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COMPARISON OF SIMULATION MODELS OF WATER EROSION USING GIS

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Abstract

This paper presents the outcomes of a research on water erosion quantification by GIS-based mathematical stimulation and modelling, carried out in a water catchment area from Romania. This paper presents the outcomes of a research carried out in a water catchment area with high slopes, where intense processes of water erosion emerge. The researchers in this field successfully use two models. The first one is USLE, within GIS Geo-Graph software and the second one is WEEP; the simulation was done in a GIS ArcView environment. The simulation and application of simulation models take place in the same water catchment area (perimeter), under the same conditions and within the same range imposed by each model. This paper contains an analysis of the outcomes and concludes on the visible differences. The USLE model stalling was done by direct measurements in the bordering area of a reservoir, where the silt depositions were measured. As a follow-up to this project, the WEEP model will also be stalled in the water catchment area subjected to study, by using aerophotograms and field data.

Key words: *comparison, GIS, modelling, water erosion.*

INTRODUCTION

At worldwide level, erosion represents one of the most important challenges humankind is facing, vital for the progress and economic stability thereof, for the environment. Out of the overall reserves of fertile soil (approx. 350 billion tons), 2.32 billion tons are eroded; at this pace, the soil reserves might become depleted in approx. 150 years (according to Word Watch Institute, USA, 1990). In Romania, this degradation process (pollution, in the modern ecological sense), covers approximately half (47 %) of the agricultural land of the country, i.e. approx. 7 million ha (Berghoff et al., 2014; Dumitrescu et al., 2014).
All watercourses of the country are characterized by erosion and by a significant transport of alluvial materials generated by both the erosion of land from the reception basins and erosion of water beds and banks (Clinciu et al., 2010; Nistor et al., 2010).
In average, approximately 1550 kg/s of bed loads flow throughout Romania, representing a quantity of 48.9 million t/year, namely an average specific flow of 2.06 t/ha, an extremely high value (Iacobescu et al., 2012; Ionita et al., 2014; Popita et al.,2014; Irimus et al., 2017).
The number of torrential beds, mostly degraded, amounts to approx. 2800, and the average annual transport of alluvial deposits is of 18.3 million m^3, out of which 58% originate from versants and 42% from beds (Biali et al., 2018; Biali et al., 2019; Bilasco et al., 2018; Chendes et al., 2011; Niacsu et al., 2012).
The negative impact of erosion and torrentiality is significant for Romania, in particular on agriculture (due to continuous decrease of soil fertility), on the hydrographic network (due to water beds and storage reservoirs silting), on the communication networks, localities located at versants basis and on the environment (due to pollution, degradation of the microclimate, damages on the landscape, of people living conditions, depopulation), (Biali et al., 2018; Niacsu et al., 2015; Williams et al., 1990).
In this context, the implementation of the Geographic Information Systems (GIS) for the above-mentioned purpose, in our country, is required and justified not only by economic reasons, but also by the safety and celerity ensured by the provision of required information "in real time" (Moore et al., 1992).

MATERIALS AND METHODS

The research of the present paper work was made in several experimental perimeters of the Ghilavesti Inferior hydrographic basin. It belongs to the upper water catchment area of the river

Berheci, in the Unit called Colinele Tutovei, and it is located in the Eastern part of Romania, in Bacau county (Figure 1). The experimental perimeters are located in the lower basin on the left slope at about 1.5 km south of Antohesti catchment). The land, private property, has an area of 9.2 ha and was initially made up of 10 rectangular parcels with width of 20-30 m oriented in the uphill-downhill. The general slope is 14% and the altitude is between 164 m and 210 m. The land studied has been to anti-erosion works by carrying out a number of six terraces. The seven strips oriented in the direction of the level curves have an average width of 40 m and a length of about 340 m except the gussets located at the uphill and downhill extremities of the polygon.

