *Sporobulus*, *Tamarix senegalensis*, *Rhizophora mangle*, *Avicennia africana*, *Acacia radiana*, *Balanites aegyptiaca*, *Salvadora persica*, *Mitragyna inermis*, *Zizyphus mauritana*. However, the fauna is represented by common mammals (jackals, warthogs, wildcats, hares, etc.), reptiles (turtles, python, Nile monitor, crocodile), a large variety of birds that coexist according to the season and the salinity of the waters, crabs and mules typical of the river valley.

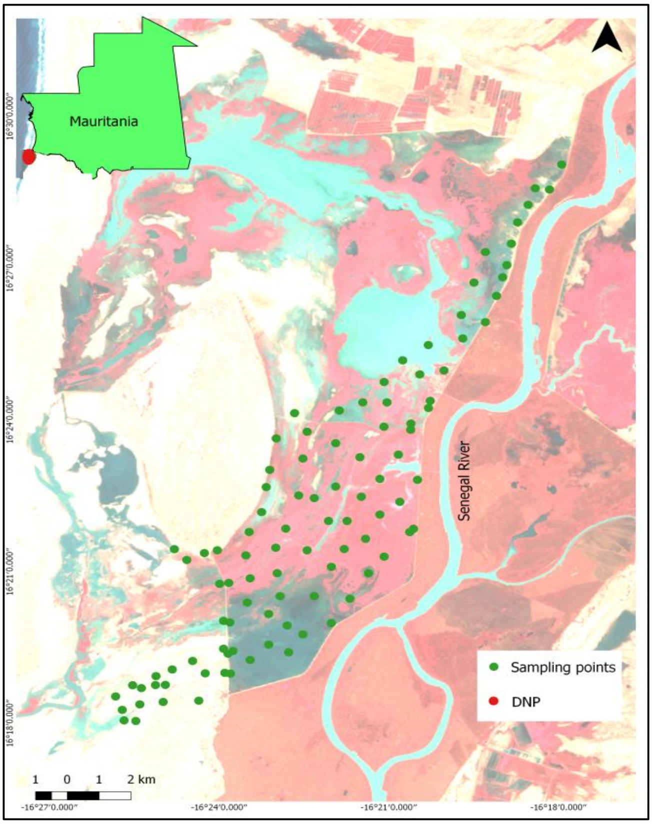

Fig. 1. Study area and soil sampling sites in the study area located in the DNP, Mauritania.

2.2. Soil sampling and interpolation methods

A sample of 100 soil electrical conductivity values was taken randomly distributed over the study area (**Fig. 1**).Samples were taken from the first 20 cm layer. The coordinates of each sampling point were collected by portable GPS (Garmin 78). The values of the electrical conductivity for each sample were obtained by the diluted extract method(El Oumri & Vieillefon, 1983; Montoroi, 1997). Statistical processing and spatial analysis of field data were performed using SPSS 20 and ArcGIS 10.3 software.

The results of several spatial analysis methods were compared:

IDW

Inverse Distance Weighting (IDW) is one of the interpolation methods used in the field of soil science (Bhunia et *al.,* 2018; Robinson & Metternicht, 2006; Seyedmohammadi et *al.,* 2016). IDW estimates are based on known locations in the vicinity (formula (1)). The weights assigned to the interpolation points are determined by the inverse of the distance from the interpolation point.

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}} \quad (1)$$

With

Z (x0) is the interpolated value; n represents the total number of sample points; x_i is the measured value, h_{ij} is the separation distance between the interpolated value and the measured value; β indicates the weighting power (β = 2).

OK

The Ordinary Kriging method is one of the interpolation techniques that is also frequently used (Mousavifard et al., 2013; Poshtmasari et al., 2012) . This technique makes it possible to estimate for an area around a sampled point (Pang et *al.,* 2011; Seyedmohammadi et *al.,* 2016; Tripathi et al., 2015). The semivariogram formula is expressed as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (2)$$

With

γ (h) is the semivariance; N (h) is the total number of data pairs separated by a distance; h is the lag distance; Z represents the measured value for soil properties; and x is the position of the soil samples.

Radial basis function (RBF)

This method brings together a series of exact interpolation techniques that involve passing the surface through each evaluated sample value. The RBF function changes according to the distance from a location (Poshtmasari et al., 2012; Seyedmohammadi et al., 2016; Wang et al., 2014). There are five different basic functions: thin-plate spline (TPS), spline with tension (SPT), completely regularized spline (CRS), multi-quadratic function (MQ and inverse multi-quadratic function (IMQ)(Bhunia et al., 2018).

Local polynomial interpolation (LPI)

LPI corresponds to the local polynomial obtained by using sampling points in a neighborhood. The interpolation is done by the weighting according to the distance (Baram et al., 2014; Hani and Abari, 2011; Seyedmohammadi et al., 2016). LPI is capable of producing surfaces that capture the short range variation (Bhunia et al., 2018; Johnston, 2004). In addition, it fits the local polynomial using points only within the specified neighborhood instead of all the data(Poshtmasari et al., 2012; Wang et al., 2014)

To compare the interpolation methods, in terms of precision and performance, the interpolated values will be extracted for the 100 sampling sites the interpolated values will be extracted from the 100 sampling sites, then compare with the actual values using the cross-validation procedure. Three performance indicators have been used:

Root Mean Square Error (RMSE): The square root of the arithmetic average of squared deviations between measured and interpolated values (eq. 3).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(y_i - y_i')^2} \quad (3)$$

The mean absolute error (MAE): the arithmetic mean of the absolute values of the differences between the measured values and those interpolated (eq. 4).

$$MAE = \frac{1}{N}\sum_{i=1}^{n}\left|y_i - y_i'\right| \quad (4)$$

Correlation coefficient (R): the standardization of the covariance by the product of the standard deviations of the variables.

$$R = \sqrt{1 - \left[\frac{\left(\sum_{i=1}^{n}(y_i - y_i')^2\right)}{\sum_{i=1}^{n}(y_i - \overline{y_i})^2}\right]} \quad (5)$$

Where: y_i indicates the measured value; y_i' is the predicted value, $\bar{y}_i$ is the average of the measured value, and n is the total number of observations.

3. RESULTS AND DISCUSSION

Table 1 summarizes the descriptive statistics of the experimental data. We note an average value of the order of 11 ms / cm. However, the measured values show a strong variability in space.

Table 1.

Descriptive statistics of the data used

	Min	Max	average	SD*	CV*	Modal value	Kurtosis	Skewness
EC (ms/Cm)	0,29	64,60	11,48	10,41	0,91	3,01	6,79	2,15

*SD: Standard Deviation; *CV: Coefficient of Variation

The PND is a special environment, strongly structured under the influence of the arrival of the fresh waters of the Senegal River and the salty waters of the ocean by the action of the tides. The control of the quantities of fresh water by the Dima dam was at the origin of the salinisation phenomena that affected the distribution of biodiversity in the area. Indeed, the nature of the vegetation in this ecosystem is strongly conditioned by the presence of salt (Duvail, 2001). Thus, the disappearance of a forest of *Acacia nilotica* which was located on the Birette dune and on the edge of the floodplains was associated with the increase of the salinity(Taïbi et al., 2007). Also, mangrove forests, a sensitive habitat, have been reduced under the combination of drought and the dam effect(Duvail, 2001; Taïbi et al., 2007).

As for *Acacia nilotica*, salinization is associated with the decrease in the surfaces of *Sporobolus robustus*, *Nymphea lotus*, plants that support the economic activities of the local population (skin tanning, matting, feeding and medication)(Taïbi et al., 2007) . Similarly, fishing has become more difficult in the park today, which has resulted in reduced catches by fishermen and especially south of the park especially in the N'Tiallakh basin (Duvail, 2001; Taïbi et al., 2007). Finally, the waterbirds that frequent the area coexist in the basins of the park according to the salinity of the water(Hamerlynck, 2000).

The evaluation of the prediction capacity of the interpolation methods has been implemented by the calculation of the performance indicators of the modeling (**Table 2**). Indeed, the methods LPI and OK show weak performances, with an error close to 8 and a correlation which remains lower than 0.7. RBF and IDW methods give similar results with respect to the correlation coefficient. Nevertheless, the IDW method shows a better quality of prediction of the electrical conductivity of the soil, with an RMSE of 0.34, a MAE of 0.09 and a correlation coefficient of 0.99 (**Fig. 3**).

Table 2.

Parameters for Evaluating Interpolation Performance

Method	R	RMSE	MAE
IDW	0,99	0,34	0,09
LPI	0,65	8,16	4,90
OK	0,59	8,73	5,40
RBF	0,98	1,08	0,41

The different interpolation methods were used to develop maps of the spatial variation in electrical conductivity (**Fig. 2**). Areas south and north of the park are characterized by high electrical conductivity compared to other park territories. These areas correspond to the two basins of N'Tiallakh and DiawlingTichilitt. It is noted that the appearance of some points, low conductivity, scattered in these areas, this can be related to the structure of the soil. According to (Duvail, 2001), the salinity phenomena in these basins are greater in magnitude and intensity than in the other basins of the park. This is explained by the effects of the floods. The salty waters from the Atlantic Ocean are responsible for the salinity of the N'Tiallakh basin which is located southwest of the PND and communicates directly with the sea by the N'tiallakh's swamp. Indeed, the electrical conductivity seems to have risen after the closure of the Diama dam. Hamerlynck (1998) postulates that the salinity of the water in these areas fluctuates greatly during the dry season, scenario that was not considered in the development of the park management plan. Other research has shown that the salinity of well water, even those near the riverbed, has been steadily increasing (Davranche & Taïbi, 2015; Taïbi et al., 2007). Also the Diawling Tichilitt basin, located in the North, is flooded by the salt water from the N'Tiallakh basin by Lekser's work. Low salinity is recorded in the center of the study area (Bell Basin). This is explained by the proximity of the structure allowing the fresh water of the Senegal River to flood this basin during certain months of the year.

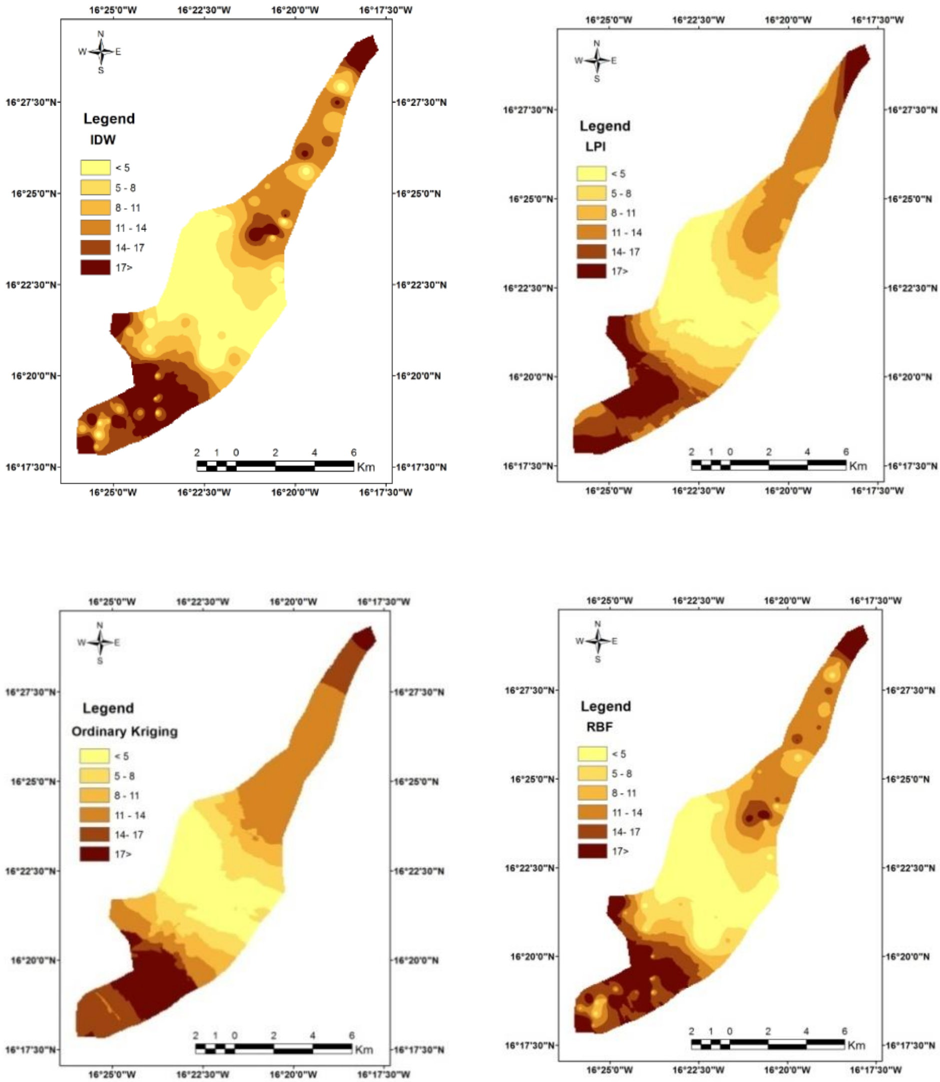

Fig. 2. Spatial distribution map of soil EC (mS / cm) by different methods.

Comparing the results obtained by this work with those found by other studies, we can cite (Emadi & Baghernejad, 2014; Karydas et al., 2009; Poshtmasari et al., 2012) who highlighted that the IDW method gives a good prediction of electrical conductivity, with an average error of 0.38 mS/cm. However,Tripathi et al.(2015) selected the OK method as the best interpolation technique for soil salinity, with an average error of about 1.6. The choice of the OK method was justified by Mohammad et al., 2010 who studied spatial distribution of soil properties by applying interpolation techniques such as IDW and OK.

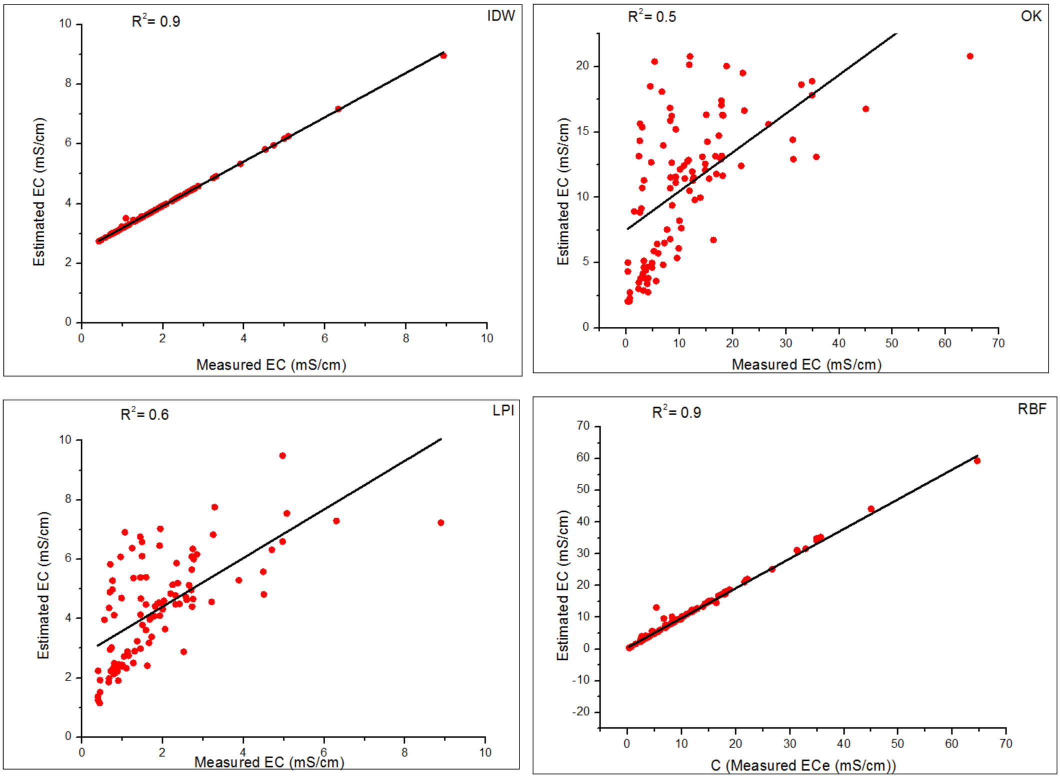

Fig. 3. Cloud of points representing the values measured according to the values predicted by different methods.

4. CONCLUSION

In this work, we studied the spatial variation of salinity at the Dawling National Park. The evaluation took place on 100 points, using different interpolation techniques. The results obtained showed a high variability of electrical conductivity from one point to another within the study area. The average value is about 11 ms / cm. The highest salinity level has been recorded in areas south and north of the PND. Low EC values were observed in the center of the study area. These fluctuations have been attributedto the processes of floods, and upstream links with the fresh waters of the river and downstream with those of the sea. The calculation of the estimation performance indicators made it possible to select the IDW method as the best interpolation technique adapted to our study area. The mean squared error is in order of 0.34 and the correlation coefficient approximates a value of 0.99.

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ROADS ACCESIBILITY TO AGRICULTURAL CROPS USING GIS TECHNOLOGY. METHODOLOGICAL APROACH

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ABSTRACT:
The access to agricultural fields represents the main factor which favours their spatial distribution and their mechanized exploitation. In addition to this it valorizes the fields by enabling their intensive cultivation, fast harvesting and product distribution to collecting, processing and sales centres, with a main impact on perishable goods. The short access time to perishable crops enables their delivery in large quantities to the market, without major losses, thus their value increases. The present study analyses the accessibility of agricultural lands included in the high class of favourability for agricultural use, based on GIS techniques, with the purpose of economically valorising the territory by identifying the lots with very good accessibility and high favourability determined by rational exploitation. The following analysis is performed in a highly agricultural area, polarised by three agricultural sales centres and characterised by a low density of European, national and county roads (which offer easy access) while there is a high density of village roads and direct roads to agricultural lots and crops. The methodology of study was structured in two interconnected stages: the SWOT analysis of the present situation in what concerns the road quality and the implementation of a GIS spatial analysis accessibility model based on integrated network analysis in order to identify the main sales centres and the allocation of each agricultural lot to a certain sales centre. Using this analysis, certain hypotheses and proposals were made for the economically valid cultivation of the land and its accessibility as well as for the identification of intermediary collecting and primary sales centres.

Key-words: *Road accessibility, GIS model, Temporal accessibility, Crops favourability, Land evaluation, Crops management.*

1. INTRODUCTION AND STUDY AREA

The quality and the constant maintenance of access roads leading to agricultural land are extremely important for the transportation of materials, machinery or workers. In the case of a poor maintenance, it determines various difficulties in moving the machinery, possible higher fuel consumption and thus, the damaging of the used vehicles (Blarel et al., 1992; Handy & Niemeier, 1997; Jaarsma, 2000; Wiggins & Proctor, 2001; Castella et al., 2005; Păcurar & Buta, 2007; Muntele et al., 2010; Páez et al., 2012; Iimi et al., 2015; Hartvigsen, 2016; Janus et. al., 2017).

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Considering the role of roads as access routes to agricultural lots, they influence considerably the evaluation of the land for various agricultural uses (Ajiboye, 1994; Janus & Taszakowski, 2015) as well as the evaluation of their economical favourability (Wang et al., 2010; Haidu & Nicoară, 2011).

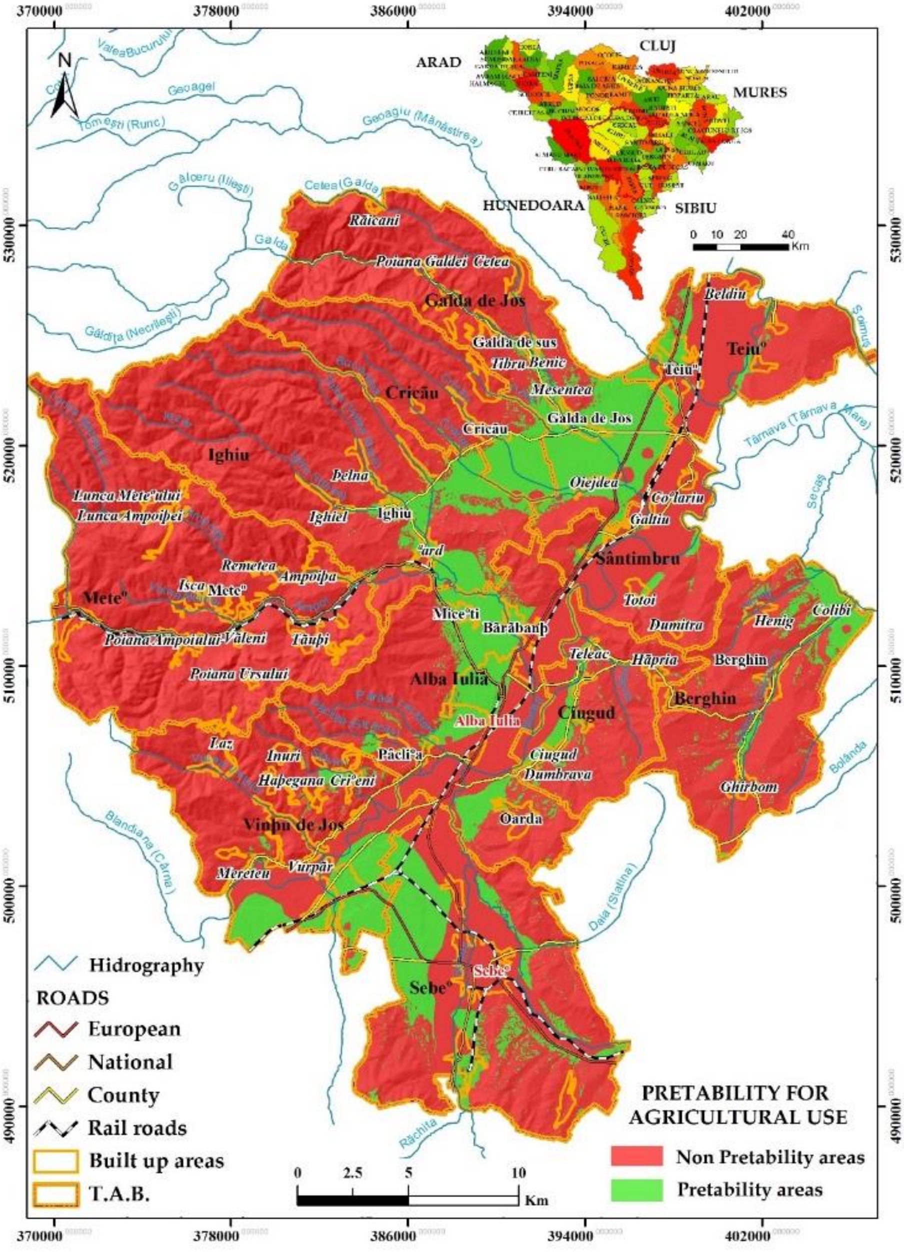

Fig. 1. Geographical position of the study area highlighting the favourability for agricultural use.

As the present study highlights economical aspects, it also focuses on the role of the roads in facilitating the access for transport and distribution.

The accessibility of agricultural lots to the main roads reduces the average time of placing the crops on the outlet market as well as the additional costs associated to the production of crops and agricultural works (Curtis & Scheurer, 2010; Dumitru et al., 2010; Bilașco et al., 2016).

In order to reach the objectives of this study, GIS technology was used to identify the agricultural favourability of various agricultural lots (Van Diepen, 1991; Halder, 2013; Roșca, 2015a,b; Moldovan et al., 2016) as well as the identification of their temporal accessibility (Thapa & Murayama, 2008; Oprea, 2011; Ivan & Haidu, 2012; Vega, 2012; Rusu et al., 2013; Nicoară & Haidu, 2011; Nicoară & Haidu, 2014; Man et al., 2015; Bobkova & Holesinska, 2017).

The study area is represented by the Alba Iulia Association for Intercommunity Development (AIDA) which includes 11 administrative units totalizing 936 km2 (14.9 % of the total surface of Alba County) (**Fig. 1**). Its functionality is based on the identification of favourability elements with the main purpose of increasing the economic prosperity and the quality of the inhabitants from this area (Moldovan, 2016). The favourability for agricultural crops has been identified in a previous study as an average between the favourability for the cultivation of wheat, barley, corn, beetroot, potato, peas-beans and sunflower, the favourability classes being determined by climatic, hydrological, pedological and geomorphologic conditions (**Fig. 1**).

2. METHODOLOGY

The analysis of land accessibility was performed through an integrated study which is based on the analysis and identification of acces road quality and the implementation of a spatial analysis GIS model which spatially identifies the acces time to the analised agricultural lots (**Fig. 2**). In this respect a spatial database was created to include the areas facourable for agricultural crops and the territorial position of the main consumption and distribution centres. The numerical database which is included in the spatial analysis model is represented by the maximum speed attainable on different road categories.

The spatial database represents the basis for the development of the spatial analysis model which is concerned with accessibility and the computation of access time in minutes to the main storage and consumption centres, as well as the allocation of land lots based on these time intervals to certain centres for storage and consumption.

The purpose of this study is directed towards highlighting the economical efficiency of the agricultural lands. This is done, on the one hand, in order to identify the closest lots to the consumtion centres (maximum accessibility, minimum access time, minimum accessibility, maximum access time) and, on the other hand, to make proposals for the establishment of intermediary centres for storage and occasional sale of the products. This is based on the allocation of agricultural lots to certain sales and consumption centres, the SWOT analysis of the access ways and the maximum access time intervals.

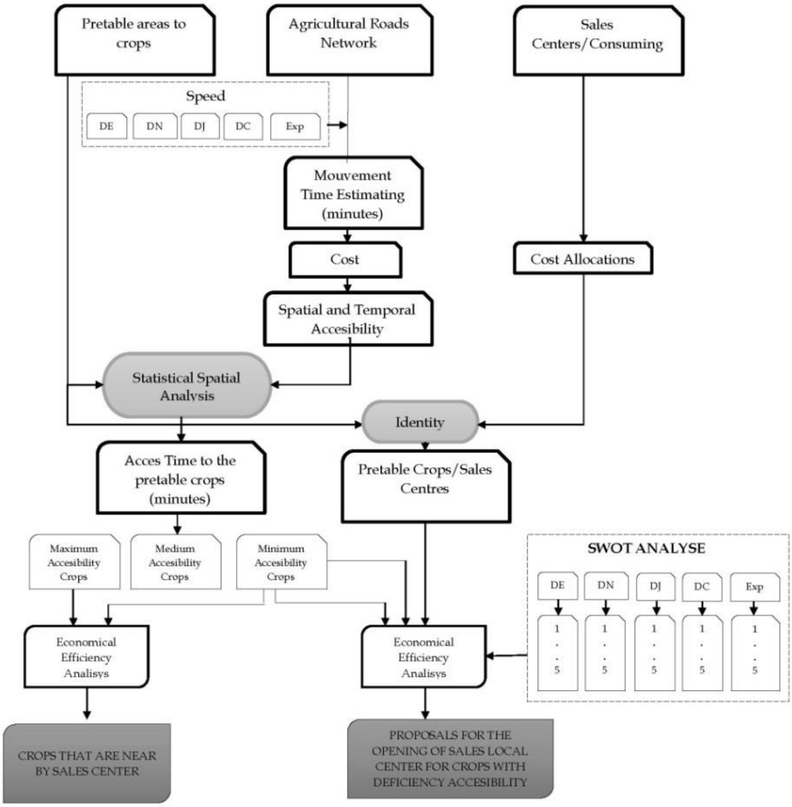

Fig. 2. Flow chart of applied G.I.S. analysis for roads accessibility in agricultural areas.

3. RESULTS

3.1 A model of temporal accessibility of agricultural lands

The accessibility of agricultural lands represents a highly important aspect in the management, exploitation and capitalisation on their specific agricultural products. The evaluation of temporal accessibility represents an important stage as the development of agriculture is of capital importance in the present European context. The main focus is laid on the development of ecological agriculture based on classical-modern technological processes and on the sale of the resulted products as quickly as possible through the local collecting centres and the regional sales centres.

The identification of the specific access time to the agricultural lots was performed using a GIS model which was developed with a specific database (**Table 1**) which puts a spotlight on the road infrastructure as a main facilitator for the access to the production lots and the local and regional sales centres.

The evaluation of accessibility was made using raster databases derived from vector databases considering the fact that the road infrastructure is not represented on the whole study area. For this, the maximum access speed to the agricultural lots was considered to be 10 km/h where the road infrastructure is absent (fields, hills).

Table 1

Structure of the database

Nr	Database	Type	Attribute						Database type
1.	Roads	vector	Type, maximum speed						primary
			Type	E	DN	DJ	CO	field	
			Speed (km/h)	100/70/50	90/50	90/50	30	10	
2.	Built-up areas	vector	name						primary
3.	Limits of administrative units	vector	name						primary
4.	Movement speed on different road types	Raster (GRID)	minutes/m^2						modelled
5.	Accessibility	Raster (GRID)	minutes						modelled
6.	Allocated areas	Raster (GRID)	Name of urban centre						modelled

At the same time, the spatial analysis model took into consideration the built-up areas as barriers which limit the access. As the whole spatial analysis model is based on raster database structures, all built-up areas were excluded from these structures, thus the access would be calculated based only on the road types from the built-up area and their specific speeds.

The spatial analysis was performed on four levels, each of them relying on the previous inferior level or on the results from the spatial analysis of the inferior database levels.

The first stage consisted in identifying the time necessary to move through a raster cell from the grid resulting from the conversion of the vectors representing the road network. Taking into consideration the average width of a two-lane road, the resolution of 10 m was selected for the raster cell resulting from the vector-raster conversion.

Using the formula proposed by Julião (1999), Drobne (2003, 2005), Bilașco et al. (2015) the time necessary to cross one cell was calculated and expressed in minutes (**Table 2**):

$$CCT = \frac{PS*60}{TS*1000},$$

where: CCT – crossing time (minutes), PS – Pixel dimension, TS – Speed (km/h)

Table 2

The maximum speed and the time required to cross a cell depending on the road type.

Nr.	Road type	Speed (km/h)			
		Built-up areas		Outside the built-up areas	
		Speed	Time (minutes)	Speed	Time (minutes)
1	European	70/50	0.0085/0.012	100	0.006
2	National	50	0.012	90	0.0066
3	County	50	0.012	90	0.0066
4	Communal	30	0.02	30	0.02
5	Field	-	-	10	0.06

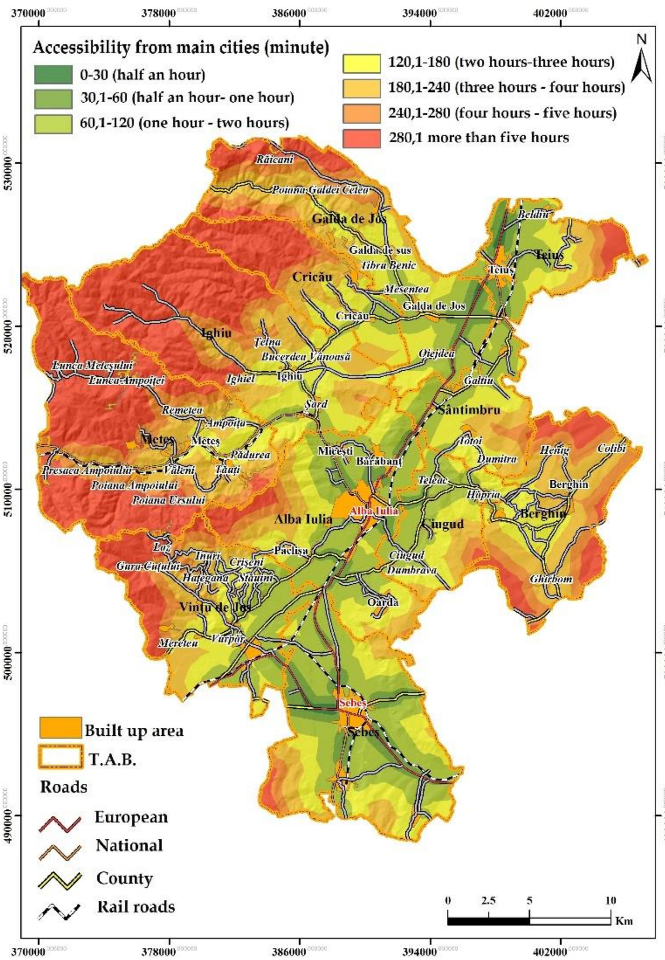

Fig. 3. Temporal accessibility map for the main towns, in minutes.

The second stage consists in modelling the access time to the main local and regional collecting centres for the entire study area, having as a support for the spatial analysis the modelled database which resulted from calculating the time required to cross one cell of the raster. In this case only the sales centres Alba Iulia, Teiuș and Sebeș were considered.

Using geoinformatic softwares and the spatial analysis functions cost distance which enable the identification of the shortest route using the time required for crossing a raster cell, the access time to the closest regional sales point was calculated considering the speed of moving the products and thus, the access (**Fig.** 3).

By analysing the results from this stage of the spatial modelling process one notices the very good accessibility of the agricultural lands from the Mureş valley and from the river's close vicinity (maximum access time of 1 hour), due to a very well developed road network represented by the fast transport network (European, national and county roads) and a highly dense network of acces roads to agricultural lands (communal and agricultural exploitation roads).

One also notices the fact that there is a relatively good access from all the built-up areas of the administrative units (maximum 2-3 hours) to the regional sales centres, which highlights their role as secondary sales centres and storage centres for product sale in the regional centres.

In addition to the density of different types of roads, another important factor which influences the access to agricultural lands is represented by topography. This acts as a restrictive factor in what concerns the development of secondary and primary access roads to agricultural lots (exploitation roads) as well as the direct access of agricultural machines. Two specific situations are highlighted in this respect: the areas from the river valley and low hills with very good accessibility (maximum 180 minutes) and the lots from the high hills and the montaneous area with an accessibility ranging between 3-5 hours and more than 5 hours.

Once the access time in minutes had been identified for the entire study area in reference to the regional sales centres, the next step was to identify the areas which gravitate towards one or more of these centres, which represented the third stage in the modelling process.

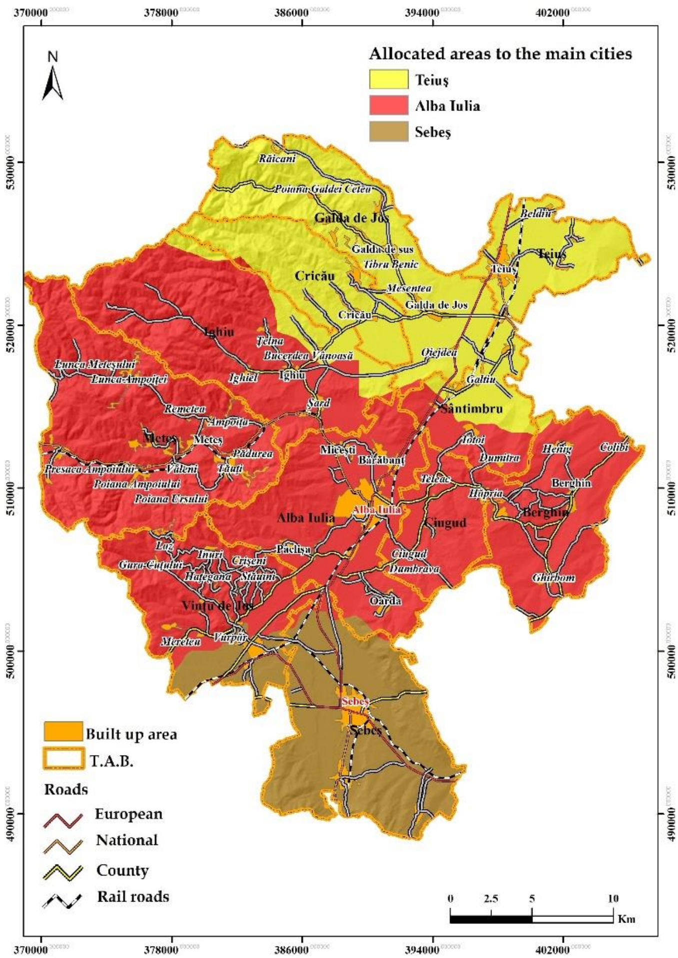

Fig. 4. Map of the areas allocated to the main towns.

Taking into consideration the fact that the transportation time of the agricultural products is very important due to their perishable characteristics, the identification of the sales centre to which each agricultural lot is allocated is a very important objective.

The identification of the areas allocated to a specific sales centre was performed by using spatial analysis with raster and vector structures and applying the function Cost Allocation, which enables the identification of the areas which are allocated to a certain point by considering the shortest access time to that point.

Thus, the areas which gravitate towards the regional sales points represented by the towns Teiuş, Alba Iulia and Sebeş, were identified (**Fig. 4**).

The analysis of the results highlights the city Alba Iulia as the main regional sales centre, with an allocated area of approximately 60% of the whole territory, followed by Teiuş, with approximately 25% of the whole territory and Sebeş, with a smaller area, representing approximately 13% of the whole territory. This small value is explained by the role of the town of Sebeș as outskirts of Alba Iulia.

As a study case for exemplifying and identifying the accessibility to agricultural lots we considered the suitable lots for agricultural crops by using morphometric and risk parameters (Bilașco et al., 2016).

By analysing the static characteristics of the lots allocated to the main sales centres, one notices the spatial extension of a suitable and unitary lot which stretches over the surface of 4 administrative units (Teiuș, Garda de Jos, Cricău, Ighiu), with 4007 hectars, which reunites most of the agricultural lands of the 4 administrative units.

A similar situation is noticed in the case of a unitary suitable lot allocated to the town of Sebeș, which extends over the surface of two administrative units and is located mainly in the valley of the Mureș and its left tributary, the Seceșul.

In what concerns the suitable lots allocated to the city of Alba Iulia, 3 unitary lots with large surfaces are highlighted: firstly, the lot which is situated in the N and the NV of the city and territorialy overlaps the agricultural lands cultivated mainly with vegetables and cereals which can supply the local city markets. Secondly, one can notice the high territorial extension of the suitable lots which had been allocated to the city of Alba Iulia and are located at the contact between the hilly sector and the Mureș floodplain, these lots being connected by a very good road network, a fact that determines a very good accessibility.

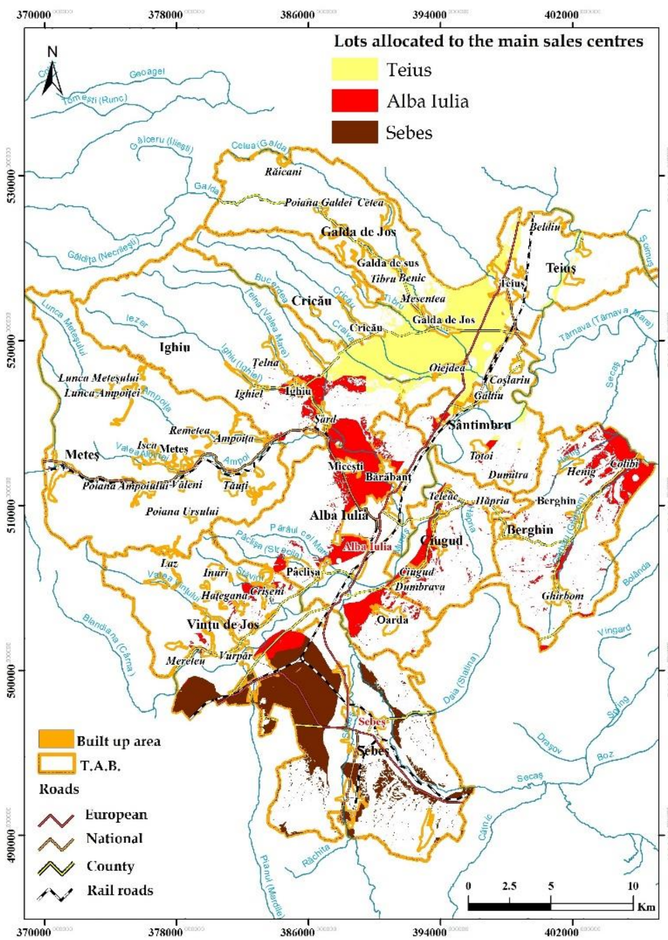

Fig. 5. Map of agricultural lots allocated to the main sales centres.

Thirdly, the lots situated in the area of low hills from the Întresecașe plateau are mainly used for cereal crops. The suitable unitary lots with very large surfaces will influence both the production and its estimated value. At present, overfragmenting the lots represents one of the main problems which arise when a certain favourable crop is planned according to the specific characteristics of the analysed territory.

Table 3.

Statistic characteristics of the lots allocated to the main sales centres

The main sales centres	Surface (ha)				No. Of lots
	Minim	Maxim	Medium	Sum	
Aiud	0.5	4007	5.96	4582.36	768
Alba Iulia	0.3	2097	2.02	4879.89	2415
Sebeș	0.6	2776	4.29	3870.74	901

For a better management of the favourable areas for certain crops, it is recommended to do microscale studies on the surface of the unitary agricultural lot in order to identify the characteristics of each territorial ecological lots and to take the best decisions regarding the choice of crop for that particular lot. The analysis performed on the average access time values to the agriculturally suitable lots highlights the very good accessibility (between 60 and 120 minutes) of approximately 91% of the analysed lots. One must notice that the large unitary lots are included in this category, which makes their use for perishable crops possible as the products can be sold in the main urban centres.

In the class of medium accessibility (240-300 minutes) there are, predominantly, the agricultural lots which are located on the outskirts of the study area, due to the scarce access infrastructure and in some places to a lack of it.

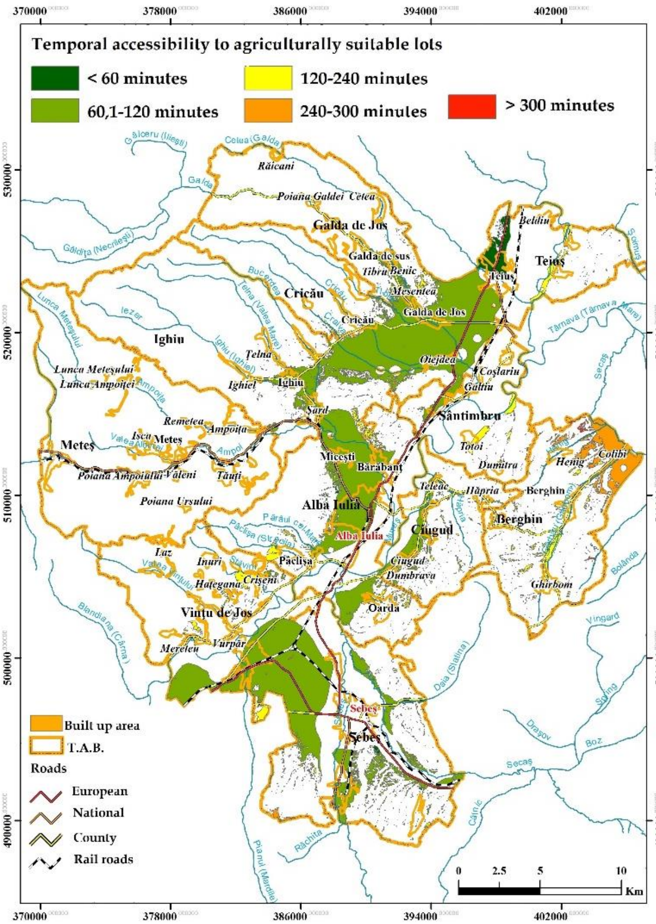

Fig. 6. Map of temporal accessibility to agriculturally suitable lots.

The unitary lot with a large surface identified on the administrative unit of Berghin is included in this class and is located at the limit of the study area. It is connected only to a county road which ensures its access from the main sales centre of Alba Iulia. In these case it is recommended to make secondary and local centres for collecting the crops from these lands or to plant other cultures which correspond to the suitability of the land and which produce crops with a low perishable degree, in order to be able to store them for a longer period of time.

3.2. SWOT analysis of road quality

In order to capture in categories and types the influence of road presence/absence and road quality over the exploitation possibilities of the agricultural lands from the study area, the SWOT analysis was used.

This method has been used since 1971 by Ken Andrew (Horvath, 2008,) graphically and numerically expresses strong and weak points, at the same time evaluating the opportunities for development, as well as the threats. In this case the strong points were analysed as advantages, the weak points as disadvantages, the present and potential dangers were also analysed in classes of road categories and the opportunities were used as specific proposals.

The SWOT analysis was used to make the inventory and the evaluation of the development possibilities for the studied region as complex as possible, considering the road density and road quality (**Table 4**).

Table 4.

SWOT analysis of roads.

EUROPEAN ROADS			
	Importance	Requency	Magnitude
Strengths (S)			
Ensures easy access to the main sales centres;	5	1	5
High average driving speed;	5	5	5
Easy access to the agricultural production units from the close vicinity;	5	2	3
Good road quality;	5	5	5
Ensures regional competitivity.	2	2	1
Weaknesses (W)			
Limits entirely the access of agricultural machines;	5	5	5
Inexistent access to the production units even in the case of a close vicinity;	2	5	5
Constitutes barriers in the territorial extension of the lots;	1	5	5
Difficult transport conditions for natural fertilisers;	3	4	2
Restricted transport of chemical fertilisers.	5	4	3.5
Opportunities (O)			
Limited hourly access of agricultural machines;	5	2	3
Implementation of vegetation barriers for decreasing the vulnerability to pollution by suspended dust and exhaust gases;	5	5	5
Enables multiple acces points to local collecting points.	5	1	3
Threats (T)			
Major pollution degree;	3	3	4.5
Major pollution risk;	5	5	5
Major accident risk;	2	1	1
Damaging of perishable products due to difficult access of transport vehicles.	5	1	5

NATIONAL ROADS			
	Importance	Frequency	Magnitude
Strengths (S)			
Ensure easy access to the main production centres from the close vicinity;	2	5	2
High average driving speed;	5	5	5
Easy access to the main collecting centres (town markets, periodic markets, storage halls on the outskirts of towns);	5	2	3
Good road quality;	5	5	5
Easy access to the main and secondary sales centres;	5	3	5
Ensure regional competitivity.	2	2	1
Weaknesses (W)			
Major degree of soil pollution;	5	5	5
Major risk of soil and crops pollution.	5	2	3
Opportunities (O)			
Limited hourly access of agricultural machines;	5	1	4
Implementation of vegetation barriers for decreasing the vulnerability to pollution by suspended dust and exhaust gases;	5	5	5
Threats (T)			
Major pollution degree;	3	3	4.5
Major pollution risk;	5	5	5
Major accident risk.	2	1	1
COUNTY ROADS			
	Importance	Frequency	Magnitude
Strengths (S)			
Easy access to the secondary collecting centres (village centres, storage halls);	5	3	5
Easy access to the agricultural units of production from the close vicinity.	5	5	5
Weaknesses (W)			
Low quality of roads;	5	3	4
Medium values of maximum driving speed.	5	4	5
Opportunities (O)			
Implementation of vegetation barriers for decreasing the vulnerability to pollution by suspended dust and exhaust gases;	5	5	5
Threats (T)			
Major pollution risk;	5	5	5
High possibility of damaging the perishable products due to low average transport speed.	5	2	3
COMMUNAL ROADS			
	Importance	Frequency	Magnitude
Strengths (S)			
Enable the access of agricultural machines;	5	4	5
Are located in the close vicinity of production lots;	5	3	3
Are maintained by local authorities in order to ensure a priority access for the harmonious development of the community;	2	5	2
Possibility of practising ecological agriculture;	5	5	5
Easy access for the use of natural fertiliser.	2	3	2
Weaknesses (W)			
Relatively low driving speed;	5	5	5

Low quality.	5	3	4
Opportunities (O)			
Exploitation of communal roads according to well determined norms (weight, access);	5	3	3
Implementation of vegetation barriers for decreasing the vulnerability to pollution by suspended dust and exhaust gases;	5	5	5
Threats (T)			
Major pollution risk;	5	3	4
Damaging of perishable products due to difficult access of transport vehicles	5	1	5
AGRICULTURAL EXPLOITATION ROADS			
	Importance	Frequency	Magnitude
Strengths (S)			
Ensure the direct access to the production lot;	5	5	5
Allow the access for all agricultural machines;	5	5	4
Are maintained by local authorities or by the farmer and their route can be changed depending on the exploitation needs of the production units.	5	5	3
Weaknesses (W)			
Low maintenance state;	5	5	5
Low quality;	4	5	5
Low average driving speed;	2	5	3
Limited quantity of products being transported at once.	2	5	2
Opportunities (O)			
Consolidation of roads for the access of modern transportation machines;	5	4	5
Development of the road system for ensuring accessibility to multiple lots;	5	5	5
Maintenance of roads by local authorities and the owners that use them.	3	5	3
Threats (T)			
Fast degradation due to their maintenance regime and intensive exploitation;	5	5	5
Fast obsolescence of agricultural machines due to their condition;	4	5	4
Major accident risk due to urestricted animal access.	2	1	2

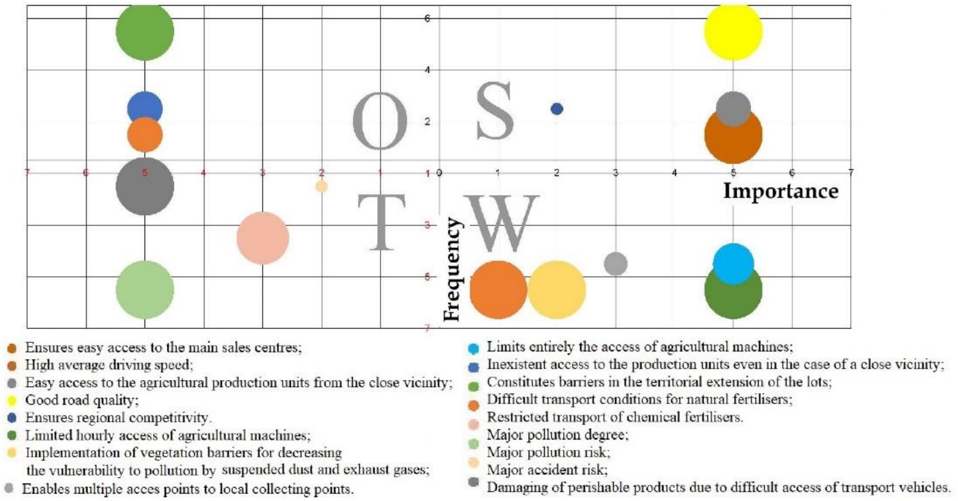

Fig. 7. SWOT evaluation for european roads.

