Environmental Engineering and Management Journal

December 2015, Vol.14, No. 12, 2959-2971
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

VULNERABILITY OF GROUNDWATER UNDER CLIMATE CHANGE AND LAND COVER: A NEW SPATIAL ASSESSMENT METHOD APPLIED ON BELIŞ DISTRICT (WESTERN CARPATHIANS, ROMANIA)

Mărgărit-Mircea Nistor[1], Ştefan Dezsi[2]*, Sorin Cheval[3]

[1]University of Modena and Reggio Emilia - Department of Chemical and Geological Sciences,
19 S. Eufemia Street, 41121, Modena, Italy
[2]Babeş-Bolyai University, Faculty of Geography, 5-7 Clinicilor Street, 400006, Cluj-Napoca, Romania
[3]National Meteorological Administration, 97 Şos. Bucureşti-Ploieşti, 013686 Bucharest, Romania

Abstract

A new assessment method of groundwater vulnerability was done using multilayer data analysis through GIS Spatial Analyst Tools. The method presented here refers at Beliş district territory and describes two tasks: (1) groundwater vulnerability determination from Water Surplus, Ecosystem Services, Aquifers map, and Infiltration map; (2) the future vulnerability assessment for 2050, considering four scenarios of land cover and climate data changes. First results, carried out by proposed method, show a very high vulnerability area of 2.44 km^2 and a high vulnerability area of 24.09 km^2 in Beliş district. The projections of land cover and climate data came to estimate the vulnerability of groundwater in 2050. Thus, the area of 3.02 km^2, with highest vulnerability was found in scenario 2, under localities area increase and precipitation decrease. The findings demonstrate that both climate change and land cover are responsible for groundwater vulnerability. Further, the vulnerability mapping and land cover scenarios could be useful for delimitations of protected areas and development of plans' management.

Key words: climate change, GIS method, groundwater vulnerability, land cover, vulnerability

Received: May, 2015; Revised final: July, 2015; Accepted: November, 2015

1. Introduction

The groundwater vulnerability may be determined in different ways. Depending of the factors which influence the quality and quantity of groundwater, the vulnerability is going to be assessed through suitable tools. In general, the vulnerability of surface and groundwater water is related to agricultural and industrial activities or to the growth of human population (Batali et al., 2014; Eshleman, 2004; Öztürk et al., 2013). The environmental changes may have a large influence, as well. Groundwater resources depend not only on human activity and land use, but also on the climate change influence (Bachu and Adams, 2003; Brouyère et al., 2004; Loàiciga et al., 2000; Prăvălie et al., 2014a).

A number of environmental factors influences the groundwater vulnerability, but primarily, the regional and local geology, climate change, and land use are the main factors that must be analysed into groundwater vulnerability analysis (Aktas, 2014; Allen et al., 2004; Civita, 2005; Craciun et al., 2011; Gavrilescu, 2009; Mattikalli and Richards, 1996; Park et al., 2001; Santos et al., 2014; Srivastava et al., 2013). In mountain areas, the status of groundwater is especially got by the climate and land cover role. In the recent decades, a large part of aquifers have changed under climate warming. Many hydrological studies argue the negative impact of climate changes on ecosystems and on groundwater recharge (Campos et al., 2013; Long et al., 2013; Parmesan and Yohe, 2003; Prăvălie et al., 2014b). In the same time, the

---

[*] Author to whom all correspondence should be addressed: e-mail: stefan@geografie.ubbcluj.ro; Phone +40745628045; Fax: +40264596988

influence of land use changes on surface water resources, watershed, and groundwater impact were called by some authors (Calder et al., 1995; Gavrilescu, 2009; Li et al., 2007; Sliva and Williams, 2001; Wang, 2001; Yan et al., 2013).

In the area of interest for this study, namely Beliş, the climate is slightly changing and the recent deforestation could be problematic for groundwater vulnerability. These two factors, combined with chaotic texture of villages and poor sewerage infrastructure, contribute to increase of groundwater vulnerability.

With a view to combat several causes of existing negative impact on water resources and to evaluate the spatial distribution of groundwater vulnerability, our methodology has come to identify and certify the vulnerability in Beliş district. Moreover, the proposed scenarios, with different type of land cover, could be a solution in the future arrangements and plans' management of the district.

The Beliş catchment area, together with Fântânele, Tarniţa, Gilău, Drăgan and Iada reservoires, are the main drinking water sources for the northwestern Transylvania. From a climate and geomorphological point of view, the reservoirs from these areas have a high capacity for water storage behind the dams. The recharge of aquifers is done by precipitations.

In this study a new assessment method of groundwater vulnerability, using GIS Spatial Analyst Tools, was developed to evaluate the impact of climate change and land cover on groundwater in Beliş district. As well as, the method could be applied in any other mountain areas, without loss in performances.

The vulnerability of groundwater is important for development planning, and there are many methods used for quantitative assessment, suitable either for springs vulnerability, aquifers or surface waters. For delineation of spring protection zones', the traditional methods are based on spring vulnerability degree, aquifers heterogeneity, surfaces runoff, discontinuities and protective cover layer in the recharge area (Civita, 2008; Pochon et al., 2008). In northern Apennines, Nistor et al. (2014) calculated the vulnerability of groundwater by VESPA index and continuous monitoring in situ of springs from fractured aquifers.

An integrated approach for mapping groundwater vulnerability, based on SINTACS and GIS, was adopted by Civita and De Maio (1998) and Civita et al. (1999). Čenčur Curk et al. (2014) determine the groundwater vulnerability under climate change in South East Europe through GIS applications. They carried out the vulnerability map, taking into account the maps of Local exploitation index, Quality index, Ecosystem services, Gross Domestic Product (GDP), using the Hungarian method. The methodology proposed by Čenčur et al. (2014) started with precipitation and evapotranspiration data, from which the Local exploitation index was calculated by the ratio of Water demand and Total runoff.

The surfaces water pollution index multiplied by aquifer infiltration factor were used to calculate the Groundwater quality index (Wochna et al., 2011).

The present work aims at (1) estimating the groundwater vulnerability in Beliş district under climate and land cover change, and (2) at providing four scenarios to explain how the vulnerability is likely to change up to the current mid-century. The scenarios refer to 2050 and evaluate the vulnerability degrees in different climatic conditions and various types of land cover.

2. Study area

The Beliş district is located in the south-western part of the Cluj County and spreads over a mountainous area of around 206 km^2, including 6 localities (Beliş, Bălceşti, Dealu Botii, Giurcuţa de Sus, Smida, and Poiana Horea) without waste water treatment. The population is connected to septic tanks and they use groundwater pumping systems for the domestic use. In some cases, e.g. Poiana Horea, the people constructed basins outside the village. Only Beliş and Giurcuţa de Sus villages are connected to sewage systems.

The Beliş district landscape presents three large mountain blocks, longitudinally separated by two main rivers from west to east: Someşul Cald in north and Beliş in south-central part. Transversal streams are crossing the mountain chain, leading to a fragmented relief. There are no heavy industry and no intense agricultural crops. In this study, we check the vulnerability in the context of the recent climate warming and land cover changes due to deforestations and grazing. Based on the International Hydrogeological Map of Europe, there are two main types of aquifers within the district: one is highly productive and the other one is classified as non-aquiferous rocks (Fig. 1).