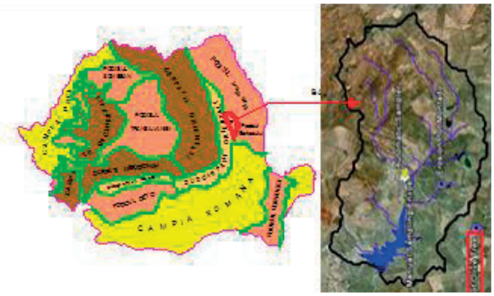


Figure 1. Location of the study area

The two mathematical models used in the project are: ROMSEM (by USLE) and WEEP.

The model USLE (Universal Soil Loss Equation) (Wischmeier et al., 1978) was developed by applying statistical methods on data obtained by experimental measurements and indicates the potential areas subjected to erosion with precision.

The USLE methodology was adapted to the Romanian soil and climatic conditions by the team of researchers of the Institute of Pedology and Agrochemical Researches in Bucharest. Thus, in 1979, Acad. Motoc M. et al. have developed the ROMSEM model (Romanian Soil Erosion Model), using the experimental data obtained at the several research stations in the country (Perieni - Vaslui county, Aldeni-Buzau county, Balcesti - Arges county, Valea Calugareasca-Prahova county and Campia Turzii - Cluj county). This model was reconfirmed in 2002 (Motoc et al., 2002). The estimated annual soil loss is based on the following equation (1):

$$E = K \cdot S \cdot L^{m} \cdot i^{n} \cdot C \cdot C_{S} \qquad (1)$$

where:

E - the average annual rate of the surface erosion (t $ha^{-1}yr^{-1}$);

K - the rainfall erosivity factor, evaluated based on the rainfall aggressiveness, obtained as a result of $H \cdot I_{15}$ (H- the amount of precipitation fallen during the entire rain event, I_{15}- the intensity of the torrential nucleus lasting 15 minutes);

S - the soil erodibility coefficient;

L^m - the slope length factor; it is determined using a function, where m = 0.3 for the straight slopes, m = 1.2 for the convex slopes and for the slopes with concave profile m = 0.6;

i^n - where i represents the slope angle (%) and n = 1.4;

C - the cover management factor;

C_s - the correction coefficient for the effect of the erosion control measurements.

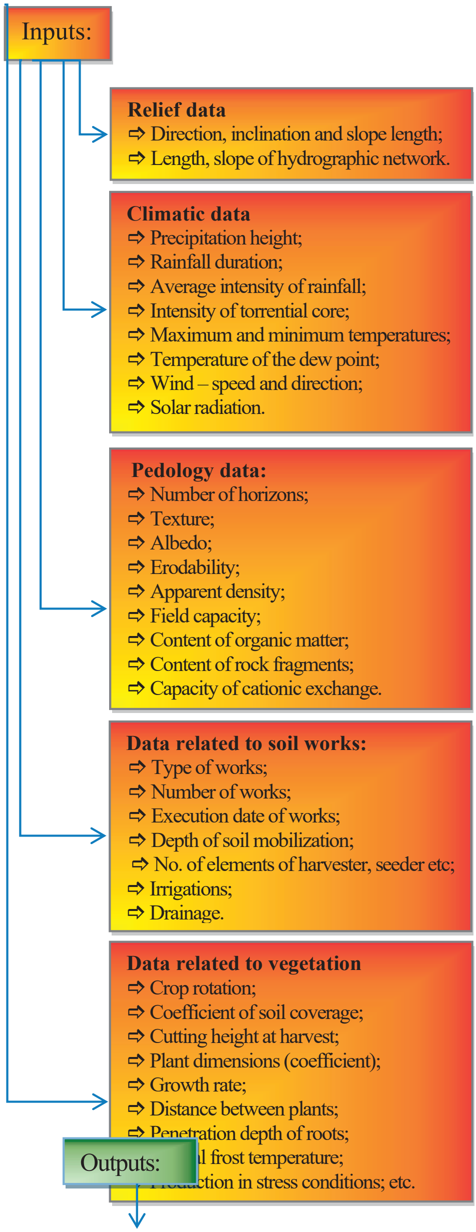
The spectacular progress that IT recorded in the last years obviously influenced the performances of the new simulation models of soil erosion.