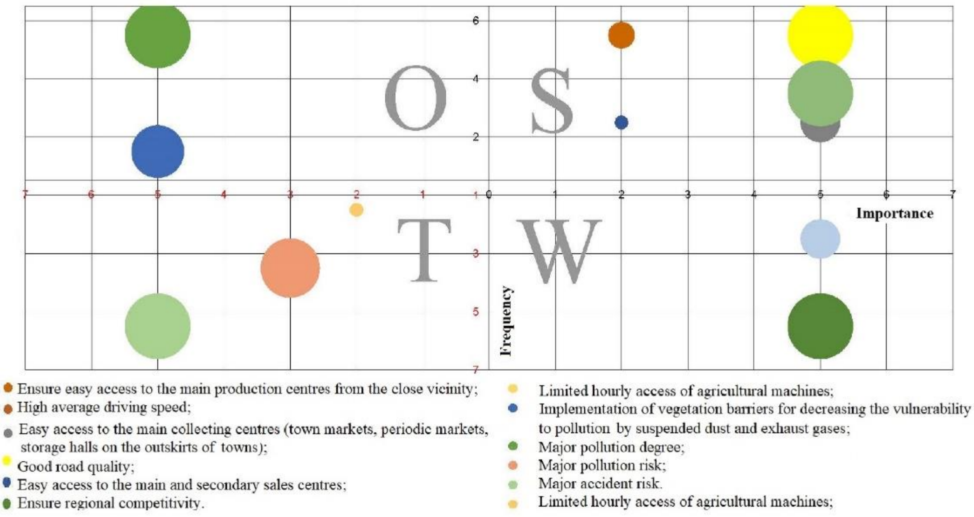

Fig. 8. SWOT evaluation of national roads.

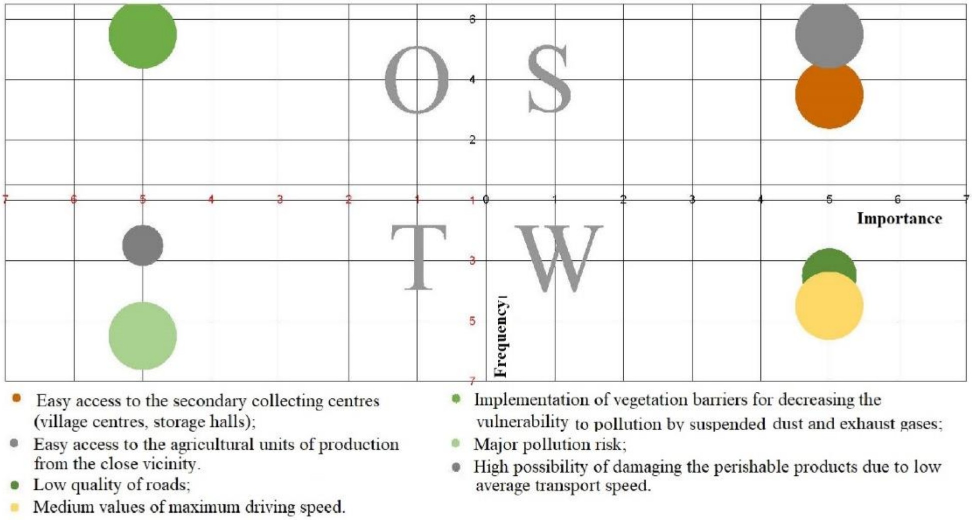

Fig. 9. SWOT evaluation of county roads.

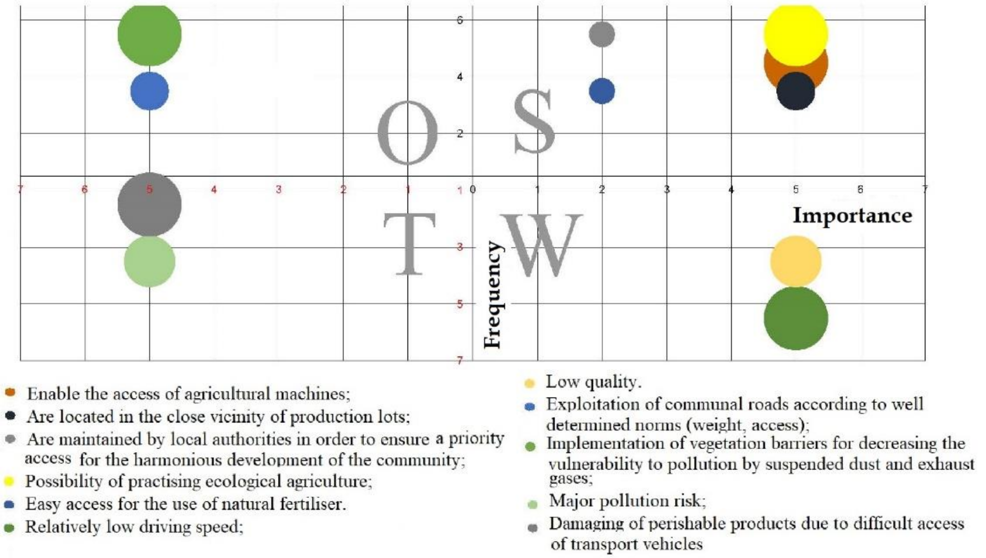

Fig. 10. SWOT evaluation of communal roads.

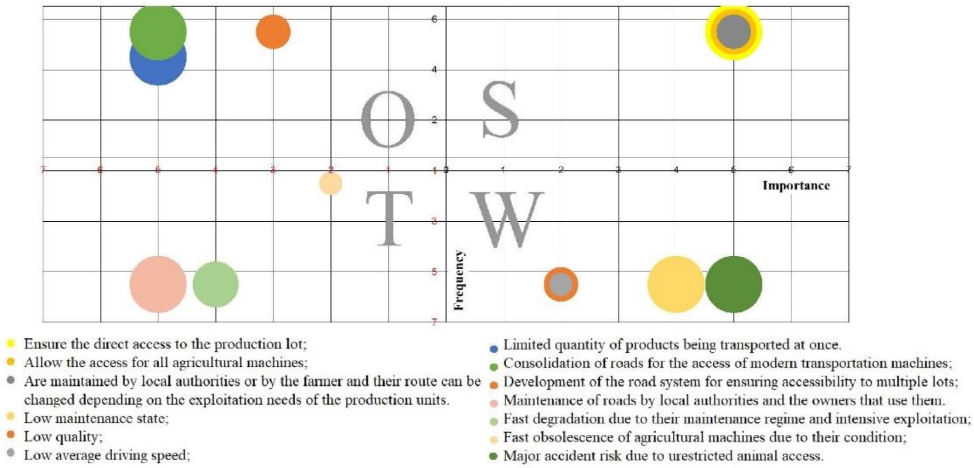

Fig. 11. SWOT evaluation of agricultural exploitation roads.

After performing the SWOT analysis, the main opportunities for the development of the Alba Iulia Association for Intercommunity Development were identified. These are the results of the facilities offered by the road network and make possible various proposals for the development of the production and sale of agricultural products.

The correspondence between the strengths and the opportunities of the region are in the quadrant I (SO). In quadrant II (WO) one notices the correspondence between weaknesses and opportunities, the degree in which the opportunities could or could not limit the influence of the weaknesses can be determined, as well as their possible transformation in strengths as a consequence of applying the specific proposals

Table 5.

Theoretical SWOT matrix.

	(***S***-*Streanghts*)	(***W***-*Weaknesses*)
(***O***-*Oportunities*)	**SO**	**WO**
(***T***-*Threats*)	**ST**	**WT**

Quadrant III (ST) represents the relationship between strengths and threats and identifies the degree in which the threats could be reduced or eliminated as a consequence of using the identified strengths.

Quadrant IV (WT) highlights the relationship between weaknesses and threats and requires the analysis of their interdependence and the identification of possibilities of reducing the negative effects in the study area.

This evaluation consisted of giving a score for the importance, the frequency and the magnitude of each indicator included in the evaluation, with values ranging from 1 to 5 (**Table 5**).

The increase of economical efficiency for the agricultural lots with maximum suitability but low accessibility towards the main sales centres requires the identification of secondary centres for collecting and for primary sale. These would take over a part of the products and store them in qualitatively high storage conditions and facilitate their fast distribution. In order to capture the influence of the presence/absence and quality of roads in categories and types, the SWOT analysis was used as a main work method, its main purpose being the identification of a short delivery time for a large quantity of products.

The SWOT analysis was also used for a complex identification and evaluation of development possibilities as well as to identify the main collecting centres for the agricultural products depending on the density and the quality of roads from the study area (**Table 4**).

As a result of the integrated analysis of the time required to access an agricultural lot in the eastern part of the study area is highlighted. Here are suitable lots to which the access requires a long time (240-300 minutes) but which are viable in what concerns the opportunities offered by the road category. Thus, for an efficient exploitation from the point of view of transporting the agricultural products to the main sales centres we propose the development of a modern collecting centre in the Colibri village. The settlement finds itself in the category of easy access for road transportation towards all the sales centres as it is located at the junction between the county roads DJ107 and DJ107B, but it has low accessibility and sometimes no accessibility to production lots.

4. CONCLUSION

Agriculture is one of the main components supporting the national economy due to the fact that most of the land is suitable for cultivation. Efficient exploitation by selling on the market the products obtained through cultivation and land maintenance makes the economical value of the land to increase exponentially with the quantity of products which are harvested and sold. Leaving aside the agricultural maintenance of the lands, the access to them represents the main factor which gives additional value and determines low maintenance and exploitation costs where accessibility is very good.

Using GIS spatial analysis models, the identification of access time, in minutes, to the agricultural lots with the highest suitability for cultivation has made possible the identification of the sales centres allocated to each lot and, thus, reducing the time required for transport between the production area and the main sales centre. In this way the costs of transport and distribution are minimised, as well as the risk of financial loss due to the alteration of perishable products.

Using the maximum travel speeds on road categories for the calculation based on the GIS spatial modeling of the access times to the agricultural fields highlights in terms of temporal access the fields located in the meadow and the first terraces of Mures and the main tributaries: Sebes, and Ighiu. For these surfaces, small access times were calculated within 0-60 minutes as access time to the main selling centers: Alba Iulia, Sebes and Teius.

Areas identified spatially with low access times are overlapping territorially with fields with high agricultural favourability, which makes this area to be considered the area with high potential for production and sales and is treated as a priority in terms of policy implementation for agricultural development in terms of rational exploitation and high efficiency of products obtained as a result of conforming cultivation.

It is highlighted that maximum access times (60-120 minutes) have been calculated for the low-favorability agricultural parcels located at the contact of the mountain with the area where the high favorability has been identified for another type of culture among which vineyard. This culture does not require short transport times to the market and secondary collection centers can be made in the respective areas and further sale in the form of engross for the high economic valorization of the production and, implicitly, of the less favorable agricultural land. Based on the access times, the territorial areas allocated as sales for each of the main centers were identified, was identified the center of Alba Iulia as the main hotspot in terms of the total surface area as sales and also in terms of assigned the agricultural parcels.

The analysis of access times for agricultural landings highlights the very short (less than 60 minutes) time needed to transport the harvested products to the main collection centers. At the same time, there were calculated high access times (120-300 minutes) for some parcels in the eastern part of the study area, for which it is proposed to set up secondary collection and selling centers in Engross regime.

Noteworthy is that integrated SWOT analysis of roadways in terms of exploitation for economical efficiency of agriculture in the studied area prove the good quality of the roads in the areas with high favorability but also good road quality that ensures fast transport (60 minutes maximum) between secondary collection centers and main sales centers showing the multiple ways to satisfy the demand for agricultural products on the consumer market.

The SWOT analysis of the general quality of the access network highlights qualitatively favourable territorial hotspots. When analysed in correlation with the areas with very low accessibility they highlight possible locations for collecting and temporarily storing the crops with the main purpose of maximising the profits on lots with maximum suitability and low accessibility.

The analysis of the complex and integrated GIS spatial analysis models, which focus on identifying the access time to production lots, gives useful information in the integrated management process (cultivation-production-storage-transport-sale) which has as its main purpose the maximising of profits for the exploitation of lands with maximum agricultural suitability.

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A GEOGRAPHIC ANALYSIS OF POST-DISASTER SOCIAL IMPACTS ON A MUNICIPAL SCALE – A CASE STUDY OF A POTENTIAL MAJOR FLOOD IN THE PARIS REGION (FRANCE)

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ABSTRACT:

In this study, a GIS methodology is developed to analyse post-disaster social impacts at the scale of municipalities. Two methods are combined here: (1) a model measuring flood damages to the structures and services necessary to populations' liveability. (2) A spatialized index, combining social variables in order to represent the recovery capability of populations. Municipalities combining a high damage ratio and a lack of recovery capability shall be closely watched during the planning process of post-disaster recovery. This study is original for methodological and conceptual reasons. The methodology combines tools which are rarely used together, whereas post-disaster impacts of the Seine flood, our case study, have not yet been fully analysed.

Key-words: *Vulnerability, Post-disaster, Recovery, Flood, Paris region*

1. INTRODUCTION

The flood of the Seine river is nowadays an issue well documented amongst crisis managers (November & Créton-Cazanave, 2017). The June 2016 floods, which triggered the evacuation of almost 20,000 people inside the Paris region (called "Ile-de-France"[3]), and the more recent January 2018 floods, have highlighted the efforts in crisis management planning that have been made, though many difficulties and challenges persist. Conversely, post-disaster management remains a poorly known and controlled topic.

This deficiency in anticipation is to be related with the lack of feedbacks concerning plain flooding lasting several weeks or months in a highly urbanized community (Masson-Planchon & Reghezza-Zitt, 2017). Indeed, the peculiarity of the Seine flood hazard is its slow onset, due to the slope of the watershed (0.01% to 0.03%), and other diverse factors, such as the time transfer between the upstream and the Paris region (between 4 and 11 days). During the one-hundred-year flood of January 1910, water levels rose on average 1m a day, while it took two months for the waters to recede (OECD, 2014). Anticipating post-disaster challenges is essential, due to the exposure of the Paris region to flood hazard – 830,000 inhabitants are indeed exposed to a one-hundred-year flood (Faytre, 2011)

1.1. Research topic and definitions: a major flood in the Paris region

To face this lack of knowledge, the topic of this paper is to develop a methodology to study post-disaster social impacts, applied to a flood of the Seine river and its tributaries, equal or superior in flow to the 1910 flood, in the Paris region. This methodology aims at quantifying and mapping those impacts at the scale of the municipalities of the region.

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1.1.1. Between physical and social impacts

A flood may be defined as the temporary covering by water of land not usually covered by water (Torterotot, 1993). It may have different origins (Chocat, 1997) and it may cause various impacts, which may be classified according to a simple typology, between physical and social impacts (Lindell, 2013). Physical impacts include the effects of floods on people's health, but also the damages to buildings and infrastructures, the natural environment, and agricultural lands (Ahern et al., 2005; Brémond et al., 2013; Torterotot, 1993). Social impacts include effects on a psychological level, on the demographic and economic structure of the community, or on a political level (Aldrich, 2012; Baade et al., 2007; Bolin & Stanford, 1991; Leon, 2004; Vigdor, 2008). If this paper is mainly focused on social impacts, it is nonetheless critical to also consider physical impacts in this analysis, as they are both deeply entangled. Decease has psychological effects, and damages to buildings hinder the return of evacuated and affected populations. On the other hand, the return of the latter also affects building and infrastructure reconstruction speed and rate (Green et al., 2007; Paxson & Rouse, 2008). As this distinction appears misleading to a certain extent, social impacts have been defined more generally, as the effects of the flood on populations.

1.1.2. Different approaches to recovery processes

Impacts may be measured according to their timing, from short-term impacts caused by the immediate consequences of the flood (flooding of living places leading to evacuations, utilities and public services shutdowns, interruption of economic activity) to long-term impacts – how the flood has disturbed, for several years or more, the demographic and social fabric of a given community (Aldrich, 2012). These long-term impacts shall be analysed in light of the recovery process. Yet, recovery is defined in various ways. Some authors rely on an economic approach, considering that a community has recovered when financial and physical capital have exceeded pre-disaster levels (Kates et al., 2006). Others consider that recovery has been achieved when a community has regained a certain degree of autonomy and is able to sustain itself without external help (Le Masurier et al., 2006). Some highlight the role of demography, defining the recovery process as the repopulation of an affected community. Repopulation may occur by the return of evacuated or displaced inhabitants, or by the arrival of newcomers (Aldrich, 2012). This last approach emphasizes the unequal nature of recovery. Inasmuch as populations are not equal in this process, social and spatial disparities are then aggravated by the recovery process with potential consequences on the social fabric of communities, as outlined by the example of the New Orleans metropolitan area after Katrina (Falk et al., 2006; Green et al., 2007; Groen & Polivka, 2010). If some researchers insist on the recovery process as a "window of opportunity" to prevent future disasters (Moatty & Vinet, 2016), this paper strictly focuses on the study of those social and spatial disparities, and the capability of populations to recover from a disaster.

1.2. Research relevance: scientific frame and methodological innovations

1.2.1. Exploring the issue of social and post-disaster impacts in Paris region

At the scale of the Paris region, though flood hazard is now a well-documented topic, there are still several research orientations which should be studied more thoroughly in regard to post-disaster and social impacts analyses. Knowledge on post-disaster processes remains deficient regarding the Seine flood hazard, apart from studies on technical networks (Beraud, 2013; Toubin, 2014). Similarly, economic impacts of a major flood in the Paris region have now been assessed for several decades (IIBRBS, 1998; OECD, 2014), which is not yet the case for social impacts.

1.2.2. A hybrid methodology: combining a vulnerability index and a damage model

This research is also relevant in regard to the general literature on risks and natural hazards. Risk is generally defined as the convolution between hazards and the vulnerability of the elements at risk (Cardona, 2003; Hufschmidt, 2011). Hazards generally refer to the features of a damaging event, or its probability of occurrence (Dauphiné & Provitolo, 2013). Approaches and definitions vary greatly amongst authors in respect to vulnerability (Adger, 2006; Hufschmidt, 2011). In this paper, vulnerability has been simply defined as the potential for losses of an element at risk (Alexander, 2000). It should not be confused with the concept of resilience, which refers to the ability to prepare for, recover from and adapt to disasters (Cutter et al., 2014). Different methods have been developed to assess vulnerability, particularly damage models and mapped vulnerability indexes. In this methodology, these two generic methods have been combined in an original fashion.

(1) Damage models aim at estimating damages (negative impacts) caused by a given hazard (Hubert and Ledoux, 1999), for different purposes (Eleuterio et al., 2008; Merz et al., 2010; Torterotot, 1993). Most of these models lead to a monetary assessment of damages to buildings and infrastructures (de Moel et al., 2015; Hammond, 2014). In this methodology, the damage model that has been developed allows measurement of the alteration of basic services and structures necessary for the everyday needs of the inhabitants. In this instance, we prefer to put aside the monetary logic that predominates most damage models for a more functional logic. Indeed, this study does not aim at assessing economic damage, but to assess the impact of the flood on the functioning of the territory in a systemic and global approach.

(2) Mapped vulnerability indexes aggregate variables in order to represent community or population vulnerability at the scale of residential blocks, municipalities, and counties (Cutter et al., 2010, 2003; Fekete, 2009; Flanagan et al., 2011; Koks et al., 2015; Rygel et al., 2006; Su et al., 2015). These indexes are however unfit for a study centered on a particular stage of a disaster. Rufat et al. (2015) highlight the temporal context of every vulnerability study – vulnerability factors are not the same depending on the disaster timing. A vulnerable person during the evacuation stage may not be vulnerable during the recovery stage. Thus, the few methods developed to map recovery capability or post-disaster displacement risk (Esnard et al., 2011; Finch et al., 2010; Myers et al., 2008) rely on a general state-of-the-art regarding vulnerability, and fail to fully consider the peculiarities of post-disaster situations. The index of vulnerability that has been developed in this paper, called Index of Social Destabilization (ISD), aims at representing the potential difficulties of a given population to recover in a post-disaster context. It differs from these former studies as it aggregates variables based upon specific literature aiming at identifying determinants of the recovery capability of populations.

To sum up, the objective of this analysis is to study post-disaster social impacts on a municipal scale, through the combination of a damage model and a spatialized index in a GIS. This methodology is applied to a case study related to a potential major flood of the Seine river and its tributaries in the Paris region. This paper is divided in three parts. First, a state-of-the-art of recovery determinants is synthesized. Second, methodology is presented. Third, results are featured and commented.

2. STATE OF THE ART: RECOVERY CAPABILITY DETERMINANTS

For the assessment of post-disaster social impacts, it is crucial to identify the determinants of the populations' recovery after a disaster. This requires a state-of-the-art based upon social and demographic post-disaster studies.

2.1. Social and demographic studies – an inventory

The main quantitative studies used in the state-of-the-art are listed in **table 1**[4]. Two kinds of quantitative studies are available: (a) demographic census analyses, which allow the observation of the consequences of a disaster on social and demographic trends (Kamel, 2012). (b) Analyses of post-disaster surveys conducted with affected households or individuals (Elliott, 2010). They both involve correlation and regression analyses of the collected data. Dependent variables nonetheless vary depending on the authors. Some study the return of inhabitants in their homes (Smith & McCarty, 1996; Xiao & Van Zandt, 2011). Others use self-reports done by the surveyed households of their own economic status (Bolin & Bolton, 1986). Most of the studies rely however on the rate of demographic change in the affected communities (Aldrich, 2012; Shimada, 2015).

Table 1.

State-of-the-art of quantitative studies concerning post-disaster recovery of populations and communities.

Authors (date)	Hazard	Study area	Nature of the study	Surveyed indiv/ household	Dependent variable	Duration of the study
Aldrich (2012)	Great Hanshin earthquake (1995)	Kobe Municipalities	Demographic trend analysis	-	Demographic change rate	1990-2008
Bolin & Bolton (1986)	Tornado in Paris, Texas (1982)	Paris, Texas (USA)	Post-disaster survey	431	Economic recovery of households	8 months after disaster
Elliott (2010)	Hurricane Katrina (2005)	Lower Ninth Ward and Lakeview, New Orleans	Post-disaster survey	179	Miscellaneous	9-16 months after disaster
Kamel (2012)	Hurricane Katrina (2005)	New Orleans Metropolitain Area	Demographic trend analysis	-	Repopulation rate of neighbour.	2005-2010
Kamel & Loukaitou-Sideris (2004)	Earthquake in Northridge (1994)	Los Angeles Metropolitan Area (USA)	Demographic trend analysis	-	Access to institutional funds	1990-2000
Morrow-Jones & Morrow-Jones (1991)	Miscellaneous	USA	Demographic trend analysis	-	Permanent displacements of populations	1974-1981
Myers et al. (2008)	Hurricanes Katrina and Rita (2005)	Gulf of Mexico counties (USA)	Demographic trend analysis	-	Outmigration rate	10 months after disaster
Shimada (2015)	Miscellaneous	Japanese Prefectures	Demographic trend analysis	-	Demographic change rate	1981-2012
Smith & McCarty (1996)	Hurricane Andrew (1992)	Miami-Dade County (USA)	Post-disaster survey	5310	Return rate (return to pre-disaster)	1-2 years after disaster
Xiao & Van Zandt (2011)	Hurricane Ike (2008)	Galveston County (USA)	Post-disaster survey	980	Return rate (return to pre-disaster)	7 months after disaster
Zhang (2006)	Hurricane Andrew (1992)	South of Miami-Dade County (USA)	Demographic trend analysis	-	Residential property values	1992-1996

[4] *Qualitative studies quoted in this paper are not listed in Table 1 for readability reasons.*

2.2. Identifying predictive determinants for the recovery of populations

Beyond the diversity of studies, some variables are regularly quoted as being potentially predictive of the capability of a given population, social group, household, or person to recover.

2.2.1. Synthesis – predictive determinants for recovery

Table 2 synthesizes those variables, which are grouped by factors. Amongst factors, a distinction has been made between pre-existing conditions and conditions created by the disaster occurrence. These variables are crucial to the understanding of the observed disparities – between communities and between affected populations – in the recovery stage. Three main factors emerge out of this set of variables – social capital, demographic, and socioeconomic individual status and post-disaster environmental conditions.

Table 2.

Post-disaster recovery determinants.

Timing	Factors	Variables	Impact on recovery rate / speed	Source (studies from table 1)
Pre-disaster conditions	Social capital	Bonding	+	Aldrich (2012); Shimada (2015)
		Bridging	++	Elliott (2010); Shimada (2015)
	Urbanisation	Population / Building density	-	Myers et al. (2008)
		Multiple-dwelling buildings	-	Kamel (2012)
	Demographic status	Household size	-	Bolin & Bolton (1986)
		Advanced age	-	Morrow-Jones & Morrow-Jones (1991)
		Woman as head of the household	-	Morrow-Jones & Morrow-Jones (1991)
	Social and economic status	Income	++	Aldrich (2012); Kamel (2012) ; Kamel & Loukaitou-Sideris (2004) ; Myers et al. (2008); Zhang (2006)
		Insurance cover	+	Bolin & Bolton (1986)
		Education	+	Morrow-Jones & Morrow-Jones (1991)
		Renter / Social housing	--	Kamel (2012); Zhang (2006)
		Racial / Ethnic minority	--	Kamel (2012); Kamel & Loukaitou-Sideris (2004); Morrow-Jones & Morrow-Jones (1991); Zhang (2006)
		Immigrant status	-	Kamel & Loukaitou-Sideris (2004)
Post-disaster conditions	Physical damages	Hazard magnitude, residential damages	--	Kamel (2012); Myers et al. (2008); Smith & McCarthy (1996)
	Environmental conditions	Business recovery	+	Xiao & Van Zandt (2011)
		Departure of people from surrounding communities	-	Myers et al. (2008)
	Post-disaster individual itineraries	Evacuation / Number of post-disaster displacements	-	Bolin & Bolton (1986)
		Geographic distance (between one's pre-disaster home and shelter / temporary house)	-	Smith & McCarthy (1996)

2.2.2. Social capital

Social capital appears nowadays at the centre of research on post-disaster recovery (Aldrich, 2012). Social capital is defined as the relationship between individuals. It is made of resources related to the belonging to a particular group (Bourdieu, 1980). The social capital of a given individual depends upon the size of the network he is able to mobilize. It is also related to the volume of the economic, symbolic, cultural capital of each person of his or her network. Social capital thus reproduces the inequalities observed in the distribution of economic, cultural, symbolic capital. After a disaster, social capital is crucial for recovery for several reasons. (a) Thanks to social capital, inhabitants can overcome collective problems that arise during the recovery stage. Amongst other things, they are able to mutualize means so as to speed up recovery. (b) People with strong social capital are also more strongly attached to their communities, and therefore more willing to stay or to come back to their communities. (c) Finally, they are able to regroup in community organizations in order to make demands to the local and national authorities to have a say in the official recovery projects (Shimada, 2015). Social capital has spatial implications in the recovery phase, as shown by Aldrich (2012) after the Great Hanshin earthquake in 1995, and Hurricane Katrina in 2005. A neighbourhood even highly damaged may recover while another may not, due to differences in social capital.

2.2.3. Individual factors

Individual status also plays a major role in recovery dynamics. On a demographic level, household configuration (gender, age, size) impacts recovery capability. Large households and families with children face pressures that other households do not – the former have more needs regarding public services, utilities, and educational systems (Paxson & Rouse, 2008; Sastry, 2009). A high proportion of elderly persons in households has adverse effects on recovery processes, in contrast to a high proportion of working-age persons – as the latter have larger incomes (Arouri et al., 2015). At last, gender discriminations overlap other kinds of racial and socioeconomic discriminations. For instance, after the Red River flood in 1997 (USA), single mothers were overrepresented in the FEMA trailers (Enarson & Fordham, 2001). On a socioeconomic level, there is a strong consensus between authors concerning income and economic capital variables (Carter et al., 2007; Green et al., 2007; Masozera et al., 2007). Higher incomes and savings allow people to recover quicker by their own means – for instance, rebuilding or finding another home. Similarly, owners may better recover than renters for several reasons – better economic situation, no rent to pay, and recovery policies favouring owners (Logan, 2006; Peacock et al., 2007; Whittle et al., 2010; Zhang, 2006; Zhang & Peacock, 2009). Finally, ethnic and racial status may also be a determinant for recovery (Fothergill et al., 1999). Minorities may not recover as quickly as the majority, for at least two reasons: (1) they have lower incomes and capital (Arouri et al., 2015); (2) racial discriminations by populations and administrations may exist which impact the recovery process.

2.2.4. Post-disaster conditions

Finally, the post-disaster environment may also impact the recovery rate and speed. The damage rate of infrastructures, utilities, businesses and dwellings is of course a crucial factor in the recovery process (Paxson & Rouse, 2008). In an obvious way, recovery is harder and slower when damages are high. Populations may not return to their former communities if businesses are closed, and water or energy utilities are shut down, and it may be difficult for parents to go back to work if schools are still closed and unable to receive their children. Conversely, if populations do not come back to their communities, companies and authorities will not be enticed to invest in rebuilding utilities or reopening public services. Nevertheless, some authors have highlighted the fact that a disaster is also an opportunity to “build back better”, which is easier when damages are so high that it is possible and less expensive to make tabula rasa (Aldrich, 2012). In contrast, this option is harder to implement when damages are moderate (when it is not required to rebuild but to repair).

3. METHODOLOGY

The methodology developed for quantitative and cartographic estimation of post-disaster social impacts is based on a combination of two models. On the one hand, it relies on a damage model, which aims at estimating the alteration of basic services and structures essential to the daily life of the populations. On the other hand, it is based upon the mapping of an Index of Social Destabilization (ISD). This spatialized index represents the susceptibility of a given population to undergo the negative impacts of a disaster in the long term, seen as an inverse function of its ability to recover. The damage model is determined by environmental variables characterizing the living conditions in a post-disaster situation. Conversely, recovery capability is estimated from individual and collective social variables, which characterize the exposed populations prior to the disaster.

3.1. Community damage model

The community damage model aims at estimating the degradation of services essential to the daily life of populations. These services are considered to be crucial to the return of inhabitants to their former homes or communities.

3.1.1. Identifying services conditioning the return of populations on an affected community

This model is based primarily on the identification of four types of structures and infrastructures hosting these basic services: housing, primary schools, food shops and supermarkets, railway stations and service stations of the rail network. The choice in this area is based on conceptual and practical reasons. From a practical point of view, the number of structures identified is limited in order to ensure the clarity of the model and its reproducibility. It must also be possible to find corresponding geolocated data, preferably free access. In this case, housing data is derived from a cross-referencing of the IGN[5], the Iau-Idf[6] and INSEE[7] databases. This cross-referencing makes it possible to locate residential buildings in the Paris region, and to estimate within each building the number of dwellings and inhabitants. The method used to make these estimates is adapted from the one used by Ast for example (2008), or by the CGDD (Office of the Commissioner-General for Sustainable Development and the Observation and Statistics Service, 2012) to estimate the number of people in the flood area. Transport infrastructure data is taken from the STIF[8] database, and business and public services data from an INSEE database on Permanent Facilities (BPE).

From a conceptual point of view, the choice of structures and infrastructures is based on the state-of- the- art drawn up previously on the post-disaster environment. Damages to businesses are central in the return (or not) of populations in a disaster area (Xiao & Van Zandt, 2011). This analysis is limited to retail trade as they are at the core of a district or town's life. They also are essential in case of crisis in order to supply populations with basic necessities. The availability of public transport is also essential to enable people to go to work, to cover their daily needs, to acquire basic necessities, to have access to medical facilities, and to be able to see their relatives and friends (Wright & Johnston, 2010). The

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[5] *"BD Topo" – topographic data (IGN: National Institute of Geographical and Forestry Information).*

[6] *"BD MOS" – land cover data (Iau-Idf: Institute of Planning and Urban Development of the Ile-de-France region).*

[7] *"BD RGP" – population and dwelling data available at the census block scale (INSEE: National Institute of Itatistics and Economic Studies).*

[8] *STIF: Ile-de-France Transport Authority.*

availability of public services is also an essential condition for recovery. Public services include schools, kindergartens and day care centers, as well as libraries (Groen & Polivka, 2010). However, it is the nursery and primary schools which are the keystone of the life of a district or town, allowing parents of young children to return to work during the working hours, and therefore allowing populations to return to a form of routine. Schools represent the reference local service, which need to be located very close to accommodations, unlike other public services. Finally, the availability of housing is a key factor in the return of the population. The latter must have a place to live and reside, which appears difficult in a context where the housing stock is partly damaged or destroyed.

3.1.2. Hazard Parameters and Damage Thresholds

Once these structures and infrastructures have been identified, it is necessary to estimate their potential damage. As a reminder, flooding causes a physical impact on the structure, as much by the prolonged contact of the water on the materials (capillarity effect), as by the hydrostatic effects (water levels) and the dynamics of the water (flow velocity, impact of floating objects) on structures (Salagnac et al., 2014, Torterotot, 1993). Multiple studies agree that the damage to the structure is effective if the water height levels are greater than or equal to one meter, or if the flood duration exceed 72 hours (CEPRI, 2012; Salagnac et al., 2014; Torterotot). Under these conditions, the finishing components of the building (secondary work), in some cases the shell (main work), must be rebuilt, which requires several months to several years. Uncertainties regarding the recovery time are numerous[9].

3.1.3. Model implementation with GIS

The model is implemented in a GIS, in two stages. First, it is necessary to cross the data related to the structures and infrastructures identified in the Paris region to the data on hazard parameters (water levels and flood duration). The water depth data used are surface data called Potential Flood Areas, available for various flood scenarios thanks to the mapping work of the DRIEE[10] and the SGZDS-Paris[11]. They were developed by the latter by crossing a hydraulic model (Alphee model – IIBRBS, 1998), and a Digital Elevation Model obtained by a LIDAR campaign (DRIEE and SGZDS-Paris, 2015). Ten flood scenarios were developed for the application of these Potential Flood Areas, from the "R0.5" scenario to the "R1.15" scenario: the figure is a coefficient, expressing the percentage of flood flow achieved during the January 1910 flood event. This article considers two scenarios: the scenario "R1" (100% of the flood discharge of 1910), and the scenario "R1.15" (115% of the flood discharge of 1910, that is the height reached by the latter at the Austerlitz hydrometric station in Paris[12]).

These two scenarios are scenarios of major flooding, of potential disasters, well-known by risk managers in the Paris region. The second scenario (R1.15) also makes it possible to

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[9]In addition to hazard parameters, building protection and prevention measures can also limit (or worsen) the physical impact of flooding (CEPRI 2012, Salagnac et al., 2014). These measures are not studied here because it is not possible to obtain this type of data at the regional scale, and because they have a low impact (in particular for cofferdam type measurements) in case of a long-term flood. Plus, the purpose of the damage model is not to give an accurate estimate on a quantitative or spatial level, but to report the post-disaster situation on an overall state, summarized at the regional, departmental or municipal level.

[10]DRIEE: Regional and Interdepartmental Directorate of Environment and Energy.

[11]SGZDS-Paris: General Secretariat at the Defense and Security Zone of Paris.

[12]The difference between flow and height is explained by the hydraulic developments that have been carried out since 1910 (EPTB Seine Grands Lacs, 2014).

study the significant threshold effects that characterize the Seine flood. The feedback from the recent floods (June 2016 in particular) cannot be used because the hydrological phenomena are not comparable and because they represent much more modest scenarios than those we study. The duration of submersion is deduced by simplification of the Alphee hydraulic model (Fujiki, 2017). In a second step, these crossed data are aggregated on a municipal or municipal district level. The data is aggregated on a municipal level because the municipality is the reference administrative level on a local scale, particularly for crisis management (Gralepois, 2008). It is also the oldest local institution, which continues to forge communities' identity: this is essential because of the role of social capital in populations capabilities to recover in post-disaster situations. The results come in the form of a ratio: structures and infrastructures damaged in relation to the total number of structures and infrastructures. A ratio is separately calculated for each type of structure and infrastructure (schools, shops, train stations, dwellings). The resulting four ratios are then summarized as an unweighted average.

3.2. The Index of Social Destabilization (ISD)

The computation of community damage makes it possible to estimate the practical ability of populations to be able to return to their homes or communities of origin. It comes with the calculation of the ISD, which makes it possible to estimate the intrinsic capability of these populations to recover.

3.2.1. ISD potential variables

The ISD is a composite index aggregating a set of variables on a municipal scale. The variables are chosen according to practical and conceptual considerations. From a conceptual point of view, the ISD is based on the state-of-the-art previously described: it aggregates the identified individual and collective variables, which may characterize a population in its capability to recover a priori. For each variable identified in the state-of-the-art, the objective is to find at least two indicators to represent it. From a practical point of view, it is also necessary to find indicators that can represent these variables on a municipal scale. These indicators must come from reliable, comprehensive sources throughout the Paris region and be relatively recent. Care must be taken to limit the number of sources used in order to avoid the constraints related to their heterogeneity and the issues of methodological compatibility. As a result, most of this data is made available by INSEE (RGP, RFL[13], DADS[14]), although data from the Ministry of the Interior and the ONDRP[15] are also used. Considering all these issues, the working data matrix of our index comprises 25 potential variables. Specific constraints arise in representing social capital since it is never directly measured, in contrast to individual variables related to the demographic or socio-economic status of individuals. Social capital can only be indirectly estimated (Shimada, 2015). As such, previous studies have identified various indicators to represent bonding-type social capital: the ratio between the number of associations created and the number of inhabitants inside a community, the residence time spent in the neighbourhood (Aldrich, 2012), income homogeneity or suicide rate (Shimada, 2015). To represent bridging-type capital, other proxies have been identified: crime rate (Shimada, 2015), and participation in political elections (Aldrich, 2012).

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[13] *Geolocated Data on Tax Revenues.*

[14] *Annual Declaration of Social Data.*

[15] *ONDRP: National Observatory on Delinquency and Penal Responses.*

3.2.2. Finalization of the index and statistical tests

A composite index, such as the ISD, is considered valid if it is conceptually coherent and statistically robust. Conceptual consistency of the index is ensured through the state-of-the-art drawn up to constitute it. Statistical robustness is checked in several steps, based on a set of methods applied particularly to the development of synthetic indexes of vulnerability. Before the data can be processed, a statistical refining (using R) is required. This refining includes rationalization and normalization of the indicators used. Rationalization consists of transforming absolute variables into relative variables (in percentage and density functions), in order to be able to compare heterogeneous municipalities both in terms of area and population (Cutter et al., 2010). Normalization makes it possible to compare indicators with each other and thus to aggregate them, regardless of the units of measurement. Normalization methods are multiple, but we have chosen the z-score method as it moderately takes into account the impact of extreme values (OECD, 2008). For a given indicator, normalization takes place so that a positive value represents a negative impact on the recovery capability.

Statistical refining also includes the imputation of missing data: concerning income data, statistical secrecy is essential for some small municipalities, which are therefore not included in the list. In the statistical tests that follow, the missing data is replaced by the average. Other methods exist, but they present significant methodological problems (OECD, 2008). A rudimentary method was thus preferred, albeit readable and easily reproducible. The final step in statistical refining includes the elimination of redundant indicators, through a Pearson correlation test: correlated indicators above the 0.9 threshold are removed (Su et al., 2015). This procedure removes statistical duplicates that could result in the overrepresentation of a given phenomenon in the synthetic index. It also makes it possible to limit the number of indicators constituting the index and to improve its methodological transparency (OECD, 2008). Subsequently, our data matrix is reduced to 22 indicators. However, a synthetic index of 22 indicators is difficult to interpret: Therefore, it is necessary to analyse the underlying structure of the index, which implies subdividing it into sub-indices or dimensions (OECD, 2008). Two approaches coexist (Cutter et al., 2003, 2010, 2014): a deductive approach and an inductive approach. The deductive approach consists in creating sub-indices based on the state-of-the-art of the researcher, without any prior analysis of the data structure. It has the disadvantage of being based on a personal appreciation of the index and its structure. We prefer the inductive approach based on a statistical analysis of the data matrix. The inductive approach is based upon a Principal Component Analysis (PCA), consisting in grouping correlated variables into principal components uncorrelated among themselves. These principal components constitute the dimensions or sub-indices of our synthetic index. Before applying PCA, it must be verified that the variables in our data matrix can be grouped together through appropriate statistical tests (Wolf and McGregor, 2013). Bartlett's sphericity test aims to refute the null hypothesis that there are no observed relationships between the variables in the data table. This test, successful in our case, remains however insufficient because it is biased when the number of observations is high. The Kaiser-Meyer-Olkin Sampling Precision Test (KMO) completes the analysis by comparing the magnitude of the correlation coefficients to the magnitude of the partial correlation coefficients, in the form of an index ranging from 0 to 1. This makes it possible to check that the variables can be clustered, and to delete the isolated variables from the rest of the data matrix. A KMO index can be computed for each variable and for the entire matrix. The OECD recommends deleting the variables with the lowest KMO until reaching a global KMO of 0.8 (OECD, 2008). Two variables are thus deleted, to finally obtain a matrix of 20 variables characterized by a KMO of 0.89. Lastly, PCA may be computed. Four main components are retained with an eigenvalue greater than 1 (Cutter et al., 2003), explaining 70% of total variance of the data matrix. A varimax rotation of these four components is performed to maximize correlation of variables with a given component and to minimize correlation with the other components (Cutter et al., 2003, Su et al., 2015). **Table 3** describes these four components and the variables most correlated with them. Each component represents one dimension of our index. The value of each dimension is computed for each municipality, based upon the coordinates of principal components. The weighted mean is then computed to obtain the Index of Social Destabilization (ISD). The weighting method is based upon the proportion of total variance that each component explains. This is the weighting method chosen by many authors (Myers et al., 2008), although some authors prefer to avoid weighting components (Cutter et al., 2010; Lee, 2014), while others have proposed alternative methods: the Pareto rank method (Rygel et al., 2006) or hierarchical analysis using the Saaty method (Barbat 2003, Barczak & Grivault 2007).

Table 3.

Variables and principal components constituting the ISD.

Principal Component	Variables
Social capital - Family and demographic situation	Abstention rate in municipal elections
	Abstention rate in presidential elections
	Population able to vote [16]
	Rate of violence to persons
	% of large families (3 + children)
	% women head of households
	% of households in building
	Unemployment rate
	% of people in social housing or housed for free
	% of immigrants
Wages and level of qualification	Median revenue
	Average hourly net salary
	% of graduates of higher education
	% of non-graduates
Working conditions	Part of employed part-time
	Share of stable employment among employees
Urban environment and socio-economic inequalities	Number of inhabitants / km²
	GINI index
	Residence time greater than or equal to 5 years
	% single women

4. RESULTS AND CONCLUSION

Through the implementation of our methodology, it is possible to compute, for each municipality, the intrinsic recovery capability of its population (via the IDS) and the community damage ratios following a large flood of the Seine (scenarios “R1” and “R1.15”). Crossing the two analyses makes it possible to identify municipalities whose population is particularly vulnerable during the recovery phase.

4.1. ISD mapping and recovery capabilities

As a first step, it is possible to identify, on a spatial level, the distribution of geographical disparities in the recovery capability of populations (**Fig. 1**). A three-fold finding emerges: first, an urban centre characterized by a higher index, and therefore a weaker recovery capability; then, an opposition between East and West Paris, in favour of the second; finally, the identification of small islands of high values, in Seine-Saint-Denis, in the "Seine" part of Val-de-Marne, in the southern suburbs in Essonne, and in the northern suburbs in the Val d'Oise.

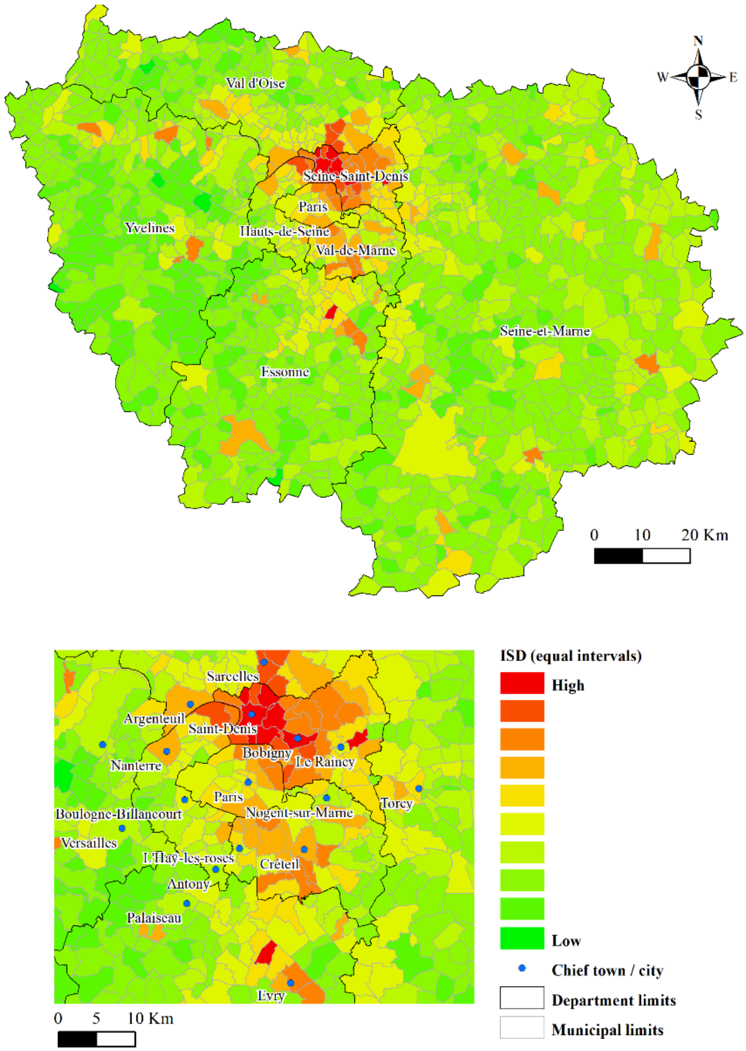

Fig. 1. Mapping the social destabilization index in Paris region.

Various explanations can be put forward, particularly by looking at **Fig. 2**, which represents the different components of the social destabilization index. Without detailing these components, the impact of urban density can be seen, as well as the distribution of income. Indeed, the mapping of the ISD covers, at least partially, that of the socio-spatial disparities that affect the Paris region (Bourdeau-Lepage, 2013; Gilli, 2014; Tovar & Bourdeau-Lepage, 2013).

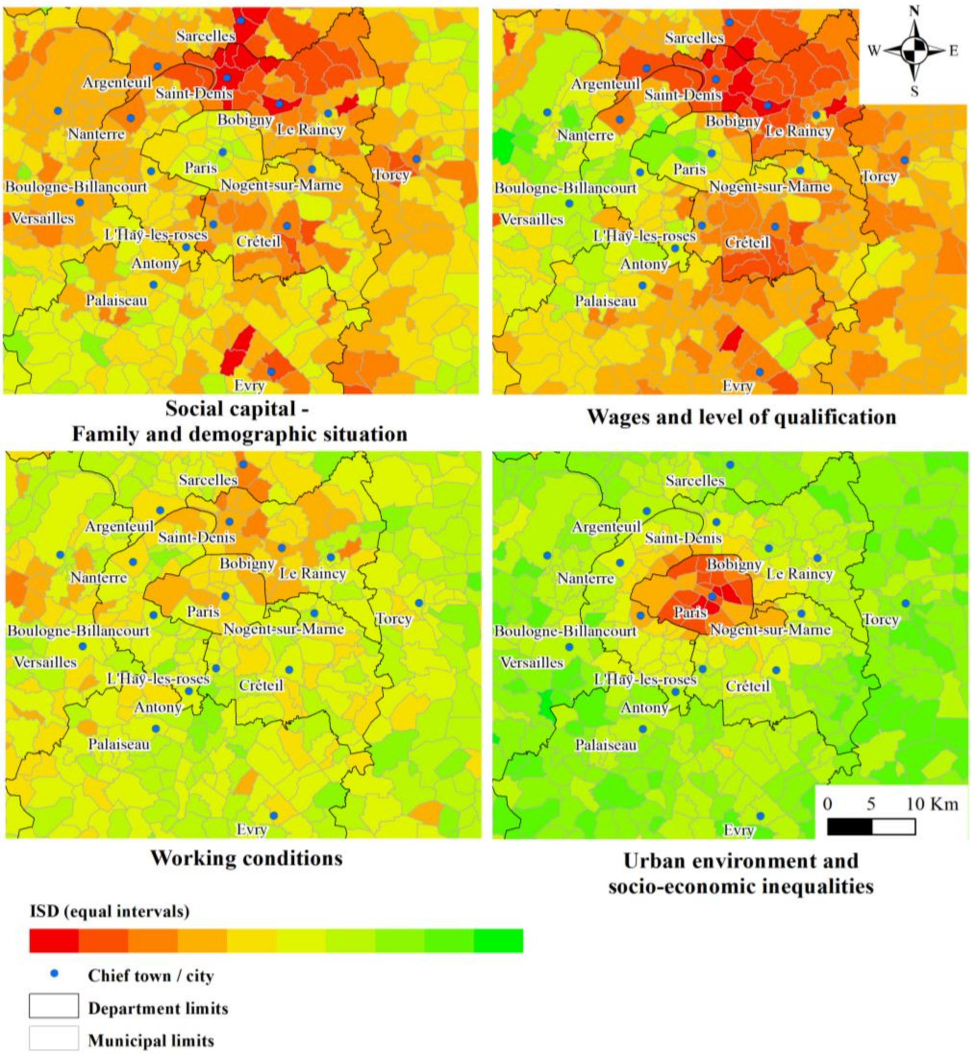

Fig. 2. Decomposition of IDS in principal components in the four central departments of Paris region.

4.2. Cross analysis of community damage ratios and recovery capability: quantified estimates and mapping

The mapping of ISD, however, is of operational interest only when faced with the estimation of community damage caused by flood scenarios. This estimation, however, must be taken with hindsight because it is very dependent on the quality of the data available.