The productive aquifers are found in the south-western part of the interest area, where the geology is constituted by dolomites and calcareous rocks. In central and northern part of district, the substrate is prevalent with metamorphic rocks (Ianovici et al., 1976), with limitation water that form the aquiclude. The karstic aquifers are highly vulnerable and aquifers with metamorphic rocks are classified as medium vulnerable (Civita, 2005; Piacentini and Zavatti, 1994).

The surface waters are preponderant tributaries to Someşul Cald River and Beliş Stream, which form a dam accumulation around 6 km^2, situated in the north-eastern part of the district. This accumulation is called Fântânele Lake and it represents the most consistent water resource from the district. The lake extends from west to east along to Someşul Cald River and from south to north along Beliş Stream. The Beliş district has a continental temperate climate, with ocean influences from western part of Europe. After Koeppen classification, the area is included in Dfb climate.

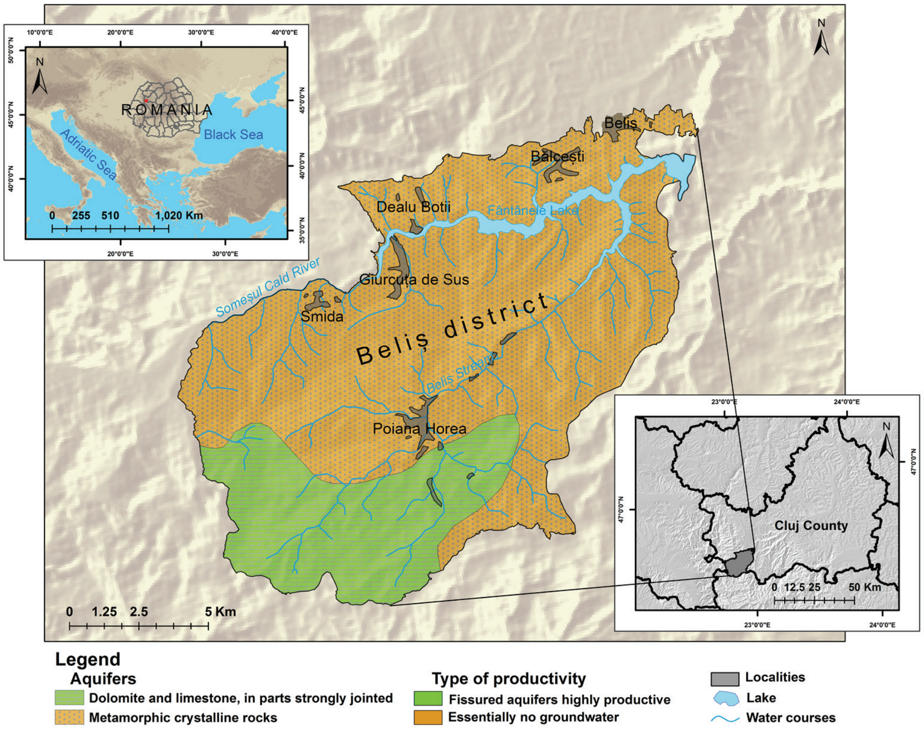

Fig. 1. Location of the study area. Types of aquifers presented in Beliş district

Because of its geographical position in west of Romania, the district feels very good the oceanic influence from Atlantic Ocean, and during the whole year, the seasons are fully humid. The Dfb climate is characterized by cold winters and warm summers (Kottek et al., 2006).

3. Materials, data and methods

3.1. Field data sets

Field input data sets are based on aerial photo dating to 2012 with a 5 × 5 m spatial resolution, International Hydrogeological Map of Europe 1500 (IHME1500), Digital Elevation Model (DEM), topographical maps 1:25000, and population statistical data of Beliş district villages. These data sets are indispensable for obtaining derived maps that serve to calculate the groundwater vulnerability.

3.2. Climate data

Annual precipitation and temperatures data for the year 2012 from Vlădeasa meteorological station served to calculate the evapotranspiration and further to mapping the runoff for present. The estimated potential evapotranspiration for the 2021-2050 period was retrieved from the results reported within the project CC-WARE (Čenčur Curk et al., 2014), using the Thornthwaite's formula (Thornthwaite, 1948).

3.3. Methods

3.3.1. Overall of the approach

Integrated analysis, based on GIS techniques and remote sensing, offers the successful treatment of spatial and temporal data (Nasef, 2012). In order to find relevant impact of recent climate warming, land cover, hydrographical network, and aquifers on groundwater, we used the Spatial Analyst Tools in aim to find the critical zones of groundwater vulnerability.

Spatial Analysis focused on Beliş, a mountain district of Western part of Transylvania, was carried out using ESRI ArcGIS 10.1 software. This software was chosen because of its high capacity in the spatial analysis and of its tools to data projection (McCoy and Johnston, 2002). Thus, a new method in three steps was bringing forward to assess the groundwater vulnerability in mountain areas: (i) preparation of vector data, (ii) raster data extraction, and (iii) vulnerability calculation through GIS Spatial Analyst Tools. Further, the future projections of land cover and climate data models published by Čenčur Curk et al. (2014) in Report 3 of CC-WARE European Projects were used to calculate the groundwater vulnerability for the year 2050. For vulnerability calculation, all features fields were normalized.

3.3.2. Vector data collection

The vector data was created in ETRS_1989_LAEA Projection. Manual vectorization, based on ArcGIS 10.1 software, was used to extract vector data of land cover and network drainage.

The district aquifers were digitized from IHME at 1:1,500,000 scale, available as WMS service on web-site (http://www.bgr.de/Service/groundwater/ihme1500/?).

The topographical maps 1:25000, elaborated by Military Topographic Directorate-MTD (1962), checked in field and remote sensing investigation by aerial photo was used in the attempt to extract network drainage vector data. Automatic vectorization was applied to transform the raster maps into vector data, in aim to compare the square area of degrees vulnerability resulted for present and for future scenarios. Elshehaby and Taha (2009), Fuller and Aboudarham (2004), Hadeel et al. (2010), Raup et al. (2007), Wilson et al. (1999), agree on the manual vectorization because of its precision, even if the method is tedious.

3.3.3. Raster data extraction

In this study, the groundwater vulnerability of Beliş district was determined by the two main factors: land cover and climate data. The basic input data are the following: the annual rainfall, crop evapotranspiration, land use, domestic water demand, hydrogeological map, DEM, infiltration coefficient. From the above mentioned data the derived raster maps (Fig. 2) that serve to groundwater vulnerability calculation by Spatial Analysis are: Water Surplus map, Ecosystem Services map, Aquifers map, Infiltration map.

3.3.4. Water Surplus map

In aim to calculate the Water Surplus (Eq. 1), the runoff (Eq. 2) and Domestic Water Demand (Eq. 3) were estimated at spatial level. The Water Surplus map became as differences between these two parameters.