The modern computer technology, with an inconceivable data storage capacity a few years ago, favored the emergence of new generation of models with an incomparable higher complexity than the previous one. These were made by the concerted effort of some groups of researchers specialized in various field such as mathematics, hydraulic, geology, agriculture, meteorology etc.

The American model Water Erosion Prediction Project - WEPP is perhaps the most representative case. The first version was launched in 1989 after which, about once a year, new improved version followed. During 1990-1994, the Soil Preservation Service of the USA created a friendly user interface in order to significantly ease the insertion of data related to relief, soil and agricultural works.

WEPP is the acronym of Water Erosion Prediction Project; it is based on processes and includes modules for infiltration, drainage, daily water balance sheet, torrential rain intensity, change of soil erodibility, plant growth. WEPP proved an efficient tool in modelling the erosion rate for a large range of climatic and other type of conditions, making it appropriate for approaching the impact of climate changes on soil erosion.

The model was subjected to many tests and compared to the observed data and the Universal Soil Loss Equation, proving satisfactory in most of the cases.
The main input/output data of the WEPP model are present in Figure 2:



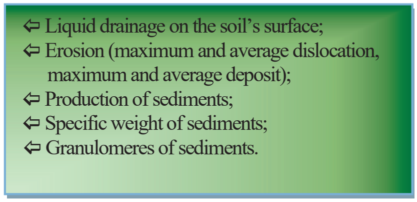


Figure 2. The main input/output parameters of the WEPP model

The effective simulation models of soil erosion, among which WEPP, are designed to work efficiently with GIS (Cochrane et al., 1999). They can use jointly the databases related to: relief, soils, vegetation, anti-erosion works etc. Finally, the capitalization of information obtained by modelling is considerably improved.
WEPP represents an important step forward in the attempt to offer new anti-erosion solutions and to prefigure the impact that such measures will have on the environment. Compared to previous models which, in fact, carried out a statistical analysis on a limited number of data, WEPP is based on process analysis. The most significant advantage consists in the ability of spatial and temporal estimation of soil and water losses on slopes used for agriculture (Burrough et al., 1988; Renard et al., 1996).
The importance of the GIS techniques integration to quantify the surface erosion risk is determined by the speed of the performing operations, the accuracy of the results and the possibility of their spatial representation. The database used for estimating the annual rate of surface erosion based on the ROMSEM model was consisting of the Digital Elevation Model (DEM), with 10 m resolution, the soil map (with information about the type, texture, structure and degree of soil erosion), the land use map, based on Corine Land Cover 2000 and corrected according to the 2005 orthophotos with a 0.5 or 1.0 m resolution, the rainfall erosivity index map in Romania and information about the distribution of soil erosion (Biali et al., 2018).

RESULTS AND DISCUSSIONS

The mathematical model used in order to determine the soil loss is based on ROMSEM model (Romanian Soil Model - Motoc M., 1983). Due to the fact that the “landscape” factor has a significant weight in the erosion process for gradient areas, the development of the Numerical Land Model (MNT) represented an important step within GIS project, and generated three information layers included in the computation algorithm of erosion-related soil loss.

The Numerical Land Model was obtained by means of interpolation, based on weighted average method for local interpolation (Biali et al., 2018; Haidu et al., 2012)

Based on the map with level curves, the obtained Numerical Land Model (MNT) provided fundamental layers for the GIS project (Biali et al., 2014), such as: Layer 1 - Hypsometric map (Figure 3); Layer 2 - Flowing direction map (Figure 4); Layer 3 - Gradient map (Figure 5); Layer 4 - Flowing length map.