On a regional level, community damage caused by a flood of discharge equal to or greater than that of the flood of January 1910 may seem relatively moderate: less than five percent of the structures and basic infrastructures are damaged for a R1.15 scenario. These figures highlight, however, a strong threshold effect between scenario R1 and R1.15: the rise in the water level of a few tens of centimetres has multiplier effects, with a doubling of the damage levels (**Fig. 3**). They also show strong disparities in the exposure of communities, to the detriment of the departments of the inner suburbs (former zones of flood expansion). For the R1 scenario, the Val-de-Marne appears by far the department the most exposed (7.7% damage). Hauts-de-Seine department may also appear as highly damaged under the R1.15 scenario (9.2% damage for the latter, 12.1% for Val-de-Marne in this scenario).

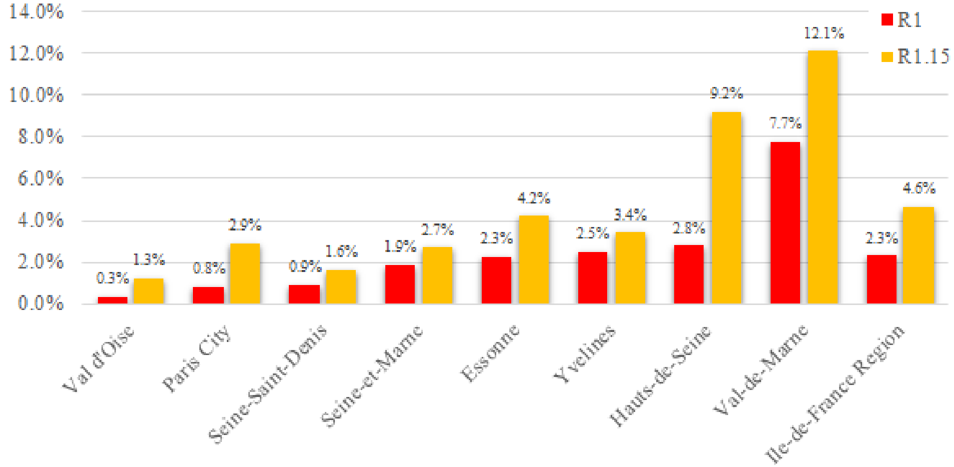

Fig. 3. Summary of community damage by department, for flood scenarios R1 and R1.15.

These disparities are even greater at the scale of municipalities (**Fig. 4, Table 4**). It is therefore possible to observe that, although regional damage ratios remain moderate, this is not the case on a lower level. Long-term social impacts remain a problem whose effects are felt most on a local scale. Thus, for a R1.15 scenario, the municipalities of Villeneuve-la-Garenne (Hauts-de-Seine), Alfortville (Val-de-Marne), Viry-Châtillon (Essonne) are characterized by a damage ratio superior to 50% of their basic structures and infrastructure. More broadly, twenty municipalities (amongst those with more than 10,000 inhabitants) have to deal with a damage ratio superior to 20%.

Crossing community damage and ISD values allows the identification of particularly vulnerable municipalities. Thus, **table 4** ranks municipalities according to the Index of Social Destabilization, according to damage ratios, and to the two combined factors. A geography of post-disaster vulnerabilities is then possible: the most sustainable post-disaster social impacts can then be identified within municipalities that combine the high damage and the high destabilization index. In the latter, the population is not only vulnerable, but it also faces severely degraded post-disaster environmental conditions, in terms of access to public services, housing, transport and businesses that are essential to daily life. As such, the municipalities of Villeneuve-la-Garenne, Gennevilliers (Hauts-de-Seine), Villeneuve-Saint-Georges (Val-de-Marne), appear as communities to prioritize during the recovery stage.

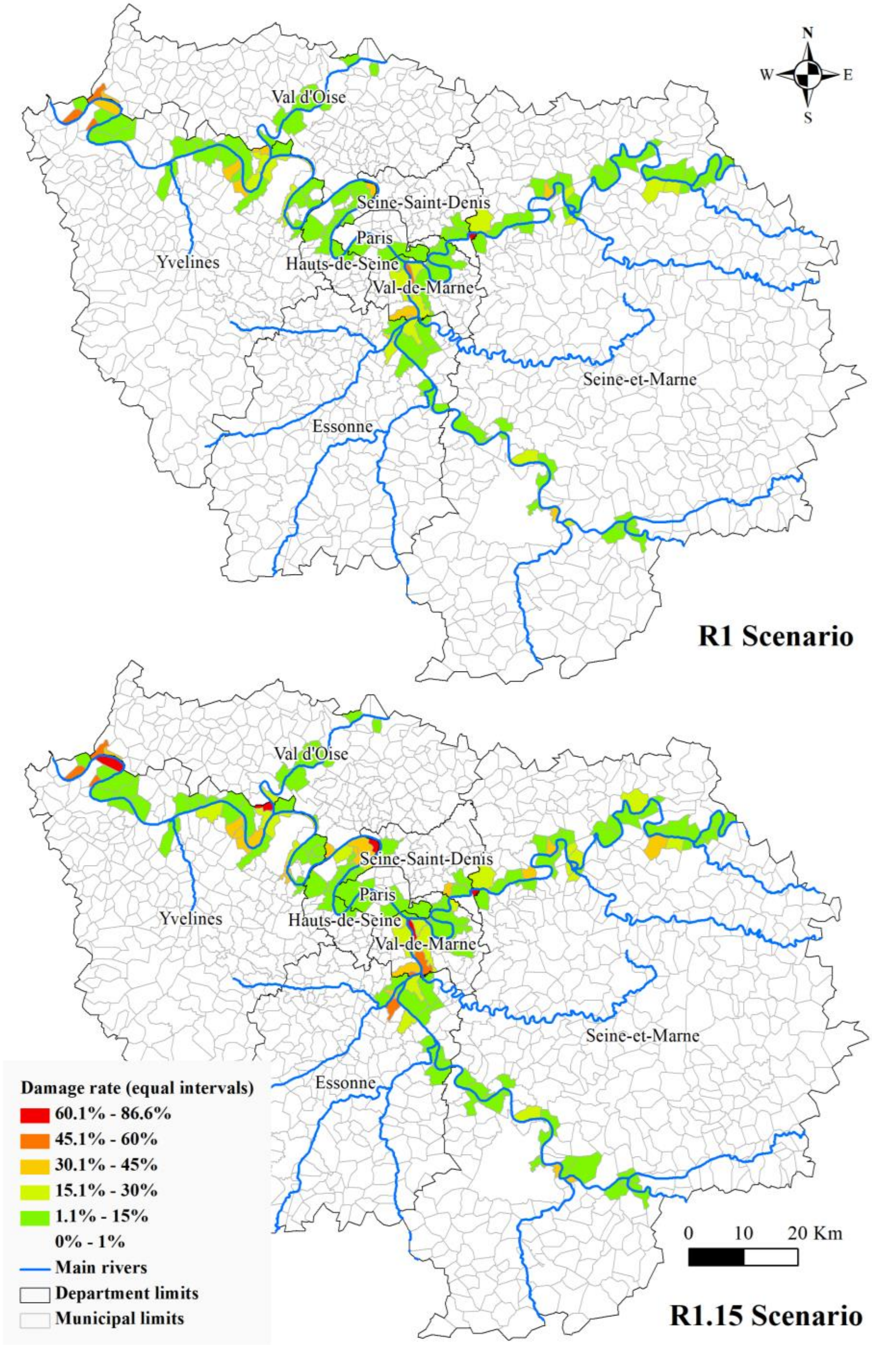

Fig. 4. Community damage ratio mapping in Paris region.

Table 4.

Classification of municipalities with more than 10,000 inhabitants according to the index of social destabilization and community damage ratio, for a R1.15 flood scenario.

Municipality name	ISD		Damage ratio		Mean rank (ISD + Damage)
	Value	Rank	%	Rank	
VILLENEUVE-LA-GARENNE	1,6	4	75%	1	1
GENNEVILLIERS	1,8	1	44%	5	2
VILLENEUVE-SAINT-GEORGES	1,6	5	50%	4	3
ALFORTVILLE	1,2	11	62%	2	4
VIRY-CHATILLON	0,8	20	52%	3	5
VILLENEUVE-LE-ROI	0,9	19	43%	6	6
IVRY-SUR-SEINE	1,5	7	26%	18	6
BEZONS	1,1	14	31%	11	6
VITRY-SUR-SEINE	1,3	10	27%	17	9
VALENTON	1,5	6	19%	21	9
LES MUREAUX	1,6	3	16%	25	11
VIGNEUX-SUR-SEINE	1,0	17	29%	13	12
MONTEREAU-FAULT-YONNE	1,7	2	14%	31	13
ASNIERES-SUR-SEINE	0,7	23	31%	10	13
CLICHY	1,3	9	15%	26	15
CHOISY-LE-ROI	1,1	13	17%	23	16
JUVISY-SUR-ORGE	0,6	28	39%	8	16
COLOMBES	1,0	16	21%	20	16
CARRIERES-SOUS-POISSY	0,7	25	31%	12	19
NEUILLY-PLAISANCE	0,5	31	42%	7	20
CRETEIL	1,1	12	15%	27	21
RIS-ORANGIS	0,9	18	18%	22	22
CHELLES	0,6	29	29%	14	23
ACHERES	0,6	30	27%	16	24
CORBEIL-ESSONNES	1,4	8	12%	39	25
MAISONS-ALFORT	0,5	32	27%	15	25
LE PECQ	0,2	44	37%	9	27
PARIS 15E ARRONDISSEMENT	0,7	24	14%	30	28
ATHIS-MONS	0,7	26	14%	33	29
GAGNY	0,8	21	9%	43	30
PONTOISE	1,0	15	5%	50	31
SAINT-MAURICE	0,5	36	14%	32	32
JOINVILLE-LE-PONT	0,5	34	13%	35	33
PARIS 12E ARRONDISSEMENT	0,6	27	9%	42	33
ANDRESY	-0,1	50	23%	19	33
ISSY-LES-MOULINEAUX	0,3	41	15%	29	36
BRY-SUR-MARNE	-0,0	47	17%	24	37
LE PERREUX-SUR-MARNE	0,2	43	15%	28	37
LAGNY-SUR-MARNE	0,5	35	12%	37	39
PARIS 4E ARRONDISSEMENT	0,8	22	5%	51	40
BOULOGNE-BILLANCOURT	0,4	38	13%	36	41
CHARENTON-LE-PONT	0,5	33	8%	45	42
SAINT-MAUR-DES-FOSSES	0,1	45	14%	34	43

DRAVEIL	0,4	39	9%	41	44
VAIRES-SUR-MARNE	0,4	37	9%	44	45
RUEIL-MALMAISON	-0,0	46	12%	38	46
LEVALLOIS-PERRET	0,4	40	8%	47	47
PARIS 8E ARRONDISSEMENT	0,2	42	8%	46	48
SAINT-CLOUD	-0,2	51	10%	40	49
VERNEUIL-SUR-SEINE	-0,0	48	7%	48	50
NEUILLY-SUR-SEINE	-0,1	49	6%	49	51

4.3. Conclusions

To conclude, this study is based on the combination of an analysis of social variables, expressing the intrinsic recovery capability of populations, and a community damage model, based on the analysis of environmental variables relating to flood hazard. In this way, it is possible to estimate post-disaster social impacts at the level of municipalities in the Paris region.

If reconstruction must be managed on a macro-geographic scale, through regional and national steering to mobilize massive logistical, financial and organizational means, long-term social impacts are felt primarily at the local scale. Municipalities characterized by both severe damage and weak recovery capability are likely to experience the most profound post-disaster changes in their socio-demographic profile: from the replacement of a given population by another to potential local desertification of the disaster area. Recovery is indeed a period marked by divergent territorial trajectories, which reproduce and accentuate pre-existing social and spatial disparities. Yet, recovery policies generally focus on physical capital reconstruction, neglecting social capital recovery and sometimes aggravating spatial inequalities in the recovery process (Aldrich, 2012, Gotham & Greenberg, 2014, Gotham, 2015). In order to avoid these pitfalls, the municipalities thus identified through our methodology must be the subject of in-depth consideration by the authorities of the Paris region in the planning process prior to the disaster.

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SYNOPTIC PROCESSES GENERATING WINDTHROWS. A CASE STUDY IN THE APUSENI MOUNTAINS (ROMANIA)

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ABSTRACT:
Windstorms are among the main factors causing damages to forest ecosystems. These meteorological phenomena cannot be predicted, prevented or controlled. They are occurring rapidly and take place in a meteorological context characterized by high velocities of the air currents. This paper analyses the characteristics of the severe meteorological events on 20 July 2011 which have led to windthrows on extended areas within the Apuseni Mountains in the Romanian Carpathians. The study highlights the evolution of the synoptic processes both at regional scale and at mesoscale. The meteorological analysis is carried out based on synoptic maps and by means of the data coming from the doppler WSR-98D radar in Bobohalma. The main results indicate the occurrence of the severe meteorological phenomena against the background of alternating atmospheric circulation types. The main cause is the transition of the zonal circulation into maritime tropical circulation. This contributed to the destabilizing of the warm and moist air masses that have generated strong storms at national level

Key-words: *Synoptic processes, Windthrows, Wind gusts, Radar images, Romanian Carpathians.*

1. INTRODUCTION

Over the last decades, windthrows have increased both in size and in frequency. The researches on future climate changes predict the enhancement of the extreme meteorological phenomena (windstorms) over the following decades (Thom & Seidl, 2015).

The causes of windthrows are both natural and anthropogenic. Many factors (meteorological, topographical, biological, and edaphic) interact simultaneously and influence the damage patterns and the recovery dynamics of these damages. As an ecological factor, the wind is no longer seen as a simple disturbance force, but as a spatial disturbance agent that causes significant damages to the forest vegetation. It affects more aspects of the disturbed forests such as community structure, individual tree growth, tree regeneration, and species diversity (Xi, 2005).

Scientific investigations estimate that approximatively 0.12% of the volume of European forests is disturbed every year (the average value for the 1950-2010 interval, after Schuck & Schelhaas, 2013).

The forests in the Carpathian Mountains represent the largest temperate forest in Europe. They are composed of beech and mixed forests, but also of many areas with spruce

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monocultures (Griffiths et al., 2014). The latter have a high vulnerability to windthrows. Windstorms are responsible for more than 50% of the damages caused to the European forests both by the biotic and by the abiotic factors (Gardiner et al 2011). The natural disturbances in the Carpathian Mountains are greatly caused by wind and snow, but forests are frequently affected also by pests, insects and industrial pollution (Oszlanyi, 1997).

Recent studies indicate that more than 28% of the forest areas in the Romanian Carpathians are vulnerable to windthrows (Savulescu & Mihai, 2012). The increase of forest vulnerability to windthrows is influenced also by forest management (Schuck & Schelhaas, 2013). Forest exploitation in Romania has intensified during the communist period (Grozavu et.al, 2012). This led to the fragmentation of the native species which have been replaced by spruce cultures, exploited for timber production (Munteanu et. al, 2014).

The main cause of the disturbances in the Romanian Carpathians is represented by windthrows (Anfodillo et al., 2008), although the extreme wind meteorological events occur once every 10-15 years (Popa, 2008). Most of the windthrows are diffuse, small scale (Costea et al., 2012; Furtuna et al., 2016). Some of them are not even being registered in the forest management books. However, greater attention was paid to windthrows in the Apuseni Natural Park caused by strong winds and storms (Costea & Haidu, 2010; Furtuna, 2017).

The reason for this study is given by the yet increasing frequency of windthrows in the Apuseni Mountains and by the intensification of extreme meteorological phenomena leading to their occurrence. Their effects are directly connected to the pressure of the wind on the brushes and by the amount of rainfall during the meteorological phenomenon. However, since 2011 there have been recorded no windthrows of such amplitude in the Apuseni Mountains.

The main objective of this study is to analyse the characteristics of the severe meteorological events on 20 July 2011 that have led to windthrows on extended areas within the Apuseni Mountains. The paper analyses to what extent is the severe weather capable of generating significant windthrows. At the same time, the paper highlights the evolution of the synoptic processes both at regional scale and at mesoscale. Understanding the interaction process between wind and forest vegetation, as well as the impact of the damages caused by the wind, is important in forest management in order to establish and implement some sustainability policies.

2. DATA AND METHODS

The analysed area is located in the north-eastern part of the Alba county, with the following coordinates: 46°21´N and 23°02´E (**Fig. 1**), overlapping the Muntele Mare and Trascău Mountains and the Câmpeni lowland area.

The climate features are directly influenced by the geographical position. The annual temperatures are closely connected to the local morphological specificities. Hence, the channelling of air and low temperature on the Arieș Valley, especially during winter, leads to lower temperatures (Maier, 2011).

The vegetation in the area is specific to the hill and mountain regions, composed of mixed {beech (Fagus Sylvatica), fir (Abies Alba) and spruce (Picea Abies)} forests. The area affected by windthrows is located at altitudes ranging between 800-1200 meters, composed of coniferous (especially spruce) and broad leaf forests.

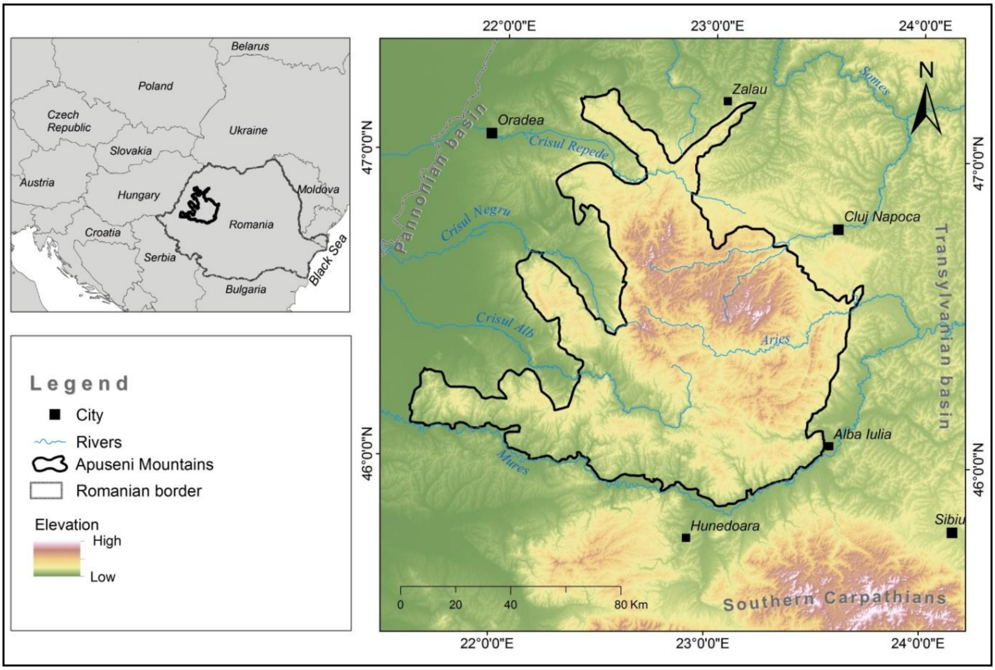

Fig. 1. Location of the study area (source Furtuna, 2017).

The methodology used for this study focused on the synoptic analysis of the meteorological conditions of the windthrows on 20 July 2011. Yet, the first stage of the study has implied the detection of the areas affected by windthrows. Based on the data referring to the extreme weather event on 11 July 2011, Landsat satellite images were used for the period before and after the meteorological phenomenon. The Landsat sensors are a useful tool for ensuring the images necessary for the assessment and monitoring of the changes induced to the forest vegetation (Vogelmann et al., 2012). The Landsat images have been pre-processed to calculate the root mean square error (RMSE) for the two images that were used and to convert the digital numbers into the surface reflection according to the established methodologies (Furtuna et al., 2015; Haidu et al., 2017).

The detection of the changes occurred in the forest vegetation after the storm (**Fig. 2**) was carried out based on the calculation of the difference between the NDVI index calculated for the image before and after the storm, respectively.

The synoptic analysis was carried out based on the synoptic maps of the European continent, the maps of the pressure field at soil level, the maps of the geopotential and temperature field of the National Oceanic and Atmospheric Administration http://www.esrl.noaa.gov and DWD - Deutscher Wetterdienst *www.wetterzentrale.de*.

In the case of sub-synoptic scale (mesoscale) or storm scale analysis, data from the Doppler WSR-98D radar in Bobohalma (Mureș county) were used. In order to determine the movement direction and the speed of storm movement, thematic radar images were used such as reflectivity, images of the convective storms movement speed, of the Vertically Integrated Liquid water (VIL), and of the cloud masses height.

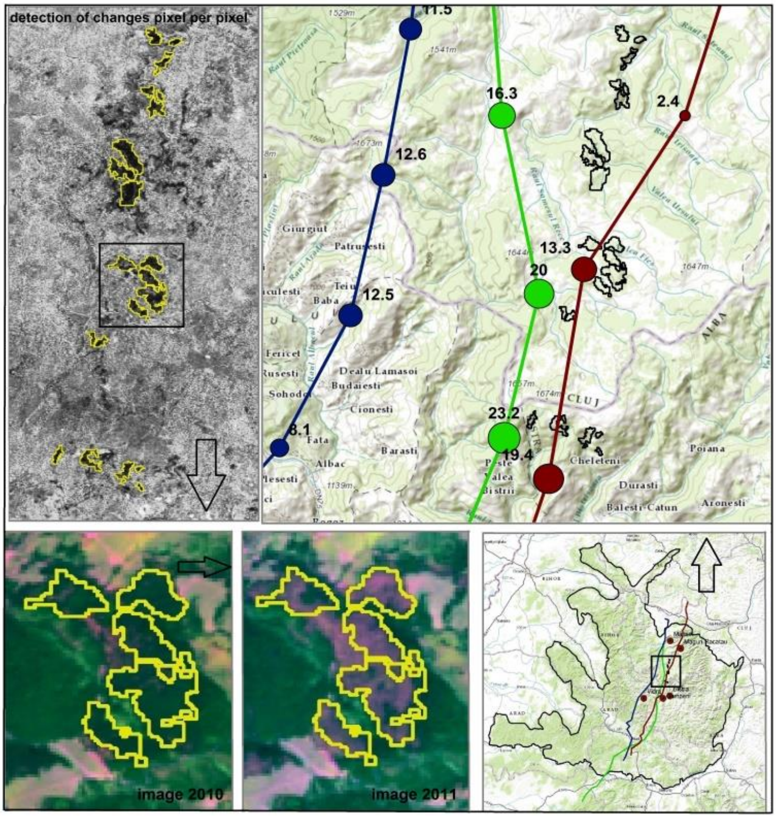

Fig.2. The detection of the areas affected by storm, as well as the paths of the convective phenomena.

When calculating the speed of wind gusts, we used the corresponding values of VIL and ET applied in the formula used also by the researchers at Air Force's Air Weather Service (1996).

$$W= [(15.780608 \cdot VIL) - (2.3810964 \cdot 10^{-6} \cdot ET^2)]^{1/2} \text{ (AWS, 1996)}$$

where: VIL is the vertically integrated liquid water volume [$kg \cdot m^{-2}$], ET is the height of the cloud (echo) [km].

The analysis methodology of the synoptic situations was carried out by means of the images with the tempo-spatial evolutions of the VIL product, extracted from the values of storm cores and superimposed over the rainfall areas. This methodology brings additional useful information in order to determine the paths of the convective phenomena depending on the moisture load and speed of travel.

3. RESULTS AND DISCUSSION

The synoptic conditions that generated the significant amounts of rainfalls and storms on 20 July 2011 leading to windthrows on more than 120 ha of forests in the Apuseni Mountains were caused by the intensification of the cyclonic activity.

The synoptic situation before the occurrence of the 20 July storm was characterized by western atmospheric circulation above our country. This synoptic configuration persisted, with slight variations, from 15 July until 19 July **(Fig. 3)**. It was characterized by a hot and dry period, with temperatures exceeding 35°C.

Following the geopotential field at the 500 hPa isobar level, the altitude difference can easily be identified, with a well highlighted core in the north of Europe, characterized by a pressure in the 995 hPa centre. A secondary core with 1000 hPa pressure is located in the centre of Europe, also affecting western Romania on 20 July.

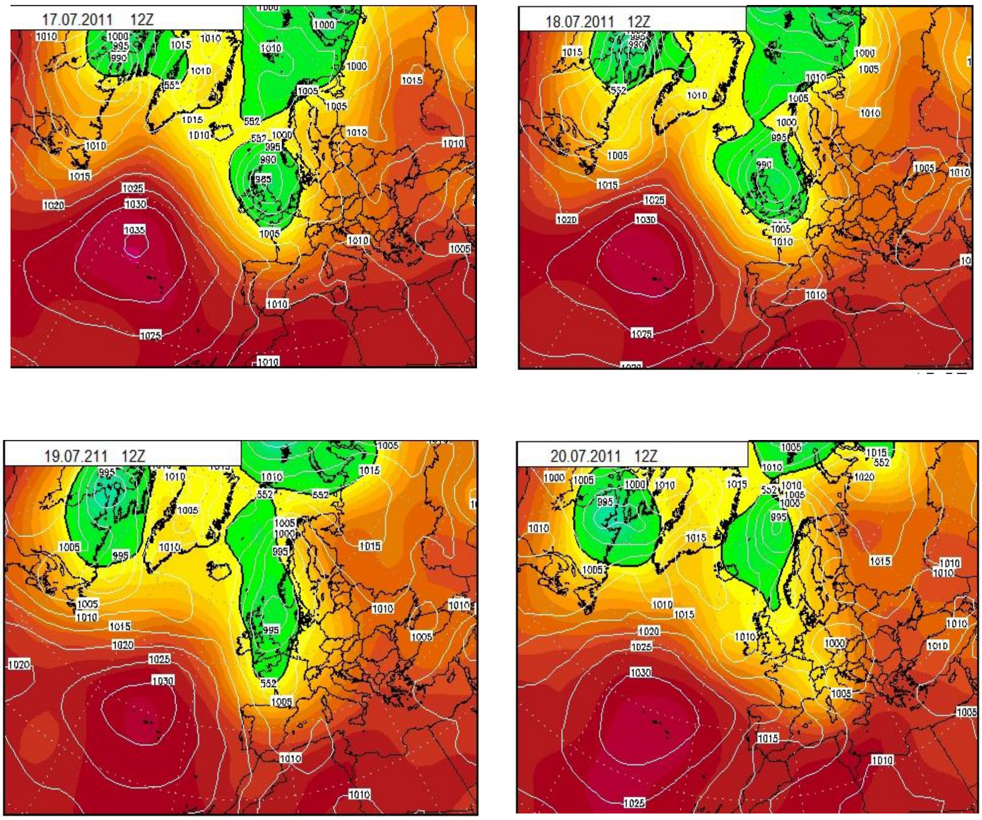

Fig. 3. The geopotential field at the 500 hPa (550 m) isobar level, the 17-20 July 2011 interval. *(source: www.wetterzentrale.de)*

The geopotential field configuration at the 500 hPa isobar level indicates a low value of the geopotential of only 5720 mgp. Based on the structure of the air temperature field at the 850 hPa level, the Western Romania fits within the 17°-18° range **(Fig. 4)**.

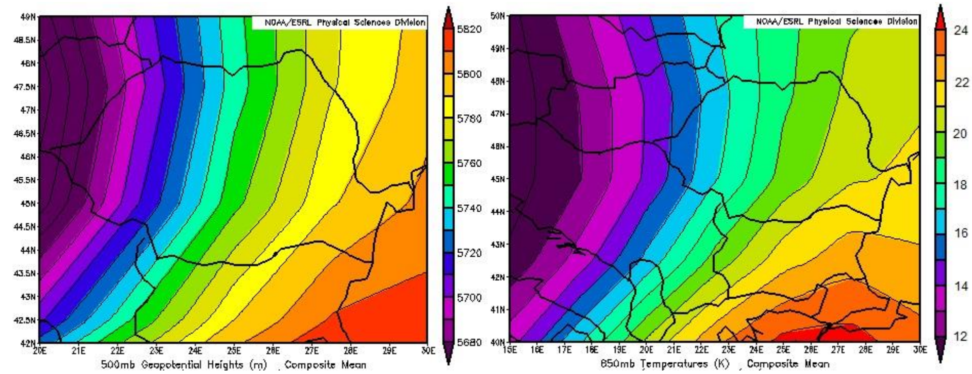

Fig.4 The geopotential field at 550 hPa and the structure of the air temperature field at 850 hPa level for the Romanian territory (processed by means of http://www.esrl.noaa.gov) for the day 20.07.2011.

The baric situation over Europe indicates the presence of an anticyclonic field at the ground level over the Western Europe and in the north of Africa. The rest of the continent was dominated by a cyclonic field, with a core located in the Pannonian Plain and the west of Romania with the 998 hPa pressure **(Fig. 5)**.

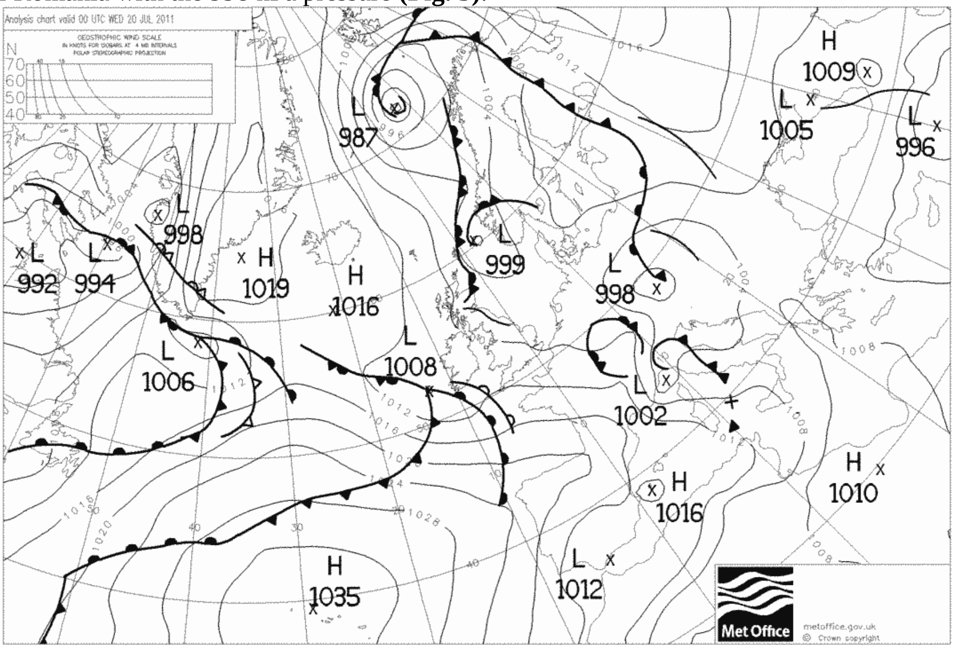

Fig. 5. The atmospheric pressure front on 20.07.2011, at 00.00, at sea level.
(*source: www.wetterzentrale.de*)

On 20 July, the transition of the zonal circulation into maritime tropical circulation, contributed to the destabilizing of the warm and moist air masses that generated strong storms at national level.

Windthrows were caused by the convective descending movements which were associated with the increase of the cumulus clouds and the development of storms (Furtună et al., 2013). Although convective winds occur suddenly and violently, these have a short duration and determine violent occurrences of meteorological phenomena at soil level.

The day of 20 July starts with a pre-front instability. The first D0 wind gust started around 12:00 GTM **(Fig. 6)**, being formed in the Zarand Mountains area. The wind gust increases in intensity with the movement to the north, reaching the speed of 23 m/s south of Vidra village.

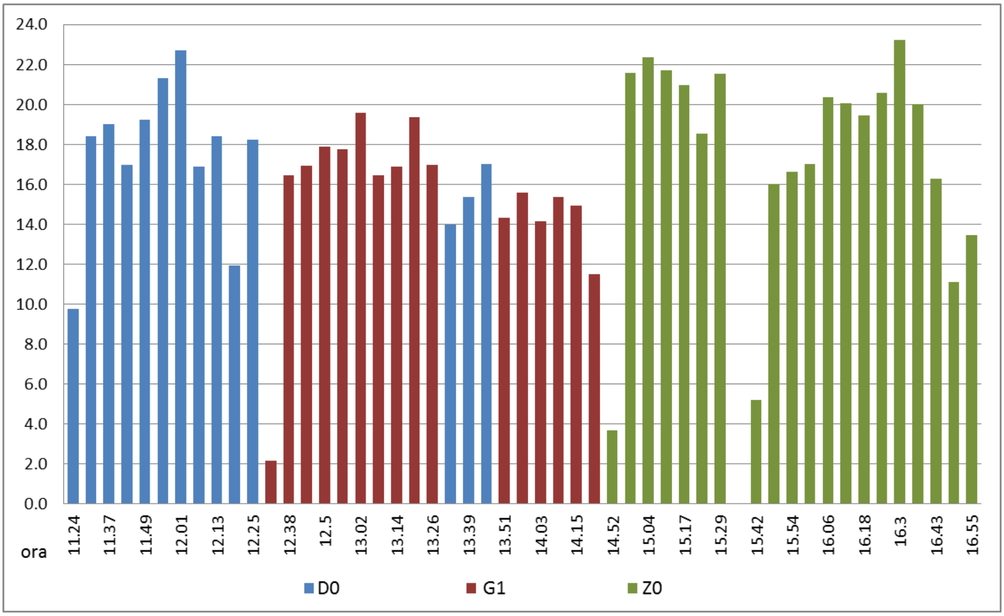

Fig. 6. The speed of wind gusts and the time interval they took place.

The second wind gust, G1, developed around 12:30 and had constant speeds, which did not exceed 20 m/s. This speed was recorded when the gust crossed the town of Câmpeni, where the windthrows occurred.

The Z0 wind gust was formed in the Poiana Ruscă Mountains area. It was stronger in intensity; it exceeded 23 m/s in the area of Câmpeni and Bistra localities when it reached the mesocyclon level (MESO - indicates the existence of wind shears within the storm). The mesocyclone is associated with a lower pressure region located in a severe storm and generating tornadoes. Such storms are characterized by strong surface winds and hail. The wind gust has lost its intensity when meeting the mountain range blockage in the Muntele Mare area **(Fig. 7).**

The graphical form of the storm core path indicates the air circulation from the lower troposphere to the middle one, i.e. from the south-east to the north-west **(Fig. 7)**. The strongest gusts recorded speeds higher than 23 m/s when crossing the affected area.

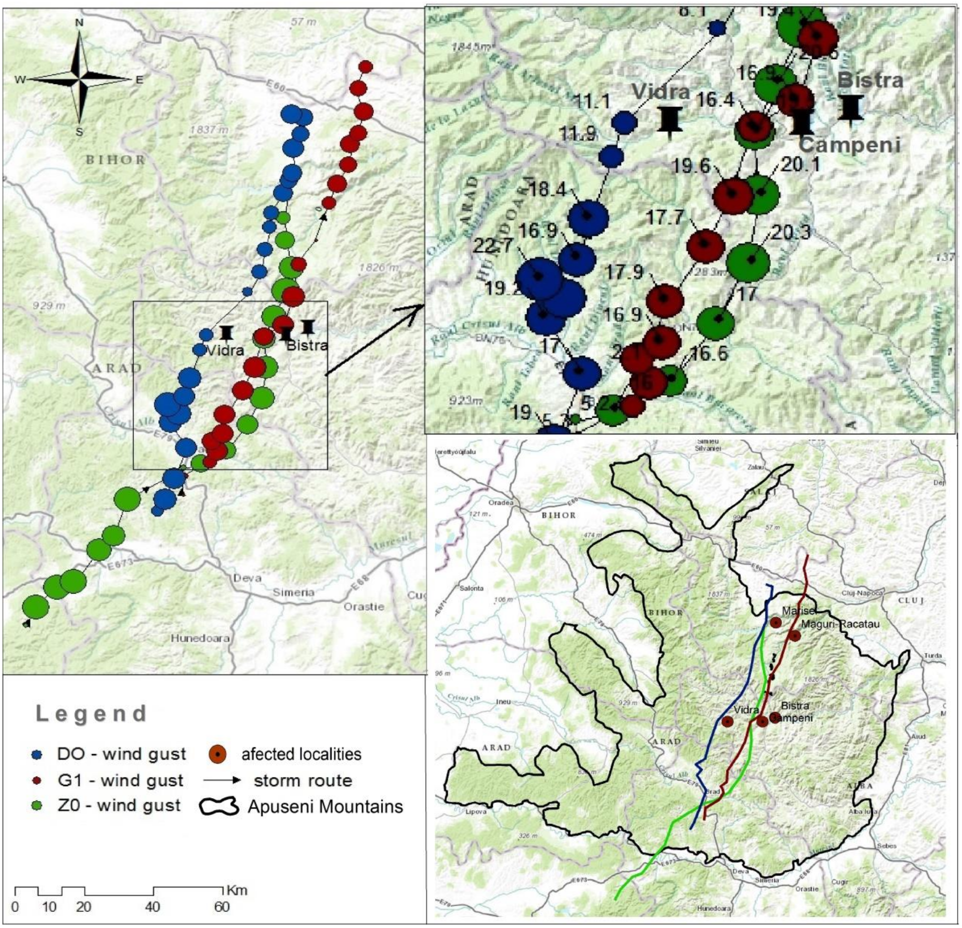

Fig. 7. The trajectory and speed of the wind gusts in the area affected by windthrows.

After this storm episode, the instability gradually decreased during the night of 20-21 July, when a new hot and dry period started.

4. CONCLUSIONS

The synoptic situation of the storm that caused windthrows on more than 150 ha of forest was favoured by the alternating atmospheric circulation types. This created a favourable context for the formation of convective cells. The windthrow was caused by the descending convective movements. All these high-altitude cold air convections remained on the valleys and caused windthrows.

The calculation of the gusts speeds by means of VIL and ET corresponding values enabled us to determine the paths of the convective phenomena and their speed of travel. The three cores had a travel direction from the south-eastern to the north-eastern sector, crossing the Apuseni Mountains. In terms of meteorological risk, the windthrow on 20 July 2011 was characterized by the occurrence of the short-term wind gusts at speeds higher than 23 m/s (almost 90 km/h).

The Apuseni Mountains area can become the stage of such phenomena whenever the zonal circulation turns into maritime tropical circulation. The instability of the warm and moist air masses is favoured by the fact that the mountains are surrounded by low lands (the Western Hills and Plain, the Transylvanian Plateau, the large corridor of the Mureş River). The elevational gradient conferred by the sudden transition to high altitudes is very important.

The morphography of the Apuseni Mountains is characterized by the high fragmentation of the landforms. This is achieved by embedding the "gulf depressions", the depressions inside the mountain range, the saddles and the large and deep valleys, which facilitates the formation of some storm corridors which are not stopped when meeting higher and more compact massifs. The mountain crests appear under the form of some suspended erosion platforms steps, rather plane, which also facilitate the sliding of the air and the wind travel. Under these morphographical conditions, the high-altitude cold air convections have installed and intensified along some valleys and saddles on a south – north trajectory and have caused windthrows. It would be interesting to study in the future which is the occurrence frequency of these storm trajectories and whether preferential travel corridors could be identified depending on the elevation baric configuration.

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THE INDIAN HIMALAYA`S UNIQUE ATTRIBUTES: HEMKUND SAHIB AND THE VALLEY OF FLOWERS

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ABSTRACT:

The Indian Himalayan ranges with towering snowclad peaks and deep valley river rapids present a variety of common geographical features. The high mountain environments gained social values due to the influence of the human ancient cultures. The spiritual dimension of the geographical space generated its unique attributes. This research investigates some of the most intriguing mountain locus which are defined by a cumulus of special characteristics. We identified the uniqueness generating factors using the geomedia techniques. Furthermore, this study analyses the interconnection between Hemkund Sahib and Valley of Flowers Geosystems` different components. Our research findings present the functionality of two selected dynamic Himalayan geosystems in a significant equilibrium state. This result of this paper will contribute to the preservation of Hemkund Sahib and Valley of Flowers' unique features and future promotion using the new technical Geography advances.

Key-words: *Himalayas, attributes, Hemkund Sahib, geo-apps, Valley of Flowers.*

1. INTRODUCTION

The Indian Himalaya's unique attributes based on the Geosystems grounded theory approach, using the modern technical Geography tools in an attempt to provide innovative solutions for the increasingly visited mountain sites (Voda et al, 2014). This paper has analyzed geographical spaces that are characterized by special features, generated from the interaction between the environmental components and the central element of any geosystem: the human being.

The Valley of Flowers National Park lies in the main valleys of Alaknanda and Dhauli Ganga in the Garhwal Himalayas in Chamoli district of Uttarakhand State in India. Valley of flowers also known in Hindu mythology as Nandan Kanan meaning "Garden of Indra in Paradise" has been declared as a National Park (VOFNP)as per Notification No. 4278/XIV-3-66-80 with effect from September 6, 1982, the intention having been declared under Notification No. 5795/XIV-3-66-80 of 1 January 1981. After notification of the Park, grazing and camping are not permitted.

Given the status of World Heritage site in 2005 VOFNP is one amongst the nine zones or part of the Nanda Devi Biosphere Reserve (NDBR) which is spread across an area of 5860.69 sq km. Located between the Latitude 30° 41' – 30° 48'N and Longitude 79° 33' – 79° 46'E VONP covers an area of 87.5 sq. km. The altitude of the valley ranges from 3200 m to 6700 m.

River Pushpawati flows through this valley which has its source in the Tipra Glacier which extends up to Ghori Parbat peak. It is a flat valley 5 km long and 2 km wide. The

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main valley portion of the Park runs in the east west direction along the banks of river Pushpawati (Gupta, 2002).

The park is surrounded by Gauri Parbat (6590m) and Rataban (6126 m) in the east, Kuntkhal (4430 m) in the west, Saptsring, in the south and Nilgiri Mountain (6479 m) in the north. The credit for the discovery of the Valley of Flowers generally goes to the British mountaineer Frank S. Smythe and R.L. Holds Worth who accidentally reached the valley after a successful expedition of Mount Kamet in 1931. Fascinated by its beauty and grandeur Frank S. Smythe revisited this area in 1937 and published book "The Valley of Flowers" (Smythe, 1938) which made it world famous.

The valley offers a rich plethora of unique floral wealth out of which 31 rare and endangered plant species including 11 species listed in the Red Data Book (RDB) of the Indian plants recorded within the Valley of Flowers National Park. The surrounding areas also have some beautiful Himalayan grassland and other valleys which bears many exquisite Himalayan flowers like the Himalayan lotus.

Fig. 1. Valley of Flowers and Hemkund Sahib in Google Earth geo-app (Google Earth, 2018).

Near the Valley of Flowers is the sacred place of Sikhs the Hemkund Sahib **(Fig.1)**. It is situated at an altitude of 4329 m, and sacred to both Sikhs and Hindus. Hemkund Shrines are one of the highest temples in India (Fonia, 1998; Kuniyal et al, 1998).

The Sikhs revere this place because their tenth Guru described its location in his holy writings, in the *Dasam Sahib* (the books of the Tenth Guru). Considered the Geosystem`s unique cultural attribute, Hemkund Sahib location was discovered in 1934 by Sant Sohan Singh in remembrance and prayer to see the place where their tenth guru, Guru Govind Singh meditated and realized his oneness with God along the banks of Lokpal Lake. A small Gurdwara was developed in 1935-36 (including enlarging the ancient Hindu "Lokpal" temple) and later in 1968 the construction for the present Gurdwara began which got completed in 1993. For the Hindu the lake known as Lokpal constitute the unique attribute of this geographical location from the Himalayas. Here, Lakshman, the younger brother of Lord Rama, had meditated. A small temple is dedicated to Lakshman and it stands next to the Gurudwara. Lakshman / Hem Ganga stream originates from the Lokpal Lake, which later meets river Pushpawati near Ghangharia and further flows as Bhyundar Ganga to join the river Alaknanda at Govindghat (Kaur, 1985).

The Sikh pilgrims have been the biggest draw for tourism in this area. Every year near about 400000 pilgrims visit Hemkund and Laxman temple before 2013 but only few thousands visits the valley. Tourism plays a very important role in the sustainable development of the area as about 95% of the indigenous population depends on it. The main influx of tourists consists of Sikhs.

There is no significant difference between the common functional attributes of the Valley of Flowers and Hemkund Sahib Geosystems. Climate is moist temperate and alpine type, with short cool summers and long severe winters influenced by southwest monsoon in the summer, and western disturbances in winter. During the snow period (7 months early October to late April) the vegetation survives under snow with the help of tubers and rhizomes.

2. STUDY AREA ACCESSIBILITY

The nearest airport is Jolly Grant, which is 306 km away from the research area. The nearest broad-gauge railhead is Rishikesh (about 271 km), while Haridwar railhead is at a distance of about 295 km by road from Govindghat which is about 25 kilometres before Badrinath. It is located on Rishikesh --Srinagar - Joshimath- - Govindyhat-Badrinath route. The Valley of Flowers is a trek of about 13 km from Pulna village which is 3 km from Govindghat. Govindghat is the base of the route to the Ghangharia base settlement (14km from Govindghat) and from Ghangharia subsequently one trail goes towards Valley of Flowers (3-4km) and another steep trail to Hemkund Sahib (6km). Four-wheel drive services are available to drop tourists from Govindghat to Pulna. Pony and palanquins are available on fixed prices by Eco Development Committee (EDC) for Ghagharia /Hemkund Sahib from Pulna. Helicopter service is also available from Govindghat to Ghangharia. The trek route for Valley of Flowers is relatively easy compared to trek stretches like from Bhyundar to Ghangharia, or that for Hemkund Sahib, which are much steeper.

Fig. 2. The access route from Rishikesh to Valley of Flowers and Hemkund Sahib (Google Earth, 2018).

This trek route from Govindghat is maintained by the PWD. The Eco Development committees of Ghangharia and Govindghat are looking after the cleaning of the trek route (Gupta, 2010).

There is no settlement within the National Park (**Fig. 2**). Four settlements exist between the Park fringe and the motor road such as the tourist settlement of Ghangharia, villages Bhyundar, Pulna and the tourist settlement of Govindghat. The local population is about 80 families/households (about 375 persons) in Pulna, the winter settlement. Except the school going children and few elderly people, these villagers migrate to Bhyundar and Ghangharia, the summer settlements from May to early October. While women stay back at Bhyundar with small children, the men folk move further 3.75 km to Ghangharia, which is the central place/base in upper valley for tourist activities for 4 months from June – September every year.

Small commercial establishments have been registered and regularized by a local NGO body known as Eco-Development Committee (EDC), Bhyundar under the aegis of the Department of Forest. Around 60 shops from Govindghat to Ghangharia and 15 shops from Ghangharia to Hemkund Sahib, while at Ghangharia itself some 40 private establishments of lodges/restaurants/photo studios/souvenir shops, etc. are registered. These establishments erected on Private/*Nap* land are called "*Chak*" and those on Forestland are called "*Chatti*" and these are either run by the villagers themselves or given on rent.

3. METHODOLOGY

This paper research based on the Geosystem grounded theory, has focused on the technical geography advances role in the unique attributes' identification and assessment from the Indian Himalayas. Being the most famous and intriguing, the Valley of Flowers and Hemkund Sahib Geosystems, situated in the Himalaya Mountains near the China border, has been selected for this study.

Data was gathered from different geomedia sources, non-structured interviews and field observations were carried on site in between May-June 2013 and September 2018. The collected data were analyzed using geomedia techniques that imply geo-coding procedures and theoretical sampling for the Geosystem`s carrying capacity assessment (Haidu, 2016; Voda et al, 2017).

Our theory consistency derives from the dynamic balance of the Hemkund Sahib and Valley of Flowers Geosystems, which are continuously developing in a self-sustainable way. There is a powerful connection between the environmental components and the human factors that generates the geosystems` functionality.

The theoretical elaboration is based on the reproducibility capacity of our defined geographical spaces. Their systemic characteristics and elements properties, inductively derived from gathered geo-data were identified and judged with respect to a number of evaluative criteria such as consistency, integration and predictiveness.

The Geosystem grounded theory explanatory power facilitates its application in different world`s regions as long as the defined geographical spaces fit to data. Constructed as a problem orientated endeavor, our geosystemic theory was created from solid data patterns, produced through the elaboration of Hemkund Sahib and Valley of Flowers plausible models.

Our research problems have been structured in accordance to the scientific inquiry task focused on the protection, conservation and self-sustainable development of identified geosystems. Once identified, the problems were selected for consideration, developed and modified.

Our geomedia techniques has also used Geosearch and Geocoding services from ArcGIS World to validate locations coordinates and Pic2Map geo-application to analyze EXIF data embedded in the photos taken on site with Xiaomi Redmi 3S and MI A2 smartphones (Ernawati et al, 2018).

4. RESULTS AND DISCUSSIONS

Domestic tourists form a major portion of the total tourists visiting the Himalayas. A key factor for this high domestic tourist inflow in the area is the presence of holy pilgrimages like Badrinath, and Hemkund Sahib. The shrines remain closed for six months during winters. Badrinath, by virtue of being one of the four Hindu sacred places (*Dhams)* of the country had been and continue to be the biggest pilgrim puller evidently, witnessing 10755883 tourist arrivals (including foreigners) in 2008 and 941092 arrivals in 2012. However, a significant decrease has been noticed in the tourist arrival at both these shrines during year 2009 over the previous year (Kandari and Gusain, 2013). The reason for this downfall can be attributed to severe road blockage due to early monsoon. The Himalayan weather problems caused by torrential rain, cloud bursts and flash floods during mid-June 2013 in this region of Uttarakhand had resulted in the severe damage to tourism infrastructure and badly affected the tourism industry and tourist traffic for the year 2013,2014 and 2015 (Gupta & Vijay, 2013).

The pilgrim/tourist traffic is witnessing erratic growth in the Hemkund Sahib and Valley of Flower areas. **Fig.3** illustrates the pilgrim/tourist traffic trends at these two places from 2005-2017. It would also be pertinent to mention here that barring Valley of Flowers, Hemkund Sahib is important from the religious/pilgrimage perspective.