The runoff value (Eq. 2) was obtained through difference between annual rainfall and crop evapotranspiration (ET$_c$).

$$\textit{Water Surplus} = \textit{Runoff} - \textit{Domestic Water Demand}, [\textit{mm/year}] \tag{1}$$

$$\textit{Runoff 2012} = \textit{Annual rainfall 2012} - ET_c, [\textit{mm/year}] \tag{2}$$

$$\textit{Domestic Water Demand for} = \textit{Locality}_{population} \times 100 \times 365, \text{[mm/year]} \tag{3}$$

Firstly, the potential evapotranspiration (ET$_0$) and evaporation were calculated, using Thornthwaite (1948) method (Eq. 4). Multiplying the ET$_0$ by crop coefficient (K$_c$), the ET$_c$ was obtained (Eq. 7).

$$ET_0 = 1.6 b_i \left(\frac{10 T_i}{I} \right)^{\alpha} [cm / month] \tag{4}$$

where:

ET_0 = potential evapotranspiration;
b_i = radiation parameter for specific latitude;
T_i = monthly air temperature;
I = annual heat index (see Eq. 5);
α = complex function of heat index (see Eq. 6).

$$I = \sum_{i=1}^{12} \left(\frac{T_i}{5} \right)^{1,514} \tag{5}$$

where: T_i = monthly air temperature.

$$\alpha = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.7912 \times 10^{-2} I + 0.49239 \tag{6}$$

where: I = annual heat index.

$$ET_c = ET_0 K_c [mm / month] \tag{7}$$

where:

ET_c = crop evapotranspiration
ET_0 = potential evapotranspiration
K_c = crop coefficient

3.3.5. Ecosystem Services map

The Ecosystem Services map is related to surfaces pollution index released by each type of land cover and surfaces waters. Based on literature of speciality (Wochna et al., 2011), we assigned a vulnerability coefficient value for each land cover from Beliş district. Summing the land cover coefficient vulnerability with fresh waters coefficient vulnerability, the Ecosystems Services map was carried out (Eq. 8). Considering the local conditions, the highest value of vulnerability factor is 4.5, chosen for localities. For the fresh waters, a minimal factor value of 0.05 was chosen, because of some pollutant sewers and spillages originated from the proximity of houses near streams. Table 1 presents the normalization values of vulnerability coefficient factor related to Beliş land cover used latter in the spatial analysis.

$$\textit{ES} = \textit{Coefficient Vulnerability of Land Cover} + \textit{Coefficient Vulnerability of Fresh Waters} \tag{8}$$

Table 1. Vulnerability coefficient factor of land cover

Type of land cover	***Normalized vulnerability coefficient***
Forest	0.55
Woodland shrubs	0.66
Pasture	0.77
Localities	1
Lake	0.05

3.3.6. Aquifers map

The Aquifers vulnerability map has taken into account the type of geological composition of the aquifers. Thus, the coefficient of aquifers vulnerability was chosen for each polygon features, using vector data, further conversed into raster data. For this study, a value of 0.66 was assigned to aquifers, formed by dolomites and limestone, and a value of 0.5 for the aquifers formed by metamorphic crystalline rocks.

3.3.7. Infiltration map

The Infiltration map represents the ratio between the infiltration coefficient of each aquifer type and slope vulnerability index (Eq. 9). In the present study, the dolomites and limestone aquifers has a value of infiltration of 0.7 and the metamorphic crystalline aquifers has a value of infiltration of 0.1. The slope vulnerability index was obtained from the reclassification of derived slope map from the DEM. Thus, four equal classes from 0 to 90 degrees for slopes were established, further reclassified in four equal classes from 0 to 1. In the Infiltration map calculation, we agree to use the slope map in detriment of the DEM, because the infiltration rate depends directly on the type of rock and slope, not on altitude. For the groundwater vulnerability, the Infiltration map is higher in the areas with high infiltration value of geological substrate and flats areas, while on the high slopes, the surfaces flow is higher and infiltration became smallest/lowest. For this reason the DEM cannot be used direct for the Infiltration map.

$$IM = Infiltration\ Coefficient / Slopes \qquad (9)$$

3.3.8. Vulnerability mapping based on GIS Spatial Analyst Tools

The maps of Water Surplus, Ecosystem Services, Aquifers, and Infiltration were integrated into spatial analysis through GIS Spatial Analyst Tools. Each of them were classified after Civita (2005) and Piacentini and Zavati (1994) criteria, in five vulnerability degrees and in the vulnerability calculation these maps were reclassified from 1 to 5 (Table 2).

Table 2. Vulnerability classes

Vulnerability class	*Normalized vulnerability class*	*Reclassification vulnerability class*
Very low	< 0.05	1
Low	0.05 - 0.2	2
Medium	0.2 - 0.6	3
High	0.6 - 0.8	4
Very high	0.8 - 1	5

The spatial analysis of multilayers data requires an equation that contains the weights from 0 to 100 for each integrated map. In order to decide the maps weights, we consulted literature of speciality (Daly et al., 2002; Dixon, 2005; Stempvoort et al., 1993) adapted to hydrology vulnerability studies. Generally, the aquifer media has a medium implication in final results and Dixon (2005) attributed a weight of 3 for aquifers and topography, for a 1-5 scale, in his DRASTIC method for groundwater vulnerability mapping. Aller et al. (1987), mentioned by Stempvoort et al. (1993), chose weight of 3 for aquifer media and a weight of 1 for topography.

For this reason, we prefer to use a 0.25 and 0.2 weights for aquifers, respectively for topography, for a 0-1 scale. Regarding at Ecosystems Services weight, a medium-high of 0.4 parameter was chosen, because in this study the major focus is on land cover impact. Dixon (2005) chose a high parameter of 5 for soil media. The difference to 1 was used for Water Surplus, so it was of 0.15 weight. For the Beliș district, the groundwater vulnerability formula was agreed in Eq. (10).

$$GW\ V = WS \times 0.15 + ES \times 0.4 + AQ \times 0.25 + IM \times 0.2 \qquad (10)$$

where:

$GW\ V$ = Groundwater Vulnerability;
WS = Water Surplus;
ES = Ecosystem Services;
AQ = Aquifers;
IM = Infiltration map.

3.3.9. Future projections of groundwater vulnerability

In aim to observe how groundwater vulnerability will change in the future, we provide four scenarios for 2050. These scenarios are based on climate change data, population increase, and land cover changes. Thus, since the precipitations are likely to decrease, an increasing of population with 30% is expected, of localities with 30%, of forest with 30%, and of pastures with 30%, the four projections of groundwater vulnerability being mapped. Land cover in five classes (Fig. 2) was obtained from aerial photo that reflects the Beliș district land cover: forest, pastures, woodland and transitional shrubs, artificial areas and lake. These classes are useful to calculate crop evapotranspiration and runoff maps.

The Buffer Tool was used to calculate the increase in area of localities, forest and pastures. Buffer Tool is a function through which the ArcGIS software creates a vector data, largest or smallest, keeping the set at an equal distance around the input features. The new obtained features were extracted from the land cover map, modified by 30% in the area, and after that being integrated again in the land cover map, in order to calculate the runoff. The future land cover projection map was clipped in favour of the Fântânele Lake, district limit and localities.

The first scenario was projected, based on precipitations decrease and on the presence of the same land cover and population. With this scenario, it follows how to change the vulnerability, if only climate will change. Decrease in precipitations and present land cover and present population were used to generate the maps that determine the groundwater vulnerability. A value of 550 mm/year was used for 2050 precipitations. The precipitation value was carried out from the precipitation grid model published in the report of Čenčur Curk et al. (2014). The temperature data were obtained from three RCMs (RegCM3 – ITCP, Aladin – CNRM, Promes – UCLM), run under the A1B SRES IPCC scenario, which presume balanced energy sources within a consistent economic growth, into the context of population increasing, until the mid of 21st century, and rapid introduction of more efficient technologies (Houghton et al., 2001).