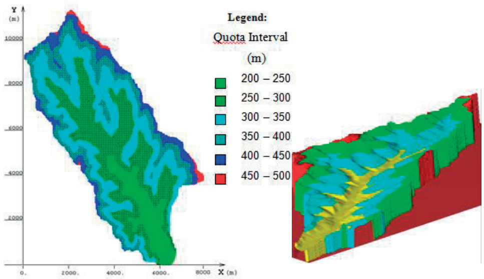


Figure 3. Hypsometric map of b.h. Antohesti. Spatial distribution of average pixel quota (Layer 1) and Digital Terrain Model (DTM) in 3D format

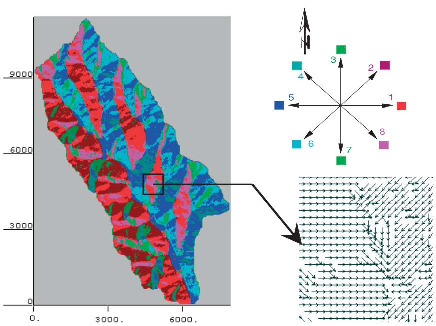


Figure 4. Map of versant exhibition - flowing direction in b.h. Antohesti (Layer 2)

Under the GIS GEO-GRAPH project, the geo-referential data is represented as layers, which facilitates the analysis of space variables and distribution of entities on the reviewed surfaces, and the overall analysis of the acquired information, which implies the concomitant approach of several layers, was performed through the so-called “overlay” technique. The “overlay” technique is based on overlaying or combination operations of several layers (based on specific algorithms – determined by the user), which generates new layers and data and attributes, respectively. These operations may be algebraical, logical, topological etc. and have graphic and non-graphic effects.

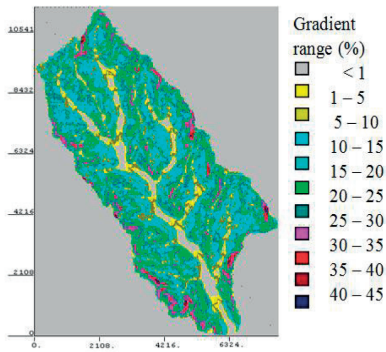


Figure 5. Gradient map (Layer 3)

Based on the status layouts of uses on versants and soil, the spatial topology methods generated the following information layers:
Layer 5 - Versant coverage and agricultural management; Layer 6 - Soil erodibility factor; Layer 7 - Effect of soil protection and preservation actions and works (Figure 6).

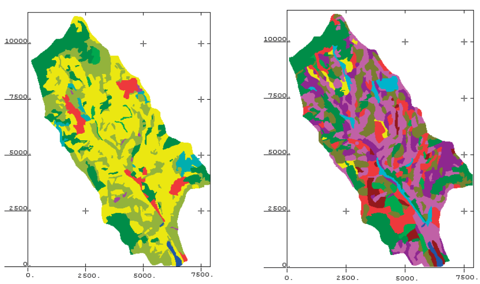


Figure 6. Versant coverage (factor C -Layer 5) and Soil erodibility (factor S-Layer 6)

By integrating the above mentioned seven layers in ROMSEN equation, under GIS Geo-Graph software, we obtained the information layer of the erosion risk - Layer 8 (Figure 7).

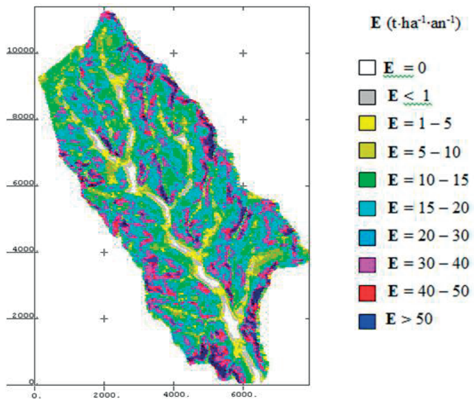


Figure 7. Soil loss due to water erosion in b.h. Antohesti (erosion risk - Layer 8)

For the WEPP model, the simulation results were compared with the data obtained by direct measurements made in the perimeters from hydrographic basin and the liquid and solid drainage was monitored.

About data assimilation we mention that all input data are examined in Table 1. For the WEPP model, we underline that 73% of their total are classified in the category of parameters obtained by direct measurements made in experimental fields. The remaining 16% were assimilated based on US data after the identification of some similarities with the climate and soils of Berheci (Table 1).