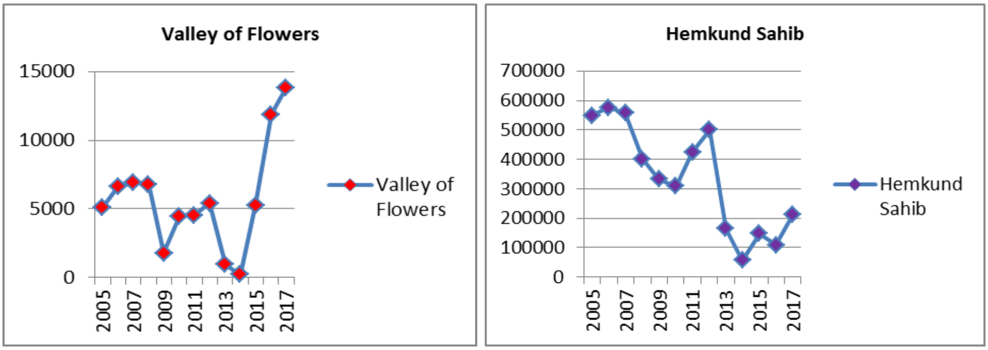

Fig. 3. The dynamic of tourist arrivals in the Valley of Flowers (left) and Hemkund Sahib (right), strongly influenced by climatic factors during 2009, 2010, 2013, 2014, 2015 and 2016.

According to Kuniyal et al (1998) the Himalayas were affected by the influence of pilgrims and the lack of infrastructural services. They proposed the sustainable reuse and recycling of the tourist garbage instead of the openly dumping of the solid waste. After 20 years the problem is solved, as we observed during our expedition in September 2018.

EDC collects non-biodegradable waste into sacks and dump it at Govindghat from where it is sent either for recycling or for disposal.

Pulna (about 3 km from Govindghat) and Bhyundar (about 9 km from Govindghat) are the only villages, which can offer shelter (by local residents sharing their dwelling units) in an emergency of trek path getting blocked on the way to Ghangharia. Camping in tents is provided with the permission of District Forest Office (DFO), Joshimath through EDC assistance, on Forest land of the non-core zone area. From Pulna normally the trek starts in the morning during onward journey to Ghangharia/Hemkund Sahib and the return treks end at Govindghat in the evening. Gurudwara at Govindghat can accommodate up to 6000 persons comfortably and the one at Ghangharia can accommodate up to 12000 visitors in the rush season (June-July). All the visitors have to sleep on floors for which enough mattresses and blankets are available, even to meet the needs of rush season.

Sikh *Gurudwaras*, managed by the trust that oversees the operation of the pilgrimage to Hemkund Sahib, offer food and lodging at Rishikesh, Srinagar, and Joshimath enroute to Valley of Flowers-Hemkund Region. Govindghat has one Gurudwara, few private lodges and forest rest house for night stay. Ghangharia is the base settlement offering accommodation facilities to the tourists for night halt either for onward travel to Valley of flowers and Hemkund Sahib or return travel to Govindghat (**Fig.4**).

Govind Dham Gurudwara is the largest accommodation at Ghangharia. Due to its high accommodation capacity, apart from free food arrangements (*Langar*), majority of the visitors who are mainly on pilgrimage to Hemkund Sahib avail the Gurudwara facility. Thus, the economic flow in favor of the local communities is highly affected. The government provided accommodation like GMVN Tourist Rest House (TRH) and Forest Rest House (FRH) charge relatively high and fixed tariffs. There are around 20 private guest houses/lodges providing relatively cheaper accommodation due to fierce competition to get high occupancy. Though the accommodation in rest houses/lodges has attached bathrooms/toilets with piped water supply, hot water that is must at these cold temperatures is unavailable through piped means. But water separately heated on large kerosene/gas stoves are provided by these establishments at a reasonable cost.

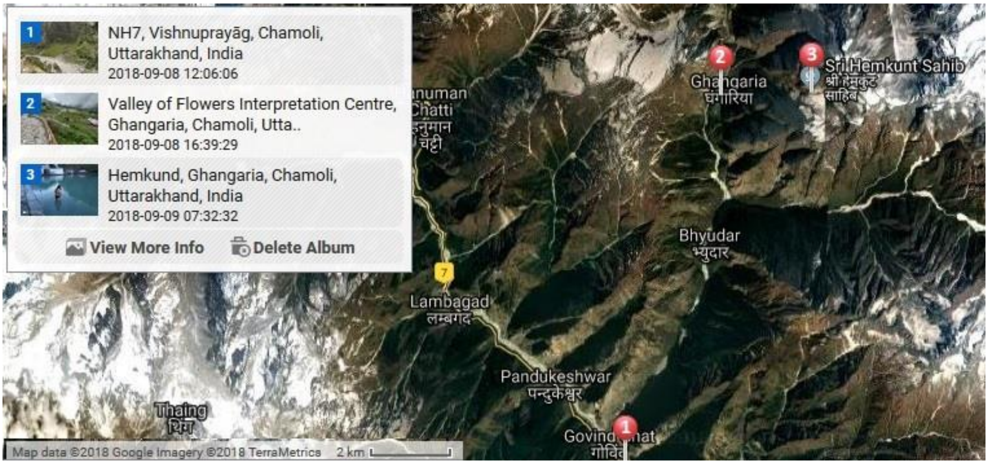

Fig. 4. The Valley of Flowers and Hemkund Sahib route from Govind Gath to Ghangharia (Pic2Map, 2018).

At Valley of Flowers, being declared the National Park night stay is not permitted. Similarly, at Hemkund Sahib Accommodation facilities are only for Gurudwara Staff and Lokpal staff in the Gurudwara and small Dharamshala respectively and they do not encourage general stay for those who are not acclimatized to stay at such heights due to conditions of severe cold and relatively low level of oxygen. Hence, visitors need to return back and stay at nights in Govind Dham Gurudwara or other accommodation at Ghangharia (**Fig.4**).

Facilities for the Holy Bath (*Ishnan*) were observed at Hemkund Sarovar. The Sarovar with considerable cold water can generate real problems for the bold tourists who enter in the lake. There are no lifeguards on site. However, the Gurudwara staff (many of them young volunteers/*sevadars*) were expected to take care of pilgrim requirements and the first aid center at Hemkund Sahib with a doctor provides emergency services and necessary medicines.

Down in the valley, the Govindghat Gurudwara has dispensary and ambulances. In *Govind Dham Gurudwara* there is a 24 hours facility dispensary room, with one doctor and two beds for nursing the patients. Also, a small government dispensary with one doctor exists near the Govind Dham Gurudwara.

Numerous small teashops, snack bars, and temporary sheds have come up between Govindghat, Pulna, Bhyundar, Ghangharia, and Hemkund Sahib to cater to the needs of tourists during summer. Food is also available at many basic restaurants at Govindghat and Ghangharia, while the Gurudwaras at Govindghat and Ghangharia offer free food at the *Langar* facility. Similarly, at Hemkund Sahib free *hot khichri* & *tea* and *prasad* is served to all the visitors. For quenching thirst with potable drinking water, one has to mainly depend on the packaged mineral water or soft drinks (mostly in plastic bottles, with exception of tetra packaging for thicker fluids like fruit drinks/juices).

Moreover, we observed that the overall spatial development and growth of Ghangharia has already happened in a haphazard manner, while structures have poor architectural aesthetics/construction quality with no proper water supply or solid waste disposal system in place. Currently, EDC collects eco-fee from so called hotels, lodges and restaurants, *Chatti's* and *Chak* Stalls for the four-month tourist season for environmental management along the trek path. Sewage is mostly disposed through individual septic tanks and soaks pits. Other effluents from kitchen/utensil wash flows down through open drains along the slopes at Govindghat**,** Pulna/ Bhyundar, Ghangharia and Hemkund Sahib. EDC has installed urinal toilets made up of pre-fabricated board body fixed on thin MS angle frames. No proper water supply is available.

Some of the EDC members from the local villages are trained guides in nature interpretation services and hence apart from their businesses they can earn additionally through guiding. From Govindghat, the taxi services are available up to Pulna village from where trek begins. Donkeys, mules (**Fig.5**), porters, and *palkies*-litter vehicles (**Fig.6**) can are hired mainly from Pulna or Ghangharia.

The pilgrims and tourists can rent mules and donkeys on fixed rate during peak season by the EDC by issuing of proper receipt by clearly showing the registration number of the Mule and Donkey-Kandi wala for Ghangharia, and Ghangharia to Valley of Flowers, Ghangharia- Hemkund or Pulna-Hemkund and back. The mule and donkey service constitute one of the local Geosystem`s special characteristics rarely met in other parts of the world.

Fig. 5. The mules and donkeys from the route to Ghangharia (authors expedition`s photos).

About 800-1000 mules operate on this trek path in peak season (about 500-600 at Pulna and 300-400 are available from Ghangharia). The quadrupeds are well trained and always supervised by local guides who permanently communicate between them.

Telecommunication service is available at Ghangharia connected to a Satellite Telephone Exchange of Department of Telecommunications. Our observations pointed out that such facilities are not good en route the trek path or at Bhyundar or Pulna. There are no good telecommunications facilities at Hemkund Sahib. However, the in case of emergency wireless facility can be availed from forest officials.

Fig. 6. The open portable litters between Ghangharia and Hemkund Sahib (authors expedition`s photos).

The pilgrimage phenomena to Hemkund Sahib generated another unique characteristic of the local Geosystems: the smaller litters in the form of open chairs, carried by one or four carriers (**Fig. 6**). During our exploratory research on the mountain trails we tried to understand what is driving this type of activity, undertaken by the local communities' men. However, the experience offered is unique and intriguing for any western tourist.

Security infrastructure is supposed to be offered by the Police posts that exist at Govindghat and Ghangharia, but they do not have jurisdiction in Valley of Flowers and Hemkund Sahib area (which basically falls under the jurisdiction of *Patwari*, Department of Revenue based at Pandukeshwar). Any accident happening in Valley of Flowers –Hemkund region is to be attended/ recorded by the *Patwari* and the Police station at Govindghat is only informed for any assistance, if required.

The Valley of Flowers nature information center at Ghangharia is available in the Forest Rest House complex. At this nature interpretation center, regular (30 minute) slide shows on Valley of Flowers and wild life are held in the evening hours (from 6:00 pm – 7:30 pm) throughout the 4-5 months of tourist season. Currently this slide show is conducted by few nature enthusiasts / interpreters / guides from the EDC members/local host community of Bhyundar / Pulna village trained by the office of the DFO & Deputy Conservator of Forest, Nanda Devi National Park, Joshimath.

The Hemkund Sahib Geosystem`s information flux is considerable better developed, aligned to the latest technological advances. The smartphone geo-application created by Mebonix (**Fig. 7**) meet the basic needs of the pilgrims in search for general information about the geographical location coordinates, accessibility, accommodation, brief historical introduction, news and weather conditions (Mebonix, 2017).

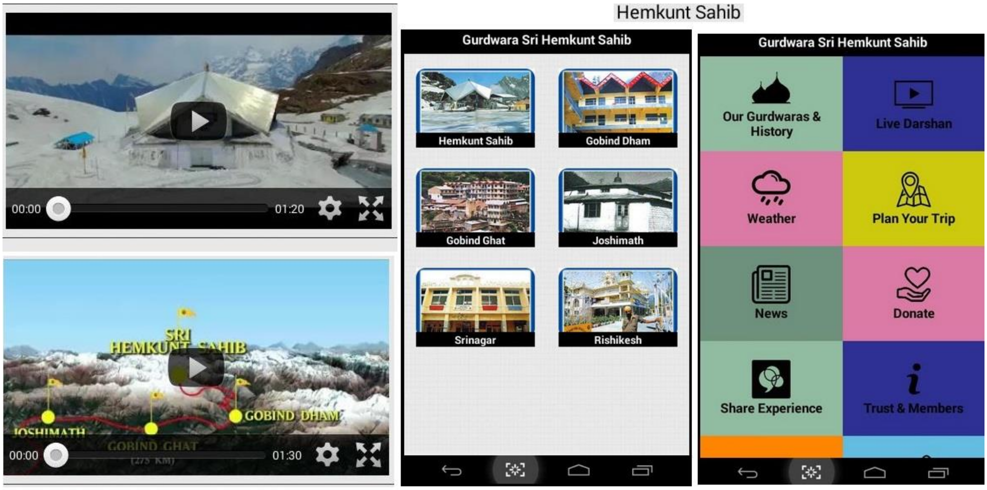

Fig. 7. The Sri Hemkund Sahib geo-application for Android (Mebonix, 2017).

Apart from the supervision of the smartphone applications development, the Sri Hemkund Sahib Management Trust is organizing and providing free accommodation (along with mattresses & blankets), *langar* food, cloak room and toilets at Gurudwaras to visitors of all faiths and nationality. They make the arrangements for health care and free medical treatment at Gurudwara dispensaries, including ambulances at Govindghat, offer support in cases of any deaths along the trek journey and bears the cost voluntarily for the body transportation down to Govindghat and then to the place of choice of their relatives within India, irrespective of the deceased person belonging to any faith or nationality.

The Sri Hemkund Sahib Management Trust is also giving funds to EDC for the entire trek path maintenance/cleanliness in each tourist season and provides assistance through

Gurudwara *Sevadars* (volunteers) for the trail repairs at higher altitudes after avalanches en route to Hemkund Sahib.

Valley of Flowers and Hemkund Sahib Geosystems coexist harmoniously in the Indian Himalayas because of the human factor, who responsibly intervened and established the institutional framework for the protection, conservation, planning and development of the geographical space. The main institutional stakeholders include the Eco-Development Committee (EDC), Gurudwara Sri Hemkund Sahib Management Trust (GSHSMT), Van Panchayat/Forest Council, Zila Panchayat (ZP) and the Department of Forests.

Eco-Development Committee (EDC)

In 2003 Eco-Development Committee (EDC) was set up under the provisions of State's Joint Forest Management Rules, and it took up the task of solid waste collection from June 2003 onwards. Their responsibilities are:

- To keep the trek trail clean and region free from polythene / plastics
- To provide employment opportunity to rural unemployed
- To conserve the environment of this valley region
- To provide facility of prepaid booking of mule/donkey
- To provide the *yatrees* /tourists all information and help

EDC collects the Eco-development fee from Mules and Commercial Establishments, utilizing funds from its revenue on training/capacity building of the local community members and local service providers with the assistance of Department of Forests.

The Van Panchayat Responsibilities mainly include Protection and Conservation of Forests under its Area as per Forest (Conservation) Act, 1980.The activities are:

- Patrolling of Forests/Land under its area and control over illegal tree felling pruning of tree branches, and fodder grazing
- Permit the individuals/tour operators to pitch tents on the Van Panchayat land at Kanjila for a nominal fee or lease for short-term for tent resorts every season.

Zilla Panchayat (ZP) has performed the following functions in the Valley of Flowers-Hemkund region:

- Maintains the ZP parking at Govindghat, fix the parking rates (large vehicle, small vehicle, two-wheelers) and collect the parking charges on contract
- Provides toilet facilities at Govindghat
- Provides land for mule sheds at Ghangharia and Govindghat.
- Fixation of rates for transportation services (mules/porters/palki) on the trek path

The Valley of Flowers-Hemkund region is a part of the Nanda Devi Biosphere Reserve (NDBR), and especially the Valleys of Flowers National Park being one of the two core zones (core zone-II) of the NDBR. The region is under active control of the Office of the District Forest Officer, Department of Forests, Joshimath. A Forest Range Officer is deployed in the region with facilities at Govindghat and Ghangharia. The management of the Valley of Flowers National Park has been based on the following objectives and considerations:

- Keeping control on the extent and wide spread growth of the fast growing and pioneering flowering herb – the *Polygonum polystachyum*.
- Development and upkeep of the trek route within the tourism zone of the park.
- Maintenance of the park and keeping it free from any kind of polluting material.
- Providing impetus to the tourism and providing local employment (through EDC, etc.).
- Strict control on illicit removal of herbs and on poaching.

5. CONCLUSIONS

The Valley of Flowers Geosystem common attributes are harmoniously functioning in an interdependent relationship with all the environmental components and generate the natural dynamic of the perfectly equilibrated geosystem. But our exploratory research goal was not limited to the assessment of the common Himalayas` attributes such as those found in the Valley of Flowers Geosystem.

This research also investigated the special attributes presence in the natural Himalayas` geosystems where the local communities were perfectly integrated. The findings confirmed that Hemkund Sahib Geosystem represents an excellent model of human-nature interaction. The results suggest that Hemkund Sahib unique functional attribute is based on the indigenous people cultural and historical heritage that helps them in the permanent adaptation to changes process. They naturally learn how to constantly adjust to new challenges. Interestingly, Hemkund Sahib- the famous Sikh Shrine is steadily emerging as a strong religious resort as well as a tourist destination despite the fact that its geographical location is not accessible by road. It involves an arduous trekking on a steep slope for the last six kilometers. Naturally, there is also dearth of way-side facilities. Despite this, the pilgrim arrivals recorded at 340578 in 2002 increased to 557129 in 2007 witnessing an overall increase by over 63.5 % and per annum average growth of over 10.5 % during the six years under reference. But similar trends followed in the year 2009, 2013, 2014 and 2015 due to climatic factors.

Statistics on non-pilgrim tourist destination, i.e., Valley of Flowers gives an idea on visitor trends to non-religious destinations located in the higher Himalayan part of India. Unfortunately, despite being world class destination for their extra-ordinary resource potential, it has largely failed to attract tourists anywhere close to the underlying potential. Valley of Flowers, the fabulously flower carpeted rock garden of Frank Smyth, which was declared as Biosphere Reserve in 1982, has been able to attract only 6944 tourists in 2007 as against 557129 pilgrims/tourists to nearby Hemkund Sahib. Such a poor share of the former appears to be all the more dismaying in view of the fact that till Ghangharia, there is common trek for the two destination and that Valley of Flowers is only about 4 km from there while Hemkund Sahib is located at 6.5 km from there and the trek is considerably arduous in case of the latter. True, that entry to the Valley is restricted on account of its highly fragile ecosystems, but still the number of visits is too less than the prevailing carrying capacity.

The research findings answer to all the access, security, hygiene, accommodation, transport and communication problems. Based on the results, we estimate an increasingly higher rate of development due to the technological advances that facilitate information sharing and the enhancement of the geographical place virtual illustration.

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EMERGENCY RESPONSE DURING DISASTROUS SITUATION IN DENSELY POPULATED URBAN AREAS: A GIS BASED APPROACH

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ABSTRACT:
Geographical Information System (GIS) has widely been used in various steps of emergency management to contain the damages during any natural or manmade disasters within limit. This study presents how effectively GIS can be used for emergency management for one of the most densely populated areas of Dhaka, the capital of Bangladesh. With the first-hand baseline information from field survey an optimum route model has been proposed to represent the travel time of road network in congested scenario. The vulnerable parts of the study area are exposed based on emergency response time of firefighting stations and medical facilities, and distance from evacuation points. Some emergency response units have been suggested to enhance the disaster preparedness of the study area. Furthermore, the state of practice spatial analyses method presented in this study can be utilized in different spatial scales especially in regard to developing countries.

Key-words: *Disaster response, Spatial analysis, Emergency management, Network analysis, ArcGIS.*

1. INTRODUCTION

Bangladesh is ranked as the fifth most natural disaster-prone country in the world (Martin, 2011). With a population of 19.58 million in 2018 with a growth rate of 3.62%, Dhaka, the capital of Bangladesh, is considered to be one of the most densely populated cities in the world (Islam, 2018). Different kinds of natural and man-made disasters have become a growing concern for this megacity. Particularly, the older part of the city is relatively more vulnerable to earthquake and it is overdue for Bangladesh as it experienced large earthquake last in 1897. The densely constructed old and unreinforced masonry buildings along with narrow local streets make the locality more vulnerable to earthquake damages. Rapid urbanization, high density of population and high-rise structures are making the situation worse (Rahman et al., 2015).

Recently a study showed that among the total reported fire incidences in Bangladesh, number of incidents were 2669 (18.17%), 2422 (15.36%), 2794(15.96%) and 2891 (16.14%) occurred in greater Dhaka district in the year of 2010, 2011, 2012 and 2013 respectively which shows an increasing trend in terms of number of occurrences. These result into huge economic loses of 1470, 960, 2400, 4070 million BDT accordingly. This study also identified older Dhaka as “Extremely high fire incidental zone” (Tishi & Islam, 2018).

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In recent past, the capital Dhaka has experienced several fatal building crashes mostly caused due to poor construction. Unplanned and congested road network delayed the rescuing operation leading to an abnormal death penalty. The most recent incident took place on 24 April 2013, where a nine-storied building ‘Rana Plaza’ collapsed in Savar killing 1127 people and more than 100 are still missing (Rahman et al., 2015). Some inherent weaknesses of the transportation network of this mostly unplanned (73% fully unplanned) city make any kind of risk management a daunting task (Mahmud & Hoque, 2010).

It is high time for a developing country like Bangladesh to adopt an advanced systematic approach to assess any imminent risk, respond quickly, and thereby keep the damages at bay with the limited available resources. In this regard, Geographic Information System (GIS) has been proving a vital tool to locate, respond, manage, and mitigate the impact of disastrous incidents and is successfully used for different phases of the disaster management, starting from planning (Montoya, 2003) and risk assessment (Church & Cova, 2000) to response (Laefer & Pradhan, 2006), recovery (Gunes & Kovel, 2000) and evacuation (Chang et al., 1997). The specific objectives of this study are to: geocode the existing land use and road networks of the study area; develop an optimum route model to be used in the network analysis; map the effective service areas of the existing emergency response facilities (i.e. Fire Stations, Hospitals, etc.); find out the most vulnerable sections of the study area and suitability analysis for initiating new facilities. The outcome of this study will provide detail information about the existing disaster management capabilities of the study area and will help to identify the most vulnerable groups of people during any disaster and thus locate critical locations for new response facilities. The optimum route model intended to be developed in this study can be used for the other parts of Dhaka city with the basic framework including particular inputs.

2. LITERATURE REVIEW

Emergency management activities can be grouped into five phases; planning, mitigation, preparedness, response and recovery (Hoyos et al., 2015). Mitigation Phase relates to analytical modeling and reveals the inherent spatial variation in hazard, vulnerability and ultimately risk. For natural hazards, the hazard model is generally either an inductive combination of the hazard layers (spatial coincidence) or a deterministic model of a physical process (Goodchild et al., 1994). Conducting vulnerability studies using GIS is a relatively new research area, but the potential for GIS to illuminate spatial issues in this area is becoming clear (Emani et al., 1993; Nicoară & Haidu, 2011).

One of the hallmark applications of GIS in Preparedness Phase and Response Phase is automated mapping. Dunn and Newton (1992) have examined the potential role of GIS in generating alternative evacuation routes. Silva et al. (1993) developed and integrated an evacuation simulation model into a GIS to support the development of evacuation contingency plans around nuclear facilities. Cova and Church (1997) described a GIS-based method for revealing potential evacuation difficulties in advance of a disaster.

GIS in Recovery Phase is an initial priority of performing a cursory damage assessment to minimize the time necessary to apply for government relief. The Global Positioning System (GPS) is also invaluable in this phase for gathering locational information. During the Oakland fire, GPS and GIS were used to map the fire perimeter and geo-reference the location and number of each damaged or destroyed structure (Difani & Dolton, 1992). Mitchell (1998) described how the fire department in the city of Tacoma, Washington used GIS to create response zones for all its functional fire stations. Amdahl (2001) pointed out the vital uses of GIS in the fire service is its ability to geocode individual incident point and present them on a map.

Church (1997) subtly reviewed the existing studies linking GIS and facility location problem and concluded that GIS has the ability to support a wide range of spatial queries that aid optimum location allocation. In GIS, an optimum route is found out by using shortest path analysis of Network Analysis tools. Haidu and Nicoară (2011) applied GIS procedure for the identification of existing infrastructure in the flooding areas to Baciu commune, having 7 settlements, situated in Cluj County, Romania. Ivan and Haidu (2012) outlined the importance and the efficiency of using GIS in collecting, processing and analyzing data and stated GIS as an effective tool for displaying the spatial distribution of accidents along the road network. They also concluded that GIS enables the rapid processing and display on the map of the information regarding accidents and it is useful in making decisions regarding the reduction and prevention of accidents. Nicoară and Haidu (2014) modeled the shortest path and closest facility problems for an ambulance to travel through a road network by creating a system based on GIS technology and applying it on the city of Cluj-Napoca, Romania. Panahi and Delavar (2008) developed a spatial decision support system (SDSS) for emergency vehicle routing by applying Dijkstra’s algorithm in spatial analysis tool of ArcGIS and concluded that dynamic vehicle routing is an efficient solution for reduction of travel time in emergency routing and powerful tool for network analysis, visualization and management of urban traffic network.

In the context of Bangladesh, Kamal (2008) used GIS mapping technique to establish a flood risk assessment for Ward no 25, 27, 28 in Dhaka city. The main motive was to develop a risk assessment procedure to estimate the flood risk of the study area. Alam and Baroi (2004) presented an assessment of the risk of fire hazards in Dhaka City in a GIS framework in order to develop a methodology to generate fire hazard categories and risk mapping. Islam and Adri (2008) tried to explore the existing capacity of Fire Service and Civil Defense authority in Dhaka city and the preparedness of the citizens in combating fire accidents. Ansary and Choudhury (2003) presented an analysis of Dhaka City’s growth and population, the occurrence of different natural disasters and disaster scenarios using GIS mapping. Maniruzzaman et al. (2001) developed a prototype Response Estimation System for Cyclones under Emergency (RESCUE), a GIS-based aid for disaster management. Azad et al. (2013) proposed a conceptual model for dealing the disaster and its management through the incorporation of mobile technology with GIS in Bangladesh. Majority of academic articles and researches acknowledge the undisputed role of GIS in the various phases of emergency response, especially, placing more emphasis on the fire and rescue service. Thus, it can be inferred that GIS can be utilized by fire service to produce an effective and efficient emergency response during a disastrous situation in densely populated urban areas.

3. STUDY AREA

The study area is located in the Dhaka South City Corporation (DSCC), ward no. 26, 27, 29 33 and 34. In Bangladesh, “Ward” is a local administrative unit and an optional division of a city or town, especially an electoral district, for administrative and representative purposes (Sikder et al., 2018). Namely, the locations are Bakshi Bazar, Siddiq Bazar, Chawk Bazar, Naya Bazar, Tanti Bazar, Kotowali, Islampur, Sadarghat, Mitford, Shoari Ghat, Bongshal, Babu Bazar, Lalbagh. **Fig. 1** shows the location and boundary of the study area. The study area is surrounded by 2 major roads, ZahirRaihan Road at the north side, Sadarghat-Gabtoli Road at the South, and two minor roads, Kazi Alauddin Road at the East and Bakshi bazar road at the west side. The rationale behind selecting this section of the city are a high density of population, nearly 1,22,000 to 1,44,000 per Sq. Km (Ansary and Choudhury, 2003), unplanned development, narrow and insufficient road network, and recent disastrous incidents in the selected localities. Additionally, the study area lays in moderate liquefaction susceptibility zone in Dhaka, therefore higher population density increases the possibility of greater damage ratio (as high as 40%) (Ansary & Choudhury, 2003). According to Alam and Baroi (2004), twenty-five fire incidences per ward are found to occur in the study area as it is located in moderately fire hazardous zones. Due to unplanned development, the land use pattern coupled with inefficient road network poses more threat for recovery and mitigation from various disastrous situations.

(a) **(b)**

Fig. 1. Locations of the study area: (a) Location in the Dhaka Metropolitan Area; and (b) Boundary of the Study Area.

4. METHODOLOGY OF THE STUDY

ArcGIS 10.3 Desktop software has been used in this study is a comprehensive, integrated and scalable system designed to perform various GIS analysis ranging from simple to complex analysis such as mapping, data management, geographic data analysis, editing, and geo-processing functions. The analyses used from the ArcGIS network extension include closest facility location, Origin-Destination (O-D) cost matrix generation, location-allocation, and service area analysis. As the shortest path is prerequisite to every analysis, a comprehensive and realistic shortest route model is proposed in this study and validated using field data.

4.1. Developing Road Network of Study Area

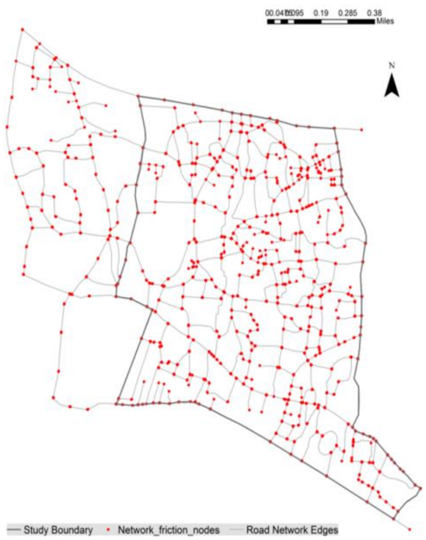
As there are no databases available with the level of details to be used in this research, the road network data was mapped in Esri shape file format in ArcGIS. For this purpose, first-hand data about the type, width, number of lanes were collected from field survey. Total 53.37 Km of the road network has been mapped within and adjacent to the study area. The roads have been classified into three different types based on their traffic, connectivity, lane width, travel speed. We measured the free flow speed and congested speed from travel time survey for different road types as shown in **Table 1**. To develop the initial road network dataset, we included the average free flow travel speed (measured at early morning from 6 am to 7 am) as a link attribute for each type of road (major, minor or dead end).

Table 1.

Field Data of Average Travel Speed in Different Roads in Different Scenarios.

Road Type	Traffic Condition	Walking speed Km/hr	Rickshaw Speed Km/hr	Drive speed Km/hr
Major Roads	Free Flow Condition	3.6	8	15
	Congested Condition	3.6	4	8
Minor Roads	Free Flow Condition	3.6	5	10
	Congested Condition	1.8	2.5	5
Roads with Dead end	Free Flow Condition	3.6	4	5
	Congested Condition	1.8	2	5

However, from the field survey we found that during different times of the day even in the same type of road or in upstream and downstream of the same road the travel time varies by a significant value. The various friction points as mapped in **Fig. 2** of the network cause this delays. To address this phenomenon, we developed a friction network in which we have assigned 2 seconds delay for the friction nodes in between two junctions and 4 seconds delay for the junctions.



(a)

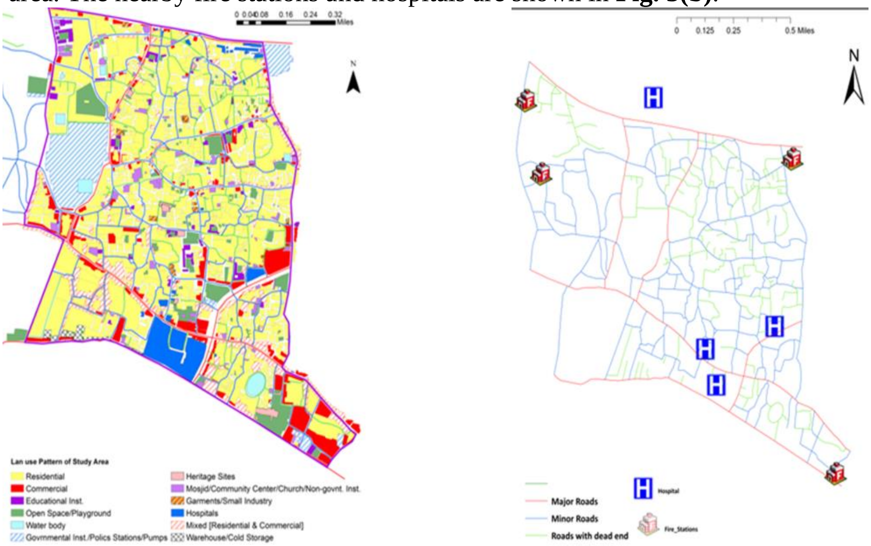
(b)

(c)

Fig. 2. Frictions in the Road Network: (a) Geo-Coded Friction Nodes; (b) Friction Nodes in the Road Network Junction; and (c) Friction Nodes in the Road Network Link.

4.2. Geo-Coding Land Use Types

The whole study area is divided based on land the use pattern. Among the various uses, twelve significant land use types have been mapped in an ArcGIS shape file as in **Fig. 3(a)**. 62% of the areas are residential plots, 8% commercial land, 8% governmental institutions, 7% mixed (commercial and residential) etc. The governmental institutions cover 8% of the area. In this type, the larger area was covered by the central jail. However, during the course of the study, the central jail has been moved to a new location. Presently, this establishment is used as a visitor's site for exhibition. For the ease of analysis, the whole study area is divided into sixty different locations prioritizing their land use pattern. The centroids of the selected locations were found out in 'WGS 1984 Web Mercator Auxiliary Sphere' projection system. Then the individual areas were calculated using Arc-GIS Field Calculator. Among the sixty analysis zones, there are 20 residential, 2 open spaces, 15 mixed, 5 commercial, 1 governmental, 1 educational, 1 hospital and 1 heritage sites in the study area. The nearby fire stations and hospitals are shown in **Fig. 3(b)**.

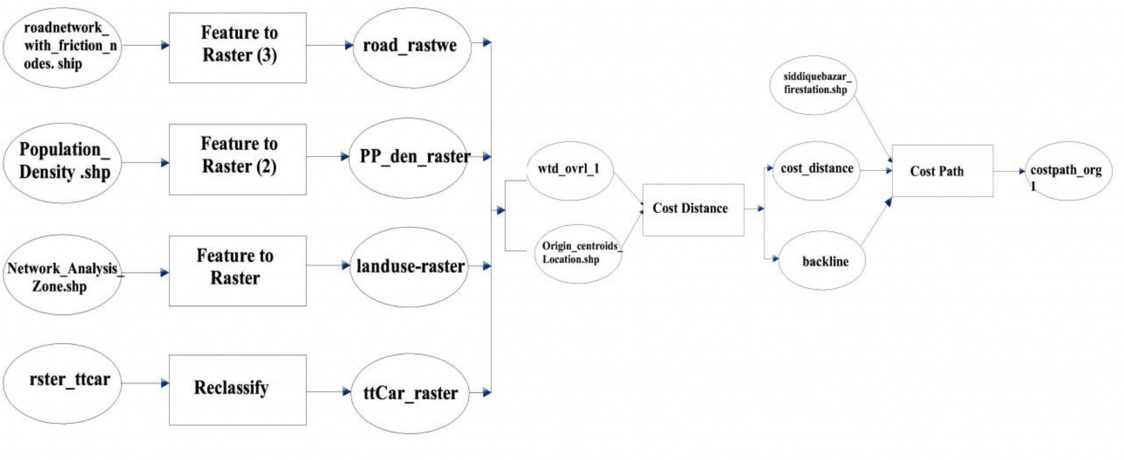


(a) (b)

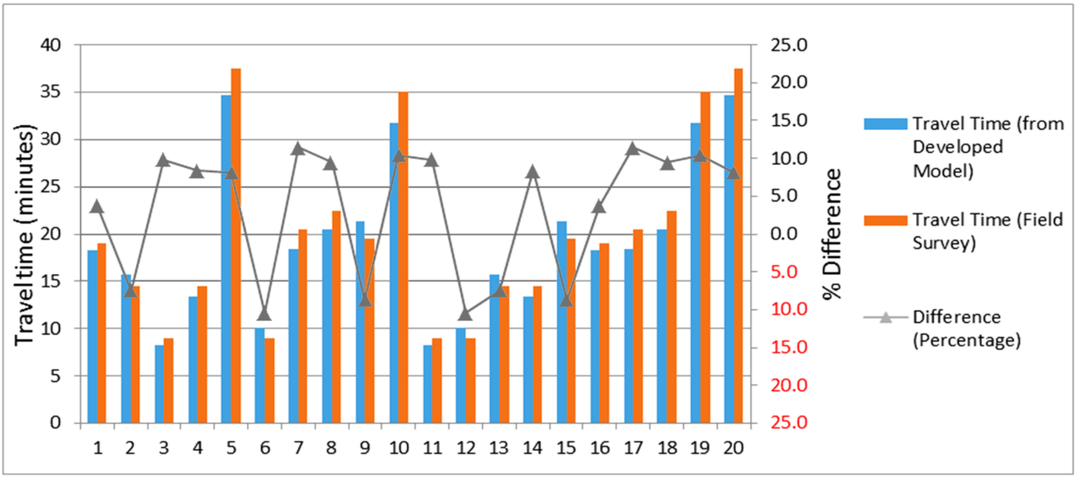
Fig. 3. Road Network and Land Use Pattern of the Study Area: (a) Road Network with location of Hospitals and Fire Stations; (b) Land use Pattern of the Study Area.

4.3. Development and Validation of Optimum Route Model

A realistic optimum route model has been developed by using the weighted overlay of three different cost values i.e. land use pattern, travel time (car), road network and population density. The percentages of weightage include 60% in travel time calculated from the average speed and length of links, 10% in land use types along which a route runs, 10% in population density which is maintained as a constant in this small area, and 20% in road network frictions. The purpose of the model is to estimate the field travel time during congested traffic condition. **Fig. 4** represents the framework of the developed model from a single origin (Siddique bazar fire station) to all other origins (60 analysis zones).



(a)



(b)

Fig. 4. Model Development: (a) Outline of Developed Optimum Route Model; and (b) Validation of Model Results with Field Data.

The outputs of the analysis using this model have been validated using field data. From the O-D cost matrix, using the scenario of the congested road network, the least travel time routes were found out. The particular routes were surveyed and travel times in peak hour were found out using the moving observer method. The difference found in developed models values and field data ranges from 11.4 % to 10.5 %. Also, it was found that around 70% of the time the differences are below 10% range. Hence, the model is considered to be fairly realistic to be used in this study.

5. EMERGENCY RESPONSE DURING DISASTER

5.1. Fire Breakout

A total of four firefighting stations are situated adjacent to the study area. Their locations have been mapped in the ArcGIS shape file. The exact coordinates are taken from

Google Earth. From network analysis tool, Origin-Destination analysis has been done with the localities as destinations and the firefighting stations as the origin.

From the O-D, the least travel time is found for 60 analysis zones to four firefighting stations in both free flow and congested scenario. In more detail analysis, it is found that during congestion scenario some of the localities have different fire station with less response time than free flow scenario. From **Fig. 5(a)**, it is seen that some of the localities have increased response time up to 1100 %, however, in respect to the increase in travel time, the highest increase is 42 minutes.

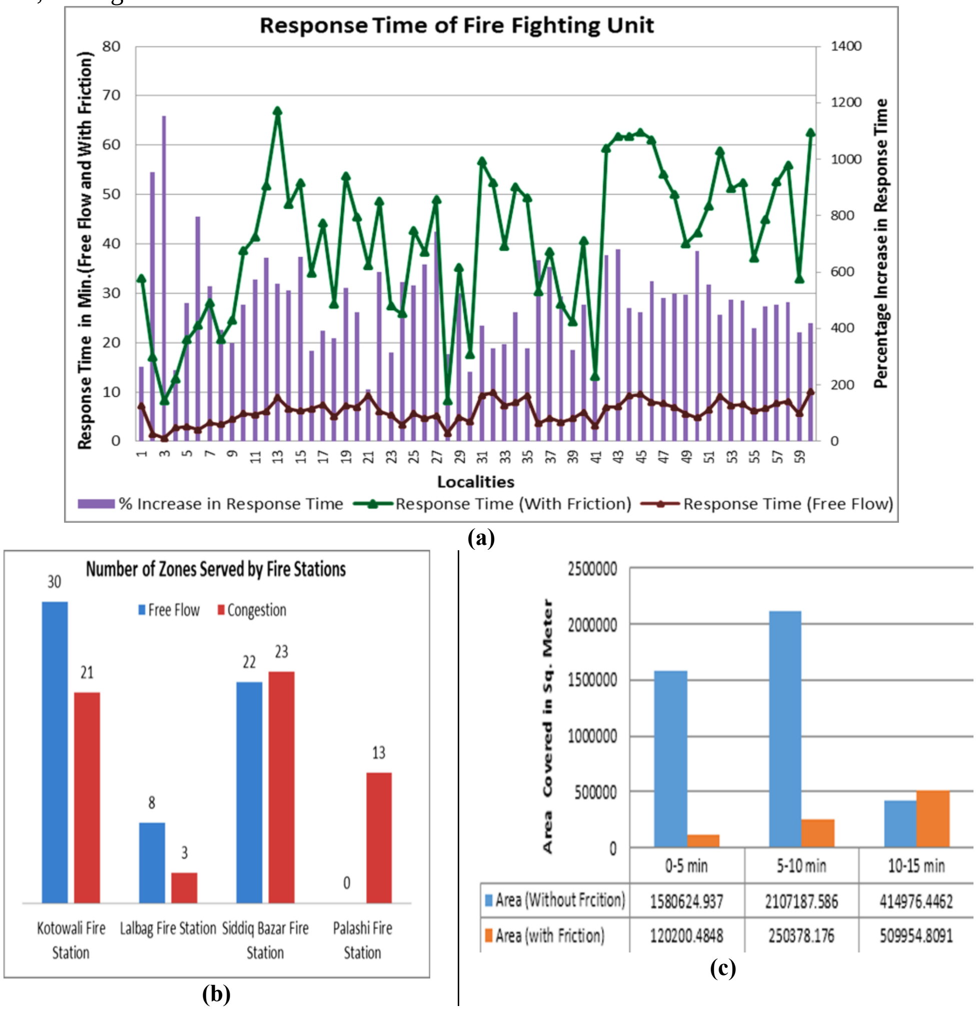


Fig. 5. Emergency Response during Fire Incidents: (a) Response Time of Fire Fighting Unit to Different Localities of the Study Area; (b) Number of Zones Served by Fire Stations; and (c) Service Area (Sq. meter) of Fire Station.

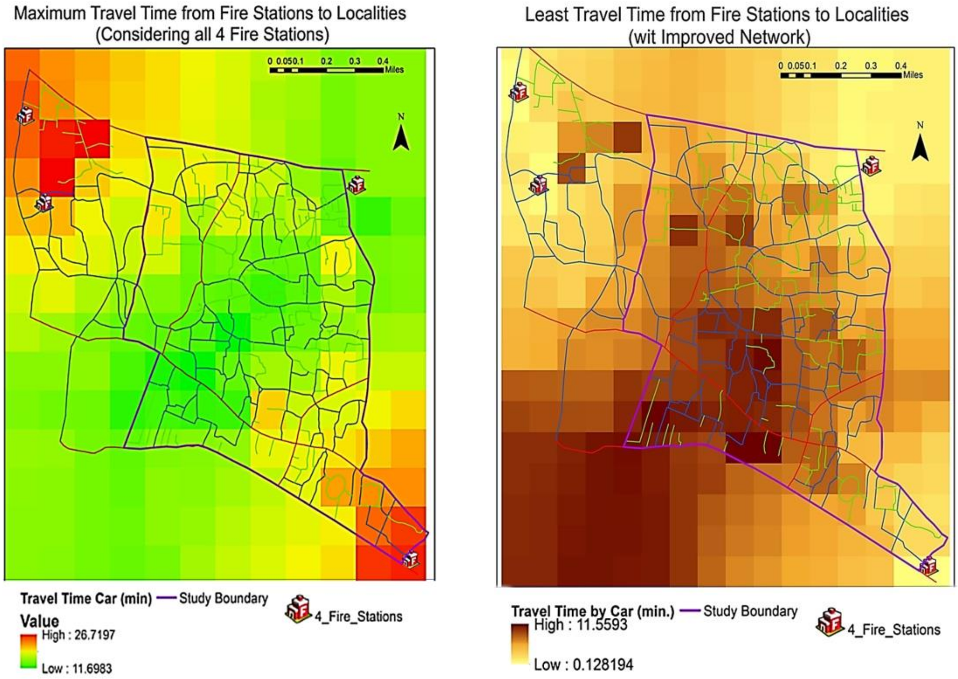
Fig. 5(b) shows the closest fire station during any fire incidents at congested and free flow condition (no shortest route connecting to Palashi Fire Station during free flow). It is clear that due to the location of Siddiq Bazar and Kotowali Fire Station, these two serves most of the study area during any roadway conditions. Siddique Bazar fire station is closest to most of the localities in congested roadway conditions (23 localities) than free-flow condition (22 localities).

The shortest path with only one criterion chose the path with the least length when the average travel speed is same in particular roadway section. Besides, the multi-criteria optimum route choses the route with the least friction and with the least travel time for quickest response. Therefore, from a certain locality, the closest fire service station is different in different conditions.

Finding out the service area of each fire station is a much more comprehensive way to determine the most vulnerable localities during any kind of fire incidents. To find the service area of the four fire stations for both roadway conditions (with friction and without friction), Service Area tool of network extension has been used. The Service Area solver is also based on Dijkstra's algorithm to traverse the network. The goal is to return a subset of connected edge features such that they are within the specified network distance or cost cutoff; in addition, it can return the lines categorized by a set of break values that an edge may fall within. From the analysis without network friction, it is found that almost the whole area can be reached from any of the four firefighting stations within 10 minutes (**Fig. 5(c)**). To entirely cover the area, 15 minutes response time will be adequate, and the area near Babubazar has the maximum response time of greater than 10 minutes (less than 15 minutes). Considering the scenario during peak hour or congested roadway condition, it is found that most of the study area falls beyond the reach of 15 minutes response zone from any of the four fire stations.

To locate the most vulnerable localities, another service area analysis is done using cut off value up to 45 minutes. The result found should be a major concern for the planners. With the current road network condition, the four fire stations can only reach 14.28% of the area within 15 minutes of any incident leaving 85.72% of the area vulnerable to fire hazards. It is seen that more than 10% area cannot be reached even within 45 minutes from any of the fire stations.

Raster analysis is done to pinpoint the exact localities which are in high-risk zones with the cell size of 150 meters by 150 meters using travel time by car as impedance factor in the friction modeled road network. As Siddiq Bazar fire station is the largest facility in the area and the number of resources and manpower it possesses is greater than the other three fire station combined. The localities those are closer to the Siddique Bazar fire station has a response time from 0.7 minutes to 7 minutes. The farthest area from the station has response time of 14.806 minutes. In an improved network with reduced network friction the average travel times from four fire stations to particular localities have found to reduce significantly. For an improved network, least response time is 0.13 minute compared to 11.7 minutes and the largest response time is 11.6 minutes compared to 20.72 minutes of prior analysis (**Fig. 6**). Hence merely reducing or controlling the friction points the response time can be decreased by 44% to 98.9% in some cases.



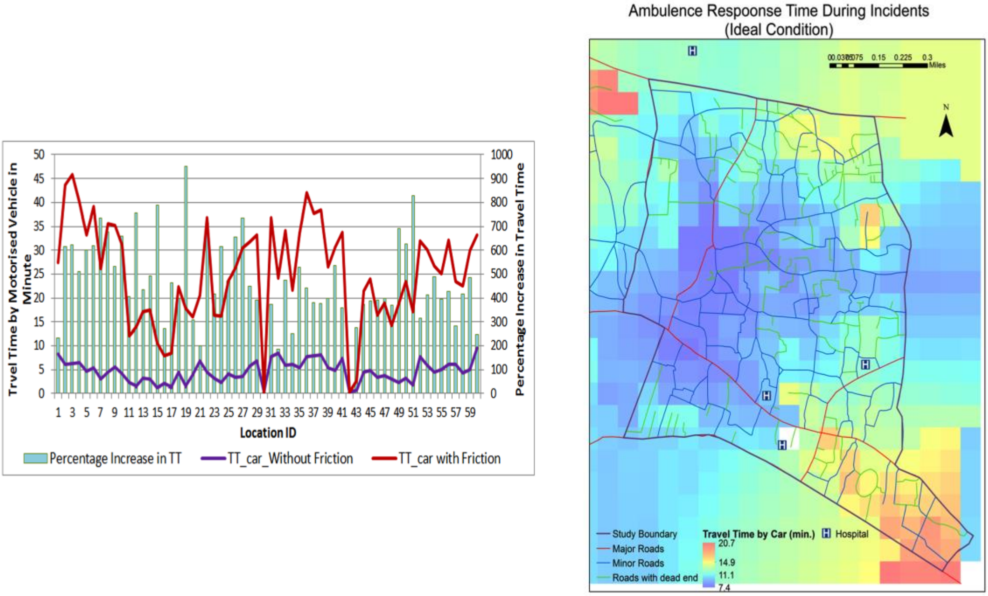
(a) **(b)**

Fig. 6. Illustration of the degree of dependence between mean of night-time light and GDP at county level.

According to National Fire Protection Agency, a six-minute standard response time for all career fire departments are set (Park et al., 2016) , and recommends that the six-minute goal should be achieved 90 percent of the time. Response time standards are not set by Bangladesh Fire Service and Civil Defense Authority and should be developed on an urgent basis. This standard will serve as a base for selecting better potential sites before putting other factors into consideration.

5.2. Response Time for Closest Health Facilities

Traditionally, the aim of a facility location problem model is to help reduce costs or increase benefits, however, in respect of emergency service delivery, the objective is often to minimize the barest minimum losses of lives and properties to the community (Aly & White, 1978). To find out the response time to any nearby medical facilities, the hospitals with emergency units and ambulance services have been identified and located in the map and travel time from the different localities to hospitals was measured and it is found that some of the localities have increased response time up to 950% (**Fig. 7(a)**), however, in respect to an increase in travel time value, the highest increase is 39 minutes. Raster analysis has also been done to find the localities with higher average travel times from the four hospitals **Fig. 7(b)**. It has been found that the average travel times of the four hospitals ranges from a minimum of 7.4 minutes to a maximum of 20.7 minutes.



(a) **(b)**

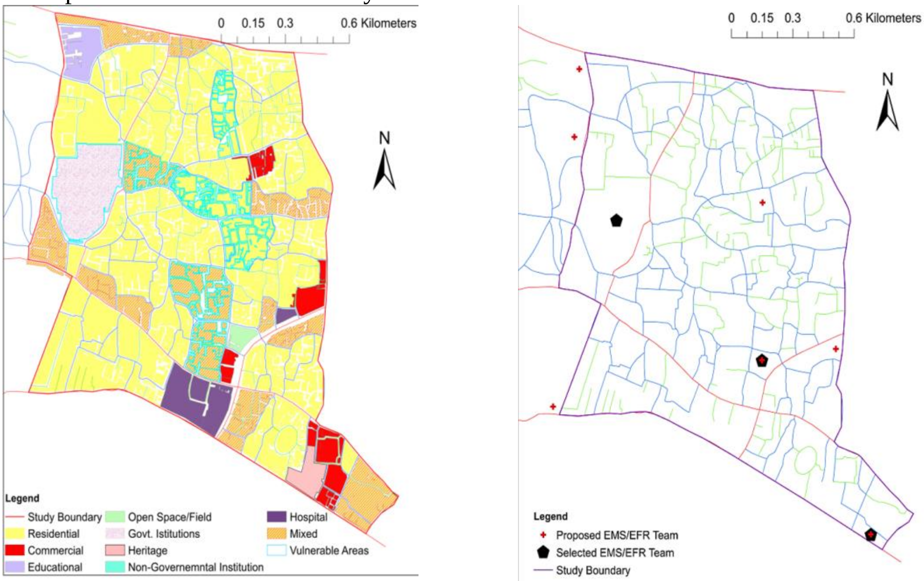
Fig. 7. Emergency Responses to Medical Facilities: (a) Least Travel Time to Nearest Hospitals from Different Localities of Study Area; and (b) Raster Map Showing Average Travel Time to Four Hospitals from Different Localities of Study Area.