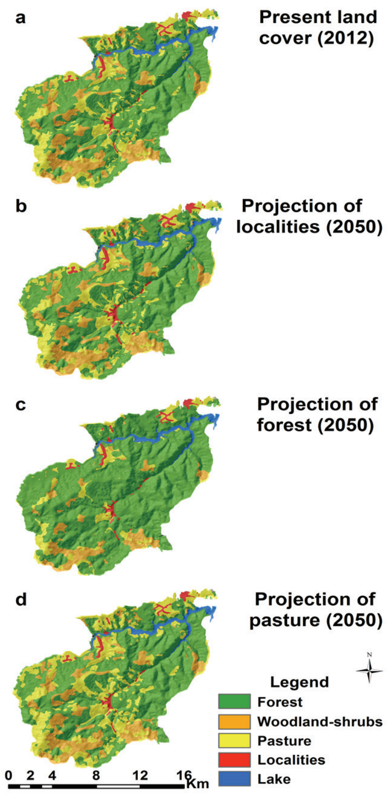

Fig. 2. Land cover and future scenarios: (a) Beliş district present land cover; (b) Localities projection with more than 30%; (c) Forest projection with more than 30%; (d) Pasture projection with more than 30%.

The second scenario takes into account the population increase with 30%, and the localities extension that will increase with 30%. In this scenario, we applied a buffer distance value of 25 m, to find the 30% increase in the area of localities polygons. In the Scenario III, the forest increase by 30% was projected. A buffer value of 155 m was established, in the attempt to obtain the 30% increase in forest area. For this scenario, the decrease in precipitations was considered and an ET_c of 637.5 mm was calculated from the land cover and actual evapotranspiration models. The forest feature was clipped under localities and Fântânele Lake polygons. The Scenario IV combines the precipitations information and land cover projected with increase with 30% of pasture area. We agree that precipitations decrease at 550 mm/year and an ET_c of 425 mm was calculated. In order to identify the right value of more than 30% in area, a buffer value of 40 m was applied at pasture feature. Table 3 resumes the main input data of each scenario.

4. Results

Overall, the results presented below show the groundwater vulnerability in Beliş district and four future scenarios, based on Spatial Analysis in GIS. The analysis was made to look for estimating the spatial distribution of the groundwater vulnerability under recent climate changes and land cover modifications. From the applied method, it is revealed that the south western part of the district is more vulnerable. At the same time, the artificial areas appear on the groundwater vulnerability map like high and very high vulnerability areas. From the first results, our method shows that the vulnerability area, with high and very high degree, extends for future decades. From the analysis of present and future groundwater vulnerability projections, it was observed that the very high vulnerability degrees are found generally in localities' areas and south-western part. For identification of the spatial distribution of groundwater vulnerability areas, we mapped and discuss below the present vulnerability map and the four future scenarios.

Figs. 3-7 depict the Water Surplus, Ecosystem Services, Infiltration map, and Aquifers map, carried out through the raster data calculation for present and future scenarios. The findings show a low vulnerability in the lands covers by forest. From Scenario III, a decrease fraction of groundwater supply resulted, due to a high capacity of forest for evapotranspiration. In this case, the advantage brought forward is that in the forest area the quality of surface waters and groundwater is higher than in the other type of land cover, because of low pollution index. A very high and high vulnerability were found by vulnerability mapping in this period in Beliş district. A total of 2.44 km^2 area of very high vulnerability and an area of 24.09 km^2 with high vulnerability were calculated for 2012. The high values of vulnerability are located in south-western part of the district (Fig. 8) and are found there because of high infiltration coefficient and of aquifers characteristics.

Table 3. Future scenarios for 2050

Scenario	*Precipitation projection*	*Land cover projection*	*Population projection*
I	Decrease of precipitation at 550 mm / year	Present land cover, no modifications	No modifications
II	Decrease of precipitation at 550 mm / year	Increase of localities area by 30%	Increase of population by 30%
III	Decrease of precipitation at 550 mm / year	Increase of forest area by 30%	No modifications
IV	Decrease of precipitation at 550 mm / year	Increase of pasture area by 30%	No modifications

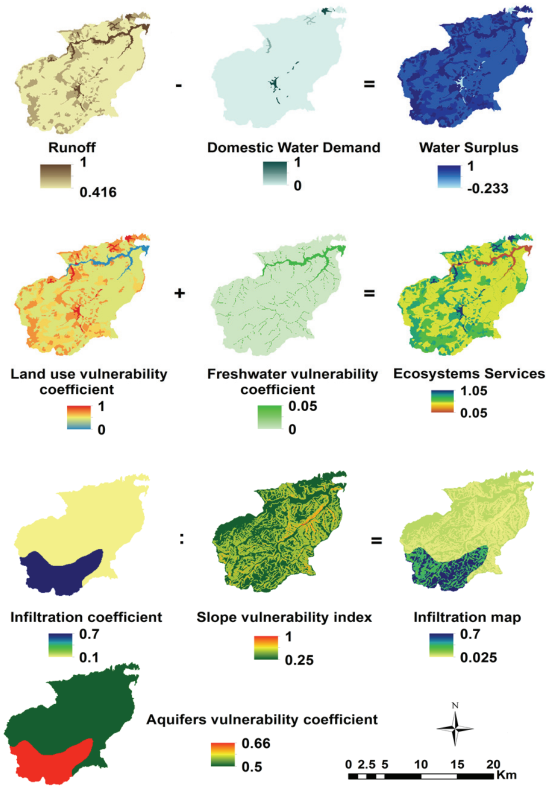

Fig. 3. Illustration of the underlying derived maps considered for Spatial Analysis related to present

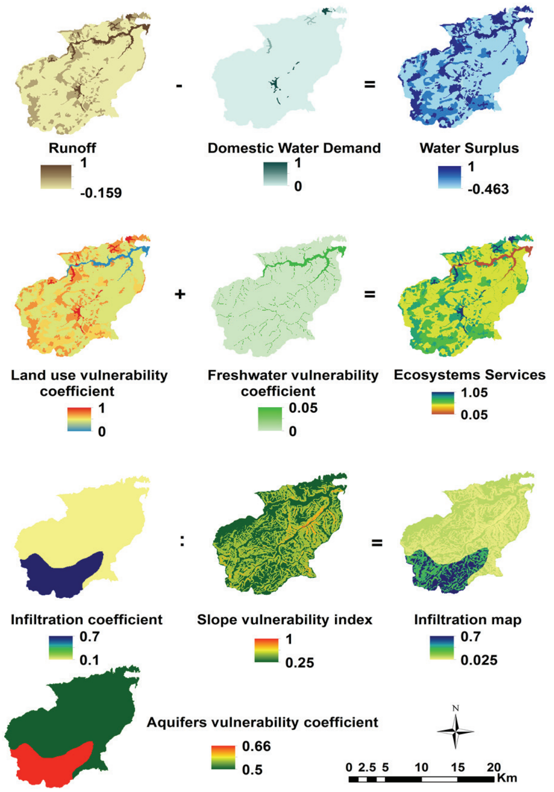

Fig. 4. Illustration of the underlying derived maps considered for Spatial Analysis related to Scenario I