Table 1. WEPP input data and data assimilation

Crt. No.	Input data	Measured data	Assimilated	Total
1	Climate	19	1	20
2	Relief	5	0	5
3	Vegetation	13	8	21
4	Soil	14	4	18
5	Mechanical works	4	7	11
	Total	55 (73%)	20 (27%)	75 (100%)

In the future, it is estimated that the share of local data will increase considerably. This will be done in the following ways: by automatic equipment of monitoring climate parameters, equipment of analysis in the field and laboratory of physical-chemical features of the soil, introduction and generalization of the geographic informational system (GIS), access to profile database of Romania.

Talking about simulation results of the WEPP model, the studies related to liquid and solid drainage (with the help of researchers from at Perieni Station) are long term studies.

The drained water was measured by the volumetric method using settling tanks with flow meters of simple divisors type without lateral contraction. The quantity of eroded soil was estimated by measuring the average turbidity of the water from the collection basins. The parcels were planted with wheat, corn and the control sample was considered the strip maintained as permanent black fallow.

Table 2 shows the results of the statistical-mathematical processing of the value measured and simulated. The data analysis was made for each crop. The linear regression equations for the liquid and solid drainages measured on standard and simulated parcels with the WEPP program for 2015-2018.

Table 2. Statistical-mathematical processing of the value measured and simulated

Crop	Erosional drainage	No. of elements	Correlation coefficient R	Equation of linear regression
Fallow	Liquid	49	0,796	Y = -0,125 + 0,744 X
	Solid	49	0,741	Y = 0,213 + 0,881 X
Corn	Liquid	23	0,899	Y = 0,636 + 0,825 X
	Solid	23	0,857	Y = -0,074 +0,763 X
Wheat	Liquid	19	0,347	Y = -0,232 + 0,079 X
	Solid	19	0,712	Y = 0,003 + 0,192 X

a) Liquid drainage

For fallow parcels, 49 events were recorded regarding liquid drainage. The correlation coefficient R = 0.796 shows a good connection between the series of measured values and the simulated ones and the distribution of the point cloud, as Figure 8 shows, is relatively close. Compared to the ideal case when the simulated values would be similar with those measured and the graph points would be located on the diagonal passing through the origin ($y = a+bx$; $a = 0$, $b = 1$), the regression line equation ($Y = -0.125+0.744X$) has a slight oversize of the simulated values compared to the measured ones. For corn parcels, 23 calculation elements were recorded. The correlation coefficient R = 0.899 shows a good connection between the series of measured values and the simulated ones and the regression equation Y = 0.636+825X a shows a slight undersize of the simulated values in the 0-5 l/m^2 interval and a small oversize in the 5-35 l/m^2 interval. The case is illustrated in Figure 9.

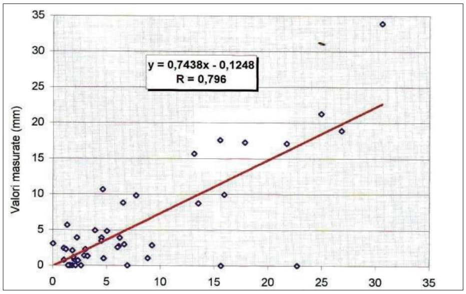


Figure 8. Liquid drainage at fallow

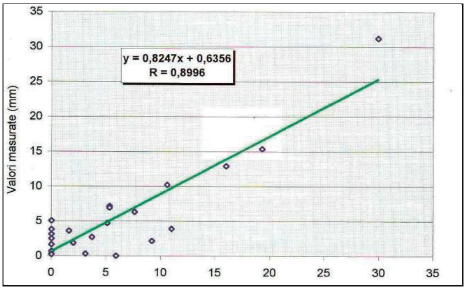


Figure 9. Liquid drainage at corn crop

b) Solid drainage

For the fallow, Figure 10 shows a more pronounced grouping of the cloud of points towards the origin of the coordinate system which indicates that, most of the times, the flows of solid drainage have small values. In more important rainfall events, the solid flows increase exponentially. The correlation coefficient (R = 0.741) a mirrors a connection between the measured and simulated values and for the 0-2 kg/m interval, the simulation results seem slightly oversized.