5.3. Evacuation

The process of evacuation planning is done in three steps. Firstly, determination of safe areas; secondly, determination of optimum path between building blocks and safe areas, and finally grouping of building blocks relating to each safe area (Naghdi et al., 2008). For reducing the displacement time and distance, the safer area connected by optimum routes must be selected. In this study, based on the accessibility and distance from to the major roads, 27 evacuation points are marked around the study area. These evacuation points are situated at the boundary roads of the study area and at or near to the major roads. Using the developed network and closest facility location of Network Extension, the closest evacuation points are mapped in the Study Area. To select the closest evacuation points, the lengths of the links have been selected as the impedance criteria. The distance of the closest evacuation point from any locality has been found to be as low as 73 meters to as high as 1095 meters. We have marked the location IDs which have an emergency evacuation point at a distance greater than 500 meters.

5.4. Most Vulnerable Sites during Disaster

The most vulnerable sites are selected as the sites which have emergency fire service and medical response greater than 30 minutes away and evacuation points greater than 500 meters away. Based on these criteria, the most vulnerable sites are the people living in the following localities highlighted in **Fig. 8(a)**. The localities and landmarks included in the most vulnerable site list are Armanian Church, Armanina School, Tara Mosjid, residential and small commercial areas under Bakshibazar, Armanitola, Bangshal, Nimtoli etc. The location of Central Jail has also been marked as one of the vulnerable areas, which is at present open for visitors as the facility has been moved to a different location.



(a) **(b)**

Fig. 8. Locating EMS/EFR Units: (a) Selected Most Vulnerable Sites (Highlighted); and (b) Proposed Location of EMS/EFR Units using Location-Allocation Tool (to maximize the Coverage Areas).

5.5. Locating Emergency Response Units

Some EMS and Emergency Fire Response team are required as a quick response to minimize the damages in the study area. So, with EMS some emergency vehicles to be used for emergency response to fire hazards are also proposed in this study. Eight sites have been proposed to establish temporary emergency units. These sites are located in the available open spaces, and also the central jail site. Among the eight proposed sites, three sites have been located with maximum coverage which is shown in **Fig. 8(b)**. The criteria for selecting the best three locations were set in such a way such that the units can respond within 10 minutes of any incident reported. The unit may consist of a single ambulance and fire vehicle with sufficient manpower to respond to any small to medium accidental incidents before the actual one arrives. These units will help to reduce the damages in the most vulnerable sites located earlier.

6. CONCLUSIONS AND RECOMMENDATIONS

In developing countries high population density and unplanned growth increase the damage risks during any disastrous situation. Developing countries also have major drawbacks in using advanced analysis tools as they do not have baseline data frames. This study is an example of how effectively GIS-based analyses can be utilized in disaster management by incorporating baseline data into a spatial format.

This study proposes an optimum route model by considering the actual roadway network frictions of old Dhaka. Current scenarios of disaster response have been assessed using spatial analysis tools of ArcGIS. The major facilities considered in this study are the response time from nearby firefighting stations and medical centers/hospitals. For ground evacuation during events like earthquake, we proposed several evacuation points and found the distance from different localities. From the analyses, we pointed out the most vulnerable locations exposed to maximum damages during any disastrous situation. As the land use of the study area is impossible to re-shape to install new roads or to widen the existing roadways, we have to come up with innovative measures. To lessen the expected damages of the most vulnerable areas some EMS and/or EFR unit has been proposed in different locations using location-allocation analysis by maximizing the coverage area. Establishing these mobile facilities will ensure an emergency response within 10 minutes of any incidents. These will provide initial support until the major services reach the affected locations.

This study has several limitations. The transportation network is inherently dynamic because the state and measures of traffic change over time. We neglected the dynamic characteristics of the traffic volume during different times of the day in developed optimum route model. Sufficient historical traffic flow data is required to develop a dynamic optimum route model for the whole city with higher accuracy.

Decision makers rely on information to arrange rescue tasks and allocate relief resources after any an emergency incident. An integrate information value theory coupled with GIS graph theory can be developed to prioritize information items based on their contributions to the successes of potential response and rescue tasks during disaster. There is no database or management information system in DCC. They do not have a GIS for roads, drains and footpaths etc. (CDMP, 2010). The authority must take timely initiatives to prepare, preserve and update this information for a citywide disaster response and management planning.

Despite the limitations, proposed state of practice spatial analyses method is one of the few studies done for disaster management in developing countries. The methodology can be utilized in different spatial scales for different localities. This study demonstrates the disaster preparedness for a built-up urban area, but the methods can be applied at the planning stages of any urban developments. This will ensure the prevention of potential damages during disastrous situations.

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AUTOMATED TOOL FOR THE EXTRACTION OF THE SURFACE PONDS BASED ON LIDAR DATA

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ABSTRACT:
The risk associated with urban flooding is expected to increase significantly in the future as a result of urbanization and climate change. It is therefore necessary to develop new strategies and tools for managing urban floods. With the increase of impervious surfaces in urban areas, due to rainfall rainwater on the surface tends to accumulate in ponds. The delimitation of these areas is important because they outline possible areas vulnerable to flooding. In this paper we have proposed the automatic identification of these ponds by developing an algorithm using the Model Builder tool of ArcGIS program. The model was applied to LiDAR data for the city of Wrocław in Poland, a city with a high risk of urban flooding. The Model Builder tool successfully delimits the ponds at the ground surface based on a Digital Elevation Model (DEM), without being necessary a manual intervention, thus saving time and energy for the users.

Key-words: *Surface pond; Automatic tool, Urban flooding, LiDAR, Wrocław.*

1. INTRODUCTION

Climate change, undersized sewerage network, urban sprawl are only a few factors that increase the risk of flooding in urban areas. Due to urbanization areas occupied with constructions, roads, parking lots, concrete or asphalt paved surfaces have increased (Ivan, 2015; Benedek & Ivan, 2018). On these surfaces, the water from the heavy rains tends to drain following the steepest slope, and in the low land areas tends to accumulate in the ponds of different sizes (Haidu & Ivan, 2016a). Ponds outline potential areas vulnerable to urban flooding (Maksimovic et al., 2009), and the identification of these areas is important in flood management.

Lately a series of flood analysis models have been developed, such as: overland flow model which involves a modeling of flow pathways and ponds on the ground surface (Boonya-aroonnet, 2008; Peng et al., 2018), or coupled models - 2D which integrates overland and underground flow model (Chen et al., 2005; Dey & Kamioka, 2006; Maksimovic et al., 2009; Son et al., 2016). However, many of the developed models do not take into account the anthropogenic influences on the ground surface such as buildings, roads or land configuration (Peng et al., 2018). The wide availability of different digital data such as DEM (Digital Elevation Model), DSM (Digital Surface Model), LiDAR (Light Detection and Ranging) from low-resolution to high-resolution elevation Digital Elevation Model make it possible to delimit the surface ponds with a high precision and accuracy. LiDAR data, however, offers the possibility of delimiting these areas taking into account the existing obstacles on the ground surface (buildings, fences or road curbs) which directly influence the water draining and water accumulation on the ground surface (Haidu & Ivan, 2016a).

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The present paper describes a new algorithm in order to automatically extract the surface ponds within an urban area (Wrocław, Poland) based on a Digital Elevation Model (LiDAR). The manual extraction of information regarding the ponds require a lot of time, energy and expertise in the field. The developed model offers the possibility of improvement of the already existing overland flow model, it can be helpful and can be used by policy makers from local level for changing and improving strategies on water management.

2. STUDY AREA AND DATA

In this paper model application has been made for the city of Wrocław, Poland (**Fig. 1**), which presents a high risk of urban flooding. Wrocław is located in the central part of the Silesian Lowland macro-region with a population of 638586 inhabitants (Local Data Bank of Poland, 2018) and an area of 292.92 km^2. In its composition the city includes smaller geographical units in the rank of mesoregions: Wrocław Glacial Valley, Wrocław Plain and Oleśnicka Plain. The average width of the glacial valley in the city is 7-10 km. Wrocław Plain stretches between Wrocław Glacial Valley and Sudetes Foreland. It stretches on the left bank of the Oder, between the valleys of Oława and Strzegomka. The highest elevation of the city is 155 m and the lowest is 105 m (Kondracki, 2009).

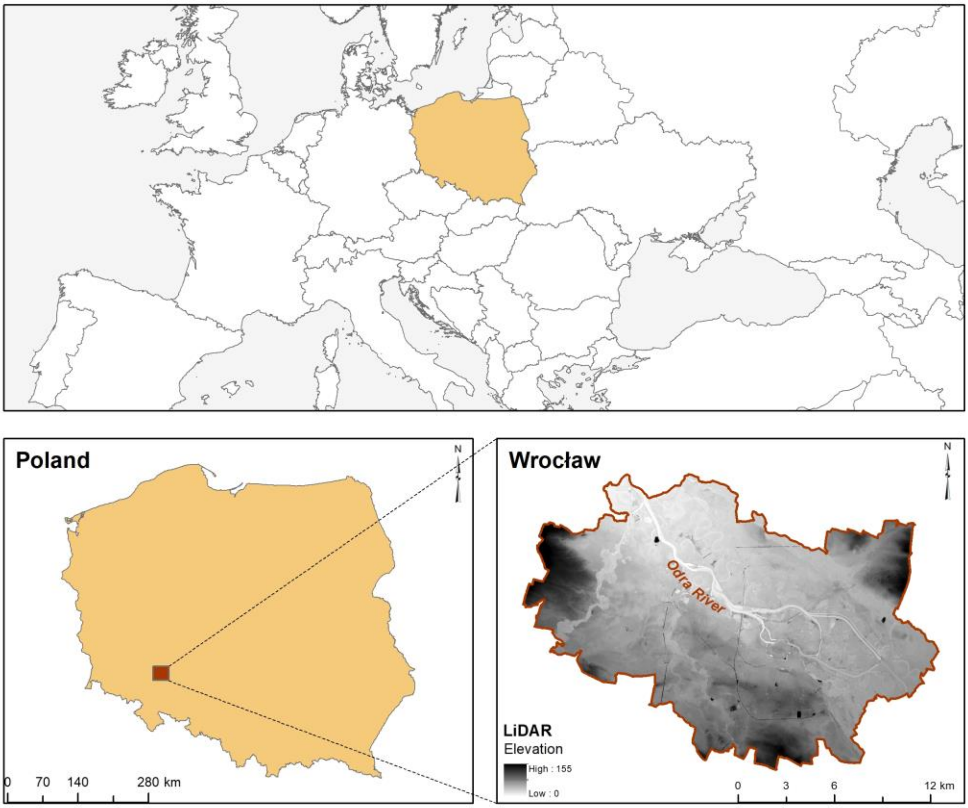

Fig. 1. Location of the study area *(Source: authors).*

The Odra, the second largest river in Poland, has enormous socio-economic importance for Wrocław. It affects the development of business, social integration and shaping the city's space. Odra divides the city into right and left-bank areas with uneven population. About 1/3 of the population of Wroclaw lives right bank of the Oder. On the section of the Odra flowing through Wrocław, strategic hydrotechnical constructions are located, including the Flood Canal, ensuring the main protection of the city through floods (SUiKZP, 2018).

During the flood of the millennium that hit Central Europe in July 1997, the waters of the Oder and its tributaries, including Bóbr, Bystrzyca, Kaczawa, Kwisa, Mała Panew, Nysa Kłodzka, Nysa Łużycka, Olza, Oława, Ślęza and Widawa flooded Wrocław. The flood waters of the Odra River broke into the city on July 12, 1997, and finally gave way in August 6. In Wroclaw, the flood of the millennium was particularly difficult because two flood waves overlapped: the Odra and Widawa rivers (Miskiewicz, 2007).

The model developed in this paper allows the extraction of surface ponds using as input data only a Digital Elevation Model. On a global scale elevation models with different resolution and precision are available. Of these models we can mention the SRTM digital elevation model with a spatial resolution of 90 m, ASTER data set with a spatial resolution of 30 m, both with low spatial resolution and precision in multiple regions (Mukul et al., 2017). Based on LiDAR data, with a high spatial resolution a detailed analysis of the ponds at the ground surface can be made, taking into account the existing objects from the ground surface as well.

In this paper surface ponds have been extracted based on a LiDAR digital elevation model with a 1m spatial resolution, obtained from CODGiK (2012). Lidar data have been used successfully by Hanus and Evans (2015) in a similar study in order to detect the medieval water reservoirs in Angkor.

3. METHODOLOGY

In the developed model GIS technology and a Digital Elevation Model has been used for the extraction of ponds. The tools available in the ArcGIS10.4 toolbox and ArcGIS Model Builder allowed us to build and automate the model. Among the tools available within ArcGIS toolbox especially tools of the Spatial Analyst extension have been used.

The methodology for extracting surface ponds have assumed the following operations (Haidu & Ivan, 2016a), illustrated in **Fig.4**:

a) *the delimitation of representative ponds*

In the first part of the model we have focused on outlining the representative areas for each pond or knoll that exist in the study area.

- At first this stage implied the identification of the lowest and highest areas of the land, based on the elevation model;
- Subsequently all the adequate concentric contours for these areas have been delimited using the *Contour* function within the *Spatial Analyst* extension of ArcGIS program;
- Concentric contours thus obtained have been transformed into polygons, and in order to obtain a single representative polygon for each pond or knoll, the *Dissolve* and *Multipart to Singlepart* functions have been used;

b) pond detection algorithm

The second part of the model consisted in the identification and separation of the ponds from knolls.

- Representative polygons for each pond or knoll have been transformed in Line feature type;
- Based on the Digital Elevation Model and with the help of the *Zonal Statistics* function, the average, maximum, and minimum altitude was calculated for each Line feature, as well the average altitude for each polygon;
- Using the expression (**Fig.2**) the detection of surface ponds and knolls have been used;

Input:
Line mean altitude (L_{mean})
Line maximum altitude (L_{max})
Line minimum altitude (L_{min})
Polygon mean altitude (P_{mean})
Algorithm:
if (P_{mean}) > (L_{mean}) then
x = (L_{min})
else
x = (L_{max})
end if

Fig. 2. The algorithm used in the delimitation of knolls and ponds.

The identification of these areas implied the following: where the average value of the cell from the polygons was higher than the value L_{mean}, the L_{min} has been taken into consideration in the delimitation, and where the value P_{mean} was smaller than L_{mean}, L_{max} has been taken into consideration in the delimitation (**Fig. 3**).

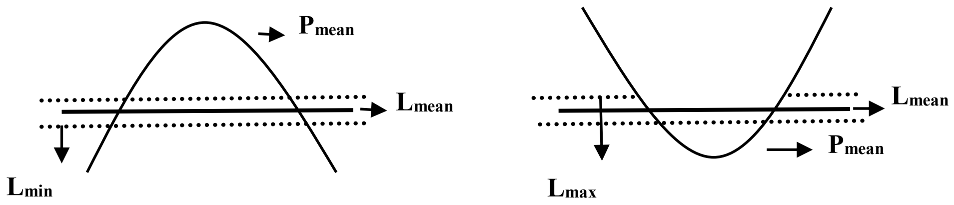

Fig. 3. Illustration of the delimitation of knolls and ponds (source: Haidu & Ivan, 2016a).

Later, following the conversion of these areas into raster files, using the *Cut Fill* tool, based on the Digital Elevation Model, the separation of the surface ponds of knolls has been carried out.

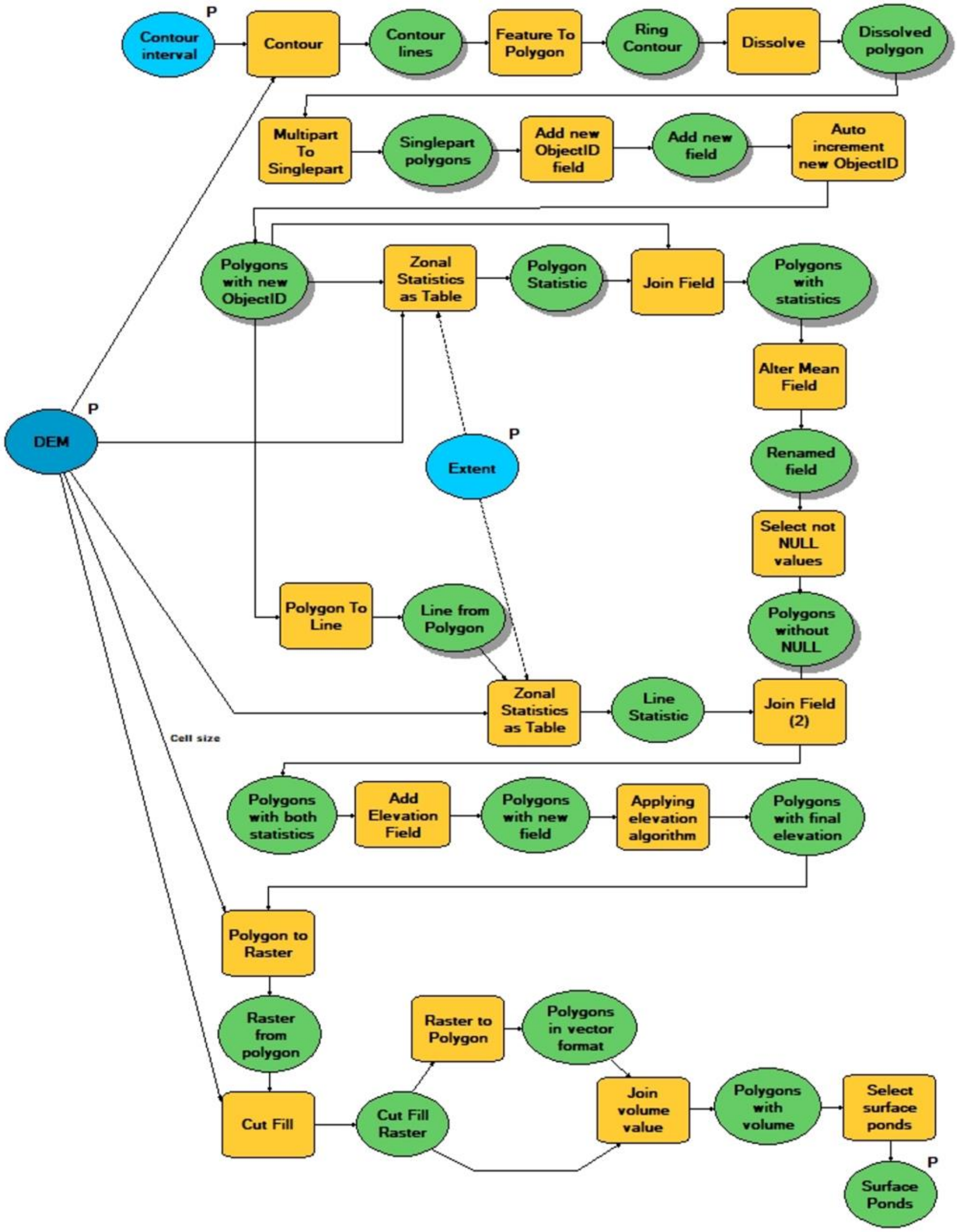

Fig. 4. Model Builder diagram showing the workflow to extract the surface ponds from the Digital Elevation Model *(Source: authors).*

4. RESULTS AND DISCUSSIONS

The model developed and presented in the present paper allows users to quickly and automatically delimit surface ponds using as input data only a Digital Elevation Model. Due to the large number of existing ponds on the ground, manual measurement or manual mapping of these ponds would consume a lot of time and energy.

In the city of Wrocław we have identified over 200000 ponds using the developed tool. Following their verification, of the total number of ponds detected, all of them have been positively identified. The ponds thus obtained have been filtered, those with a surface smaller than 100 m² have been considered insignificant in this study and have been eliminated. By filtering the pond areas from the total number of 219923 ponds, 210124 ponds have been eliminated, resulting in the end a number of 9799 ponds with a surface greater than 100 m² (**Fig.5**).

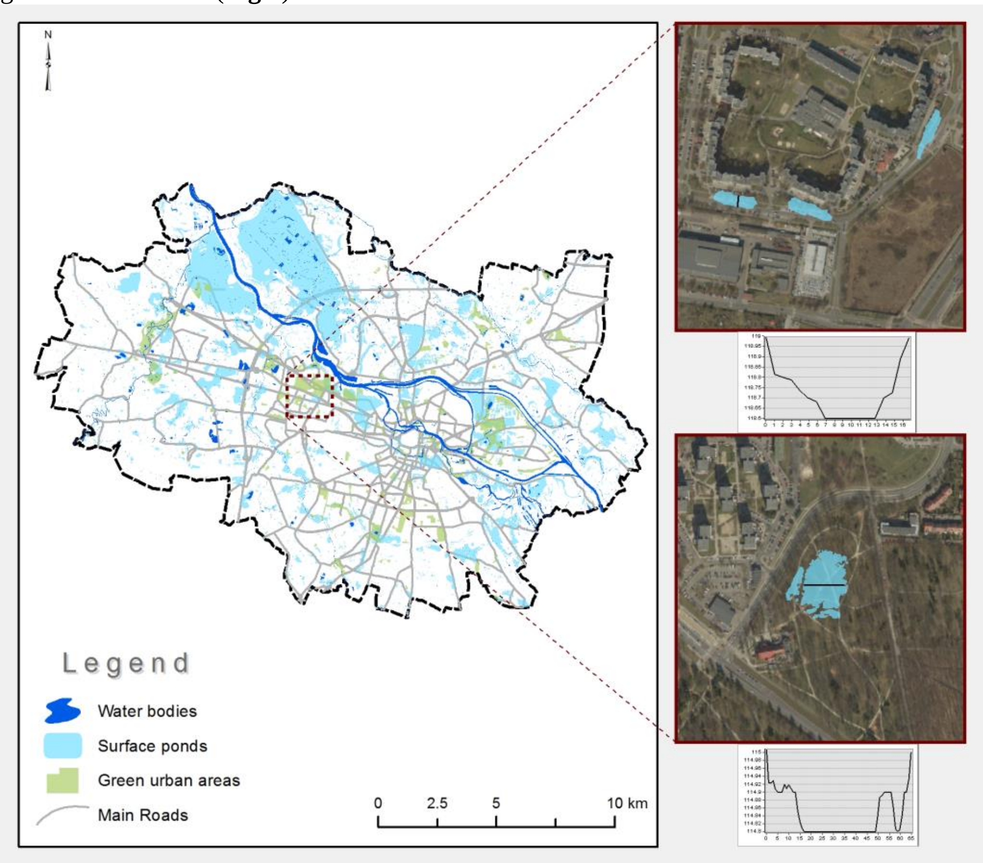

Fig. 5. Illustration of surface ponds identified in the city of Wrocław, Poland, based on LiDAR data *(Source: authors).*

From the remaining 9799 ponds, 68 ponds were identified with high influence (the ponds surface greater than 0.1 km^2), 382 ponds that have medium influence (the ponds surface between 0.01 km^2 and 0.1 km^2), 1664 ponds with low influence (the ponds surface between 0.001 km^2 and 0.01 km^2) and 7685 ponds that have very low influence (the ponds surface between 100 m^2 and 1000 m^2). After analyzing and interpreting the data, we have found that these ponds are likely to occur near the rivers, green urban areas or road intersections.

The automated tool developed for filtering Lidar data can detect the ponds with different depths and dimensions based on a DEM, but it is necessary to classify them according to their surface which could disrupt the daily activity or transport. Depending on how high/medium/low limits are sets, the automated tool developed in the present study can be applied to other urban areas.

This tool has been designed to automatically identify natural or artificial surface ponds which are capable of retaining water during or after rainfalls. These temporary water storage nodes (Boonya-aroonnet, 2008) can be viewed as areas prone to flooding. The tool developed in the study has been successfully tested in several subwatersheds, such as those in Cluj-Napoca, Romania (Haidu & Ivan, 2016a; Haidu & Ivan, 2016b) as well as in France (Haidu & Ivan, 2016c). Therefore we can say that this tool is reliable and can be used by policy makers in order to find and implement measures to prevent urban flooding that can have major effects on the population.

Early knowledge of these areas can help local authorities to develop new flood management strategies. From effective flood control techniques we can mention: detention basins which can help reduce the peak flow (Ardeshir et al., 2013), green roofs, separated sewerage systems or paving the parking lots with permeable pavements which allow the pluvial water infiltration into the soil (Haidu & Ivan, 2015).

5. CONCLUSIONS

Urban pluvial flooding, often caused by the exceeded the capacity of the drainage system, or the clogging of drain holes, is a rapid and direct consequence of precipitations. They appear unexpectedly, without prior warning, most often in areas which are not prone to flooding. Their consequences can have pronounced effects on the population, on the environment and can sometimes lead to major economic losses.

The model developed in the present paper allows the early identification and knowledge of possible areas vulnerable to floods - surface pond - and may stand as a valuable tool for local decision-makers, in order to improve water management strategies. After analyzing the surface ponds we have found that the ponds having a surface greater than 100 m^2 could cause problems during heavy rainfalls to traffic or to civic life, if the sewer system is blocked by certain objects or materials or when the sewer system is under pressure. The model automation offers the user the ability to easily use it, saving time and energy and can underpin the improvement of other existing models.

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PROJECTION OF ANNUAL CROP COEFFICIENTS IN ITALY BASED ON CLIMATE MODELS AND LAND COVER DATA

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ABSTRACT:
Nowadays, a multitude of world changes are coming to affect the ecosystems, urban landscapes, and natural resources. Land use and land cover patterns represent an interactive layer between Earth surface and underground entities which is often consider in the hydrogeological studies. Many factors such as climate parameters and human activities affects the groundwater recharge, quality of water resources and also changes in the hydrologic regime. Crop evapotranspiration plays an essential role in the water balance and water deficit investigations. Here, we use the seasonal crop coefficients to calibrate the annual crop coefficients for the Italian territory. These values could be useful for the temperate zone area. Four stages of annual crop coefficients were set (initial, mid-season, end season, cold season) to perform the calculation of annual crop coefficients. The annual crop coefficients (AKc) have been extracted from the annual ETc. CORINE land cover data and high resolution climate models of potential evapotranspiration (ET0) were the key datasets for AKc projection in Italy. These findings and original maps that we show in the paper represent important tools for the agriculture, environmental, and urban planning.

Keywords: land cover, seasons, crop coefficients, crop evapotranspiration, land cover projections, Italy.

1. INTRODUCTION

In several cases, the climate change have had negative impact on surface water resources and groundwater (Loàiciga et al., 2000; Parmesan & Yohe, 2003; Brouyère et al., 2004; Campos et al., 2013; Prăvălie et al., 2014). It was shown that the ecosystems and it's ecolines are very sensitive to climate change, biodiversity and composition can have consistent changes. In addition to climate change, the land cover and land use pattern play an important role in the interface of land and atmosphere.

Slightly changes of land cover may disturb the entire functions of the ecosystems, which preserve the equilibrium in various domain: e.g. effect on water vulnerability in the regional and local hydrology, cultivation patterns in agriculture, and the evapotranspiration regime as a climatic parameter.

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Both climate and land cover are direct responsible for the evapotranspiration phenomena, fact for which many hydrological studies used the potential evapotranspiration and actual evapotranspiration for water balance and water surplus investigations (Li et al., 2007; Rosenberry et al., 2007; Gowda et al., 2008). The land cover changes on short-term could be detected by satellite images (Angelini et al., 2017), which are now available at high resolution. In the last years, Adamo et al. (2014) predicted the shoreline changes using the coastal erosion model based on altimeters and directional wave spectrum. Rogana & Chen (2004) have applied the remote sensing to identify and monitor the land cover and land use changes. In their study, the techniques of data collection from sensors, spatial resolution and data processing were discussed. Moreover, geographic information systems (GIS) and image analysis systems, become together strong tools in the land cover changes mapping (Treitz & Rogan, 2004). However, in this study, we have focused on CORINE Land Cover and Hercules models, because these databases are already validated and available for scientists' community.

A substantial contribution was the FAO Paper no. 56 (Allen et al., 1998) and Allen's work (Allen, 2000) that proposed a complex methodology to calculate the crop evapotranspiration (ET_c) and to carry out the K_c/evapotranspiration rate for different type of crops. In the same years, Grimmond & Oke (1999) done the measurements of evapotranspiration in various cities from United States and further they calculated the K_c related not only for crops and plants, but also for urban areas and impervious fractions. Integrating the K_c in the formula of ET_c, Nistor et al. (2017) calculated the ET_c for regional scale in four seasons for the Pannonian basin. They extracted the K_c from the CORINE Land Cover database and, considering the growth of crops period they divided the year months in the crop calendar. Thus, initial, mid-seasons, end season and cold seasons were the main periods for which they have calculated the seasonal ET_c. Summing the values of seasonal ET_c, the total annual ET_c was found.

The aim or our work was to complete the spatial distribution of seasonal K_c related to four stages of crop calendar and to calculate the annual K_c for the Italian territory. We choose this land because is composed by a heterogeneous landscape including almost all relief types and extends on more than 10 degrees in latitude, which implies an advantage for the annual K_c calculation in temperate zone. Moreover, Italian territory has a large coastal zone, with a diversity of vegetation cover, but also and the climate is complex in Italy. The findings carried out through our methodology are a huge contribution for climatologist and hydrogeologists due to a final product map annual K_c for present and future.

2. STUDY AREA

Italian territory extends from 36°38' to 47°4' North and 6°38' to 18°32' East (GCS_WGS_1984 Projection) and is located in south of Europe (**Fig. 1**). Italy is a Mediterranean country, with a large coastal lines, various orography and complex climate. Thus, the eastern coast is bordered by Adriatic sea from North to South, the South and southeastern sides of the country are mainly bordered by Ionian Sea and Mediterranean Sea, when the northwestern and western sides of Italy are bordered by Ligurian Sea respective Tyrrhenian Sea. Attached to Italy are also Sicily and Sardinia Islands, but also many small islands.

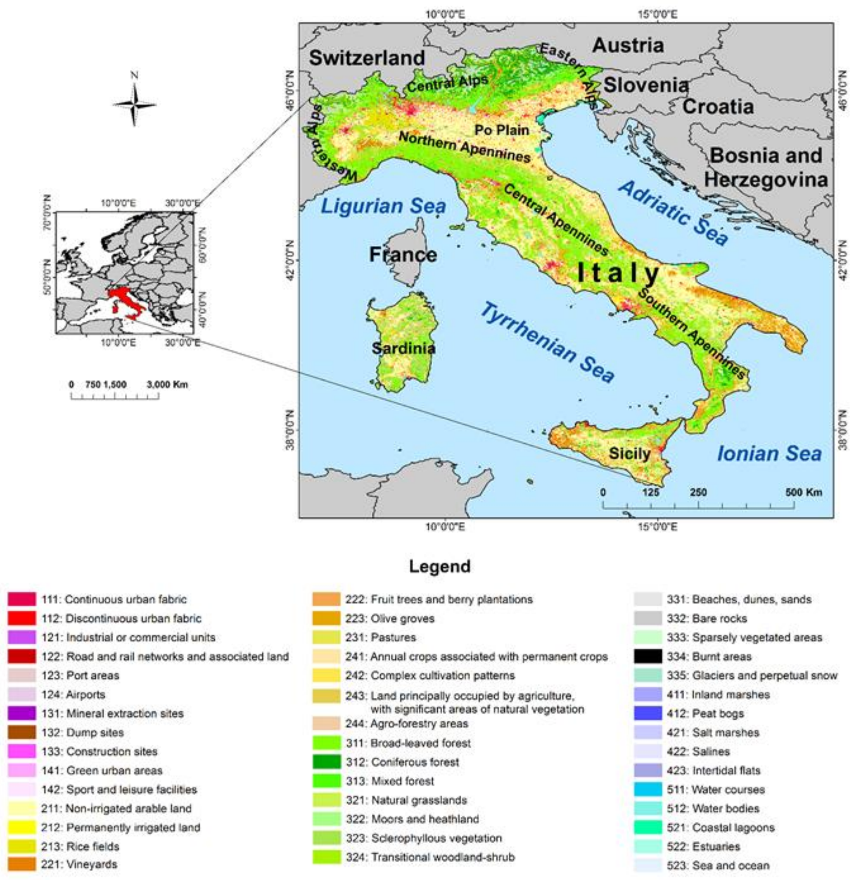

Fig. 1. Location of the Italy on the Europe map (left) and land cover of the Italian territory (right).

Regarding the relief of the Italy, the major mountain belts are the Alps Mountains in North (Western Alps, Central Alps, and Eastern Alps) and Apennines Mountains (Northern Apennines, Central Apennines, and Southern Apennines) that extends from northwestern to southeastern through the central part of the Italian Peninsula. The main lowlands are Po Plain and Po River Delta, located in North sides of the country, but also the Adriatic coast represents the realm with lows elevations.

From climate point of view, the Cfa and Cfb are the main climate in the North of the country (Kottek et al., 2006) with Csa climate in the South. The mean annual temperature for the actual period in the study area ranged from -0.5 °C in North to 18.4 °C in South. The mean annual precipitation in the present period exceeds 1800 mm year^{-1} in many locations of Alps and Northern Apennines and the maximum values reach 2100 mm year^{-1} in the Northern Apennines. The ET_0 in Italy ranged from 367 mm up to 927 mm. The maximum values of ET_c (1299 mm) are found in the South of the Italy, but also the values over 1200 mm of ET_c are found in Sicily and West side of Sardinia. The highest value of ET_c in that area is influenced by the high temperatures and high K_c of vegetation (e.g. broad-leaved forest). The adapted vegetation at orography and climate were identified in Italy. In mountains areas the main covers are coniferous and mixed forest which included species as oak (Quercus), beech (Fagus), elms (Ulmus), and hornbeam (Carpinus) (European Environment Agency, 2007), pasture and transnational woodland and shrubs. The lowlands and plains are mainly covered by hay, herbaceous vegetation and agricultural lands. In the hilly areas and in the meadows along rivers are presents more broad-leaved forests and shrubs. The coastal areas are predominantly with Mediterranean vegetation as Italian stone pine (Pinus pinea), green areas, and sclerophyllous vegetation. On the coast zone are also located the ports areas, the lagoons and marshes.

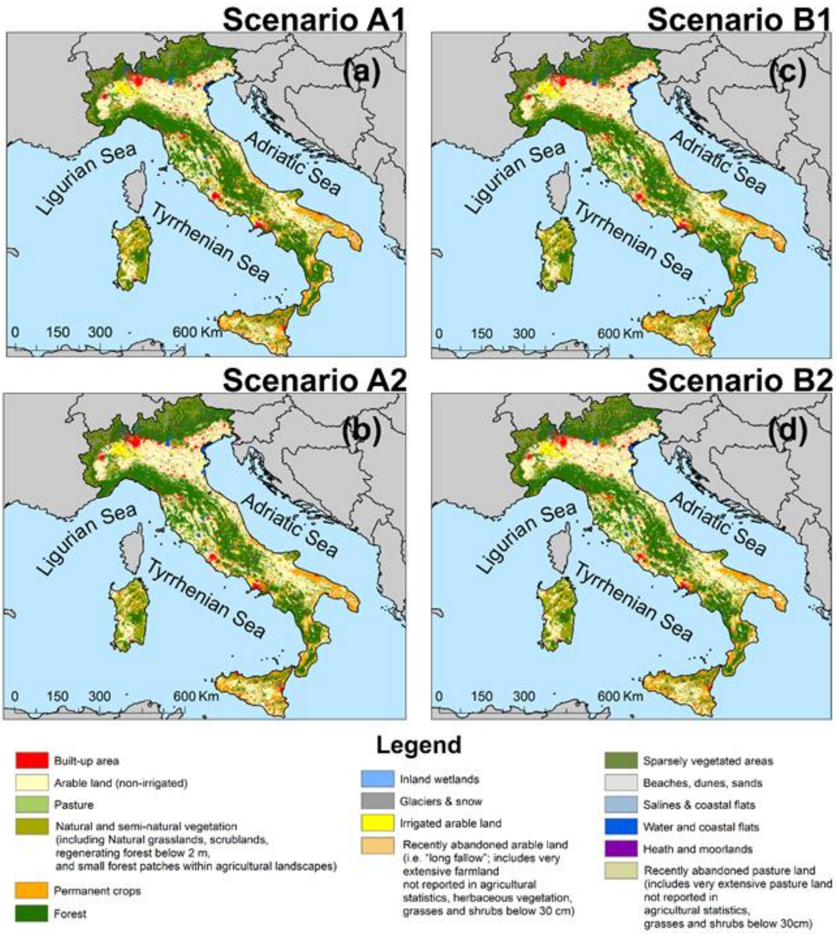

Fig. 2. Land cover projections of Italy. (a) Scenario A1. (b) Scenario A2. (c) Scenario B1. (d) Scenario B2. Source: Sustainable futures for Europe's HERitage in CULtural landscapES" project (http://www.hercules-landscapes.eu/).

3. MATERIALS AND METHODS

3.1. CORINE land cover data

Raster data with 250 m spatial resolution of CORINE Land Cover 2012 served to identify represent the land type categories in Italy for the present period. This database was elaborated by Copernicus Land Monitoring Services (2012) and cover the northern, southern, western and central sides of Europe.

Dynamic spatial changes of the land use and land cover for the future period have been depicted using the Hercules models carried out in the "Sustainable futures for Europe's HERitage in CULtural landscapES" project, GA no. 603447 (Schulp et al., 2015). Using four scenarios, Schulp et al. (2015) projected the land cover of Europe by 2040 based on macro-economic and land use models for which they set fourteen trajectories in the land trend considering the urbanization, agriculture and forestry.

The raster data of future Hercules models are available on website (http://www.hercules-landscapes.eu/) while the procedure of the trajectories, indices and mapping cultural landscapes is highlighted in the Report no. 1 off the Hercules project (Schulp et al., 2015). Four scenarios as A1, A2, B1, and B2 in sixteen classes (**Fig. 2**) built for 2040 were used for the present paper to represent the spatial distribution of seasonal K_c.

3.2. Seasonal crop coefficients (Kc)

According to Allen et al. (1998) and Grimmond & Oke (1999), for each land cover type was assigned a certain crop coefficient (K_c) value. Based on these values, the ET_c calculation for four season and annual periods were done.

Allen et al. (1998) have mentioned tested values and a detailed analyzed K_c for various climate zones (e.g. Tropics, Temperate, and Mediterranean) in the Food and Agriculture Organization report. The K_c related to the urban areas and bare soil have been calculated and published by Grimmond & Oke (1999). Four stages of crop growth and specified K_c for have been considered in this study, as follow: initial season ($K_{c\ ini}$) during the March, April, May; mid-season ($K_{c\ mid}$) during June, July, August; end season ($K_{c\ end}$) during September and October; cold season ($K_{c\ cold}$) during January, February, November, and December. Here, we adopt the Nistor et al. (2017) methodology to illustrate the spatial distribution of K_c in Italy and to carry out the annual crop coefficients (AK_c). At regional scale, due to the overlap of growth crops calendar, the scientists insert this stage in the initial season (Nistor et al., 2017). The standard K_c values for initial season, mid-season, end season, and cold season related to the present and future are reported in the Table 1, respective Table 2.

Table 1. Corine Land Cover classes and representative seasonal Kc coefficients for the present in Italian territory

Corine Land Cover		Kc ini season	Kc mid season	Kc end season	Kc cold season
CLC code 2012	CLC Description	Kclc	Kclc	Kclc	Kclc
111	Continous urban fabric	0.2	0.4	0.25	-
112	Discontinuous urban fabric	0.1	0.3	0.2	-
121	Industrial or commercial units	0.2	0.4	0.3	-
122	Road and rail networks and associated land	0.15	0.35	0.25	-
123	Port areas	0.3	0.5	0.4	-
124	Airports	0.2	0.4	0.3	-
131	Mineral extraction sites	0.16	0.36	0.26	-
132	Dump sites	0.16	0.36	0.26	-
133	Construction sites	0.16	0.36	0.26	-
141	Green urban areas	0.12	0.32	0.22	-
142	Sport and leisure facilities	0.1	0.3	0.2	-
211	Non-irrigated arable land	1.1	1.35	1.25	-
212	Permanently irrigated land	1.2	1.45	1.35	-
213	Rice fields	1.05	1.2	0.6	-
221	Vineyards	0.3	0.7	0.45	-
222	Fruit trees and berry plantations	0.3	1.05	0.5	-
223	Olive groves	0.65	0.7	0.65	0.5
231	Pastures	0.4	0.9	0.8	-
241	Annual crops associated with permanent crops	0.5	0.8	0.7	-
242	Complex cultivation patterns	1.1	1.35	1.25	-
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0.7	1.15	1	-
244	Agro-forestry areas	0.9	1.1	1.05	0.3
311	Broad-leaved forest	1.3	1.6	1.5	0.6
312	Coniferous forest	1	1	1	1
313	Mixed forest	1.2	1.5	1.3	0.8
321	Natural grasslands	0.3	1.15	1.1	-
322	Moors and heathland	0.8	1	0.95	-
323	Sclerophyllous vegetation	0.25	0.9	0.8	-
324	Transitional woodland-shrub	0.8	1	0.95	-
331	Beaches, dunes, sands	0.2	0.3	0.25	-
332	Bare rocks	0.15	0.2	0.05	-
333	Sparsely vegetated areas	0.4	0.6	0.5	-
334	Burnt area	0.1	0.15	0.05	-
335	Glaciers and perpetual snow	0.48	0.52	0.52	0.48
411	Inland marshes	0.15	0.45	0.8	-
412	Peat bogs	0.1	0.4	0.75	-
421	Salt marshes	0.1	0.3	0.7	-
422	Salines	0.1	0.15	0.05	-
423	Intertidal flats	0.3	0.7	1.3	-
511	Water courses	0.25	0.65	1.25	-
512	Water bodies	0.25	0.65	1.25	-
521	Coastal lagoons	0.3	0.7	1.3	-
522	Estuaries	0.25	0.65	1.25	-
523	Sea and ocean	0.4	0.8	1.4	-

Kc - crop coefficient for plants, Ks - evaporation coefficient for bare soils, Ku - crop coefficient for urban areas, Kw - evaporation coefficient for open water, Kclc - crop coefficient for land cover. Source: From Allen et al. (1998); Nistor et al. (2017)

Table 2. Corine Land Cover classes and representative seasonal Kc coefficients used for the future scenarios in Italian territory

Corine Land Cover			Kc ini season	Kc mid season	Kc end season	Kc cold season
CLC code 2012	CLC projection code	CLC Description	Kclc	Kclc	Kclc	Kclc
133	0	Built-up area	0.16	0.36	0.26	-
211	1	Arable land (non-irrigated)	1.1	1.35	1.25	-
231	2	Pasture	0.4	0.9	0.8	-
321 and 324	3	Natural and semi-natural vegetation (including Natural grasslands, scrublands, regenerating forest below 2 m, and small forest patches within agricultural landscapes)	0.45	1.1	1	-
411	4	Inland wetlands	0.15	0.45	0.8	-
335	5	Glaciers and snow	0.48	0.52	0.52	0.48
212	6	Irrigated arable land	1.2	1.45	1.35	-
321	7	Recently abandoned arable land (i.e. "long fallow"; includes very extensive farmland not reported in agricultural statistics, herbaceous vegetation, grasses and shrubs below 30 cm)	0.3	1.15	1.1	-
241	8	Permanent crops	0.5	0.8	0.7	-
313	10	Forest	1.2	1.5	1.3	0.8
333	11	Sparsely vegetated areas	0.4	0.6	0.5	-
331	12	Beaches, dunes and sands	0.2	0.3	0.25	-
422	13	Salines	0.1	0.15	0.05	-
423 and 521	14	Water and coastal flats	0.3	0.7	1.3	-
322	15	Heathland and moorlands	0.8	1	0.95	-
231 and 324	16	Recently abandoned pasture land (includes very extensive pasture land not reported in agricultural statistics, grasses and shrubs below 30cm)	0.6	1	0.9	-

Kc - crop coefficient for plants, Ks - evaporation coefficient for bare soils, Ku - crop coefficient for urban areas, Kw - evaporation coefficient for open water, Kclc - crop coefficient for land cover. Source: From Allen et al. (1998); Nistor et al. (2017)

3.3.Climate data

Mean monthly air temperature models related to 2011 to 2040 served to carried out the seasonal ET_0 in the present study and to calculate the seasonal and annual ET_c. The climate models are in raster grid format at very high spatial resolution with a temporal average of 30 years. Based on the ANUSplin software, Hamann et al. (2013) have completed the air temperature models for Europe. These models are courtesy by Andreas Hamann from Alberta University, Canada. The climate models were generated using the ClimateEU v4.63 software package (see http://tinyurl.com/ClimateEU) and followed the methodology described by Hamann et al. (2013).

3.4. Annual crop evapotranspiration (ET_c) and annual crop coefficient (AK_c)

The AK_c is the ratio expression of ET_c and ET_0. Based on the seasonal values of K_c and climate data, the seasonal and annual ET_c have been calculated. Firstly, for the each set season was performed the ET_0 using the Thornthwaite (1948) method (Eq. 1). By multiplying the ET_0 of season K_c, the ET_c related to the four seasons were calculated (Eqs. 4-7). The annual ET_c is the sum of initial ET_c, mid-season ET_c, end season ET_c and cold season ET_c (Eq. 8). Divided the annual ET_c at the ET_0, the AK_c (Eq. 9) was found for the present and further, implemented for the future scenarios. Further, from the annual ET_c and ET_0, the average value of AK_c for each land cover type was extracted. Using the pinpoint verification on the Italian map, the specific value of the AK_c were assigned to the respective land cover type.

$$ET_0 = 16\left(\frac{10T_i}{I}\right)^{\alpha} \tag{1}$$

$$\mathrm{I} = \sum_{i=1}^{12} \left(\frac{T_i}{5}\right)^{1.514} \tag{2}$$

where:

ET_0 monthly potential evapotranspiration [mm]

T_i average monthly temperature [°C], ET_0=0 if $\overline{Tm}$ <0

I heat index (Eq.(2))

α complex function of heat index (Eq. (3))

$$\alpha = 6.75 \times 10^{-7}\mathrm{I}^3 - 7.71 \times 10^{-5}\mathrm{I}^2 + 1.7912 \times 10^{-2}\mathrm{I} + 0.49239 \tag{3}$$

where:

I annual heat index

$$ET_{c\,ini} = ET_{0\,ini} \times K_{c\,ini} \tag{4}$$

$$ET_{c\,mid} = ET_{0\,mid} \times K_{c\,mid} \tag{5}$$

$$ET_{c\,end} = ET_{0\,end} \times K_{c\,end} \tag{6}$$

$$ET_{c\,cold} = ET_{0\,cold} \times K_{c\,cold} \tag{7}$$

$$Annual\ ET_c = ET_{c\,ini} + ET_{c\,mid} + ET_{c\,late} + ET_{c\,cold} \tag{8}$$

$$AKc = \frac{ETc\ annual}{ET0\ annual} \tag{9}$$

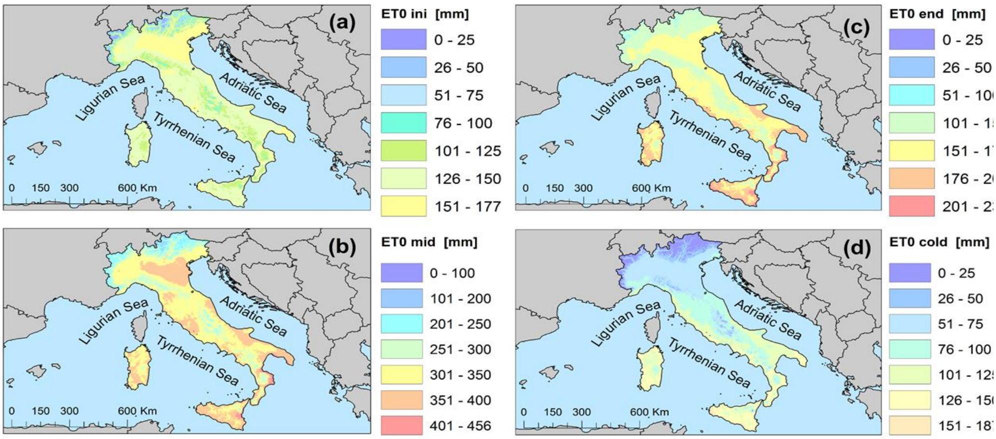

Fig. 3. Spatial distribution of seasonal ET_0 in Italy. (a) $ET_{0\,ini}$ for the initial season. (b) $ET_{0\,mid}$ for the mid-season. (c) $ET_{0\,end}$ for the end season. (d) $ET_{0\,cold}$ for the cold season.

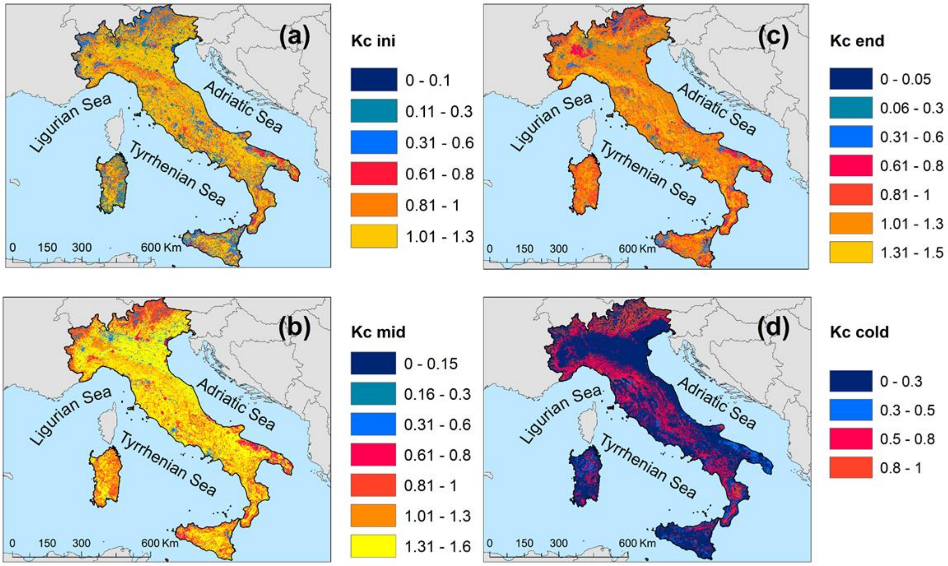

Fig. 4. Spatial distribution of K_c in Italy related to the present land cover. (a) $K_{c\ ini}$ for the initial season. (b) $K_{c\ mid}$ for the mid-season season. (c) $K_{c\ end}$ for the end season. (d) $K_{c\ cold}$ for the cold season.