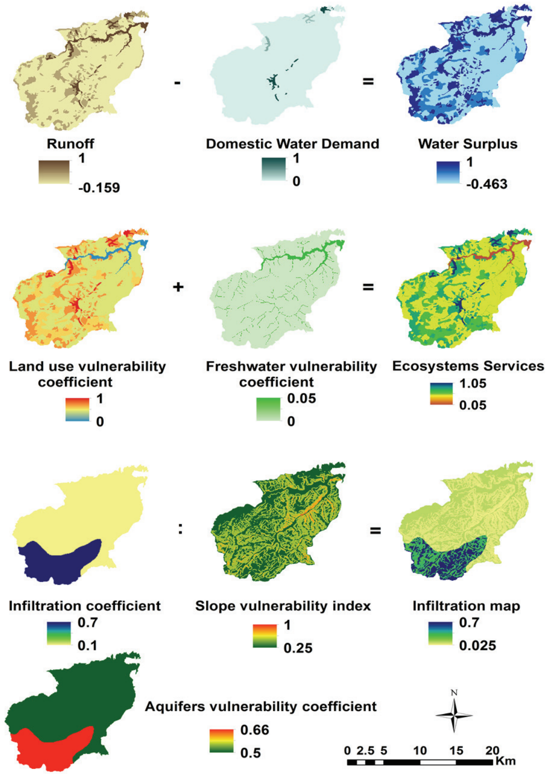

Fig. 5. Illustration of the underlying derived maps considered for Spatial Analysis related to Scenario II

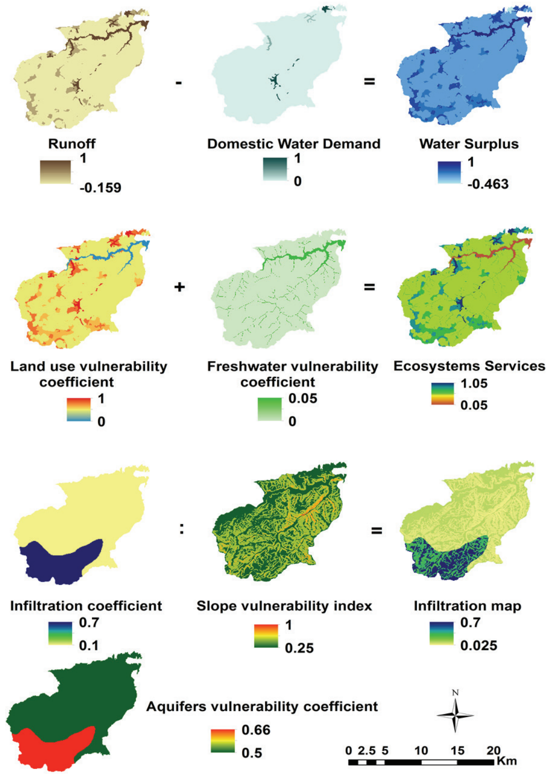

Fig. 6. Illustration of the underlying derived maps considered for Spatial Analysis related to Scenario III

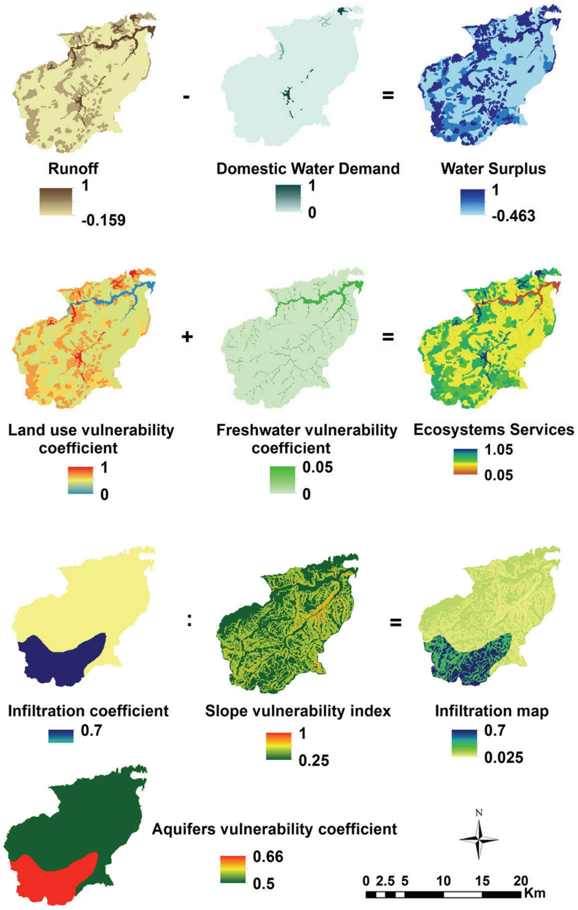

Fig. 7. Illustration of the underlying derived maps considered for Spatial Analysis related to Scenario IV

Only 5.55 km^2 of area was generated by ArcGIS software for very low vulnerability that represents the fresh waters territory. Expectedly, the largest areas for this scenario have medium and low vulnerability.

The Scenario I was generated with the present land use data and present domestic water demand, using the decrease of rainfall. The results (Fig. 9) of Scenario I indicate an increase of very high vulnerability with 1.8 km^2. In the same time, the areas with high vulnerability increase from 24.09 km^2 to 40.08 km^2. The medium and low vulnerability areas decrease and the very low vulnerability areas remained constant. In the Scenario II, localities and domestic water demand were projected, with an increase of 30%, and rainfall decrease was considered.

The largest area resulted in such a low vulnerability (Fig. 10), as that with 93.77 km^2, followed by medium and high area of 43.99 km^2, respectively of 39.87 km^2. An area of 3.02 km^2, with a higher vulnerability was calculated.

An increase in forest area with 30%, to the detriment of pastures and woodland-transitional shrubs area, was projected for 2050 in Scenario III. Climate change criteria were applied in calculation of runoff, considering the decrease in rainfall data. In Scenario III, the medium and low vulnerability areas are predominant (Fig. 11). Thus, 118.54 km^2 of low vulnerability area and 45.02 km^2 of medium vulnerability area were obtained. The very high vulnerability area occupied 1.77 km^2, and 14.51 km^2 represent the area with high vulnerability.

The last scenario takes into account the decrease of rainfall and increase of pasture area to the detriment of forest and woodland-transitional shrubs. A substantial area of 41.31 km^2 was calculated for high vulnerability area and 50.04 km^2 for medium vulnerability area. The low vulnerability area occupies 87.67 km^2 and it extends in the central and northeast part of Beliş district (Fig. 12). The very high vulnerability area diminishes with 0.62 km^2, in terms of the present scenario.

We anticipated these findings, because of a high infiltration coefficient of geological substrate in this sector of district. Scenarios I, II, and IV are very similar and present almost the same trend of high vulnerability values. Oppositely, the values of Scenario III are similar to the present values of groundwater vulnerability map, even if the rainfall amounts are decreasing. These results are very good, with a view to encourage and protect the future groundwater safety.