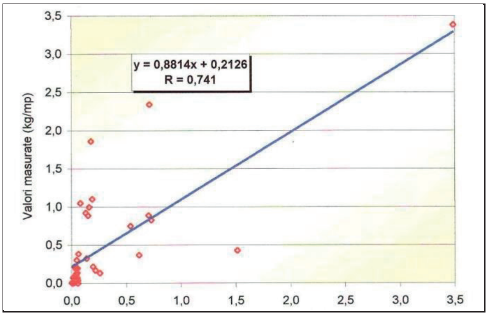


Figure 10. Solid drainage at fallow

For corn crop, most of the points plotted in Figure 11 are grouped on the 0-0.5 kg/m^2 interval and the correlation coefficient R = 0.857 shows a good connection.

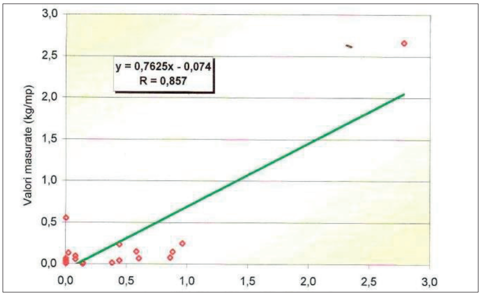


Figure 11. Solid drainage at corn crop

The analysis of this large data volume allowed some major improvements of the soil loss equation:

- Evaluation of the rain indicator of erosion in accordance with the local features of precipitations;
- Evaluation of the soil's erodibility factor;
- Evaluation of the effects of crops and anti-erosion works on the erosion;
- Evaluation of the effects of the interaction between the crop system, productivity level, soil mechanical works and the level of vegetal residues.

Modeling with WEEP showed the look of the maps similar to the result with Geo-Graph but obviously there is a different percentage, there are differences in the final maps (Figures 12, 13, 14).

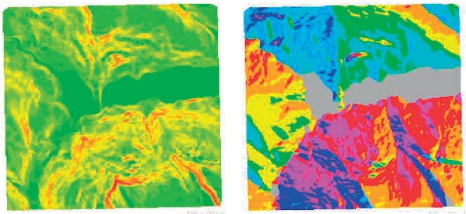


Figure 12. Slope map and aspect map

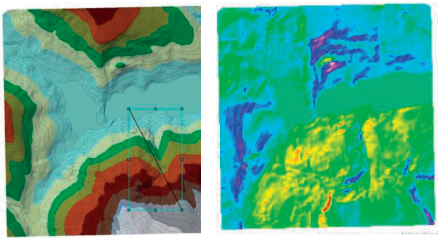


Figure 13. Hypsometric map and hills map

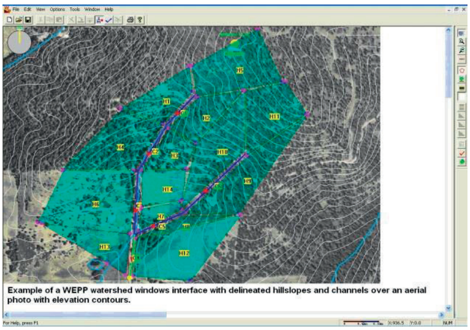


Figure 14. Example of WEPP watershed window

CONCLUSIONS

Compared to previous models, we are carrying out a statistical analysis on a limited number of data but WEPP is based on process analysis. The most significant advantage consists in the ability of temporal and spatial estimation of water and soil losses on the slopes used in agriculture. In other words, the model simulates in very much detail the entire chain of processes defining soil erosion and namely: dislocation, transportation and deposit of sediments.

An important advantage of the WEPP model is that the simulation results may be represented graphically and analytically. We may choose the graphic display of the evolution in time of parameters or the representation in cross-section of the areas with processes of sediment dislocation and deposit. Also, the data can be rendered synthetically under multiple forms of daily, monthly or annual reports.

The high complexity of the mathematical models in soil erosion at the same time represents a disadvantage due to the great number of parameters requested for input. This makes the data input procedure in a difficult activity and many times this is not easily accessible for less experienced users. In Romania, the chance of capitalizing the WEPP model or other similar models according with the projected performances is closely related by the use of GIS.