4. RESULTS

Figure 3 depicts the seasonal ET_0 in Italy, carried out from the monthly ET_0. For the initial season, the ET_0 varies from 0 to 177 mm, the maximum values were found in the Po Plain and southeastern sides of Italy, on the coastal area. The mid-season ET_0 ranges from 0 to 456 mm, with the several places where the values exceed 300 mm. These sides overlap to Po Plain, coastal areas, central sides of the country and to the Sicily and Sardinia Islands. The values of the ET_0 in the end season varies from 0 to 230 mm, the southern parts and the islands are the main land with the high ET_0. As we expected, the cold season illustrates lower values of ET_0, especially in the North of Italy. In the Central Apennines, northern plains, and in the Alps regions the ET_0 fall below 75 mm. In the South, South-East, and South-West, but also in the Sicily and Sardinia Islands, the ET_0 register values above 100 mm in the cold season. In aim to calibrate the AK_c for the Italian territory, an detailed analysis of the K_c spatial distribution were done. Thus, the $K_{c\ ini}$ varies in the present period from 0 to 1.3 showing a large part of Italy with high coefficient. In the northern sides, excepting the Alps area and cities, the K_c register values above 1. The same trend is also on the Tyrrhenian and Adriatic coast, while in the South of Italy the values are around 0.81 – 1 in most of the territory, and fall below 0.6 in South of Sardinia, West and East of Sicily. The $K_{c\ mid}$ ranges from 0 to 1.6 and indicates high values in the Po Plain, northern and eastern coast, in central and south-central Italy, and on western coast. The southeastern, southern and northern parts of Italy shows values between 0.61 and 1. The most part of Sicily and Sardinia are covered by lands with values of 0.61 to 1.3 for $K_{c\ mid}$, but there are also values which exceed 1.3. In the end season the $K_{c\ end}$ varies from 0 to 1.5 and the major part of territory has values between 0.81 and 1.3. The North of Italy, especially in the Alps Mountains, but also around the big cities, southeastern sides of country, West and East of Sicily the $K_{c\ end}$ fall below 0.6. During the cold season, 0.3 and less values are predominantly in the Italian land. In this season, opposite to the others, the Alps, Northern Apennines, and Central Apennines, and elevated parts of Sicily and Sardinia indicates highest values of the $K_{c\ cold}$ due to the presence of the forest cover, which has the high evapotranspiration rate also in the cold seasons. **Figure 4** illustrates the K_c spatial distribution in Italy during the four seasons related to the present period.

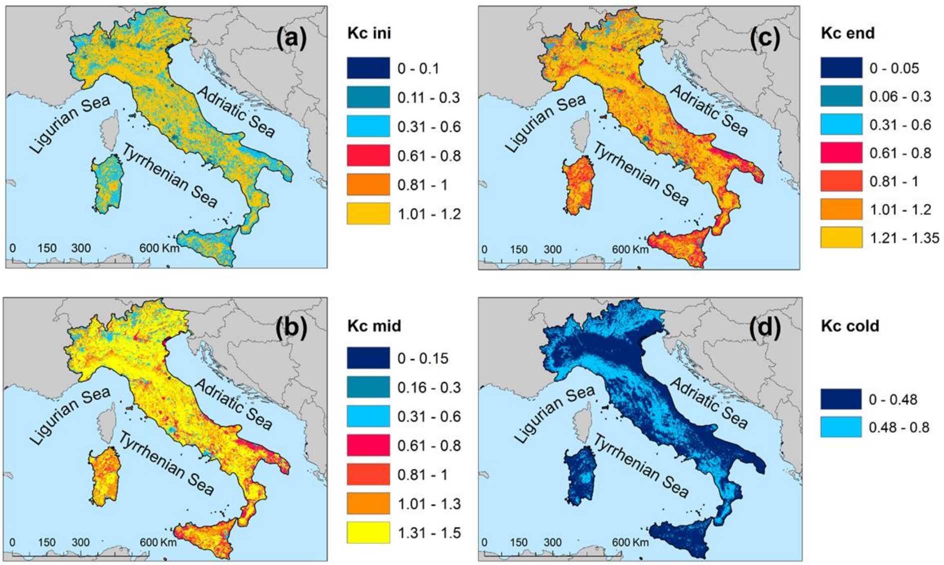

Fig. 5. Spatial distribution of K_c in Italy related to the projection of scenario A1. (a) $K_{c\ ini}$ for the initial season. (b) $K_{c\ mid}$ for the mid-season season. (c) $K_{c\ end}$ for the end season. (d) $K_{c\ cold}$ for the cold season.

The future projection of the land cover indicates slightly differences of the K_c pattern for all seasons due to the simplified land cover classes carried out for 2040. The $K_{c\ ini}$ varies in the future from 0 to 1.2 with values between 1 and 1.2 in the northern and inside central peninsula sides, while on the coastal areas, major land of Sicily and Sardinia, and Alps Mountains the values of $K_{c\ ini}$ ranges from 0.11 to 0.6. The K_c in the mid-season increase up to 1.5 and shows large parts of Italian territory with $K_{c\ mid}$ values over 1.3. These values extends in the North of the country, central and South of the Italian Peninsula. Southeastern and some southern sides of Italy, western, northern, and eastern parts of Sicily, central and North of Sardinia has medium values of $K_{c\ mid}$ (0.6 to 1). The Kc end varies for the future scenarios from 0 to 1.35, with elevated values (1 to 1.35) in the central and northern areas of Italy, while the southern areas of Italy, Sicily and Sardinia are cover more by land with Kc end values between 0.6 and 1.

The lowest values are located in the elevated mountains and surrounding the large urban areas and in the metropolitan area of the capital. In the cold season, the $K_{c\ cold}$ illustrates the lowest values of evapotranspiration rate and, more than this, only values below 1.

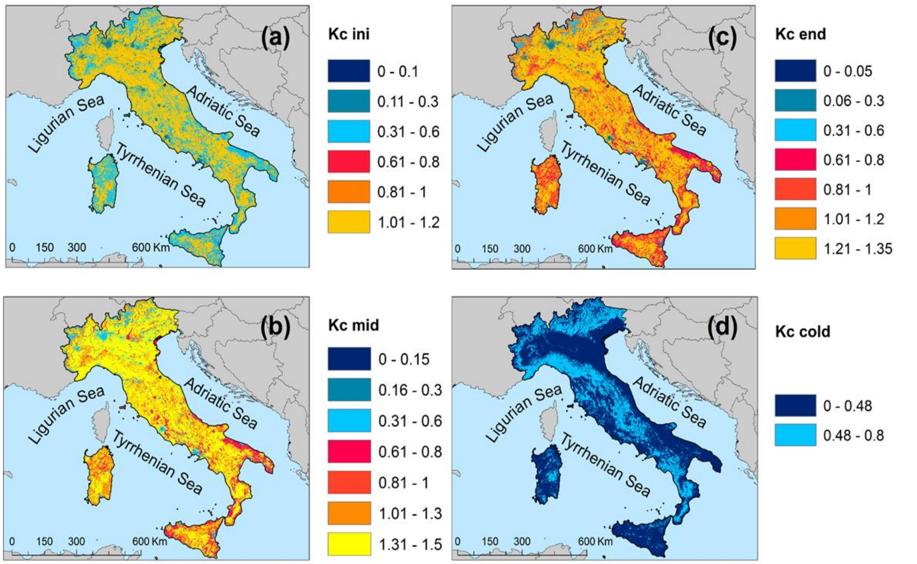

Fig. 6. Spatial distribution of K_c in Italy related to the projection of scenario A2. (a) $K_{c\ ini}$ for the initial season. (b) $K_{c\ mid}$ for the mid-season season. (c) $K_{c\ end}$ for the end season. (d) $K_{c\ cold}$ for the cold season.

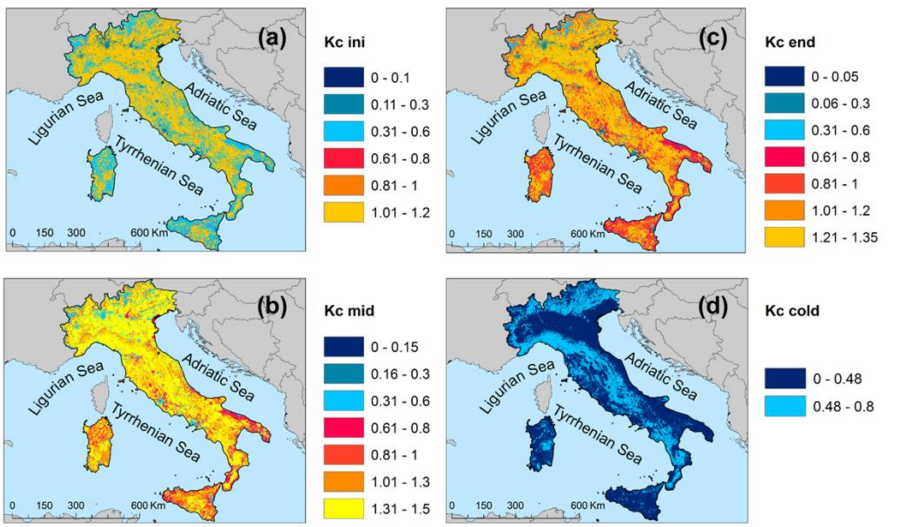

Fig. 7. Spatial distribution of K_c in Italy related to the projection of scenario B1. (a) $K_{c\ ini}$ for the initial season. (b) $K_{c\ mid}$ for the mid-season season. (c) $K_{c\ end}$ for the end season.

(d) $K_{c\ cold}$ for the cold season.

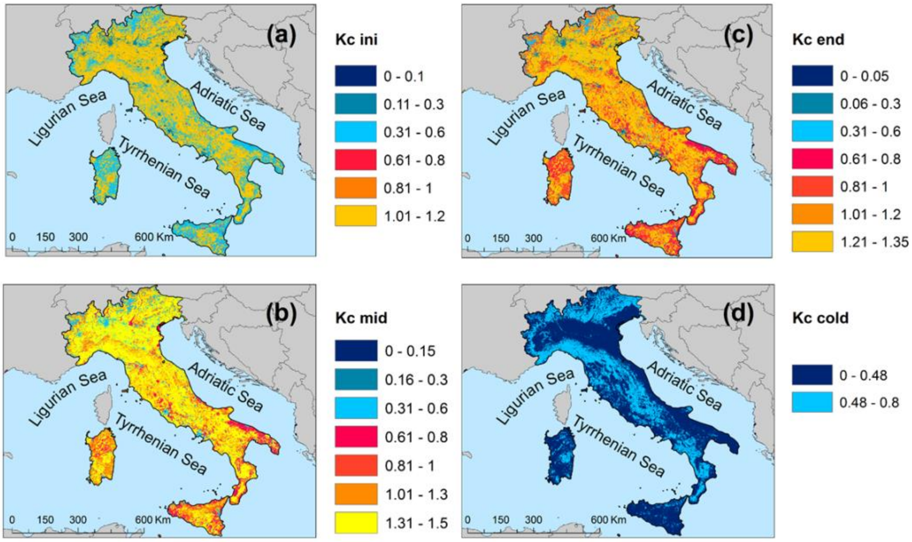

Fig. 8. Spatial distribution of K_c in Italy related to the projection of scenario B2. (a) $K_{c\ ini}$ for the initial season. (b) $K_{c\ mid}$ for the mid-season season. (c) $K_{c\ end}$ for the end season. d) $K_{c\ cold}$ for the cold season.

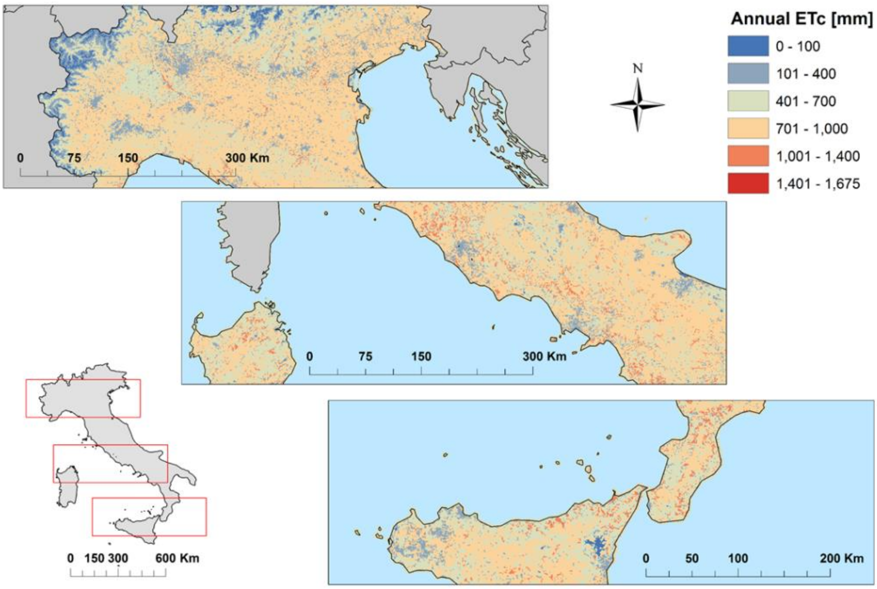

Fig. 9. Spatial distribution of annual ET_c in Italy related to the present (details of three sides).

Thus, in the mountain areas covered by forest and trees, the $K_{c\ cold}$ varies from 0.48 to 0.8, while in the plains, coastal areas, urban areas, Sicily and almost whole territory of Sardinia the values are 0. The pattern of $K_{c\ ini}$, $K_{c\ mid}$, $K_{c\ end}$, and $K_{c\ cold}$, are very similar for all scenarios. **Figures 5 – 8** show the variation of K_c in the Italian land considering the four seasons. Following the presented methodology, from the seasonal ET_0 and seasonal K_c, the annual ET_c was calculated for the present in aim to extract the AK_c. **Figure 9** illustrates three sheets of Italian Peninsula where the annual ET_c is more diversified and the values pattern can be observed in details.

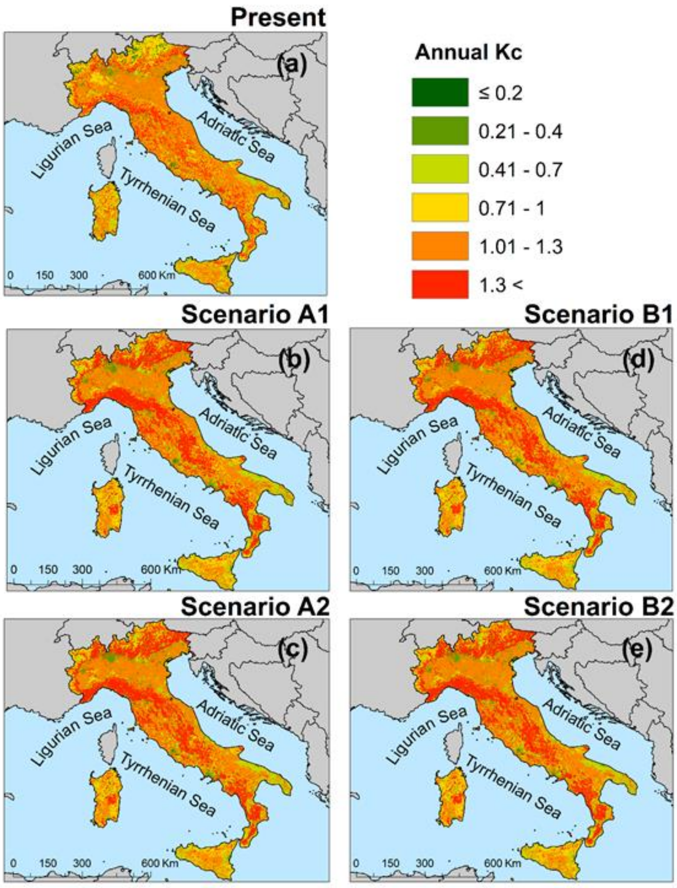

Fig. 10. Spatial distribution of AK_c in Italy related to the present and future projection. (a) AK_c for the present. (b) AK_c for the Scenario A1. (c) AK_c for scenario A2. (d) AK_c for the scenario B1. (e) AK_c for the scenario B2.

The annual ET_c ranges from 0 to 1675 mm, indicating the lowest values (below 400 mm) in the mountain areas, in the urban and in the no vegetated areas. The high values of annual ET_c were depicted in the all three set sheets, especially in many sides of the North, central and South of Italy, where the ferest area is located. After the ratio of ET_c and ET_0, the AK_c have been calculated for Italy using the present climate and land cover layers.

Figure 10 depicts the AK_c spatial distribution for the present and future. Few territories has low values of AK_c (below 0.2) and are located in the North of Italy, some sides of Tyrrhenian coast, and in the agglomerated urban areas. The highest values (above 1.3) of the AK_c could be found in the Alps and Apennines Ranges while in the plains, and coastal areas the values of AK_c varies from 1 to 1.3. The southeastern part of Italy, western and eastern parts of Sicily, the AK_c has values between 0.4 and 0.7. Table 3 reports the calibrated values of AK_c for the present and Table 4 reports the AK_c for the future.

5. DISCUSSION AND CONCLUSIONS

Spatial distribution of seasonal K_c in Italy have been mapped for the present and future period. From the annual ET_c calculation, the AK_c specified for all classes of land cover was found. Due to the detailed division of CORINE Land Cover up to 4^{th} level, the present AK_c map illustrates a distribution of crops presence mare diversified than in the future scenarios. In all cases, the high values of AK_c extends in the North of Italy, more precise in Prealps areas between Po Plain and Alps, in the Northern and Central Apennines, where the forest and the crops with evapotranspiration capacity rate rise over 1.3, but also in some sides of the South of Italy, Sicily and Sardinia. The lower AK_c (below 0.4) were depicted din the high mountains areas and surrounding the big cities.

Under the land cover projections, the land with high values of AK_c extends up to 2040, the scenario A1 is the most alarming for the Italian territory. Is the evolution of land cover will follow this scenario, the direct negative effects on agriculture and water resources will affected due to the irrigation water quantity requires.

Our work has obvious some limitations, not really from the calculation survey but more related to some aspects of missing field measurements. The complex land of Italy and the spatial extension no not allow us to complete an exhaustive study by tensiometers and lysimeters. For the same reason, in the Thornthwaite equation, the latitude factor of sunshine was set at 1. These limitations doesn’t affects the investigations considering the large scale of the study, but also the appropriate results carried out here are in range with other studies about K_c and ET_c in central and southern Europe.

Present and future maps of seasonal K_c and AK_c at spatial scale of Italy represent significant tools for climatologists and hydrogeologists from one of the larger and complex country from Europe. Based on these maps, the water deficit and water surplus for different locations of the country may be calculated.

Acknowledgements

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Table 3. Corine Land Cover classes and annual Kc calculated for present in Italy.

Corine Land Cover		Kc annual				
CLC code 2012	CLC Description	Kc	Ks	Ku	Kw	Kclc
111	Continous urban fabric	-	-	0.29	-	0.29
112	Discontinuous urban fabric	-	-	0.21	-	0.21
121	Industrial or commercial units	-	-	0.3	-	0.3
122	Road and rail networks and associated land	-	-	0.25	-	0.25
123	Port areas	-	-	0.39	-	0.39
124	Airports	-	-	0.3	-	0.3
131	Mineral extraction sites	-	-	0.26	-	0.26
132	Dump sites	-	-	0.26	-	0.26
133	Construction sites	-	-	0.26	-	0.26
141	Green urban areas	-	-	0.21	-	0.21
142	Sport and leisure facilities	-	-	0.21	-	0.21
211	Non-irrigated arable land	1.14	-	-	-	1.14
212	Permanently irrigated land	1.25	-	-	-	1.25
213	Rice fields	0.94	-	-	-	0.94
221	Vineyards	0.5	-	-	-	0.5
222	Fruit trees and berry plantations	0.68	-	-	-	0.68
223	Olive groves	0.66	-	-	-	0.66
231	Pastures	0.7	-	-	-	0.7
241	Annual crops associated with permanent crop	0.67	-	-	-	0.67
242	Complex cultivation patterns	1.16	-	-	-	1.16
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0.92	-	-	-	0.92
244	Agro-forestry areas	0.92	-	-	-	0.92
311	Broad-leaved forest	1.42	-	-	-	1.42
312	Coniferous forest	1	-	-	-	1
313	Mixed forest	1.33	-	-	-	1.33
321	Natural grasslands	0.97	-	-	-	0.97
322	Moors and heathland	0.92	-	-	-	0.92
323	Sclerophyllous vegetation	0.62	-	-	-	0.62
324	Transitional woodland-shrub	0.83	-	-	-	0.83
331	Beaches, dunes, sands	-	0.23	-	-	0.23
332	Bare rocks	-	0.15	-	-	0.15
333	Sparsely vegetated areas	0.48	-	-	-	0.48
334	Burnt area	-	0.1	-	-	0.1
335	Glaciers and perpetual snow	-	-	-	0.5	0.51
411	Inland marshes	-	-	-	0.5	0.45
412	Peat bogs	-	-	-	0.4	0.37
421	Salt marshes	-	-	-	0.3	0.32
422	Salines	-	0.1	-	-	0.1
423	Intertidal flats	-	-	-	0.6	0.64
511	Water courses	-	-	-	0.6	0.63
512	Water bodies	-	-	-	0.6	0.64
521	Coastal lagoons	-	-	-	0.7	0.68
522	Estuaries	-	-	-	0.6	0.62
523	Sea and ocean	-	-	-	0.7	0.74

Table 4. Corine Land Cover classes and calculated annual Kc for future scenarios in Italy.

Corine Land Cover			Kc				
CLC code 2012	CLC projection code	CLC Description	Kc	Ks	Ku	Kw	Kclc
133	0	Built-up area	-	-	0.3	-	0.26
211	1	Arable land (non-irrigated)	1.1	-	-	-	1.14
231	2	Pasture	0.7	-	-	-	0.7
321 and 324	3	Natural and semi-natural vegetation (including Natural grasslands, scrublands, regenerating forest below 2 m, and small forest patches within agricultural landscapes)	0.9	-	-	-	0.9
411	4	Inland wetlands	-	-	-	0.45	0.45
335	5	Glaciers and snow	-	-	-	0.51	0.51
212	6	Irrigated arable land	1.3	-	-	-	1.25
321	7	Recently abandoned arable land (i.e. "long fallow"; includes very extensive farmland not reported in agricultural statistics, herbaceous vegetation, grasses and shrubs below 30 cm)	1	-	-	-	0.97
241	8	Permanent crops	0.7	-	-	-	0.67
313	10	Forest	1.3	-	-	-	1.33
333	11	Sparsely vegetated areas	0.5	-	-	-	0.48
331	12	Beaches, dunes and sands	-	0.2	-	-	0.23
422	13	Salines	-	0.1	-	-	0.1
423 and 521	14	Water and coastal flats	-	-	-	0.66	0.66
322	15	Heathland and moorlands	0.9	-	-	-	0.92
231 and 324	16	Recently abandoned pasture land (includes very extensive pasture land not reported in agricultural statistics, grasses and	0.8	-	-	-	0.76

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FLUNETS: A NEW MATLAB-BASED TOOL FOR DRAINAGE NETWORK ORDERING BY HORTON AND HACK HIERARCHIES

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ABSTRACT:
This work presents FLUNETS (FLUvial NETwork Sorting tool), a new MATLAB-based tool designed for channel network ordering by Horton and Hack hierarchies. Differently to Strahler and Shreve hierarchies, Hack and Horton orderings allow organizing a drainage network in a hierarchy, identifying the parent segment over the child segment, giving as a result a network where the value of a river remains unchanged from the mouth upstream to the headwater. The novelty of FLUNETS is that it allows the user to choose the hierarchy attribute. Therefore, a fluvial network can be ordered by distance to the mouth or by accumulation upstream. In addition, FLUNETS offers a wide set of optional parameters, which turns it into a friendly tool to attain a highly tailored ordered fluvial network. A continuous fluvial network is the starting point for multiple landscape analysis applications. The source code is available in the authors' GitHub account (https://github.com/geouned/FLUNETS).

Key-words: *Hydrology, Fluvial hierarchies, Channel network, Horton, Hack, Geomorphology.*

1. INTRODUCTION

In the last three decades advances in modelling Earth's surface have been made due to the development of algorithms and computer simulation models (e.g. Refice et al., 2012). Land surface analysis, hydrogeology assessment, drainage network analysis, etc., they all had an extensive development since the 1980s (Jenson, 1985, O'Callaghan and Mark, 1984), and keep developing today (Schwanghart and Kuhn, 2010, Jasiewicz and Metz, 2011). Regarding hydrology analysis, many flow-related algorithms have been developed, such as flow direction (Lindsay, 2003, O'Callaghan and Mark, 1984), flow accumulation, flow length, stream order, among others. In addition, numerous geomorphologic indices and other quantitative analysis based on the fluvial network have been developed. These indices provide information on landscape evolution (Antón et al., 2014, Tucker and Hancock, 2010, Whipple K.X. et al., 2003, Daxberger et al., 2014, Pastor-Martín et al., 2017b). Based on streams characterization, those analysis help to understand fluvial systems and landscape responses to external drivers such as climate, tectonics, human actions, etc. (Antón et al., 2012, Font et al., 2010, Pedrera et al., 2009, Johnson and Finnegan, 2015, Scherler et al., 2016, Shugar et al., 2017).

Most of the flow-related algorithms are implemented in Geographic Information System (GIS) software and have been developed for non-spatial software, such as MATLAB (MathWorks, 2012) or Octave (Eaton et al., 2014). Regarding channel network

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ordering algorithms, the majority of GIS software offers only topological network orderings, based on joining segments, such as Strahler or Shreve orderings. These systems provide single segments between junctions but not complete streams. To approach many studies related to geomorphology or hydrology, it is necessary to start the study from the extraction of a continuous fluvial network, in which each stream is identified as a complete river. Therefore, other channel network hierarchies are required, such as Horton and Hack. Hack and Horton hierarchies provide a continuous channel network, where the river value remains unchanged from the mouth up to the headwater. These two hierarchies ease to tackle stream long profile analysis (for example Jiménez-Cantizano et al., 2017, Pastor-Martín et al., 2017a) and most geomorphic indices calculations.

Attaining a suitable channel network for landscape analysis is still a challenge. The aim of this paper is to present FLUNETS, a new tool for channel network ordering by Horton and Gravelius/Hack hierarchies. Relying on the set of MATLAB functions for relief analysis provided by TopoToobox (Schwanghart and Kuhn, 2010, Schwanghart and Scherler, 2014), FLUNETS is designed to address the construction of an ordered fluvial network. The wide set of parameters this tool offers turns it into a very suitable tool for the correct extraction of a continuous channel network from a Digital Elevation Model (DEM) that serves as the starting point for multiple terrain analysis. Finally, we present the functionality with a case study investigating the channel network in the Pisuerga watershed, in the Iberian Peninsula.

2. FLOW-RELATED CONCEPTS

2.1. Fluvial concepts

Flow refers to a natural watercourse that goes from one place to another. Normally a fluvial network can be idealized as a planar tree where a channel is a branch and the master channel is the tree trunk. The furthest point downstream is the channel network outlet or mouth. Points furthest upstream are called stream heads or headwaters. The points where two channels join are called junctions or confluences.

2.2. Drainage network ordering

Drainage network ordering refers to the method to sort a channel network. There are multiple methods to order a drainage network. The most common ordering methods included in conventional GIS software are Strahler method (Strahler, 1957) (**Fig. 1.A**) and Shreve method (Shreve, 1967) (**Fig. 1.B**). In addition to these sorting hierarchies, there are other network orderings, such as original Horton hierarchy (Horton, 1945) (**Fig. 1.C**) and normal stream hierarchy proposed by Gravelius (1914) also known as Hack’s main streams (Hack, 1957) (**Fig. 1.D**).

The main difference between the above mentioned sorting methods relies on that for Horton and Hack hierarchies the network is sorted from the mouth upstream direction until finding the headwaters. In contrast, Strahler and Shreve methods sort the channel network from the headwaters downstream towards the mouth.

Strahler remains to an idealized topological model, where the stream order changes from the watershed mouth point up to the stream head (Strahler, 1957). The smallest fingertip tributaries are designated with order 1. When two segments of the same order n join, a segment of order $n + 1$ is formed. When two segments of different order meet, they form a segment of maximum order of both (**Fig. 1.A**). The master stretch is therefore the segment of highest order. Shreve hierarchy is similar to Strahler hierarchy. Fingertip segments are of order 1. When two segments join, the resultant segment downstream order is the sum of the segments' order joining. Hence, the magnitude of a segment is equal to the total number of stream heads ultimately tributary to it (Shreve, 1967) (**Fig. 1.B**). Both hierarchies, Strahler (1957) and Shreve (1967) are purely topological hierarchies, where the interconnected segments between junctions do not involve lengths, shapes, accumulation rates or orientations of the segments comprising the channel network.

In contrast, Gravelius proposed one of the first attempts to classify drainage networks on the basis of branching (Gravelius, 1914, Hack, 1957). Starting from the watershed outlet, the main stream is designated as order 1 and smaller tributary streams are designated with increasingly higher orders, from the stream confluence upstream to the headwaters. When a parent channel of order *n* meets a junction, ascribes order *n* + 1 to the joining tributary (**Fig. 1.D**). On the contrary, Horton considered that the main stream should be the one with the highest order and that unbranched fingertip tributaries should always be designated as order 1. Tributaries of second order receive only tributaries of first order, third order tributaries receive tributaries of second order but may also receive first order tributaries, and so on (Horton, 1945) (**Fig. 1.C**). To determine which the parent segment is and which is the child segment in a junction, Horton considers that the stream that forms the greatest angle with the parent is of lower order. If both joining streams form the same angle with the parent, the shorter stream is taken as of the lower order.

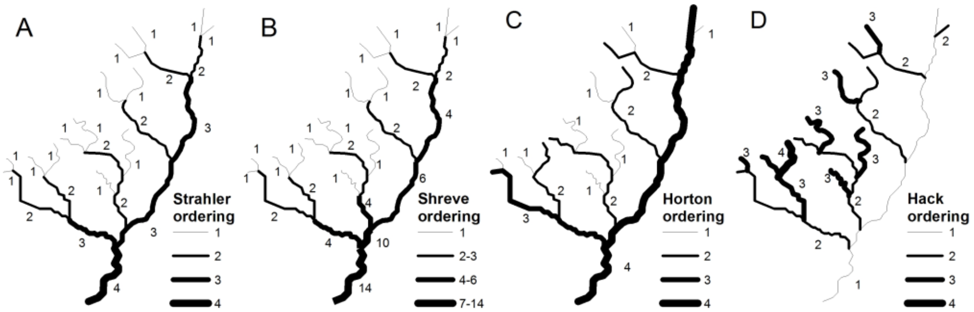

Fig. 1. Stream network orderings: (A) Strahler (Strahler, 1957), (B) Shreve (Shreve, 1967), (C) Horton (Horton, 1945), (D) Hack (Hack, 1957).

3. METHODOLOGY

FLUNETS relies on TopoToolbox 2 (Schwanghart and Kuhn, 2010, Schwanghart and Scherler, 2014), thus it requires download the set of functions freely available on the authors' webpage (physiogeo.unibas.ch/topotoolbox). Technical requirements for its use are explained in detail in the user guide and readme files available on the author's GitHub repository (https://github.com/geouned/FLUNETS).

3.1. Tool-related concepts

In this tool, the furthest point downstream of the channel network is called outlet. The point where two channels join is called confluence and the point before the cell where two channels converge is called pour point.

3.2. Parameters

FLUNETS requires setting a set of mandatory and optional input parameters prior to its execution. Mandatory parameters are the following: (i) selecting the DEM file. This can be an ASCII or TIFF/GeoTIFF file; (ii) the sorting method: Horton or Hack and (iii) the hierarchy attribute which defines the hierarchy of a segment over another when two or more segments converge in a confluence. It can be upstream accumulation or upstream distance.

If two channels have the same hierarchy attribute value at the pour point, elevation is compared as a second parameter. In such case, the branch with lowest elevation at the pour point will be given the highest order (Jasiewicz and Metz, 2011). Upstream accumulation and upstream length replace Horton's previous idea to give the greatest order to the branch that has a smaller angle with respect to the parent branch (Horton, 1945). This idea was discarded because it resulted in unrealistic drainage structures (Ai, 2007).

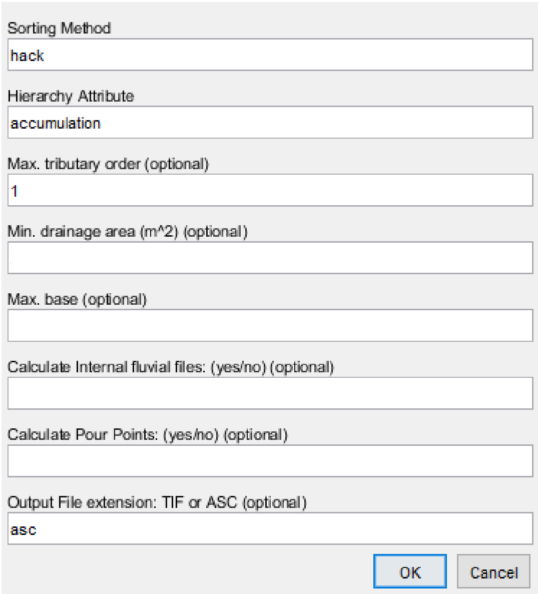

Fig. 2. FLUNETS user interface.

There is also a set of optional parameters. The aim of the optional parameters is to attain a more customized channel network to avoid the tedious steps of post processing the data, hence to provide a valid output to be the starting point for multiple terrain analysis. If these parameters are left empty, a default value for each of them will be set. The optional parameters are the following: (i) the maximum tributary order, which is the '-ith' order up to which the channel network will be sorted; (ii) the minimum drainage area, which refers to the minimum drainage area of a channel -at the pour point-; (iii) the maximum base level, which is the height an outlet must have to be considered. This parameter is useful to select only outlets located at a certain elevation; (iv) the pour points location and the flow-related matrices can be provided as raster output files; (v) and finally, the raster format for the sorted channel network. It can be either ASCII or TIFF/GeoTIFF –in case of having the

MATLAB Mapping Toolbox package installed, a GeoTIFF file can be generated for the TIFF option, else a normal TIFF file will be given-. The output channel network is also given as a CSV file. The CSV contains a record for each cell of each river sorted. The fields store the following information: the x and y coordinates for each cell (these coordinates represent the cell center), the height, the order (Hack's or Horton's), the accumulation, the accumulated drainage area in square meters, the river identifier, the distance downstream in meters, the pour points and the outlets of the network. Fig. 2 shows an example of the FLUNETS user interface.

3.3. Extraction and sorting processes

The internal process of this tool is shown in **Fig. 3**. The initial points are the outlets. From these points, the drainage network skeleton is performed in upstream direction, finding pour points along the river until reaching the head of the channels. These pour points will be the starting points to extract new channels of the network until reaching the headwaters.

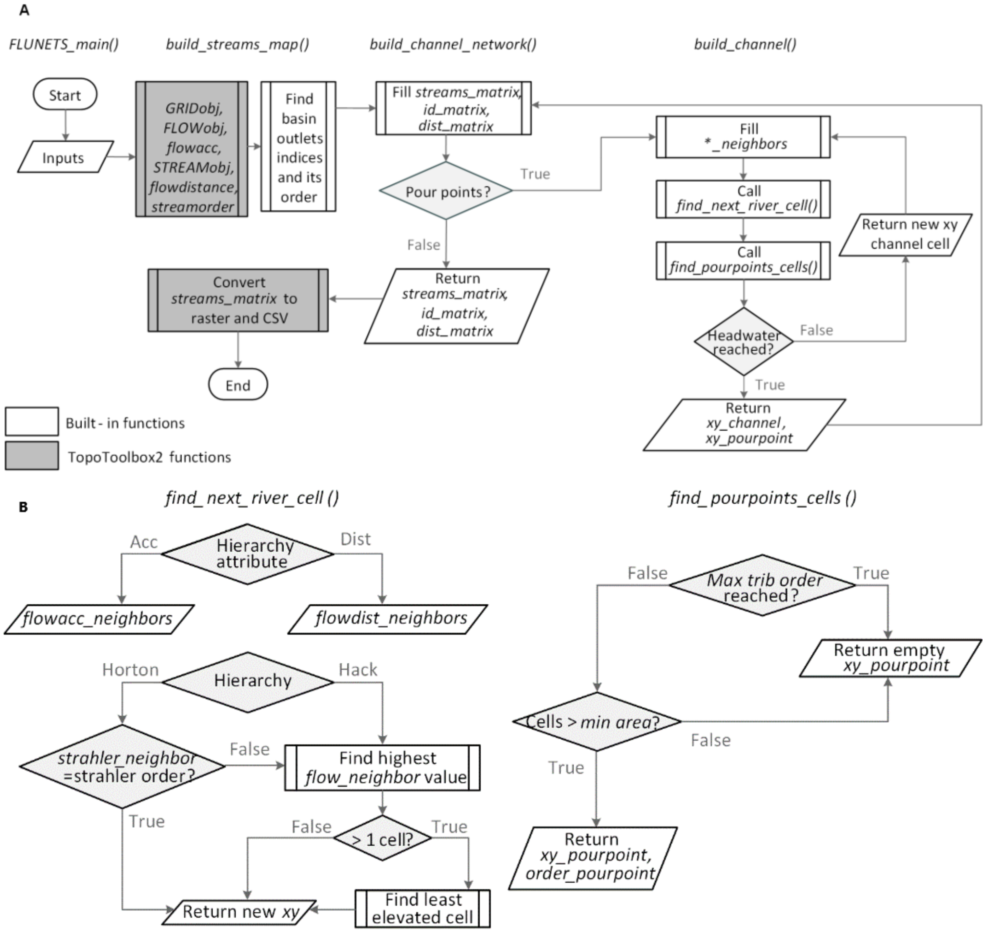

Fig. 3. Workflow of the processes for the extraction and ordering by Horton or Hack hierarchies. (A) Complete workflow. (B) Schemas of *find_next_river_cell* and *find_pourpoints_cells* functions.

The first step is to compute the flow-related matrices. To initially generate the flow-related matrices functions from the TopoToolbox 2 (Schwanghart and Kuhn, 2010, Schwanghart and Scherler, 2014) are applied. This is done in *build_streams_map* function, where the *GRIDobj* function reads the DEM file, *FLOWobj* generates the flow direction model from the DEM, *flowacc* calculates the accumulation model, *STREAMobj* and *flowdistance* compute a flow distance model and finally, if Horton is chosen as the hierarchy method, a Strahler model is created. Once this first step is achieved, the process of extracting a channel network begins. The *build_channel* function is responsible for extracting each single channel, from the pour point up to the headwater. The first channel cell to assess is the watershed outlet. To assess a channel cell, a 3x3 auxiliary window matrix is created around it (**Fig. 4**). Six empty arrays –named as **_neighbors* in **Fig. 3.A**– are created, and each array is filled with neighboring cells values of the following matrices: elevation, flow direction, flow accumulation, flow distance, Strahler (only for Horton hierarchy) and neighbors' linear indices. When the auxiliary arrays are filled, *find_next_river_cell* function finds the neighbor that will become the next channel cell and, hence, the next cell to be addressed.

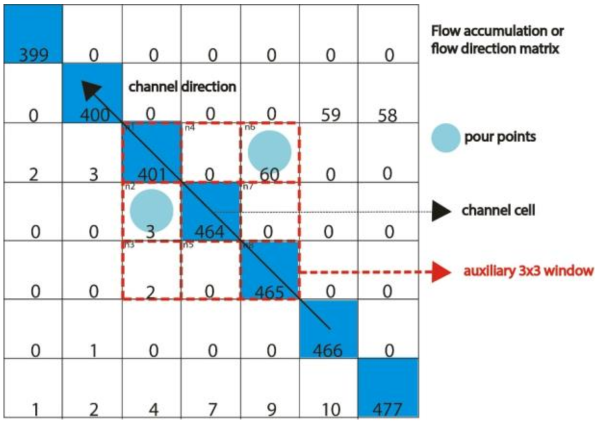

Fig. 4. Building a 3x3 auxiliary window around the channel cell to obtain the cell values of the eight neighbors from the DEM, flow direction, flow accumulation, flow distance and Strahler matrices and their linear indices. Values are stored in the arrays ending as "_neighbors".

The last step in the process is to identify the pour points that will become the initial cells to delineate tributaries. The *find_pourpoints_cells* checks the value set in the minimum watershed area parameter. Only the neighbors with equal or higher watershed area than the value set, except for the neighbor already identified as the next channel cell, will be stored as pour points (**Fig. 3.B**). The *build_channel* function continues to loop until it finds the headwater of the channel, which remains to the end of this channel. *build_channel* function returns *xy_channel* and *xy_poipoint* arrays, where the river cells and the pour points cells have been stored. Then starts looping over the newly found pour points to begin a new process of channels extraction. This process keeps on looping until the outputs are successfully generated. The CSV output file is filled with data from the **_matrix* variables, which are auxiliary variables used during the stream network extraction process to store river cell values, such as elevation, accumulation upstream, distance to the mouth, etc.

3.4. Case of study

The case of study is located in the Pisuerga watershed (**Fig. 5**) in the Iberian Peninsula. Pisuerga river is 270 km in length with a watershed of 15,700 km^2. Five of its main tributaries are Arlanza, Odra and Esgueva rivers, on the left side, and Carrión and Valdavia rivers, on the right side. The used DEM was taken from the Shuttle Radar Topography Mission (SRTM) (Rabus et al., 2003) version 4.1 of 90 m of spatial resolution.

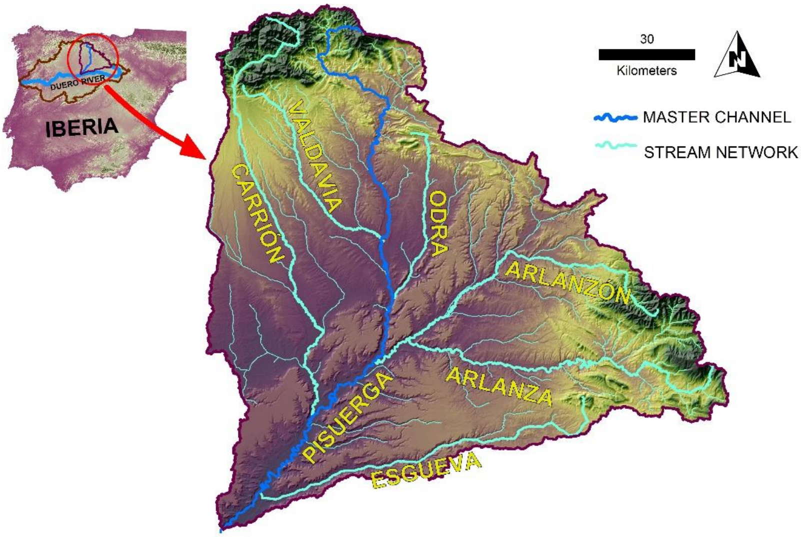

Fig. 5. Pisuerga basin SRTM v.4.1 DEM showing the master channel and main tributaries: Carrión, Valdavia, Odra and Esgueva rivers and the Arlanza-Arlanzón system.

FLUNETS was used to investigate the Pisuerga watershed. Table 1 shows the results of applying FLUNETS to the Pisuerga basin and the different parameters used. These output networks were filtered and the main first-order tributaries with a length over 80 km were selected. In addition, the Arlanzón river was added to the filtered networks, because some hierarchies have considered it as part of the main river (**Fig. 6**). The channel networks were equivalent to the tributaries of Carrión, Valdavia, Odra, Esgueva, Arlanza and Arlanzón recognized as main tributaries by the Confederación Hidrográfica del Duero (CHD) and by the Instituto Geográfico Nacional (IGN) (**Fig. 6.E**).

4. RESULTS AND DISCUSSION

The trajectories of the channels coincide with the channels provided by the CHD and IGN (**Fig. 6**). The cases in which the upstream distance was the hierarchy attribute, the river identified as the main channel follows the Pisuerga path recognized in the topographic maps of the IGN (**Fig. 6.A** and **Fig. 6.C**). In addition to this, in Hack hierarchy (**Fig. 6.A**), tributaries of Carrión, Valdavia, Odra, Esgueva and Arlanza were identified as first order tributaries, and Arlanzón river as second order tributary, resembling the CHD and IGN channel networks for the Pisuerga watershed (**Fig. 6.E**).

However, the two channel networks that were ordered by upstream accumulation (**Fig. 6.B** and **Fig. 6.D**), have identified Arlanzón river as part of the main river, turning the Pisuerga upper reach into a tributary of this one. In these two channel networks, Arlanzón river, accumulates more water at the pour point than Pisuerga upper reach.

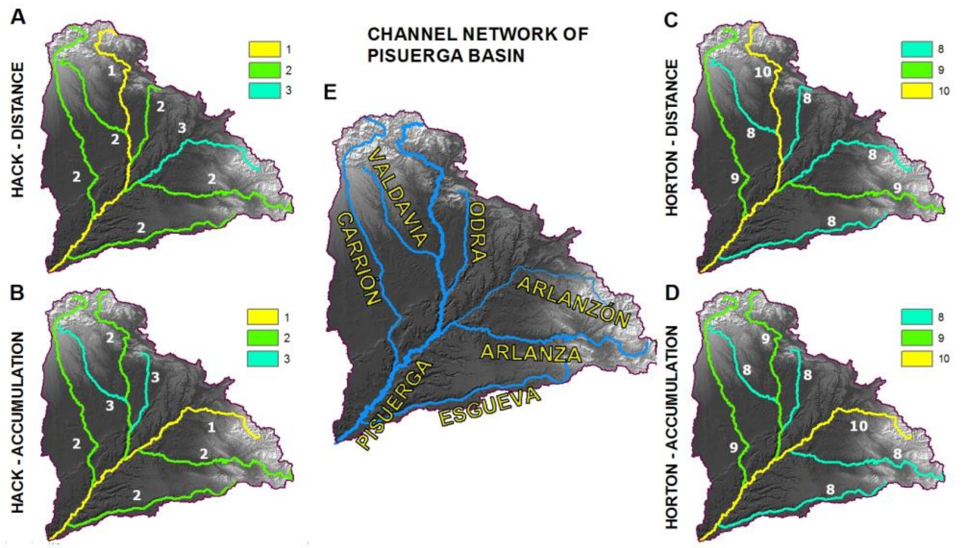

Fig. 6. The channels represented in the subfigures were obtained by filtering first order tributaries larger than 80 km in length for each channel network. In addition, the Arlanzón river was added to the filtered networks, because some of the hierarchies considered it as part of the main river. (A-D) Different combinations of the hierarchy method with the hierarchy attribute. (E) Official hydrological network from the CHD at 1: 50,000 scale.

Table 1: Results of FLUNETS applying different parameters.

Sorting type	Hierarchy attribute	Max. tributary order	Total number of channels	Number of 1st order tributaries	Number of 2nd order tributaries	Min. channel length [m]	Max. channel length [m]	Min. order	Max. order
Hack	Acc.	2	997	158	838	1,409	243,335	1	3
Hack	Dist.	2	967	183	783	1,558	272,985	1	3
Horton	Acc.	2	993	164	828	1,409	247,335	3	10
Horton	Dist.	2	978	188	789	1,589	271,778	3	10

The combination of factors that in the past determined the hierarchy and the headwaters location of a drainage network varies depending on the place. These historical reasons determine the fluvial networks presented in nowadays-topographic maps. The drainage networks extracted using FLUNETS, may not totally agree with the channel's hierarchy presented in the topographic maps, although they represent a way to sort a continuous channel network that describes more realistically the topography. This is because depending on the parameter that is chosen as hierarchy attribute, the channel network will be sorted in a certain way according to the elevation values and the topography. Therefore, the hierarchy of the tributaries will be determined by the river extracted as master channel.

Nevertheless, FLUNETS provides a highly customized continuous channel network. Not only does FLUNETS provide a sorted channel network but also information about the drainage watershed from which it can be inferred other information such as the topography and geomorphology of the terrain.

In addition, a sorted network by one of these two hierarchies eases the following steps in the analysis of a watershed. For instance facilitates previous steps for the automation of geomorphological indices, such as Valley Height-Width Ratio (Vf), Stream Length-Gradient Index (SL), basin asymmetry factor, etc., which require a continuous channel network previously extracted from the DEM. These indices give a more extensive knowledge of the characteristics and properties of a watershed, and the combination of these indices provides very significant information on fluvial morphology useful to understand landscape evolution in terms of tectonics, climate change or geomorphological processes.

5. CONCLUSIONS

In this paper, we present FLUNETS, a new MATLAB-based tool for drainage network sorting in a non-spatial environment. The tool offers two ordering hierarchies, Hack and Horton. This tool is applicable to any DEM. In this work, the tool was applied to the Pisuerga watershed, a subbasin of the Duero river, and the differences in the results derived from the different combination of parameter values support its robustness.

Up to our knowledge, nowadays no tool was available for non-spatial software that allowed the ordering of stream networks by Hack and Horton hierarchies. In addition to this, this tool allows choosing the hierarchy attribute to lead the sorting process, between upstream accumulation and upstream distance. Also, the high number of optional parameters enables to attain a highly tailored sorted drainage network that best suites the user's requirements, such as selecting the maximum order of tributaries instead of extracting a complete and dense channel network. The multiple information provided in the CSV file enable an in deep analysis of the channel network (longitudinal profiles extraction, length and ordering analysis and/or filtering, etc.) and facilitate the data management.

Horton and Hack hierarchies provide a continuous drainage network, as each channel retains the same value from its mouth up to the headwater. Unlike nodes graphs, this type of ordering eases the analysis of terrain properties that can be inferred from them. A channel network sorted by Hack or Horton hierarchies are necessarily the starting point for landscape evolution studies and terrain analysis, by the extraction of longitudinal profiles or the calculation of geomorphometric indices.