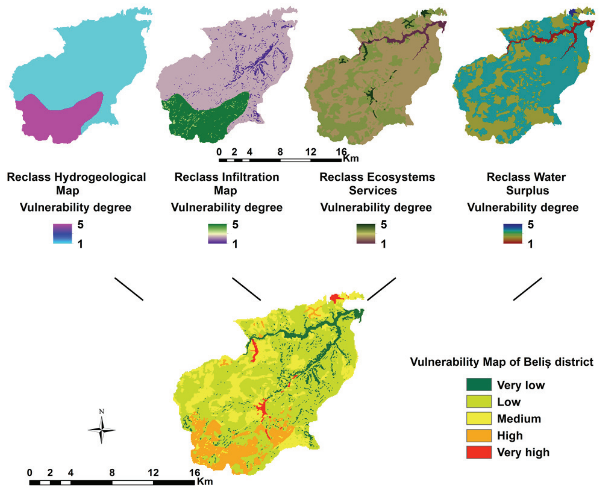

Fig. 8. Groundwater vulnerability map of Beliş district related to present

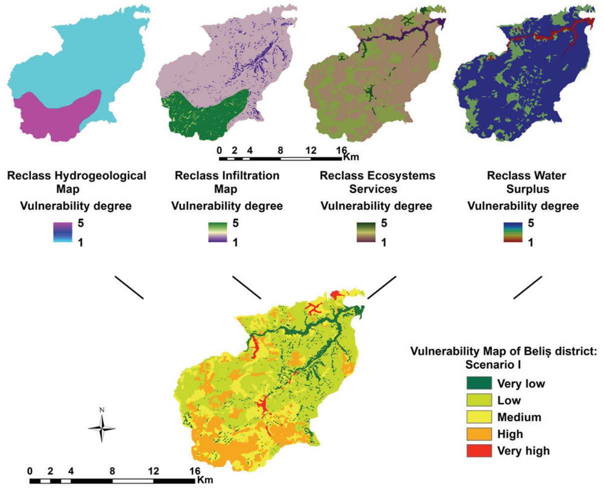

Fig. 9. Groundwater vulnerability map of Beliş district related to Scenario I

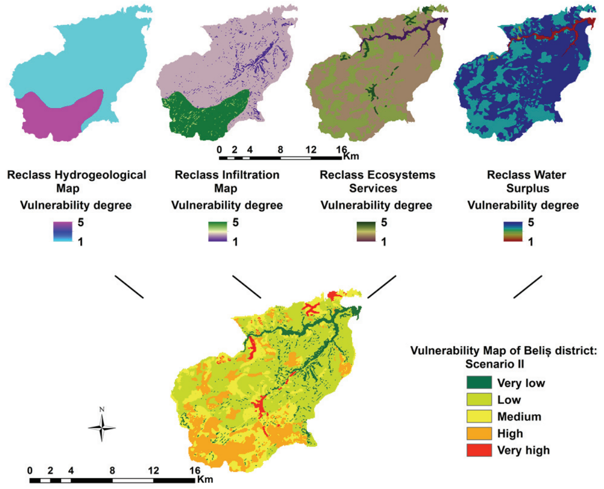

Fig. 10. Groundwater vulnerability map of Beliş district related to Scenario II

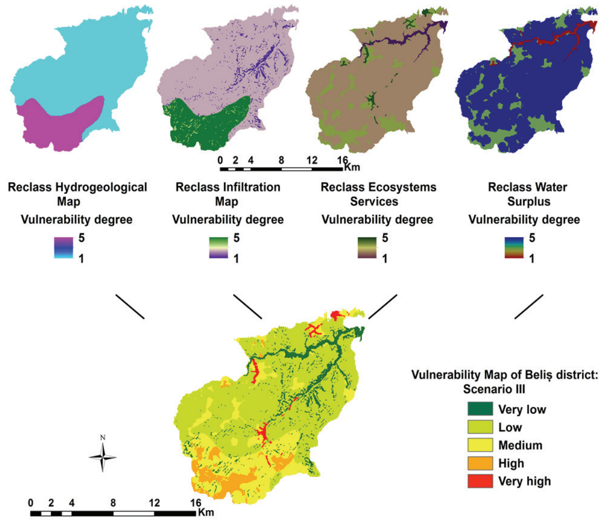

Fig. 11. Groundwater vulnerability map of Beliş district related to Scenario III

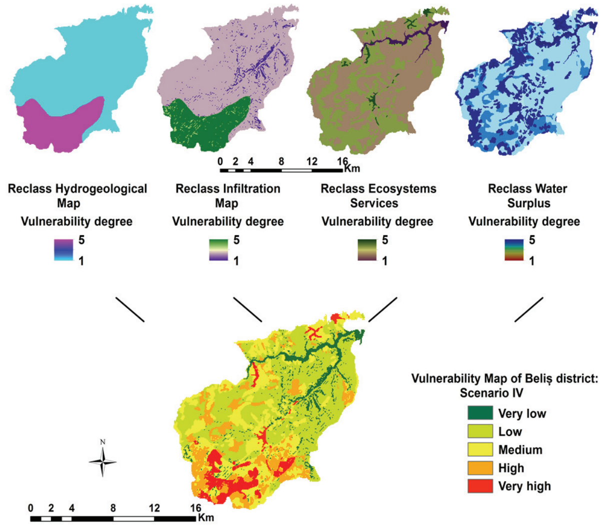

Fig. 12. Groundwater vulnerability map of Beliş district related to Scenario IV

5. Discussion

The main goal of the present paper was to map the vulnerability of groundwater in Beliş district, under climate data and land cover for 2012 year and to predict the vulnerability for 2050, using four scenarios. Spatial Analysis in ArcGIS 10.1, supported by climate data and remote sensing, would demonstrate that vulnerability mapping of groundwater was possible, attributing five vulnerability degrees with spatial reference.

Overall, the groundwater vulnerability maps carried out by us for the Beliş district are in line with maps carried out by Čenčur Curk et al. (2014). They used the Spatial Analyst Tools and the weights were attributed after Hungarian method. On the maps presented by Čenčur Curk et al. (2014) the Beliş district territory has medium and low vulnerability. They obtained only two classes of groundwater vulnerability, because of 25 x 25 km grid resolution. The differences between our method and Čenčur Curk et al. (2014) method is that we used the Water Surplus map into spatial analysis, while the they used the Local Water Exploitation index.

The topology and morphological features of the terrain is our new proposed method, taken into account the Infiltrations map, while the Čenčur Curk et al. (2014) integrated the Gross Domestic Product map.

In the method presented here, the land cover projections were done through a new approach, based on buffering, while in the study presented by Čenčur Curk et al. (2014), the future scenarios of land cover were used from PRELUDE future land use change scenarios, published by the EEA (2007).

The most important factor that influenced the degree of groundwater vulnerability is climate change, land cover and aquifers characteristics.

Table 4. Percentage area of groundwater vulnerability calculated in Beliş district

Vulnerability classes	***Related to present (%)***	***Scenario I (%)***	***Scenario II (%)***	***Scenario III (%)***	***Scenario IV (%)***
Very high	1.3	1.6	2.2	1.6	7.5
High	12.4	20.2	20.2	6.8	15.0
Medium	21.1	22.9	22.5	23.4	26.1
Low	57.9	48.0	47.8	60.3	44.2
Lower	7.3	7.4	7.3	7.9	7.2

It was observed that the decrease of precipitation has a direct negative impact on runoff and Water Surplus, which is easily distinguished from the future vulnerability maps. With regard to the present vulnerability, groundwater map was related into results that the largest area is low vulnerable and occupied by forest. In the same time, we expect to obtain high values for vulnerability in proximity of village's area, but we didn't expect a very high vulnerability in Giurcuța de Sus, because it is almost a small settlement, but it is possible, due to population water demand.