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TOURIST FLOWS BETWEEN CENTRAL EUROPEAN METROPOLISES (IN THE CONTEXT OF METROPOLISATION PROCESSES)

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ABSTRACT:
This paper focuses on the tourist flows between Central European metropolises. The main aim is to identify these flows and to evaluate position of metropolises within the spatial structure of the Central European tourism. The core of the analysis lies in the evaluation of the main tourist flows and their spatial distribution. Hence, the paper measures the appropriate quantitative network characteristics of tourist flows and visualizes them. For this purpose, it is also necessary to find a method that allows quantifying tourist flows, because current statistics cannot capture tourist streams at the level of individual metropolises. Finally, the results are discussed in the context of metropolisation processes. The results reveal the importance of the Vienna network connection, as the most important analysed tourist destination, to the rest of the metropolises. The weakness of the network connection has been confirmed especially in Polish metropolises, while Berlin can be considered an important transit hub.

Key-words: *urban tourism, tourist flows, network analysis, metropolis, Central Europe*

1. INTRODUCTION

Nowadays, tourism is a global branch of the world economy. Just international tourism's share of the global GDP amounts to 10% and makes up about 7% of the global export. In this context, tourism ranks third among the most significant export industries in the world (UNWTO, 2017). Trips to cities represent quite significant part of the global tourism. Urban tourism is considered by United Nations World Tourism Organisation (UNWTO) to be an important segment of the international tourism, and as such, it plays a significant role in economic as well as in social environment of many urban destinations. According to World Travel Monitor (IPK International, 2015), Trips to cities make up about 22% of all holiday flows; moreover, between 2007 and 2014 the number of such trips went up by 82%. Obviously, the importance of urban tourism is reflected also in the role of tourism within urban economy (e.g., Dumbrovská & Fialová, 2014). Development of urban tourism in cities can also be a driving force of their economic, social and spatial transformation, which is projected for instance in revitalisation of public spaces, development of public infrastructure, interconnection of residential and recreational functions of the cities, enterprise enhancement and development of partnership between public and private sectors, or attracting other trade industries and services (UNWTO, 2018).

In addition, we can witness urbanisation processes which are probably, on a long-term basis, most visible outcomes of the global socio-economic development (Viturka et al., 2017). These days, more than 50% of the world population live in cities and make up more than 60% of the global GDP. By 2030, the share of city population will increase to about 66%, whereas this number will double in developing countries, and the built-up area could

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be even three times larger (UN-Habitat, 2015). That implies that metropolisation may be considered as a higher stage of urbanisation, which is no longer primarily focused on the concentration of population, but on the concentration of importance. On one hand, the source of importance comes from the concentration of production services, finance, technologies, trade and people in one place, which creates space for the economies of scale and for creation of synergies. In this context, we can talk about agglomeration effects which influence, through labour mobility, also the background of metropolises (Pařil et al., 2015). On the other hand, interconnection of metropolises is an even more significant factor which stimulates horizontal and vertical cooperation of metropolises as an important tool for enhancement of national and regional competitiveness (Viturka et al., 2017). Metropolises functioning within networks have stronger ties with one another than with the surrounding hinterland (Jałowiecki, 2006). Additionally, there does not exist just one global network of metropolises, but on the contrary, the networks are internally specialised and hierarchically arranged (Castells, 2008). It corresponds also to the assumption (for more information see Viturka et al., 2017) claiming that human advance is characteristic due to hierarchic differentiation of social systems and their integration through spatial division of labour. Furthermore, Viturka et al. (2017) state: *"The resulting spatial arrangement ensures coherence of social systems reflecting the achieved level of balance between economic, social and ecological factors. As for the spatial integration of the systems, the following driving forces are considered to be decisive: labour interactions on a microregional level, production interactions on a mesoregional level, administrative interactions on a macroregional level and trade interactions on a global level."*

Beyond doubt, the international tourism contributes to such processes. It enhances connection to global space systems both on a transport level and a trade level (congress and trade fair tourism), or a socio-culture level (creative industries, attractiveness of the city, culture and social life).

Contemporary literature dealing with tourist mobility is particularly extensive (Ferrante, Abbruzzo, & De Cantis, 2017). Travel routes analysis dominates over publication outcomes; at least five studies analysing tourist flows in various localities have come into existence in the course of the last quarter century (Mings & McHugh, 1992; Lue, Crompton, & Fesenmaier, 1993; Flognfeldt, 1999; Lew & McKercher, 2002). In total, 26 various types of travel itineraries were identified, distinguished according to the way of transport, distance, number of stops and in-land and cross-border journeys. Subsequently, McKercher and Lew (2004) came to create four fundamental patterns of visitors' mobility: The simplest itinerary style involves a single main destination, there and back journey with or without a side trip. The second itinerary style includes a journey to a main destination, out of which the visitor sets out for a round tour while staying overnight in various places. After the round tour is completed, the tourist comes back to his/her original destination and via the same journey he/she leaves the destination. The third type of journey is just a round tour with multiple stops, there is no transit to the main destination. The last style of travelling is a hub-and-spoke, which means that tourists come to a main destination and make individual (one-day or more-days) trips always returning back to the original destination. Thus, the spatial structures of the tourist flows analysis is based on the application of the network analysis methods (D'Agata, Gozzo, & Tomaselli, 2013; Lee et al., 2013; Luo, MacEachren, 2014; Hong, Ma, & Huan, 2015) and the methods of sequence alignment (Shoval & Isaacson, 2007; McKercher, Shoval, Ng, & Birenboim, 2012). There are also studies coming to light that simulate tourist flows through gravity approaches (Khadaroo & Seetanah, 2008).

The aim of this paper is to identify ties between Central European metropolises, and based on this identification to evaluate position of individual centres within the network. Taking into consideration the data availability, the fundamental task of this paper is to find a method which makes the quantification of tourist flows between individual centres possible. The contemporary statistics is not able to capture tourist flows at the level of individual cities. Therefore, it is necessary to find a method which will be able to estimate such flows.

2. METHODOLOGY AND DATA

The fundamental file consisting of 27 analysed metropolises has been taken over from the article The Metropolisation Processes – A Case of Central Europe and the Czech Republic (for more information see Viturka et al., 2017). Selection of the metropolises is based on three qualitative and quantitative components: the population of the metropolis, a sufficient size of which is regarded to be an initial assumption for commencement of the metropolisation process, the economic profile emphasising representation of knowledge-based industries, and finally, the investment attractiveness reflecting high quality of entrepreneurial and social environment. The Central European region includes Germany, Switzerland, Austria, Poland, the Czech Republic, Slovakia, Hungary, and Slovenia.

Intensity of tourist flows is spatially determined by attractiveness of destinations, population size of source centres and distance between the centres. Modelling of tourist flows is based on the information on proved demand for the studied metropolises and identification of sources of such demand by means of a gravity model. We obtained an overview on geographic structure of metropolises' attendance in 2015 from TourMIS (see Wöber, 2003) database, or alternatively from the national statistical offices. The data is available according to individual source countries. Therefore, it was necessary to estimate a share of tourist arrivals which will be attributed to studied metropolises in each country. At first, based on a share of the number of inhabitants of all metropolises on the number of inhabitants of a given state we estimated the tourist arrivals to all metropolises in the particular country. Next step was an estimation of the tourist arrivals contributed to individual metropolises. We used a gravity model which estimates capacity of interactions under conditions of insufficient availability of the data:

$$G_{ij} = \frac{m_i \times m_j}{d_{ij}} ,$$

whereas G_{ij} = economic force acting between metropolises, m_i = overall foreign attendance of a metropolis, m_j = number of inhabitants living in the source metropolis, and d_{ij} = distance between the involved metropolises.

To measure the distance, we considered the length of the fastest highway/motorway connection (taking into consideration the maximum daily driving limits for trucks according to the EU Regulation which correspond to a maximum distance of 600 – 700 kilometres). As a result, we got a set of tourist flows for each pair of studied metropolises (origin-destination matrix).

With the aim to map the structures of the identified tourist flows and to evaluate the integration capacity of the Central European metropolises we applied the network analysis method. The outputs are created in Gephi 0.9.2, by means of which various types of networks are modelled. Gephi has its own data laboratory with an Excel-like interface to manipulate the data columns, search and transform the data (Bastian et al., 2009). After selection of desired criteria, the program can adjust the size and colour of nodes so as the appearance of the network could be visualised from various perspectives. By using the module which divides the network nodes into positions according to latitude and longitude, it is easy to link the network analysis also with a spatial perspective (e.g. Luo, MacEachren, 2014; Bobková, Holešinská, 2017). Moreover, Gephi offers variety of other advanced visualisation technologies for which it uses various algorithms influencing the arrangement of nodes and network shapes, which allows easy understanding of identification of critical points and opportunities in the studied structures.

Specific algorithm in Gephi software, which offers a simplified view on a certain part of reality, proved to be a suitable tool for modelling. By means of modelling, the studied phenomena can be better understood, and behaviour of such systems can be found out by observation. However, to get a plausible depiction of a model, the target needs to be specified beforehand and quality data background must be prepared.

The assessment of ties and structures is based on the number of network matrices. The key ones deal mainly with centrality which is most frequently used for identification of key positions. The centrality analysis makes comparison of the structure and functioning of various networks possible. The centrality represents placement of nodes within the network. The nodes can be clustered within the network according to their degree. They are expressed by the number of links between individual stakeholders (Hanneman & Riddle, 2005). In our case, a degree of centrality can be distinguished into in-degree (thus, the links ending at a given node; input) and out-degree (the links starting at a given node; output). Based on the in-degree value it is possible to identify the so-called hubs within the network.

Centrality does not have to be assessed just according to a degree. It is also possible to use, for instance, the so-called closeness centrality, which means that the node is in the centre of affairs and it has a favourable position to be linked with other nodes. The nodes with the highest level of closeness centrality have, in a figurative sense, the best overview of what is happening within the network (Hanneman & Riddle, 2005).

Another centrality is represented by the so-called betweenness centrality. The nodes with high betweenness centrality are regarded to be intermediaries since they link the clusters and have a favourable position for control of information spread; although, the number of their edges within the network does not have to be of great importance. They generate opportunities for innovations and growth in the network because they have, thanks to their proximity to other clusters, access to different perspectives and ideas unknown to other network nodes (Hoppe & Reinelt, 2010).

3. RESULTS AND DISCUSSION

According to statistical offices in relevant countries, accommodation in all studied countries was provided to 40.5 million foreign tourists in 2015. However, attendance of metropolises is significantly spatially differentiated. Determinant deviation of attendance is higher than the average value for the whole set of metropolises. More than half of the cities do not reach the boundary of 1 million foreign visitors per year. **Fig. 1** demonstrates a set of metropolises which have entered the analysis and their categorisation with respect to their tourist importance. Such importance was determined on the basis of layout of their overall foreign attendance by using Jenks natural breaks classification method. The global importance category includes only three metropolises: Prague (5.7 mil.), Vienna (5.5 mil.) and Berlin (4.9 mil.). Those cities generate almost 40% of the entire attendance. The second most important group is created by three German metropolitan regions of Rhein-Ruhr, Frankfurt am Main, Munich, and also Budapest, Hungary. The third group includes most popular Polish cities of Warsaw and Krakow, and German metropolises of Hamburg and Mannheim, and Zurich, Switzerland. Position of the other metropolises in respect to tourism is not of great importance.

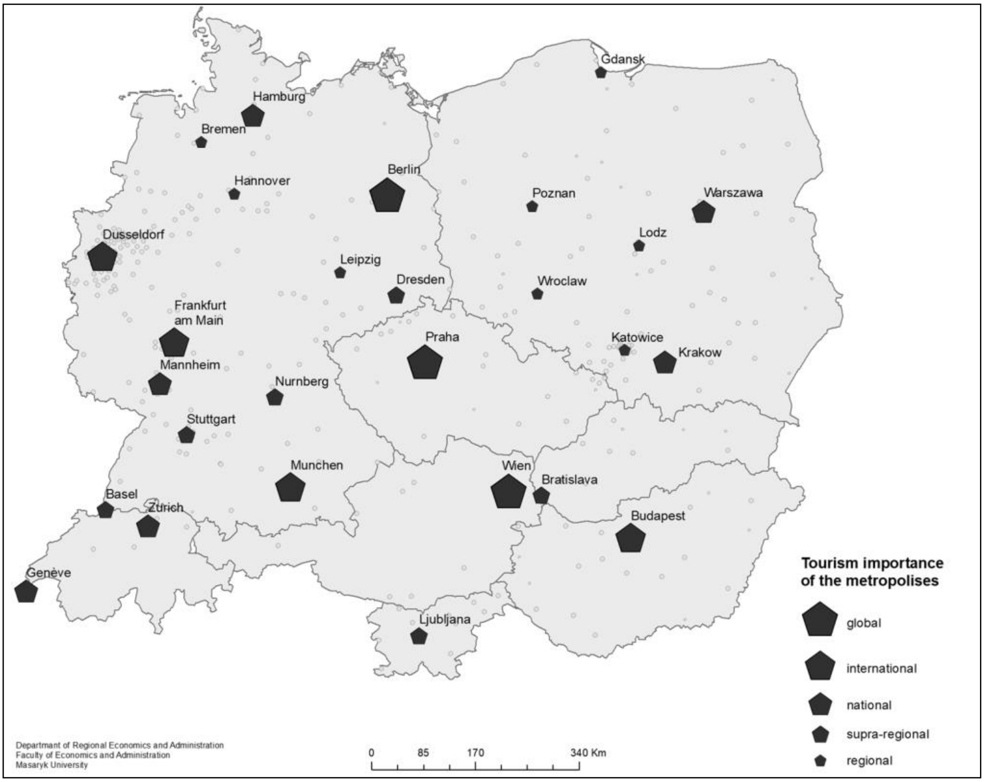

Fig. 1. Location of the study area (Source: TourMIS database, 2017; original work).

By application of a gravity model, we identified 261 tourist international flows; each flow includes a two-way stream of tourists. The overall volume of interactions reaches a value of 2.77 million visitors. A share of the Central European metropolises within the general performance of cities is only 7%. On one hand, such a low share is determined by less than 1/3 share of studied cities in the overall population of the Central European region. On the other hand, it indicates globality of the international tourism, whereas the most of performance is generated by the countries outside the Central European region. Above-average ties to the Central European region were found in Wroclaw (16%), Poznan (14%) and Bratislava (11%). On the contrary, the weakest ties were found in Budapest and Krakow (Prague is slightly below the average).

On the basis of a geography analysis of individual tourist flows it can be concluded that the differences regarding their force are very significant. About half of their volume is generated by the first 24 interactions. In the layout of flows, strong ties between Germany, Austria and Switzerland (9 out of 15 most important ties fall upon the mentioned area) become evident. In this context, Vienna plays a fundamental role as the most important destination of all studied metropolises. The most important interaction whatsoever can be found between Vienna and Munich, followed by interlinking of Vienna and Berlin and other German cities (Hamburg, Rhein-Ruhr region, Frankfurt am M., etc.). Strong ties are also between Zurich and Munich and Berlin (see **Table 1**). High rate of interlinking of German-speaking countries is disrupted only by Prague and its ties to both Western and Eastern Europe, and by Budapest and its ties to Vienna and Berlin (Prague occupies the sixth position of the most visited European cities, and Budapest is included in the TOP 10).

With respect to the tourism, Poland is not linked much to other Central European countries. Warsaw, Wroclaw and Krakow have stronger ties, mainly to Germany. Despite clear attractiveness of Krakow, its periphery position prevents from having stronger position within the network of tourist flows. Its strongest tie to Berlin is as down as in the 62nd position, and it ranks only fifth among Polish cities (behind Warsaw and Wroclaw).

Table 1.

Inbound and outbound tourism in the metropolises.

	Inbound	**Outbound**	**Total**	**The main sources of inbound flows**	**The main destinations for outbound flows**
Vienna	620,774	424,522	1,045,296	Munich, Rhine-Ruhr, Berlin, Frankfurt	Munich, Berlin, Prague, Hamburg
Prague	496,603	108,593	605,196	Berlin, Vienna, Bratislava, Rhine-Ruhr	Bratislava, Vienna, Budapest
Zürich	127,412	276,618	404,030	Rhine-Ruhr, Munich, Stuttgart, Vienna	Munich, Berlin, Vienna, Hamburg
Berlin	192,723	202,938	395,660	Vienna, Zürich, Basel, Geneva	Vienna, Prague, Budapest, Wroclaw
Munich	188,239	197,304	385,542	Vienna, Zürich, Basel, Geneva	Vienna, Prague, Zürich, Budapest
Rhine-Ruhr	104,634	219,517	324,151	Vienna, Zürich, Basel, Geneva	Vienna, Prague, Zürich, Budapest
Budapest	185,105	96,307	281,412	Vienna, Berlin, Rhine-Ruhr	Vienna, Prague, Munich, Krakow
Basel	58,036	161,698	219,734	Rhine-Ruhr, Stuttgart, Munich, Frankfurt am M.	Berlin, Munich, Vienna, Rhine-Ruhr
Hamburg	91,270	103,342	194,612	Vienna, Zürich, Basel, Geneva	Vienna, Prague, Budapest, Zürich
Frankfurt am M.	62,718	127,302	190,020	Vienna, Zürich, Basel, Geneva	Vienna, Prague, Zürich, Budapest

Source: original work

The stated conclusions are well illustrated in the following graphic outcomes of network analysis by using the algorithm Geo Layout which is able to coordinate position of nodes within the network according to their latitude and longitude (**Fig. 2**). In this way visualisation of nodes and edges in real space was made possible. The colour of a node corresponds to a particular country, whereas thickness of the edge depends on the number of tourist arrivals.

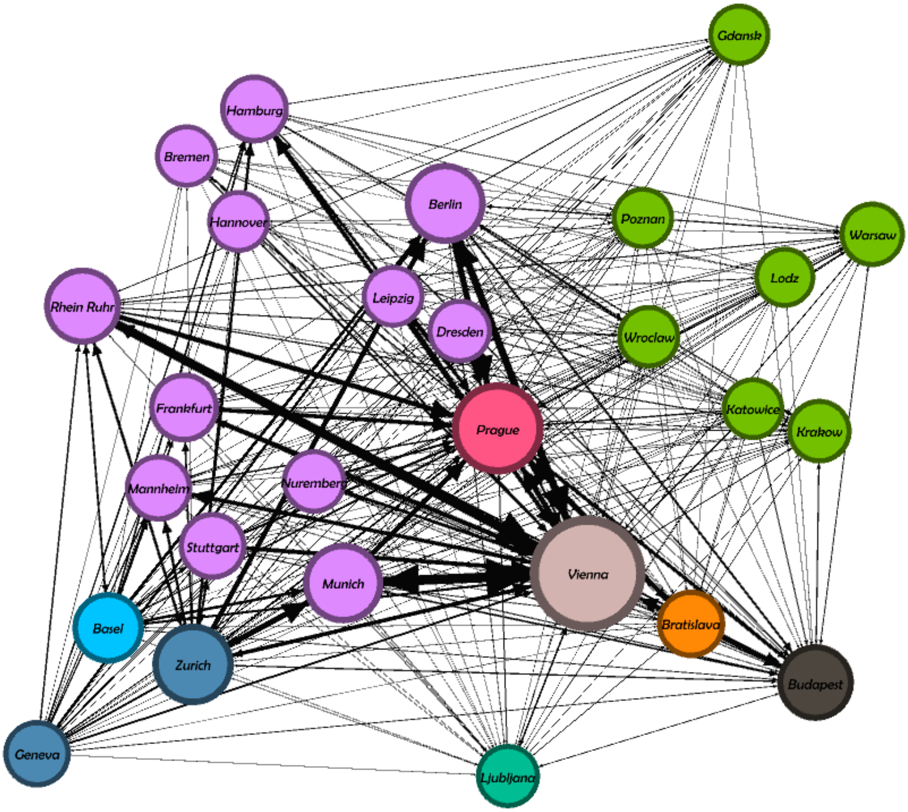

Fig. 2. Visualization of tourist flows in real space (Source: original work).

Within simulation, the network can be manipulated also by means of setting various filters. In this case, **Fig. 3** includes only edges expressing more than 15,000 or alternatively more than 45,000 journeys. The other edges have been deleted. This procedure clearly indicates the importance of axis Hamburg – Berlin – Prague – Vienna – Bratislava – Budapest, interlinking the North-western part of the region with the Eastern part. The second important metropolitan axis is Zurich – Munich – Vienna – Budapest, and last but not least, it is a tie between Rhein-Ruhr and Vienna, and then Prague, marginally. The picture shows that the flows are in the shape of a funnel, narrowing from the west towards the east. It means that despite a great number of the Western European metropolises the tourist flows go only to several selected metropolises in the Central and Eastern part of the region (Prague, Vienna, and Budapest). Moreover, this feature of spatial arrangement tends to grow stronger towards the Western part of the region. As a characteristic feature is the absence of ties to Polish cities and Ljubljana, Slovenia.

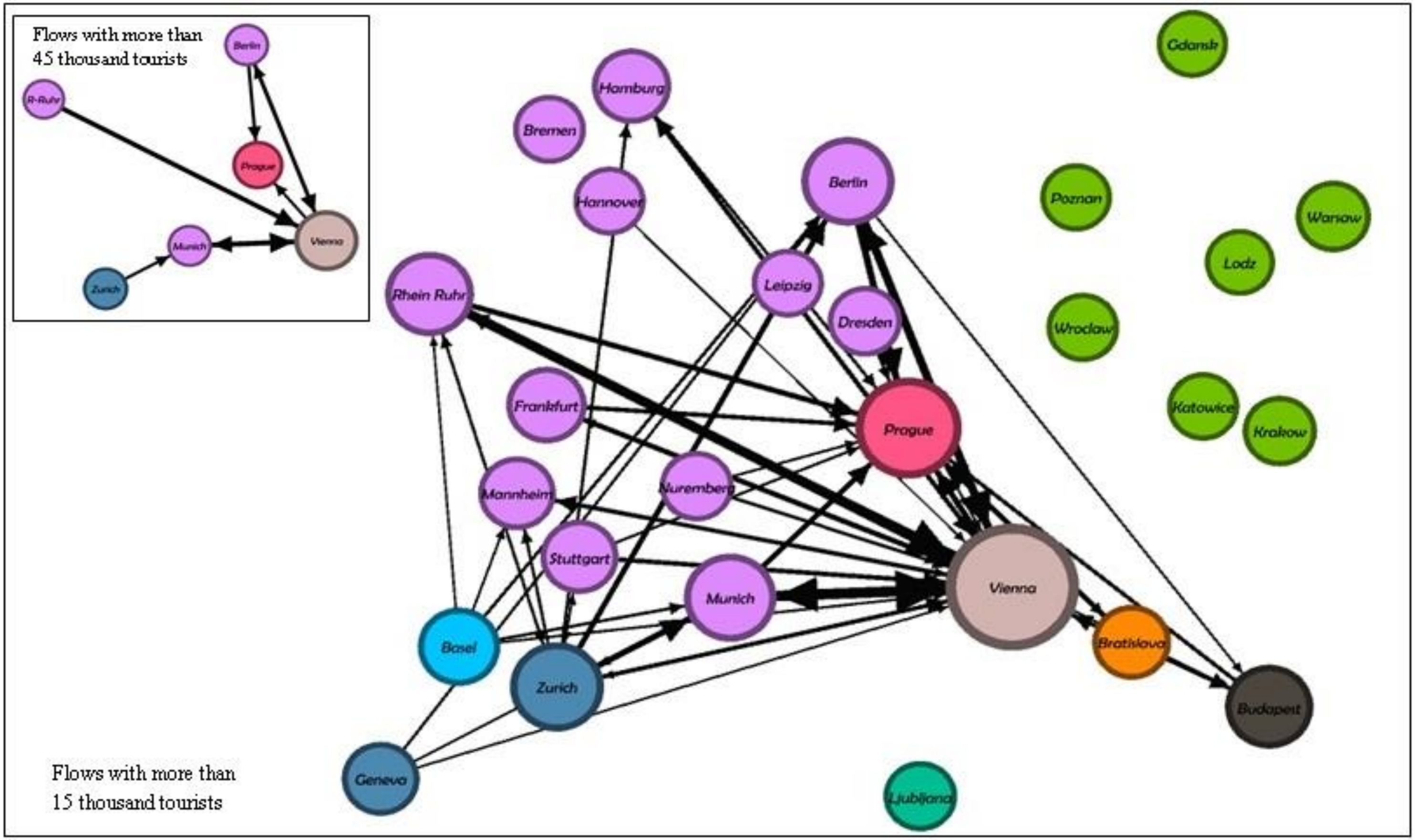

Fig. 3. Metropolises and their weighted flows connections (Source: original work).

The central position within the network is occupied by Vienna. According to **Table 2**, Vienna achieved the highest values in all basic features of the network, whether it is the centrality degree (degree, in-degree, out-degree), closeness centrality, or betweenness centrality. These markers indicate not only the frequency and importance of Vienna being linked to the other metropolises, but also its position towards the others. Vienna represents some sort of a bridge between the Western and Eastern parts of the studied region (betweenness centrality is by 47% higher than Berlin, which ranks second).

Table 2.

Network metrices in analysed metropolises.

Metropolises	State	In-degree	Out-degree	Degree	Closeness centrality	Betweenness centrality
Vienna	AT	25	21	46	0,83871	126,5635
Zurich	CH	15	19	34	0,78788	50,44158
Prague	CZ	26	16	42	0,72222	67,5744
Berlin	DE	15	15	30	0,70270	86,29246
Budapest	HU	24	15	39	0,70270	46,12996
Geneva	CH	6	14	20	0,68421	7,298279
Basel	CH	11	14	25	0,68421	22,88105
Rhein Ruhr	DE	9	14	23	0,66667	21,47345
Munich	DE	10	13	23	0,63415	15,99586
Frankfurt a. M.	DE	7	13	20	0,63415	9,195914
Hamburg	DE	6	11	17	0,60465	6,507387
Warsaw	PL	14	8	22	0,59091	6,28049
Stuttgart	DE	4	11	15	0,57778	1,710847
Katowice	PL	2	7	9	0,57778	0,453968
Ljubljana	SLO	9	7	16	0,57778	1,982782
Bratislava	SK	13	6	19	0,56522	2,094234
Hannover	DE	2	8	10	0,54167	0,385439
Nuremberg	DE	6	8	14	0,54167	1,435536
Krakow	PL	15	4	19	0,54167	2,83594
Poznan	PL	5	4	9	0,54167	0,786429
Wroclaw	PL	12	4	16	0,54167	2,83594
Bremen	DE	2	7	9	0,53061	0,385439
Lodz	PL	1	3	4	0,53061	0
Mannheim	DE	6	5	11	0,50980	0,859274
Dresden	DE	6	6	12	0,50980	0,736519
Leipzig	DE	3	4	7	0,49057	0,076923
Gdansk	PL	5	2	7	0,48148	0,786429

Source: original work

Concurrently, it is as strong as the pole which attracts the attendance also as a source of attendance for other metropolises. Zurich has a similar position, except for one difference – it has significantly weaker betweenness markers. This is due to its crucial focus on Western metropolises in Germany and Austria. As for closeness centrality, the third position is occupied by Prague. Prague profits from its high attractiveness (as for arrivals, it is the second most visited city of all studied metropolises; it comes after Vienna); as a source destination for journeys to abroad it has weaker position. Therefore, it has been overtaken by Zurich. Another important metropolis within the network is Berlin which achieves, similarly as Vienna, high betweenness levels. Therefore, it can be regarded as an important transit hub. Moreover, it is necessary to mention Budapest which is well anchored within the network, despite its relatively peripheral location. In addition, the network analysis has proved a weak position of Polish cities, in particular, Lodge, Gdansk and Poznan.

Fig. 4 demonstrates differences in the layout of metropolises within the network with respect to outbound and inbound tourism. The outbound tourism is unambiguously affected by purchasing power, or alternatively, by differences in economic development of the studied metropolises. Tourist flows are dominated by Western Europe, with Vienna, Berlin, Munich, Rhein-Ruhr and Zurich in the lead. Typical feature of such countries is also high intensity of outbound tourism (the number of outbounds per capita) and strong mutual networking (German speaking countries). For instance, the intensity of outbounds performed by Vienna inhabitants is almost three times higher than in Prague. Polish cities achieve even lower outbound intensity level (one fifth of the Prague level).

The figure depicting inbound flows fundamentally affects the performance of Prague, as one of the most attractive destinations in Europe. Significantly weaker trend, but similar, can be seen in Budapest. On the other hand, the importance of Switzerland metropolises in inbound tourism is declining, which is due to the peripheral position of the region in connection to the studied area and price non-competitiveness for possible visitors coming from the countries of the Visegrad Group (V4).

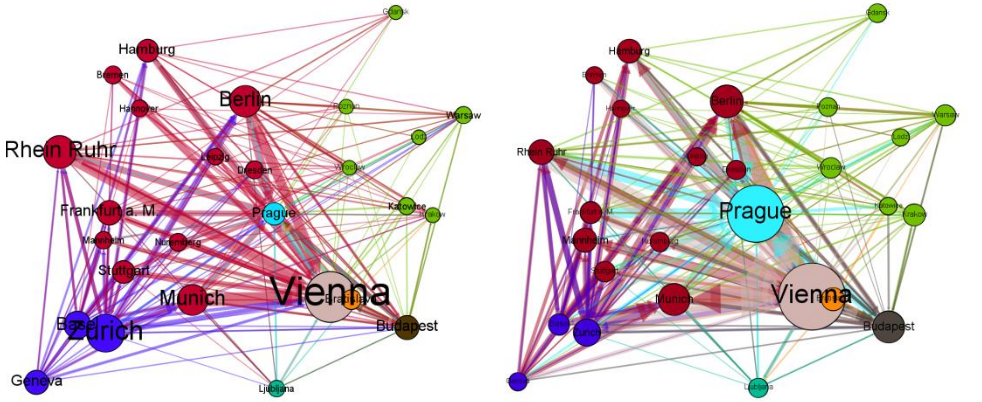

Fig. 4. Metropolises in the context of a) outbound and b) inbound tourism (Source: original work).

The last part of the tourist flows and their networks analysis is devoted to modelling of interactions by using force algorithm ForceAtlas 2, which helps to visualize the structural proximity within the network and thus, it shows the effect of forces on the nodes (Jacomy et al., 2014). Furthermore, the simulation includes the so-called modularity which clusters elements within the network and stipulates the level of separation of communities. If positive values are achieved, it indicates that community structures might be present

(Newman, 2006). The extent of network structuration in a form of separation of communities may be highlighted on the basis of clusters distinguished by colours according to their modularity.

Application of algorithms generates two basic clusters, whereas the first one is created by metropolises from Germany, Austria and Switzerland, and the second one is focused rather to the East (mainly the V4 countries), provided that Budapest and Katowice tend to focus on the Western bloc. Yet, each of them has different reasons. As for the tourism, Katowice is not attractive, and its position is determined by force of outbounds to Germany and Austria. On the contrary, Budapest attracts attention of the Western European source markets. The third cluster is not complete, a dominating city is Berlin. In respect to modularity, the importance of Berlin for Polish cities is noticeable, and with respect to force algorithm, the results prove ambiguous position within the network divided between the above mentioned main clusters.

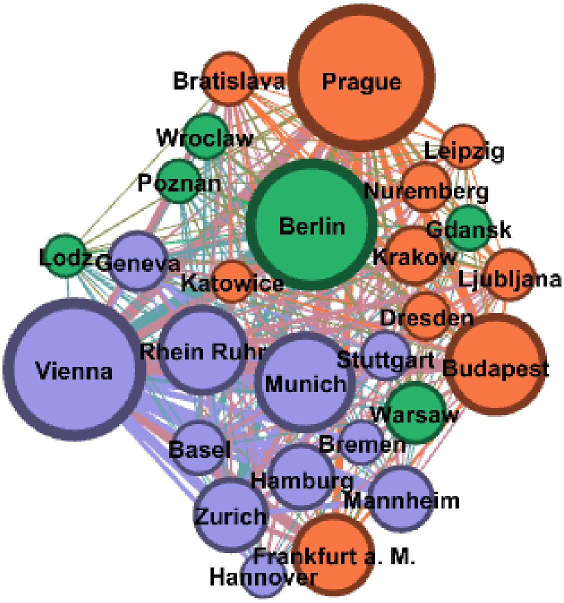

Fig. 5. Tourist flows in the context of structural proximity (Source: original work).

4. CONCLUSIONS

Based upon results of the implemented analyses we can emphasize three conclusions, as follows. Firstly, spatial organization of tourism and its order structuration demonstrate rather small influence of the market proximity factor. The studied metropolises are not fundamentally integrated within Central Europe. This fact holds true especially for the most significant destinations such as Prague, Budapest or Berlin which are integrated within the network of global integrity. However, Vienna is an exception as it has strong ties both to the Central Europe area and the global area. Central European network of metropolises has somewhat significant influence on second cities (Šauer, 2016); which means, the cities operating mainly in the European market (Wroclaw, Bratislava or Poznan).

Secondly, the analyses have revealed the fact that even after thirty years an imaginary boundary between Western and Eastern areas of the region has still been in existence. Probably, mental division of Europe into West and East is still persisting (e.g., Applebaum, 2017; Meinhof, 2018). This image is somewhat disrupted by Prague and Budapest that gradually constitute a new axis of Berlin – Prague – Vienna – Bratislava – Budapest. Polish cities remain outside the main flow. On one hand, they are challenged by German markets and V4 markets. In case of linking to V4 countries, higher degree of integration is limited by the quality and expansion of transport infrastructure, or by accessibility for remote source markets. On the other hand, their development might be successful due to the involvement into global processes. In reality, this approach is feasible only for Warsaw and Krakow.

The final conclusion is of methodological character. In respect to the tourist flows analysis, the network analysis is limited. High rate of interlinking (supported by using gravity model, the result of which is represented by ties of a n:n type) leads to a small differentiation of network matrices. This method is suitable, in particular, for the systems which are typical for larger diversity of behaviour of network elements, e.g. personal or other social networks.

ACKNOWLEDGMENT

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PERCEIVING THE IMPACT OF BROWNFIELDS ON THE REAL ESTATE PRICES: A CASE STUDY FROM FOUR LOCATIONS IN THE CZECH REPUBLIC

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ABSTRACT:
The abandoned buildings and areas - brownfields are continuously an integral part of settlements across Europe. One form of interaction between brownfields and the surrounding area is through the property market when it is clear that brownfields affect the value of real estate in its neighborhood. The subject of our research was why and with what intensity this is happening. The research was conducted between 2017 and 2018 in four municipalities in the Czech Republic (Olomouc, Skrbeň, Stonava and Životice) through a questionnaire survey aimed at identifying factors that determine the specific perception of the impact of brownfields on the value of surrounding real properties. The results of the research clearly supported the logical assumption that brownfields are perceived completely negatively in the context of their existence and the impact of their presence on the surrounding residential property values of the inhabitants of the selected municipalities. The findings are a desirable public interest argument for finding solutions to brownfield issues. It is necessary to suppress the negative side of brownfields and transform it into the potential for further development of the area and regions.

Key-words: *Brownfield, Residential property values, Real estate price, Czech Republic.*

1. INTRODUCTION

Brownfields, abandoned and unused areas and objects, are an integral part of the urban consequences of human activity, which can transform into a source of untapped potential for development in both the regional and transnational spheres (Turečková et al., 2018). The increasing dynamics of socio-economic change is continually accompanied by the transformation of residential and living space, where inappropriate areas are left "to their fate" so that some of them may find new, alternative uses in the future. While the empty brownfield is characterized by a number of negative externalities, the effects of positive externalities are reflected in the process of its regeneration, increasing the social surplus not only resulting from the restoration of public space but also from the environmental responsibility and cultural link of our ancestors (Navrátil et al, 2018). Brownfields are perceived as significant, albeit specific, elements of territorial development and spatial arrangement of the cultural and natural environment (Brown, 2012 or Krzysztofik et al., 2016). Within the framework of the modern (modern) approach and in the context of economic development and the simultaneous dynamic deepening of the quality of life. The new use of temporarily abandoned areas and areas helps to reduce the pressure on construction on greenfields in the urbanized area and maintain the compactness of the current built-up area (Sucháček, 2013). The argument of the undesirable effects associated

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with suburbanization and urban sprawl also speaks for the reuse of abandoned areas (Frantal et al., 2015, Putman, 2000, Oliver 2001, Jackson, 2002 or Sýkora, 2003).

Indeed, boosting support for brownfield regeneration might contribute to more sustainable development of cities and rural municipalities from the perspective of their physical compactness (Kladivo and Halas, 2012), might reduce consequent environmental and health risks (Litt et al., 2002, Eiser et al., 2007) for local population and significantly contribute to an increase of attractiveness of cities and municipalities (Andrés and Grésillon, 2013 or Somlyódyné Pfeil, 2017). Such support might also help to enhance our responsibility (Morvay, 2017) for implications of our industrial history and business activities (Pakšiová, 2016) that is still significantly affecting face and structure of our contemporary cities, countries and Europe Union. Generally, support for brownfields regeneration might strengthen our nowadays more environmentally friendly path of thinking about urban space that prefers utilization of existing properties over those that are being built on greenfields (De Sousa, 2003). Therefore, due to the importance for wider development, this branch is also subject of the EU financial support (Melecký and Staníčková, 2017).

The content of this paper is to analyze one of the unwanted speeches that brownfields in the built-up area are related to, and their property to influence the value of the real estate that is adjacent to the brownfield. This area of research is addressed in terms of perception of the local population of four municipalities in the Czech Republic where the research was carried out. This research builds on earlier primary research in three other cities of the Czech Republic, and further specifies the subject (see Turečková et al., 2017a, Turečková et al., 2017b, Škrabal et al., 2017 and Chmielová et al., 2017). Based on the logical assumption that brownfields are perceived negatively in the context of their impact on the value of the (residential) immovable property, which is undesirably transformed into the reduced price at which these properties are traded on the market (e.g. Bowes and Ihlanfeldt, 2001). Through this lower property price, there is a social loss from the economic point of view and the social surplus decreases. By identifying the undesirable factors associated with brownfields, it is possible to define the possibility of mitigating their negative impact on the prices of surrounding properties and to better activate remedial measures (Turečková, 2018). The aim of the paper is to examine the influence of brownfields on the residential property values that are located in their neighbourhoods, as perceived by the local population.

It can be assumed that proximity of neglected, abandoned and decaying grounds impacts values of residential properties. Reasons behind this hypothesis lie for example in the lower level of aesthetic quality that is usually connected to such abandoned or neglected brownfields. Next reason could be linked to possible contamination of these sites, their bad technical state or occurrence and concentration of socio-pathological phenomena in these buildings (like homelessness, high level of criminality etc.).

Our results and findings are based on primary research conducted between 2017 and 2018 through a questionnaire survey in four villages in Moravia, Czech Republic. Municipalities Stonava and Životice are located in the Moravian-Silesian Region and the city Olomouc and village Skrbeň in the Olomouc Region. It is to be expected that differences in the location of municipalities will be reflected in respondents' answers. Because while Stonava and Životice are located in the Ostrava-Karvina agglomeration, typical of the huge occurrence of brownfields after heavy industry and mining, Olomouc and Skrbeň are located in the agricultural area of Haná. The number of respondents was 352.

2. THEORETICAL FRAMEWORK OF THE STUDY

It is not possible to define a brownfield uniformly because its explanation depends on the time, geographical, political, economic and social perception of the given concept (Turečková, 2018). In general, we can characterize the brownfield in the widest possible sense as an abandoned area (an object, building, area, land) that previously performed a certain economic activity but which has already been terminated and new use has not been found for this area (Martinát et al., 2017). With reference to former economic activity in a given brownfield, we are divided into brownfields for industrial, mining, military, transport, agricultural and brownfields for former amenities (shopping centers, hospitals, restaurants, apartment buildings, etc.) (Martinát and Turečková, 2016). Brownfields can also be ecologically polluted, contaminated and dangerous from a technical construction point of view. Because these sites are decaying (even decades), they disrupt the urban structure and architectural style of the site, are unsightly, and are the usual place of concentration of socially pathological phenomena (especially homeless and drug addicts). Within the European Union, brownfields are defined by the Organization for Economic Cooperation and Development (2017), which defines brownfields as a land and property located inside urbanized areas that have lost their function and use and are likely to contain environmental burdens. The National Brownfield Regeneration Strategy of the Czech Republic (CzechInvest, 2008) or previously Alker (2000) or Yount (2003) define brownfield as the real estate property (land, building or ground) that is insufficiently utilized, neglected and might be also contaminated. The occurrence of brownfields is usually perceived as a weakness or a threat for future development of cities, towns and municipalities. On the other, brownfields might also be considered as an opportunity for development (Adams et al., 2010). These sites are usually unsightly and aesthetically do not meet requirements of the local population how the city should look like which significantly affect the perception of these sites (Martinat et al., 2017). The problem of brownfields is especially distinct in cities that are heavily affected by the recent decay of the heavy industry and mining, where it might be assumed that brownfields are specifically perceived (Krzysztofik et al., 2012). Systematic regeneration of brownfields might undoubtedly contribute to the improvement of the quality of life in these cities (Pediaditi et al., 2010) and at least partially contribute to a more environmentally friendlier way of thinking of nowadays society (Apsan, 2002).

The occurrence of brownfields significantly affects values of residential properties that are located in neighbourhoods of these sites (e.g. De Sousa, 2000, Kaufman and Cloutier, 2006, Mihaescu and vom Hofe, 2012, Sun and Jones, 2013) and has significant fiscal consequences (Růžičková and MacGregor Pelikánová, 2014, Jánošíková and MacGregor Pelikánová, 2017). It is also well known that the property prices are constructed by characteristics of the local real estate market where geographical location belongs to factors of crucial importance (e.g. Can, 1992 or Hesse, 2004). Undoubtedly, values of residential properties in the neighbourhood of brownfields are also considerably influenced by the way how population perceive these sites (Munroe, 2007). Willingness to purchase the real estate in the proximity of brownfield is affected by the mix of factors, part of them might be described as “hard” factors (like already mentioned geographical location, accessibility of the site, availability of infrastructure) and part of them as “soft” factors where perception surely belongs. These soft factors are usually not of static, but more of dynamic nature that might be changed due to course of time as the process of particular brownfield regeneration approaches. On the contrary, once brownfield regeneration process is finished, values of residential properties in neighbourhoods usually increase.

3. METHODOLOGY AND DATA

The primary research involved on perceiving the influence of brownfields on the value of nearby properties and its real estate prices. As was mention these present results are the next in a series of extensive research on the territory of Morava (the part of territory of the Czech Republic). Individual phases of conducted research were performed simultaneously in one city (Olomouc) and tree rural municipality (Skrbeň, Stonava, Životice) of the Moravian-Silesian Region and The Olomouc region in 2017 and 2018 (see **Figure 1**). The primary research was relies on questionnaire survey and its aim was to ascertain opinions and attitudes of the local population on the issue of the influence of brownfields on prices of the neighbouring real estate.

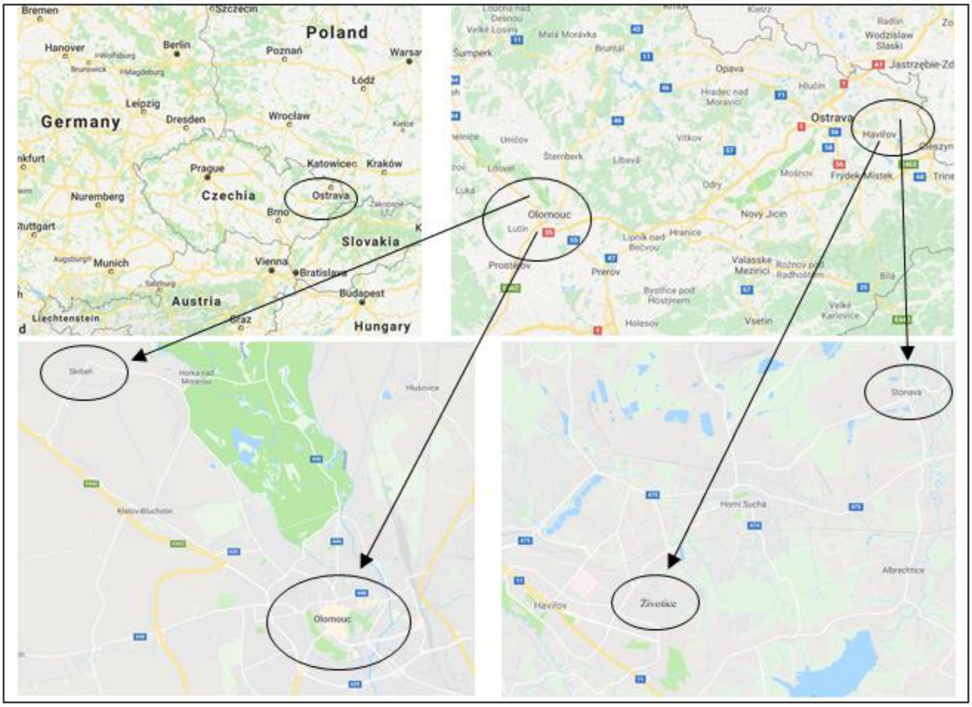

Fig. 1 Location of the four case study municipalities
Source: Google Maps, authors processing

Firstly, was to determine the number of brownfields and describe its characteristics in selected municipalities by the observation method. On the basis of open access brownfields inventories (CzechInvest and Invest More) and own research, a database for the four municipalities was developed. For the purposes of this paper there was necessary the information about number of brownfields and its expanse (area). In Olomouc was determined 14 brownfields, in Skrbeň 4, in Stonava 11 and in Životice 6 brownfields. This information is important in context of respondents' views on the influence of brownfields on the price of surrounding properties. It can be assumed that the more respondents have direct experience with brownfields, the more negative they will perceive,

Secondly, the data on perception of residential property values were gathered by means of the questionnaire survey. The questionnaire has been created on the basis of previous studies and contained 12 questions. A preliminary survey was conducted in March 2016 to be sure that individual questions are clearly defined and to avoid any misinterpretations. Individual questionnaires were gathered by trained university students by a face-to-face communication with respondents. The questionnaires were completed by the method of semi-structured interviews. Last year we had 347 respondents from tree municipalities: Karviná, Orlová and Dětmarovice (see Turečková et al., 2017) and in this year a number of respondents that participated in the research were 352 in total (120 respondents from Olomouc, 80 respondents from Skrbeň, 50 respondents from Stonava and 102 respondents from Životice). A number of respondents, who participated in the survey, were ensured to be at least 3.4‰ of the total population of individual municipalities. All respondents lived in selected municipalities and their socioeconomic, demographic, educational and gender structure of the population was balanced (please see **Table 1** for the structure of respondents). Factors behind were also determined to ensure why and how the occurrence of brownfields affects the value of local residential properties. Respondents were selected to be sure that all parts of municipalities, where brownfields are located, are represented.

Segmentation of respondents of surveys in four municipalities. Table 1

Variables	Municipality	**Olomouc**	**Skrbeň**	**Stonava**	**Životice**
	Population (year)	99809 (2015)	1206 (2012)	1828 (2012)	1322 (2017)
	Number of questionnaires	**120**	**80**	**50**	**102**
Gender	Female	59%	56%	56%	61%
	Male	41%	44%	44%	39%
Age	18-25 years	32%	50%	8%	6%
	26-45 years	39%	31%	38%	56%
	46-65 years	21%	19%	34%	25%
	65 and more years	8%	0%	20%	13%
Education	Elementary	12%	6%	6%	11%
	Secondary without final exam	35%	17%	38%	28%
	Secondary with final exam	29%	63%	46%	37%
	Higher professional education	8%	6%	4%	9%
	Tertiary	16%	8%	6%	15%
Social status	Employees	43%	50%	48%	25%
	Students	26%	31%	8%	20%
	Entrepreneurs	4%	0%	6%	24%
	Unemployed	4%	0%	0%	9%
	Retired persons	9%	0%	30%	15%
	On maternal/parental leave	14%	19%	8%	8%
Habitation	Own residential house	25%	67%	54%	66%
	House in rent	3%	0%	0%	34%
	Dormitory	8%	0%	0%	0%
	Own apartment/flat	34%	28%	0%	0%
	Cooperative apartment	0%	0%	0%	0%
	Apartment in rent	30%	5%	46%	0%

Sources: set of own surveys (n=352) and Czech Statistical Office

Table 2 shows selected indicators of municipalities and brownfields on its territory. For purpose of our research was useful to set by authors the index named index of civic proximity to brownfield which is calculated as:

$$\text{index of civic proximity to brownfield} = \frac{\text{share of areas of brownfields on area of municipality}}{\text{area of municipality per capita}}$$

The value of index is within the range (0, ∞) and the smaller value of index is better because means, in generally, less experience of inhabitances of municipalities with the brownfields from a spatial point of view. The higher value of this index constitutes that the inhabitants of a given village or city live closer to brownfields than lower value. If is the value of index of civic proximity to brownfield is zero it means no brownfields on the territory of the municipality. This information given via created index will be connected with the results of questionnaire survey in the next part of this paper.

Table 2.

Selected indicators of municipalities and brownfields

Indicator/Municipality	**Olomouc**	**Skrbeň**	**Stonava**	**Životice**
Area of municipality (ha)	10336	787	1387	430
Number of brownfields	14	4	11	6
Area of brownfields (ha)	55	0.584	115	0.71
Share of area of brownfields on area of municipality	0.53%	0.07%	8.30%	0.17%
Population	99809	1206	1828	1322
Area of municipality per capita (ha)	0.10	0.65	0.76	0.33
Index of civic proximity to brownfield	0.05	0.00	0.11	0.01
Order by index	3	1	4	2

Sources: set of own surveys and Czech Statistical Office
Note: the smaller index value is better

As we can see from the Table 2 through comparting the value of index of civic proximity to brownfield and also with other values of selected indicators present in table there is clear that, in general, the largest personal experience with brownfields should have the inhabitants of Stonava. Eleven brownfields in Stonava have the largest share of size of area of brownfields on size of area of municipality (8.30%). This factor is very strong even in fact that the area of municipality per capita is the smallest (0.76 hectare per capita). On the other hand, village Skrbeň in the Olomouc Region has only 4 brownfields with very small size of their area and relatively large area of municipality per capita (0.65) what indicated assumption that inhabitants from Skrbeň should have the lowest direct experience with brownfields in spatial and residential point of view. Whether these findings correspond to the findings of the primary research are set out in the next chapter 4 called Results - perceiving the impact of brownfields on the real estate prices.