In the future period, the generated scenarios came to support the quantification of groundwater vulnerability under climate change and land cover changes. It was demonstrated that Scenario I, Scenario II and Scenario IV are very similar. In both scenarios, the runoff decrease as rainfall decrease and a considerable area of low vulnerability switches in medium class (Table 4).

In the Scenario II, the very high vulnerable area extends because of localities area extending. Expectedly, the Scenario III generated the largest area with low groundwater vulnerability. The increase of forest area makes the vulnerability of groundwater in forested area to decrease, even if the climate change has a strong impact.

In the case of Scenario IV, the future pastures expansion contributes to a high vulnerability extension, in comparison to present and a decrease of low vulnerability by 14.72 km^2. Eshleman (2004) reports in generally that the forest soil has a high infiltration capacity. Consequently, it is easily to understand that the forest represents the better ecosystem for quality water. For a high quality of groundwater, the forest ecosystems services provide the optimum land cover, but they have a major rate for ET$_c$ (Calder et al., 1995; Li et al., 2007) and from the quantity point of view, the aquifers' recharge is smallest. The study has demonstrated that the forest area indicates a low vulnerability. The high and very high area of vulnerability in Beliș district is caused by two different reasons, depending on spatial spread of settlements and geological substrate composition. Thus, even if there is no hard industry in Beliș district, the villages and human activities could cause a high degree of vulnerability. The main sources are the missing seepage and septic tanks.

The limitation of our research is given by a lack of determination of groundwater vulnerability through other methods. The springs monitoring and groundwater measurements with piezometers may be some solutions. On these aspects, the study could be more precise in particular locations of the districts, but cannot be generalized to the entire area of Beliş district.

For these reasons we consider that GIS Spatial Analyst is the best tool to assess the groundwater vulnerability under climate change and land cover at spatial level. Moreover, we strongly believe that these limitations influence the results in a less measure, and we think that the methods presented here may be applied to others mountain areas.

6. Conclusions

The vulnerability of groundwater, based on climate change and land cover, sometimes is hardly to be determined, because of multiple factors, which affect the entire hydrological system. Using GIS applications, a new assessment method presents how to determine the groundwater vulnerability in mountain area, integrating the land cover, geological substrate, anthropogenic component, and climatic data.

The high potential of GIS Spatial Analysis allows us a detailed vulnerability study of the groundwater in the present and future, indicating how the degree of vulnerability changes, if the land cover, populations, and climate data will changes. During the research, it was related that a high vulnerability areas of groundwater are more influenced by the calcareous and dolomitic substrate in the south eastern part of the district, but also the threats of groundwater are surrounding the localities. Our new assessment methodology provides also a simply method to project the future scenarios of land cover, based on buffer tool.

The findings are very helpful for hydrogeology studies from Western Carpathians and for sustainable environment. In our future activity, we want to focus on wells measurements and pollution discharge points, in an attempt to make chemical analysis of water samples and to establish the vulnerability, based on test sites. The present work contributes significantly to the possibility of protection delineated zones and of making future plans of management. Until now, no publications related to groundwater vulnerability and future scenarios have been published about Western Transylvania, an area where Cluj-Napoca city and others important localities have their own water supplies.

References

Aktas O., (2014), Impacts of climate change on water resources in Turkey, *Environmental Engineering and Management Journal*, **13**, 881-889.

Allen D.M., Mackie D.C., Wei M., (2004), Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada, *Springer-Verlag Hydrogeology Journal*, **12**, 270–290.

Aller L., Bennett T., Lehr J.H., Petty R.J., (1987), *Drastic: a standardized system for evaluating ground water pollution potential using hydrogeological settings*, EPA-600/2-87-035, U.S. Environmental Protection Agency, Ada, Oklakoma.

Bachu S., Adams J.J., (2003), Sequestration of CO_2 in geological media in response to climate change: capacity of deep saline aquifers to sequester CO_2 in solution, *Energy Conversion and Management*, **44**, 3151–3175.

Batali L., Dimache A., Iancu I., Popa H., Frunza G., (2014), Groundwater - underground structures interaction in urban environment in Bucharest area, *Environmental Engineering and Management Journal*, **13**, 1787-1800.

Brouyère S., Carabin G., Dassargues A., (2004), Climate change impacts on groundwater resources: modelled deficits in a chalky aquifer, Geer basin, Belgium, *Springer-Verlag Hydrogeology Journal*, **12**, 123–134.

Calder I.R., Hall R.L., Bastable H.G., Gunston H.M., Shela O., Chirwa A., Kafundu R., (1995), The impact of land use change on water resources in sub-Saharan Africa: a modelling study of Lake Malawi, *Journal of Hydrology*, **170**, 123-135.

Campos G.E., Moran M.S., Huete A., Zhang Y., Bresloff C., Huxman T.E., et al., (2013), Ecosystem resilience despite large-scale altered hydroclimatic conditions, *Nature*, **494**, 349-353.

Čenčur Curk B., Marcaccio M., Errigo D., Ferri D., Zinoni F., Corsini A., Ronchetti F., Nistor M.M., et al., (2014), *CC-WARE Mitigating Vulnerability of Water Resources under Climate Change. – WP 3 report version 4 Vulnerability of Water Resources in SEE*, On line at: http://www.ccware.eu/output-documentation/2-uncategorised/23-output-wp3.html.

Civita M., (2005), *Applied hydrogeology and environmentCEA*, (in Italian), Milano, Italy, pp. 794.

Civita M., (2008), An improved method for delineating source protection zones for karst springs based on analysis of recession curve data, *Hydrogeology Journal*, **16**, 855–869.

Civita M., De Maio M., (1998), *Mapping groundwater vulnerability by the point count system model SINTACS,* In: *Managing Hydrogeological Disasters in a Vulnerable Environment*, Andah K. (Ed.), cosponsorized by IHPUNESCO, Pubbl. GNDCI 1900, pp. 243-273.

Civita M., De Maio M., Vigna B., (1999), *A GIS methodology for evaluation active aquifer recharge*, Proceedings of the 3rd nationalist convention on the protection and management of groundwater in the third millennium. Papers of applied geology, 291-303.

Craciun I., Giurma I., Giurma-Handley C., Telisca M., Boboc V., (2011), evaluating the climatic changes in the hydrological flow regime of the Moldavian areas, *Environmental Engineering and Management Journal*, **10**, 1983-1986.

Daly D., Dassargues A., Drew D., Dunne S., Goldscheider N., Neale S., Popescu I.C., Zwahlen F., (2002), Main concepts of the "European approach" to karst-groundwater-vulnerability assessment and mapping, *Hydrogeology Journal*, **10**, 340–345.

Dixon B., (2005), Groundwater vulnerability mapping: A GIS and fuzzy rule based integrated tool, *Applied Geography*, **25**, 327–347.

Elshehaby A.R., Taha L.G.E., (2009), A new expert system module for building detection in urban areas using spectral information and LIDAR data, *Applied Geomatics*, **1**, 97–110.

EEA, (2007), Land-use scenarios for Europe: Qualitative and quantitative analysis on a European scale, ISSN 1725–2237, EEA Technical report No 9/2007.

Eshleman K.N., (2004), Hydrological Consequences of Land Use Change: A review of the state-of-science, ecosystems and land use change, *Geophysical Monograph Series*, **153**, 3-29.

Fuller N., Aboudarham J., (2004), Automatic Detection of Solar Filaments versus Manual Digitization, *Knowledge-Based Intelligent Information and Engineering Systems Lecture Notes in Computer Science*, **3215**, 467-475.

Gavrilescu M., (2009), Emerging processes for soil and groundwater cleanup - potential benefits and risks, *Environmental Engineering and Management Journal*, **8**, 1293-1307.

Hadeel A.S., Jabbar M.T., Chen X., (2010), Application of remote sensing and GIS in the study of environmental sensitivity to desertification: a case study in Basrah Province, southern part of Iraq, *Applied Geomatics*, **2**, 101–112.

Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K., Johnson C.A (Eds.), (2001), *IPCC TAR WG1, Climate Change 2001: The scientific basis, Contribution of working group I to the third assessment report of the intergovernmental panel on climate change,* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ianovici V., Borcoş M., Bleahu M., (1976), *Geology of Western Carpathian Mountains*, (in Romanian), Academy Publisher, Bucharest, Romania.

IHME1500 (International Association of Hydrogeologists, Commision for the Geological Map of the World, Subcommission for Hydrological Maps), (2013), International Hydrogeological Map of Europe *1500,* Published by Bundesanstalt für Bodenforschung und UNESCO, On line at: http://www.bgr.de/Service/groundwater/ihme1500/?.

Kottek M., Grieser J., Beck C., Rudolf B., Rubel F., (2006), World Map of the Köppen-Geiger climate classification updated, *Meteorologische Zeitschrift*, **15**, 59–263.

Li K.Y., Coe M.T., Ramankutty N., De Jong R., (2007), Modelling the hydrological impact of land-use change in West Africa, *Journal of Hydrology*, **337**, 258– 268.

Loàiciga H.A., Maidment D.R., Valdes J.B., (2000), Climate-change impacts in a regional karst aquifer, Texas, USA, *Journal of Hydrology*, **227**, 173–194.

Long Y.Q., Cui T.T., Yang Z.P., Li W., Guo Y.B., (2013), A coupled karst-porous groundwater model based on the adapted general head boundary, *Environmental Engineering and Management Journal*, **12**, 1757-1762.

Mattikalli N.M., Richards K.S., (1996), Estimation of surface water quality changes in response to land use change: Application of the export coefficient model using Remote Sensing and Geographical Information System, *Journal of Environmental Management*, **48**, 263–282.

McCoy J., Johnston K., (2002), *Using ArcGIS™ Spatial Analyst*, GIS by ESRI, Redland, USA.

MTD (Military Topographic Directorate), (1962), *Topographical maps 1:25,000,* Ministry of Armed Forces RPR. Cluj Region, Beliș district.

Nasef M.A.A., (2012), Using GIS and statistical methods to detect the multi-decadal variability for temperature trends on Egypt: 1960-2000, *GeographiaTechnica*, **1**, 46-60.

Nistor M.M., Ronchetti F., Corsini A., Cervi F., Borgatti L., Errigo D., Marcaccio M., (2014), *Vulnerability of groundwater in fractured aquifers, under climate and land use change in Northern Apennines*, National Meeting on Hydrogeology, Abstract volume Flowpath 2014, Viterbo June 18-20, 152-153.

Öztürk M., Copty N.K., Saysel A.K., (2013), Modeling the impact of land use change on the hydrology of a rural watershed, *Journal of Hydrology*, **497**, 97–109.

Park Y.J., Lee K.K., Kim J.M., (2001), Effects of highly permeable geological discontinuities upon groundwater productivity and well yield, *Mathematical Geology*, **32**, 605–618.

Parmesan C., Yohe G., (2003), A globally coherent fingerprint of climate change impacts across natural systems, *Nature*, **421**, 37-42.

Piacentini D., Zavatti A., (1994), *Studi sulla vulnerability degli acquiferi,* vol. 6, L'Appennino Modenese, Pitagora Publisher, Bologna.

Prăvălie R., Sîrodoev I., Patriche, C.V., Bandoc, G., Peptenatu D., (2014a), The analysis of the relationship between climatic water deficit and corn agricultural productivity in the Dobrogea Plateau, *Carpathian Journal of Earth and Environmental Sciences*, **9**, 201 – 214.

Prăvălie R., Sîrodoev I., Peptenatu D., (2014b), Detecting climate change effects on forest ecosystems in Southwestern Romania using Landsat TM NDVI data, *Journal of Geographical Sciences*, **24**, 815-832.

Pochon A., Tripet J.P., Kozel R., Meylan B., Sinreich M., Zwahlen F., (2008), Groundwater protection in fractured media: A vulnerability-based approach for delineating protection zones in Switzerland, *Hydrogeology Journal*, **16**, 1267-1281.

Raup B., Kääb A., Kargel J.S., Bishop M.P., Hamilton G., Lee E., Paul F., et al., (2007), Remote sensing and GIS technology in the Global Land Ice Measurements from Space (GLIMS) Project, *Computers & Geosciences*, **33**, 104–125.

Santos R.M.B., Sanches Fernandes L.F., Moura J.P., Pereira M.G., Pacheco F.A.L., (2014), The impact of climate change, human interference, scale and modeling uncertainties on the estimation of aquifer properties and river flow components, *Journal of Hydrology*, **519**, 1297–1314.

Sliva L., Williams D.D., (2001), Buffer zone versus whole catchment approaches to studying land use impact on river water quality, *Water Resources*, **35**, 3462-3472.

Srivastava P.K., Singh S.K., Gupta M., Thakur J.K., Mukherjee S., (2013), modeling impact of land use change trajectories on groundwater quality using remote sensing and GIS, *Environmental Engineering and Management Journal*, **12**, 2343-2355.

Stempvoort D.V., Ewert L., Wassenaar L., (1993), Aquifers vulnerability index: a GIS – compatible method for groundwater vulnerability mapping, *Canadian Water Resources Journal/Revue canadienne des ressources hydriques*, **18**, 25-37.

Thornthwaite C.W., (1948), An approach toward a rational classification of climate, *Geographical Review*, **38**, 55–94.

Wang X., (2001), Integrating water-quality management and land-use planning in a watershed context, *Journal of Environmental Management*, **61**, 25-36.

Wilson D.J., Smith B.K., Gibson J.K., Choe B.K., Gaba B.C., Voelz J.T., (1999), Accuracy of digitization using automated and manual methods, *Journal of the American Physical Therapy Association*, **79**, 558-566.

Wochna A., Lange K., Urbanski J., (2011), The influence of land cover change during sixty years on non point source phosphorus loads to Gulf of Gdansk, *Journal of Coastal Research*, **64**, 1820 – 1824.

Yan B., Fang N.F., Zhang P.C., Shi Z.H., (2013), Impacts of land use change on watershed streamflow and sediment yield: An assessment using hydrologic modelling and partial least squares regression, *Journal of Hydrology*, **484**, 26–37.