4. RESULTS - PERCEIVING THE IMPACT OF BROWNFIELDS ON THE REAL ESTATE PRICES

The key finding of our survey is (what was also expected base on previous research) that the living in the neighborhood of brownfields is problematic for the majority of respondents (see **Figure 2**). Quite surprising is the result from municipality Životice where only 6% of respondents do not mind living near brownfields while in other 3 municipalities it is between 26% - 33%. It could be assumed that local population is more used to live in the neighborhoods of these sites than in Životice.

This result and differences among individual municipalities can be explained rather a consequence of negative phenomena that are usually connected to the occurrence of brownfields (criminality, homelessness etc.) and, especially in case of Životice, it could be the fact that it is a small village with a higher population density (0.33 ha per capita) in combination with character of its 6 brownfields. Brownfields in Životice are made up of a ruin of a local castle and skeletons of agricultural areas, all of them are located in the center of the village and therefore in the eyes of the inhabitants of the village.

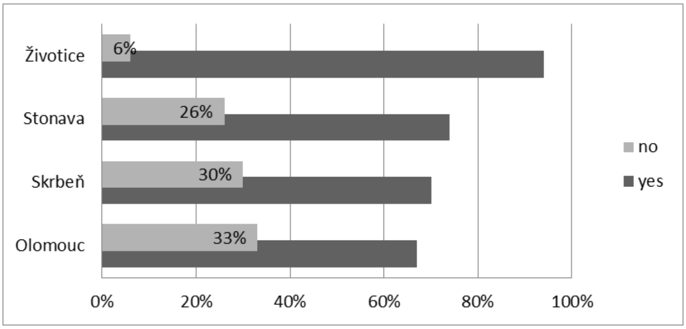

Fig. 2. Unwillingness to live in the neighbourhood of brownfields.
Source: own survey (n=352)

Much more impressive differences in opinions of respondents were found in a question, how the local residential property values are affected by the occurrence of brownfields? While the opinions of the respondents from Olomouc and Skrbeň are not very different, the answers of the respondents from Stonava and Životice are more peculiar (see **Figure 3**). The respondents of these two villages do not admit any influence of brownfields on the prices of surrounding properties on the one hand but on the other hand about 48% of respondents stated that due to the occurrence of brownfields the residential property values are lower between 20% - 40% and 14% of respondents of Stonava and 46% of respondent of Životice (…) are lower by 50% in comparison to other parts of the city without brownfields.

Overall, for more than three quarters of respondents, the existence of brownfields has some (smaller or larger) impact on the value of residential properties. This result could be supported by other responses (results are presented in **Figure 4** and **5**). In the next step, we asked the respondents if they would buy a residential property in the neighbourhoods of brownfield if its price was about 20% lower than the usual price. It seems that our hypothesis related to the specific perception of brownfields in Stonava and Životice are confirmed as the population of these two municipalities again evaluates this problem again differently (with much higher polarity) in comparison to other two cases (Olomouc and Skrbeň). We assume that this might be caused by the dense occurrence of brownfields in Stonava and Životice and significant everyday experiences of the local population with life with brownfields and consequent occurrence of socially problematic phenomena.

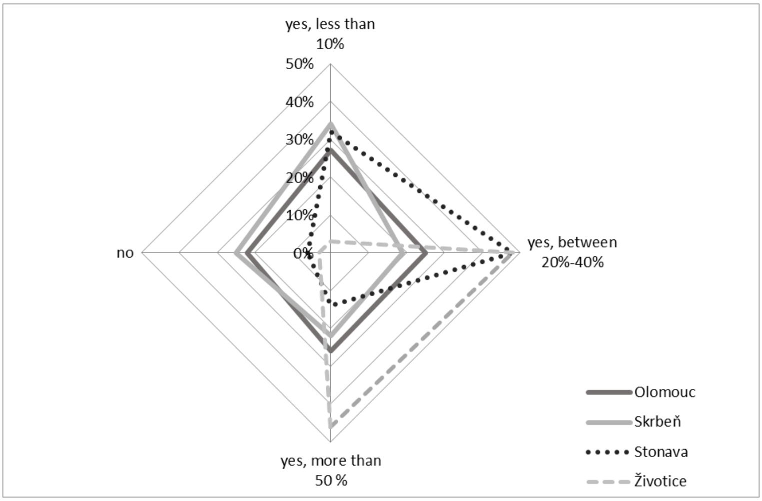

Fig. 3 Influence of brownfields on residential property values in four municipalities.
Source: own survey (n=352)

When we asked respondents to evaluate their willingness to buy the residential property in immediate proximity of brownfield if the price is lower by 20% the response were significantly negative replies among respondents from Životice and Stonava where only 5%, respectively 14%, of them were open to buy such residential property (see Figure 4). Respondents from Skrbeň and Olomouc were not so negative in their answers and more than 56%, respectively 45%, of them would be opened to buy such real estate without any problems.

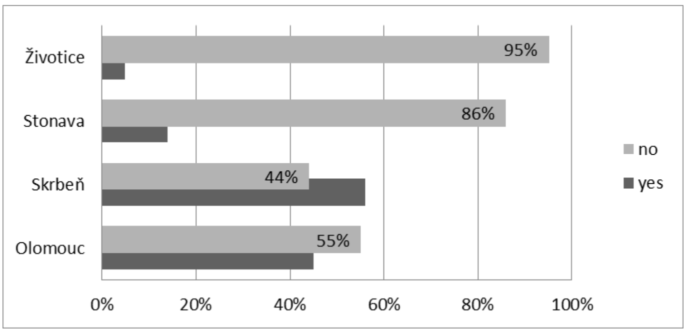

Fig. 4. Willingness to buy residential property in immediate proximity of brownfield if price is lower by 20 %.
Source: own survey (n=352)

Part of the research was also to determine the factors that people brownfields perceive negatively and which affect opinions of respondents that brownfields significantly affect the value of residential properties in their neighbourhoods. The reasons why brownfields are undesirable are as follows: (1) the brownfield is usually dangerous from a construction and technical point of view, (2) there is no certain future use of brownfield, (3) brownfield is aesthetically unsightly, (4) brownfield is dangerous due to possible contamination and pollution that threatens health, (5) brownfield blocks development of the city, and (6) social-pathological phenomena are concentrated in the brownfield.

Respondents could select out of these six defined answers. Shares of positive and negative answers are graphically displayed in **Figure 5**. Generally, it was found that respondents of all municipalities connect occurrence of brownfields much more strongly to negative consequences because of social-pathological phenomena (like homelessness, criminality, possible contamination and health risks for population etc.). The second and third major reasons for negative attitudes towards brownfields are dangerous outgoing from a construction and technical state of brownfields and dangerous due to possible contamination and pollution that threatens health. What was surprising was that usually reduced aesthetics of non-regenerated brownfields was not taken into account as a serious problem, similarly as consequences for urban planning (brownfields block development of the city, there is no certain future use of brownfields).

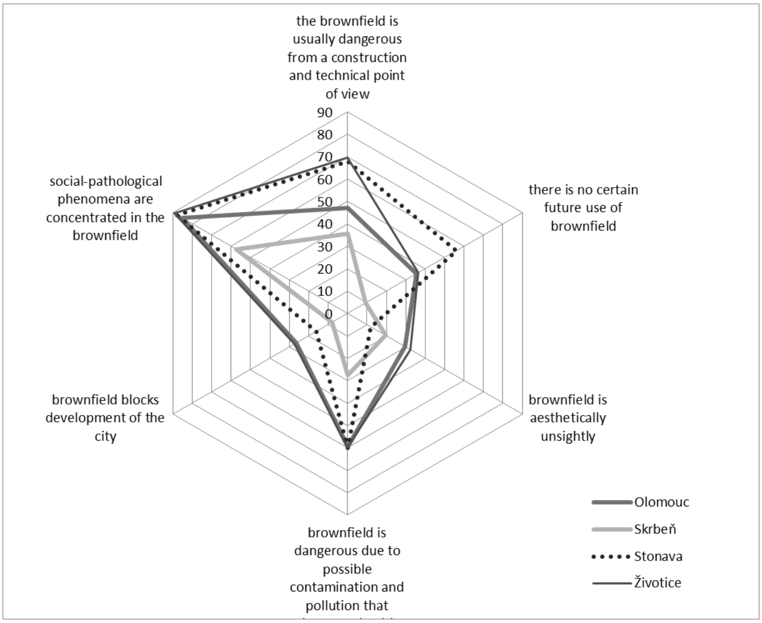

Fig. 5. Reasons why brownfields have significant influence on the residential property values.

Source: own survey (n=352)

The largest share of respondents (on average 86%) is convinced that brownfields as an abandoned sites are problematic and rather dangerous which is the fact that reduces prices of the neighbouring real estate. Main reasons for such argument were identified in the concentration of socially pathological phenomena in brownfields (like homelessness, higher rates of criminality, drug dealing, vandalism etc.) (chosen at 80%). The second factor that was found as important (around 55 %) were technical state of brownfields. Respondents were expressing their fears that brownfields are dangerous as for the bad quality of their technical infrastructure, and not usually secured against the intrusion of people who should not be there. They perceive that risks connected to bad statics and neglected maintenance of individual buildings, or failures of concrete structures due to corrosion of materials are very high. The environmental and health risks (occurrence contamination of soils and pollution) that might affect the health of the population that is living in the neighbourhoods was identified as a third important factor (around 52%). This factor might be interpreted as some kind of distrust that majority of contamination have been removed or cleaned up. The population was quite unsure that these contaminants are safe and do not bear any health risks. Reasons why brownfields negatively influence the price of the neighbouring real estate are for 34% of respondents connected to uncertainty concerning future use of the site. They usually argued that it is not sure what will be built on a particular brownfield in future and how the site will be used. The 23% of respondents believes that lower real estate prices of buildings in proximity to brownfields are connected to aesthetics of brownfields. These sites are usually abandoned and neglected, sometimes aesthetically unsightly with peeled façade or are ruined, covered by weed or walls are damaged by graffiti etc. Only 19.5% of respondents perceived brownfields as barriers for the further development of the city. We can say respondents were not so optimistic when thinking about the future development of their city. It seems that this distrust towards future reduces demand for housing within the city and indirectly it noticeably reduces the value of the local real estate.

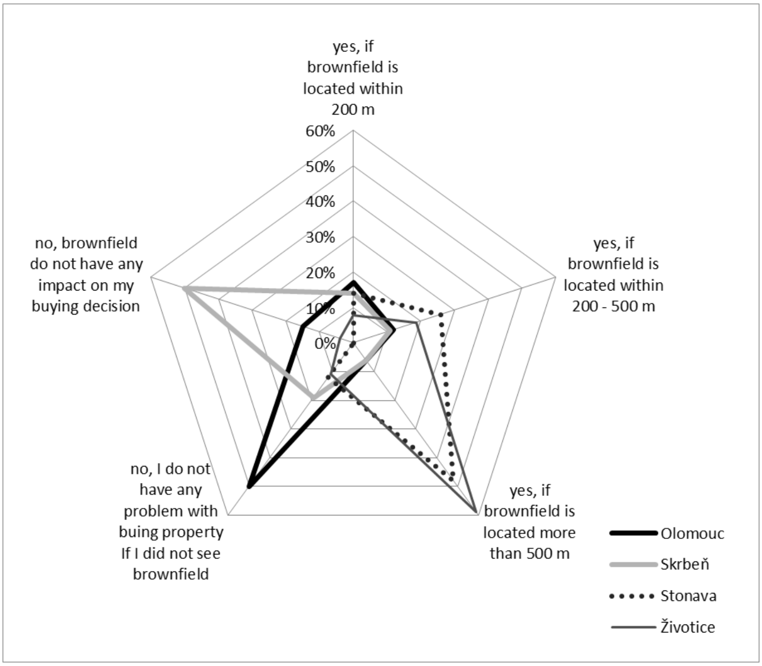

Fig. 6. Influence of brownfields on real estate buying behaviour of respondents.
Source: own survey (n=352)

The last presented research results are answers to the question where respondents were asked to evaluate the possibility to buy the real estate in the proximity of brownfields (see **Figure 6**). The answers to this question confirm previous findings. While the citizens (in 50% - 60%) of Stonava and Životice would consider buying a property if it was more than 500 meters away from brownfields, the respondents from Olomouc in 40% do not have any problem with buing property in neighborhood of brownfields if they do not see them. This should be given in matter of fact that the Olomouc is quite big city with a different approach to housing than in the village. What was suprising, for respondents from Skrbeň (in 50%) brownfields do not play a role in influence their decision to buy real estate or (in 19%) if they did not see brownfield. This could be explained via low negative experience with brownfields (see **Table 2**).

5. CONCLUSIONS

Brownfields, the reasons for their origin, the effects of their existence, the problems associated with them and the proposals for their solution are the current topic for professional and lay discussion across public and private bodies and institutions involved in this issue. In the context of the existence of brownfields, it is a priority to find their new, beneficial use. This enables the brownfield to see the potential for further development of the region, together with its regeneration, the growth of economic and social activity and the increased attractiveness of the area for all stakeholders. Leaving abandoned areas without the effort to find alternative uses for them, regional development is hampered by the fact that it prevents the development of the built-up area, adversely affects the environment and society and has an adverse impact on the entire territorial unit.

The aim of the paper was to examine the perception of brownfields on the values of residential properties, as perceived by the local population. The set of semi-structured interviews has been conducted in four municipalities (Stonava, Životice, Skrbeň and Olomouc) that are significantly affected by the occurrence of brownfields. By means of our survey hypothesis was confirmed that the occurrence of brownfields significantly affects the value of the residential properties. Brownfields are perceived quite negatively as the local population believes that they reduce prices of residential properties. This finding is in line with the results of previous studies (e.g. Bond et al., 2004). Respondents of our survey also claimed in their majority that they would not buy the real estate in the proximity of brownfield even if the price was reduced by on fifth in comparison with other locations within the same city or municipality. Such exact finding can be hardly generalized, however, the stand-off of local population from purchasing the real estate in the neighbourhoods of non-regenerated brownfield seems to be clear. This argument might utilized while arguing for the speeding-up of the brownfield regeneration process.

Factors that the most significantly influence such decision is a concentration of socially pathological phenomena, dangerous due to possible contamination and pollution that threatens health and risks connected to possible contamination of brownfields and health risks for the local population. This confirms the expectation that the inhabitants of Stonava and Životice, who comes from the area affected long-term coal mining industry and will be loaded towards brownfields negatively tuned than residents of rural areas Olomouc and Skrbeň, where attitudes to brownfields are not so pronounced and associated with unwanted prejudices.

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DESCENDING MOUNTAIN ROUTES FUTURE: THE NORTH YUNGAS AND FĂGĂRAȘ GEOSYSTEM`S COMPARATIVE STUDY

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ABSTRACT:
The Yungas region geographical position on the Eastern slopes of Cordillera Real and the Făgăraș Mountains East-West alignment generated unique Geosystems. A single gravel road links La Paz with Amazonia Boliviana: *El Camino de la Muerte* and only one road crosses the Făgăraș Mountains: the *Transfăgărășan*. Mountain roads networks are connecting communities and their resources all over the world. This research is adding value to the old mountain roads systems using the new technical Geography advances and transforming them in tourist sites. The cultural ecosystem services have a growing popularity that can be valorized for the locals benefits if managed accordingly. This paper focuses on the special descending sections identification and assessment for the mountain recreational activities development. The North Yungas and the Făgăraș areas represent unique Geosystems from the Bolivian Andes and the Romanian Mountains, analyzed using Geomedia techniques. Here we show that our *Death Road* model can securely allow tourist access, increase locals' livelihood and protect mountain environments. Our research results prove that the South American Geosystem`s unique attributes can constitute a functional reference for a considerable number of world`s mountain routes future sustainable development.

Key-words**:** *Geomedia, Smartphone, Ecosystem services, Geosystem, Transfăgărășan; Yungas*.

1. INTRODUCTION

The North Yungas Geosystem reflects changes in the field of community-based tourism by presenting new research approaches using the smartphone`s Android emerging technologies. The *Death Road* frame model developed with Geomedia techniques will help mountain communities around the world to mitigate their poverty problems. It provides insight into the mountains' natural resources virtual exploitation issues. The Geomedia techniques are using the digital geo-information from different media sources (earth observing media such as Google Maps, Google Earth, social media such as Facebook and geo-located mobile apps) to virtually illustrate the unique characteristics of special geographical locations, spatially defined as Geosystems (Ernawati et al., 2018; Voda et al., 2017) and having a corresponding geodatabase (Nicoara and Haidu, 2011).

A considerable number of people are affected by poverty, struggling to survive in the mountains or leave. Currently, the increasing migration rate to the European developed countries is positioning Romania after Syria, which is in the midst of a civil war (UN DESA, 2017). The Bolivian mountains impoverished citizens are living in difficult conditions.

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Bolivia`s human development index ranks 118th out of 188 countries and territories (UNDP, 2016).

Valorizing the mountain roads potential for recreational activities constitute an environmentally friendly solution for the future as the cultural ecosystem services such as trekking, wildlife photographing or mountain biking, have become popular in the recent years (Newsome and Davies, 2009; Winters et al., 2011; Webber, 2007; Morckel and Terzano, 2014; Goeft and Alder, 2001). The Bolivian and Romanian policy makers have to take into account the creation and communication of the cultural ecosystem services knowledge (Fish, 2016; Voda et al., 2017). Community decision factors can administrate the designated sections and local inhabitants can contribute by offering accommodation, guiding and traditional farming experiences. The local organization, the self-control of the social networks and the innovative technology support represent the answers for the rural communities in search for alternative livelihood provided by the cultural ecosystem services development (Lew and Cheer, 2018; Ernawati et al., 2018).

The *Death Road* phenomenon proves our Yungas Geosystem theory in which the tourist flow constitutes the matter; the locals symbolize the energy while the internet, the social media and the smart apps represent the information input. Here we show the dynamic equilibrium between the matter, energy and information input and output fluxes, quantified by the *Death Road* recreational ecosystem services. The North Yungas functional attributes can be identified in the Făgăraș Geosystem and many other mountainous environments throughout the world. The mountain tourism characteristics, such as trails, gravel roads and guideposts are present in most of the world`s ranges with their wilderness subjugated by human intervention. Descending on mountain bikes in Bolivia represent an adventure recreational activity, geographically located in the *Cordillera Real* wilderness, which is generally characterized by dense tropical forest and steep slopes (Walter, 1982; Beedie, 2003).

The Death Road frame model has to stimulate new, important questions: how to educate local communities to keep the Geosystem balanced; which are the development acceptable limits, according to the local environment physical capacity of support? Our grounded theory was constructed based on Death Road phenomena to emphasize the value of the North Yungas Geosystem`s unique attributes and anticipate prospective changes in Romania and other world`s mountain communities.

A significant number of websites, social media and smartphone apps promote the *Death Road* (*El Camino de la Muerte*) route, located in Bolivia, which unites the snowy highlands above the seat of the country government (La Paz) with the Yungas region, in the jungle. It covers about 64 kilometers and exceeds a drop of more than 3,600 meters, starting on the tarmac road from the 4,470 meters of altitude. The pavement is left for the gravel and the width of the road is narrowed to a merely 3.2 meters, although there are sidings. Fog and rain are frequently registered along the jungle section with descending left side precipices of up to 800 meters of free fall (Camino de la Muerte, 2009).

Recreational ecosystem service development using the Geomedia techniques facilitate the opening of new mountain routes not only in Bolivia or Romania but anywhere in the world. As new technological advancements and especially smart applications are progressively seen as an answer for many ecosystem services and tourism activities development, it is efficacious to investigate their impact in Bolivia, which has the most famous descending mountain route in the world, the *Death Road*.

Various investigations have explored the subject, notably Sil et al. (2016), Kumar and Kumar (2008), Boyd and Banzhaf (2007), Sherrouse et al. (2011), Wimpey and Marion

(2011), Wescott and Andrew (2015), emphasizing the importance of the world`s mountainous regions in provisioning ecosystem services. The recreational experiences are quantifying people`s non-material benefits offered by different environments through the cultural ecosystem services (MEA, 2005; Sanna and Eja, 2017). Fish et al. (2016) advanced a relational approach to cultural ecosystem services, based on the human`s contact with the natural landscapes.

Buhalis and Law (2008) observed the smartphone applications linkage to the tourists' independent travels development. Schwanen and Kwan (2008) showed that modern technology facilitates the personal interconnection and leisure activities organization. Dickinson et al. (2014) argued that travellers have all the needed information about a destination in their smartphones. Martínez-Graña et al. (2017) proved that the local natural and cultural resources are considerably better protected and disseminated with the help of mobile phones smart applications. The geographical representation of various Geosystems evolved from paper maps to smartphone apps (Voda, 2013). Lapenta (2011) believes that Geomedia`s augmented reality displays our environmental features through the digital visualization systems. Ernawati et al. (2018) found that images with geolocation could be transformed into the Geosystem`s scientific illustration with the help of Geomedia techniques. Inal et al. (2017) showed the smartphones` GPS efficiency for the historical sites coordinates validation. Baiocchi et al. (2017), emphasized the Global Navigation Satellite Systems (GNSS) techniques relevance for the smartphones maps accuracy. The geolocated images and virtual maps sharing processes through the social media channels are controlling the Geosystem`s information and energy fluxes, interconnecting people and geographical spaces (Lapenta, 2011; Voda and Negru, 2015; Zheng et al., 2010).

Our study will show how Geomedia techniques were used to analyze the North Yungas Geosystem`s characteristics and future development capabilities. The *Death Road* tourist site can be a model for the virtual imagery elaboration of the Transfăgărășan road or other mountainous region`s descending routes. With the help of the new modern geographical technologies based on WebGIS, smart apps and geolocation, the mountain communities will identify their particular natural assets and transform them into emerging tourist sites.

2. METHODOLOGY AND MATERIALS

The geospatial indicators of the North Yungas and the Făgăraș Geosystems were identified based on available satellite imagery, regional bio-geographical maps, social media assessment and WebGIS analysis. The *Cordillera Real* gravel roads network were explored on motorbikes and mountain bikes in April-May 2017 and April 2018.

We analyzed, assessed and digitally processed the North Yungas and Făgăraș Geosystems`s natural and anthropogenic components. For both mountainous regions, the natural common attributes are represented by the towering peaks, deep valleys, steep rocky slopes and tumultuous river rapids. The anthropic interference with the mountains generated other standard characteristics such as rural settlements, passage roads, but also created the indigenous culture, which produced the unique functional attributes. Based on our Geosystem grounded theory where the inputs and outputs of matter, energy and information have to be constantly balanced in a dynamic equilibrium state, we used the Geomedia techniques to digitally transform and integrate all the relevant environmental components into virtual functional illustration of the analyzed geographical spaces (Mac, 1996).

The field work of our exploratory research was carried out with Garmin GPS, Iphone8+ and Xiaomi Redmi 3S embedded geolocation systems for the data collection and spatial layers validation. The photos taken on the mountain trails registered the exchangeable image file (EXIF) data for the coordinate determination and mapping purposes.

The Geomedia technique incorporates the spatial geographical characteristics into virtual Geosystems where all the environmental components are interconnected. Following the human experience of the geographical space, the Geosystem`s elements were synthetized and transformed into visual imagery structures (Park and Santos, 2017). Furthermore, the multi-scale modeling process required the components assessment and the different attributes recognition. According to Haidu (2016), when operating with information from various levels, the characteristics of the Geosystem`s structure-components interrelation determination and the digital processing of geographical data is possible and generates the technical character of the research.

Google Maps™ and Google Earth datasets of the Cordillera Real sections, Coroico and Coripata were utilised for maps creation. The descending mountain tracks were charted on orthophoto maps and vectorized using satellite images of 30 m resolution from Google Earth, ESRI, EarthStar Geographics and the international GIS user communities. The Geomedia technique approach to the mountain communities' development contributes to the identification, evaluation and valorisation of the existent natural and cultural resources. The Geosystem grounded theory is based on the *Death Road* phenomena whose functionality will be validated by the new technological advancements, regulated and coordinated by the social networks and the smartphone applications. Our research scope was to design Geomedia techniques able to extend the Yungas Geosystem`s qualities and externalize its virtual representation functionalities.

3. RESULTS

Although the Bolivian North Yungas and Romania`s Făgăraș region integrate the common functional characteristics of the world`s mountains, the international tourists are attracted to the areas by a unique Geosystem attributes, generated by a cumulus of internal and external factors.

The Yungas Geosystem`s special features were developed in time with the local and international media contribution, which amplified the hazardous factor associated with the specific rough geographical characteristics. Everywhere in the world, the creation of a future tourist site is fundamentally influenced by the media (Milne et al., 1998). Considering the physical challenges determined by the transition from altitudes of 4470 m in the Andes to 1000 m in the Amazon rainforest, the media virtual imagery was easily exaggerated. Before visiting a geographical location, people's mind generates *naïve* images about the place, built on collective conventional images (Cheriffi et al., 2014). The *Death Road* stereotypical image was constructed based on its unique functional attribute: dangerousness. The transformation of the most intriguing mountain road into a tourist site followed. The findings were evaluated; the North Yungas and the Făgăraș Geosystems attributes were determined and compared.

Formerly, there were no roads to the Yungas or the Amazon for motor vehicles, only routes on foot or "loin of beast", the best known was the path of "Choro". Apart from the Choro there are three other pre-Columbian roads, which are the Sillu Tinkara, the Huancané, and a third that leaves Challapampa. Currently covered by vegetation, each one has a rehabilitation project with no definite term. Despite being still used by automobile traffic, the old road to Coroico, named "*El Camino de la Muerte*" due to the number of vehicles that fall from it every year, now serves as a mountain bike trail for hundreds of tourists per year, who pay between 40 and 60 US $ for the service to La Paz agencies. At the same time, Coroico has become in recent years a visited tourist center that has a wide range of services, including accommodation, restaurants and outdoor activities (Coroico, 2018). Haukeland et al. (2010) argues that recreation could be a motivational factor for adventure tourism.

3.1. The North Yungas Geosystem

The need to connect La Paz with the Yungas, an area located northeast of the La Paz city in the Central Andes, determined the road construction in a region dominated by dense wilderness, coca plantations and mountain ecosystems, in a very rainy climate and with frequent mists (Yungas, 2018).

El Camino de la Muerte is one of the most dangerous roads in the world, especially in the section that descends from *La Cumbre* (4470 m) to Yolosa for approximately 64 km, the average of vehicles descending to the abysses of 800 meters is more than two a month. Imboden (2012) emphasized the risks importance in adventure tourism, stating that the experiences offered have to be presented as safe and secure in order to be desired. In 1995, the Inter-American Development Bank named La Paz to Coroico route "the world's most dangerous road." The international media started to contribute to the tourist site creation. This road was built by Paraguayan prisoners during the Chaco War in the 1930s. It is one of the few routes that connect the Amazon rainforest in the north with the rest of the country, following the former Inca Choro trail (Chaco, 2009).

The tourist *Death Road* (DR) starts on tarmac from the highest La Paz- Choro connection route, altitude of 4470 m (Tarmac Road_DR) descending for 32 km up to the gravel road (GR) section (DR_GR). Usually accompanied by a tourist guide from La Paz agencies, the biker groups learn this section rule of driving and proceed for another 32 km on gravel to Yolosa small community, the *Death Road* end point (DR_GR_end) (**Fig. 1**).

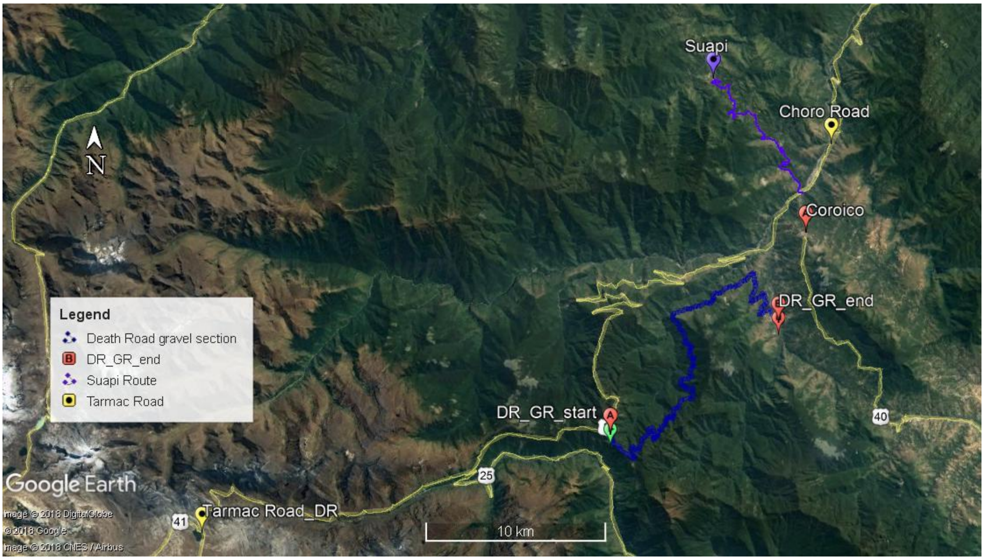

Fig. 1. The North Yungas Geosystem`s map with the *Death Road* extension (from Tarmac Road_DR to DR_GR_end).

It was once the only way of communication between the Amazon Coca farms and the La Paz highlands, this meant that there was a huge traffic of people and mechanisms in both directions, mainly trucks and heavy buses, which had to make difficult maneuvers to pass on the road and many fell into the abyss. This is how it got its name: "the route of death".

Because Paraguayan prisoners of the Chaco War (in the 1930s) were the ones who built the road and then were thrown into the void, a legend tells that the prisoners cursed this road and promised to take souls to death with them. The legend was born and the countless accidents explained through a local mystical approach. The new two-lane road has 54 bridges and a slope stabilization number (The Death Road, 2018). When driving on this road the left must be maintained, (it is the only place in Bolivia where vehicles are driven on the left side) so that the drivers from the left side are able to observe more easily the edge of the road, which in almost all crossing places is an abyss, which can reach in some places 800 m vertically. The law indicates that the driver who drives up the hill (in the direction of La Paz) has priority over the one that goes down (in the direction of Choro), so the vehicle that descends must stop when another one climbs. In 2011 there were a total of 114 accidents (the second route with the most incidents in Bolivia after the road between La Paz and Oruro), with a total of 42 deaths (Blind Worlds, 2017).

The danger posed by this route made it a popular tourist destination since the 1990s. In particular, mountain bike enthusiasts use it for its steep descents and the exquisite scenery of the 32 km long gravel road section, from DR_GR_start to DR_GR_end (**Fig. 2**).

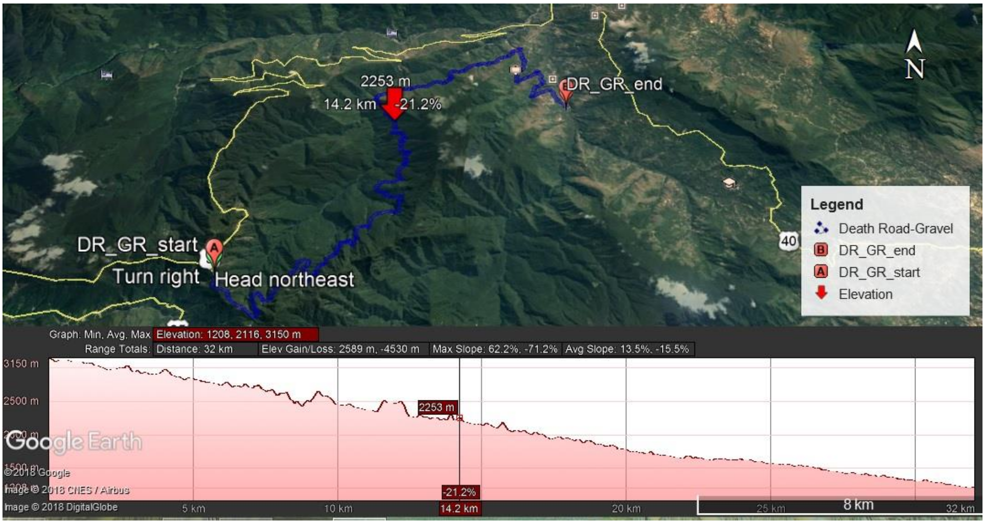

Fig. 2. The Death Road gravel sectors start (DR_GR_start) and finish (DR_GR_end) points.

The *Death Road* model is defined by the gravel road section which represents the quintessence of the North Yungas Geosystem. As one descends the Northern mountain slopes from 3150 m (DR_GR_start) to 1200 m (DR_GR_end) in Yolosa, the tourist groups constitute the matter input in the Geosystem. They pay a 25 *Bolivianos* ($us 3,50) fee at the local community checkpoint. La Paz travel agencies generate the Geosystem's energy, providing means of transportation to the geographical location. Small resorts spread in the *Río Coroico* valley, therefore, after the mountain bike descent, the tourists interact with the locals, taste the local food and relax in the swimming pools before heading back to La Paz. The information flux is created on the social networks such as Instagram, Facebook and WhatsApp once the adventurers start sharing their experience. Although written details can be found in the LonelyPlanet, Fromer's, or Rough Guides pages, the modern tourists prefer the smartphone applications. Furthermore, the participants' opinion and pictures are counted and the virtual representations validated online by the reviews and rating systems (Ernawati et al., 2018).

Apart from *El Camino de la Muerte*, two other routes were identified in the North Yungas region. The first one is a gravel road that connects Suapi village to the *Río Coroico* main valley and the second represents an Inca paved route that starts from Coroico settlement and penetrates the mountain dense forest down to the same river valley.

The Suapi route follows a left Coroico river tributary and crosses spectacular mountain ridges from 1000 m to 1650 m altitude along a 16 km long dirt road. Small forest sections, Coca plantations, beautiful meadows and majestic waterfalls can be admired on this alternative adventure route. Small community households are scattered in the Suapi track vicinity, easing the potential future tourist-local inhabitant interaction (**Fig. 3**).

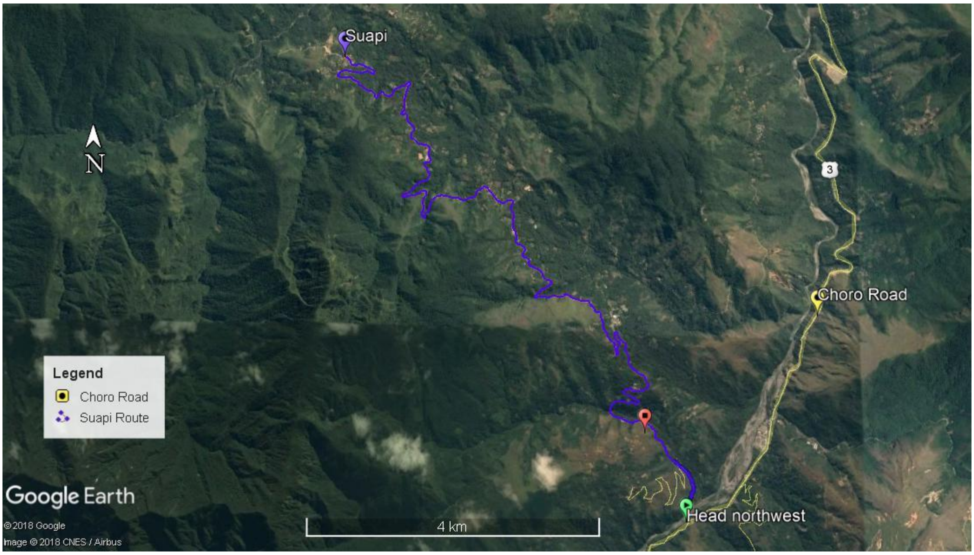

Fig. 3. The Suapi route potential development from Rio Coroico`s Choro road.

The Inca route that connects Coroico with the homonym valley consists of a narrow mountain track paved with rounded riverbed rocks. The common functional attribute of this route is represented by the mountain steep slopes and dense tropical forest characteristics. Dangerous under rainy conditions because of the slippery rocks, the Inca route from Coroico to the Coroico river valley is one of the unexplored sections of the North Yungas region (**Fig. 4**).

The *Death Road* model offers a different approach to the cultural ecosystem services development opportunities, taking into account all the nonconsumptive outputs of the North Yungas Geosystem. The Bolivian people`s comprehension of their Geosystem`s unique attributes functionality is giving rise to the mountain inhabitants well-being.

3.2. The Făgăraș Geosystem

Romania`s Făgăraș Mountains represent the country`s highest range (2544 m on Moldoveanu Peak) forming a natural border between Transylvania and Walachia historical provinces. The Făgăraș Geosystem`s common attributes are illustrated by the glaciated alpine mountain range with dense forests, flat top ridges, sharp edged peaks, cirques and small troughs (Martonne, 1917). The Romanian shepherds' annual migration from Transylvania to the South conducted to the Făgăraș Geosystem unique attribute conservation: the ancient Romanian habits and peculiar customs. It is the quintessence of the Romanian national identity, validated by the distinctive Latin language preservation throughout the centuries of barbaric invader waves (Martonne, 1917; Mac, 1996).

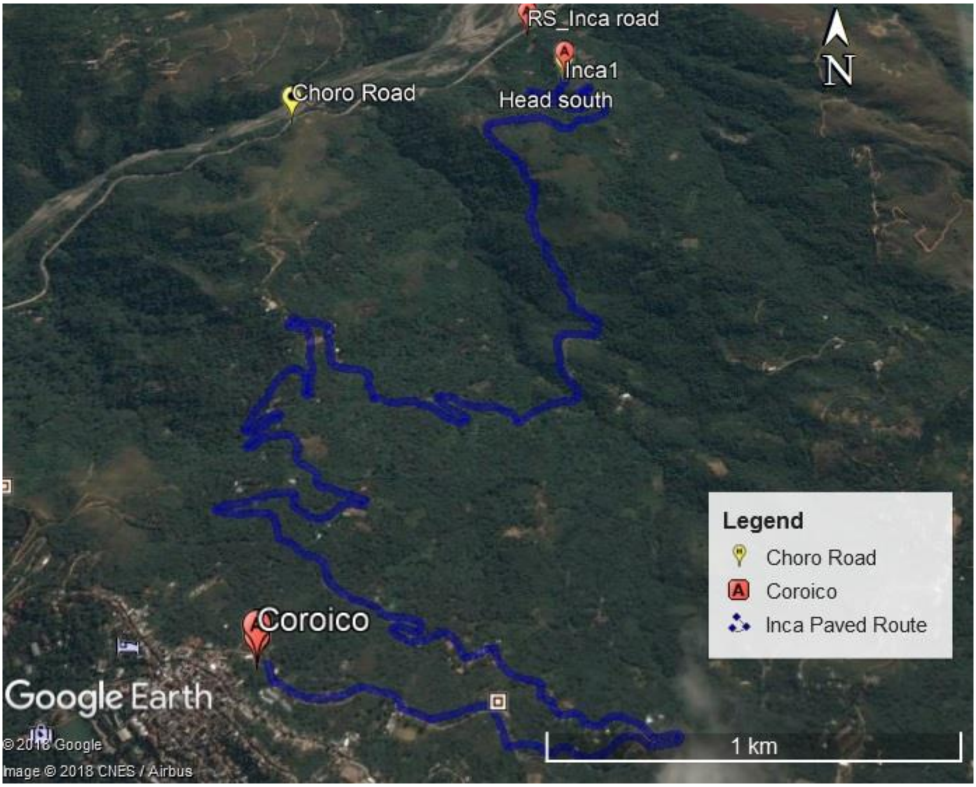

Fig. 4. The Inca trail from Coroico to Choro road down to the river valley.

The Transfăgărășan road is considered a unique functional attribute of the Făgăraș Geosystem which facilitates the matter, energy and information fluxes. It was built between 1970 and 1974 for strategic reasons generated by the Russian military invasion of Czechoslovakia in 1968. The Romanian military deflagrated 6250 tons of dynamite to dislocate the massive rocks (Moceanu, 2017). It has the longest (887 m) high altitude tunnel (2045 m) that connects 80 km of dangerous mountain roads from the last Southern village of Căpătaneni to Cârtisoara in the North. It represents the world`s best road trip according to Top Gear (TopGear, 2010; Transfăgărășan, 2017; LosApos, 2018).

The road construction works required 3.8 million tons of rock displacement, decreasing the shear strength of the slopes and triggering the dynamics of today`s geomorphological processes (Urdea, 2000; Urdea et al., 2009). Chiroiu et al. (2016) used the tree-ring techniques for the Northern Făgăraș slope stability determination. Based on dendrochronological analysis and the aerial photographs they proved that the deforestation activities associated to the Transfăgărășan road construction activated rockfalls and avalanches, unbalancing the Geosystem`s natural equilibrium. On the 17th of April 1977 an avalanche killed 19 kids from Brukental Lyceum in Balea Lake.

Fig. 5. The Transfăgărășan road from Poienari Castle to Cârtisoara village.

Many human lives were lost along the Transfăgărășan route (**Fig. 5**), before, during and after the road construction. Căpătaneni's village name (*căpătani* meaning heads) is related to the bloody Posada battle from 1330s and the considerable number of skulls with fighting helmets found into the local grounds. The fights with Mehmet II Fatih throughout the year of 1462 determined Vlad Tepes`s wife to throw herself from a Poienari Citadel window thus generating the legend of *Raul Doamnei* (Lady`s River). Bram Stoker`s Dracula character was inspired by Vlad Tepes (the Impaler), the cruel Walachian prince (LosApos, 2018; Ernawati et al., 2018).The Transfăgărășan cultural ecosystem benefits are associated with the Romanian national identity and the *miorita* (the little ewe) space. *Miorita* is an ancient pastoral ballad that defines the Romanian people`s strong attachment to the mountains (Babuts, 2000). The Romanian policy makers should focus more on people rights to explore the mountain gravel road networks and facilitate the development of cultural ecosystem services as services that integrate human built structures, individuals and social capital to initiate recreation and cultural distinctiveness production.

3.3. Descending recreational activities and locals livelihood

Our research offers comprehensive recommendations for the Romanian policy makers regarding the cultural ecosystem services and for the Bolivian government to extend the *Death Road* recreational model to other descending routes from the Yungas region. Our study proposes modern solutions for the local communities' future development in terms of new technology trend awareness and adoption.

The Yolosa, *Río Selva*, Coroico, Căpătaneni and Cârtisoara young hosts are aware of the local assets potential to be developed as tourism attractions. Smartphones technological advancements facilitate digital processing of any asset images. A photo can be transformed into a designed composition using the golden ratio mean. The better framed images are needed to transmit the locals' message to the international viewers. Any community asset image with the golden ratio is considerably better handled by the human mind. The brain sends the message that such an image is aesthetically pleasing (Patkar, 2015).

Analyzing the Airbnb phenomenon, Ert et al. (2016) emphasized the image relevance for the internet website credibility construction, demonstrating the Geosystem`s virtual imagery efficiency. The geographical space personalization with distinctive photos in transforming any Geosystem`s image, increases the Airbnb`s platform authenticity and functionality. Tussyadiah and Pesonen (2016) pointed out the local community`s importance in the host-guests social relationships. Sigala (2017) claims that Airbnb is leading the world`s peer to peer accommodation system. Due to the modern smartphone application reviews and ratings, the North Yungas and the Făgăraș Geosystems` virtual image will attract more tourists, encouraging the local inhabitants to become superhosts and improve their livelihood (Wang and Nicolau, 2017; Liang et al., 2017; Gunter, 2018).

The *Death Road* and Transfăgărășan are considered dangerous and untamed roads. Their stereotypical collective images have the same unique functional attributes that can be valorized in the future. Moreover, the Făgăraș Geosystem`s access routes to the main mountain ridge can develop cultural ecosystem services due to their richness in specific customs and ancient Romanian traditions. If developed accordingly, the Suapi route, the Inca`s paved trail from Coroico to the river valley and the Coripata-Rio Beni gravel road can considerably contribute to the local inhabitants' income increase in the future. The smartphone application advancements allow direct contact between tourists and community members, without La Paz travel agencies as intermediaries. In addition to the mountain biking experience, complementary activities such as whitewater rafting, canyoning, wild temperate forest or jungle exploration should be offered in order to keep tourist for another day in the region. Moreover, the local households can be adjusted and transformed to become exquisite Airbnb accommodations and provide extra-income.

4. DISCUSSION

The world`s mountains represent elaborate eco-social Geosystems where biodiversity has to be protected and the recreational activities developed in a sustainable way (Eriksson et al., 2012; Lai et al., 2016; Voda et al., 2017). Our developed Geomedia technique identifies the valuable assets of a geographical place evaluating the natural and cultural resources from a Geosystemic approach. The common and unique functionality of the Geosystem`s attributes were analyzed from a dynamic equilibrium perspective. The Geomedia means of promoting the natural and cultural values of a place should significantly increase the North Yungas locals experience in terms of balancing the conservation and recreational activities (Lai et al., 2016; Voda and Negru, 2015). Currently, the South American *Death Road* appears to be one of the world`s most famous mountain bike descending route (**Fig. 6**) (Ridersmate, 2016; Verity, 2016). The cultural ecosystem services can provide benefits for the rural inhabitants of Căpătaneni and Cârtisoara villages situated in the Transfăgărășan proximity just as the *Death Road* is sustaining the benefits for the North Yungas

Geosystem`s locals. The collective imagery of the North Yungas and the Făgăraș Geosystems was created with the social networks sharing capacity to maintain the information fluxes between the virtual and the real geographical spaces (Voda et al., 2014; Colvin et al., 2015). The social media contribution to the internet community building is undeniable, representing a place where the geographical locations virtual images are developed (Wheaton et al., 2016). Although it has been suggested that tourists flow can destroy the environmental physical capacity of support, it is generally agreed that the modern technology advancements can regulate and organize the information, matter and energy fluxes using the online smartphone applications.

Fig. 6. The *Death Road* virtual image (Coripata-left and Coroico-right).

The *Death Road* frame model implementation in Transfăgărășan or other North Yungas Geosystem`s areas such as Suapi or Coripata has advantages and potential disadvantages. Community-based tourism success could reduce social inequality, encouraging the local inhabitants' identity expression and development. On the other hand, supplementary costs intervene when a local household is transformed into an Airbnb accommodation. Alternatively, biodiversity destruction might constitute a threat to the mountain ecosystem`s integrity. Overall, the community`s benefits are considered more valuable in most cases.

It is generally agreed that mountains are generating cultural values for humans. Firstly, the Romanian public access to the Fagaraș Geosystem`s mountain roads should be granted. Babuts (2000) emphasized the significant impact that *Miorița* virtual space has had on the Romanian psyche. Their value of wellbeing comes from seeing the mountain streams, the glacier lakes, the untamed scenic views. Secondly, the viewing sites placement and picnic areas establishment is compulsory. Thirdly, an integrated management and controlling system based on a collaboration among the local administration, the regional forest service, police enforcements and protected areas authorities need to be implemented.

Compared to the Romanian restrictive mountain laws, the Bolivian policy makers seem to better understand the positive effects of the cultural ecosystem services development in the North Yungas Geosystem.

5. CONCLUSIONS

Our main finding prove that any community can use Geomedia tools to create the virtual imagery of their living environment, scientifically illustrated through intelligently constructed photography of the Geosystem`s unique functional attributes. In the North Yungas, for example, the cultural goods are essentialized through the *Death Road* organized recreational activities, Yolosa, Rio Selva and Coroico locally produced food and drinks.

The impressive technological evolution availability and the recent smartphone applications advancements based on the GPS capabilities for the geo-location and photos geotagging, support the semantic connotation identification of the special Geosystem`s assets. The North Yungas and the Făgăraș Geosystems` cultural ecosystem services benefits such as spiritual enrichment or aesthetic experiences are generating unquantifiable value and a different sense of wellbeing for the visitors that is indirectly reflected on the locals' welfare. The research results can be applied not only in the Făgăraș for the Transfăgărășan route development or in the North Yungas region to extend the mountain bike descending routes from Coroico to Coripata, down to the Beni river valley, but anywhere in the world`s mountains, allowing the creation of the *Death Road* type recreational frameworks for the benefit of the poorest communities. The cultural ecosystem services development helped to the formation of a unique *Death Road* identity that can be reframed in other geographical locations.

There are a number of limitations to be considered, given the technical challenges of the Geosystem`s identity creation processes: one would be the North Yungas and the Făgăraș communities' specialized education in terms of sustainability and environmental balance maintenance between biodiversity conservation and recreational activities development, another, the poor access to technology. The sustainability of ecosystem services in the natural North Yungas Geosystem are not encumbered by governmental policy schemes such as Romanian Forest Law that forbids public access into the mountain gravel roads (Forest Law, 2015). Bolivia is progressing to assisting its impoverished rural inhabitants adopting various development programs to alleviate poverty (Fredette, 2017; World Bank, 2018).

Further research is required to analyze the local authorities' managerial capabilities of effectively coordinate sustainable recreation activities in the Cordillera Real and Făgăraș Mountains for their own community welfare. The Bolivian authorities should make the North Yungas Geosystem a focus of attention and properly valorize the potential of its unique attributes in the future.

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Aims and Scope

Geographia Technica is a journal devoted to the publication of all papers on all aspects of the use of technical and quantitative methods in geographical research. It aims at presenting its readers with the latest developments in G.I.S technology, mathematical methods applicable to any field of geography, territorial micro-scalar and laboratory experiments, and the latest developments induced by the measurement techniques to the geographical research.

Geographia Technica is dedicated to all those who understand that nowadays every field of geography can only be described by specific numerical values, variables both oftime and space which require the sort of numerical analysis only possible with the aid of technical and quantitative methods offered by powerful computers and dedicated software.

Our understanding of ***Geographia Technica*** expands the concept of technical methods applied to geography to its broadest sense and for that, papers of different interests such as: G.I.S, Spatial Analysis, Remote Sensing, Cartography or Geostatistics as well as papers which, by promoting the above mentioned directions bring a technical approach in the fields of hydrology, climatology, geomorphology, human geography territorial planning are more than welcomed provided they are of sufficient wide interest and relevance.

Targeted readers:

The publication intends to serve workers in academia, industry and government.
Students, teachers, researchers and practitioners should benefit from the ideas in the journal.

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