Testing the WEPP model for the natural conditions of Ghilavesti Inferior hydrographic basin rendered good and very good results. Therefore, the analysis of solid and liquid drainages for the 177 calculation elements recorded shows a close connection (R = 0.604) between the simulated and measured elements on experimental parcels. A slight oversize of the simulated values was observed.

With the help of this model, several long-term forecasts were made regarding the surface erosion and its influence on the soil productivity. The results of simulation were highlighted corresponding to the scenarios of a greater importance for agricultural practices in the conditions of Berheci catchment area.

REFERENCES

Berghoff A., Berning A., Wortmann C., Möller A., Mahro B. (2014). Comparative assessment of laboratory and field-based methods to monitor natural attenuation processes in the contaminated groundwater of a former coking plant site, *Environmental Engineering and Management Journal,* 13, 583-596.

Biali Gabriela, Patriche C.V., Pavel V.L. (2014). Application of GIS techniques for the quantification of land degradation caused by water erosion. *Environmental Engineering and Management Journal.* October 2014, Vol.13, No. 10, 2665-2673.

Biali Gabriela, Cojocaru Paula (2018). *Use of GIS technique for hydrological modeling of sheet erosion* 18th International Multidisciplinary Scientific GeoConference SGEM. Vol 18, Issue 2.3, Section Cartography and GIS, Bulgaria, 2018, pp. 705-712.

Biali Gabriela, Cojocaru Paula, Schneider Petra (2019). *Research concerning the improvement of the characteristics of soils affected by landslide*. 19th International Multidisciplinary Scientific GeoConference SGEM 2019. Section Soils, Vol. 19, Issue 3.2, pp. 341–348. ISBN 978-619-7408-82-9, ISSN 1314-2704.

Biali Gabriela, Schneider Petra (2018). *The use of GIS in the delimitation of the surface water bodies (homogeneous hydrographic basins*. 18th International Multidisciplinary Scientific GeoConference SGEM 2018. Section Cartography and GIS, Vol 18, Issue 2.3, pp. 665–672. ISBN 978-619-7408-41-6. ISSN 1314-2704.

Biali Gabriela, Cojocaru Paula, Boboc V. (2018). Modeling erosion degradation on slopes using GIS. Lucrări Ştiinţifice, Seria Horticultură, Vol. 61, nr.2, USAMV "Ion Ionescu de la Brad" Iasi ISSN–L 1454-7376 (Print)-ISSN 1454-7376 (Online) ISSN 2069-8275.

Bilasco Şt., Rosca Sanda, Pacurar I., Moldovan N., Vescan I., Fodorean I., Petrea D. (2018). Roads accesibility to agricultural crops using GIS technology methodological aproach. *Geographia Technica*, Vol 13, Issue no. 2/2018, pp. 12-30. DOI: 10.21163/GT_2018.132.02

Burrough P.A. (1988). Fuzzy mathematical methods for soil survey and land evaluation, *Journal of Soil Science*, 40, 477-482.

Chendes V. (2011). *Water resources in curvature subcarpathians. Geospatial assessments* (in Romanian), Romanian Academy Publishing House, Bucharest, 339.

Clinciu I., Petritan C., Nita M.D. (2010). Monitoring of the hydrotechnical torrent control structures: a statistical approach, *Environmental Engineering and Management Journal*, 9, 1699-1707.

Cochrane T.A., Flanagan D.C. (1999). Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models, *Journal of Soil and Water Conservation*, 54, 678-685.

Dumitrescu L., Maxineasa S.G., Simion I.M., Taranu N., Andrei R., Gavrilescu M. (2014). Evaluation of the environmental impact of road pavements from a life cycle perspective, *Environmental Engineering and Management Journal,* 13, 449-455.

Haidu I., Costea G. (2012). Remote Sensing and GIS for the forest structure assessment at the small basins level in the Apuseni Natural Park, *Studia Universitatis Babes-Bolyia Geographia*, 1, 98-112.

Iacobescu O., Barnoaia I., Bofu C. (2012). An up-to date land degradation inventory in Suceava Plateau, *Environmental Engineering and Management Journal*, 11, 1667-1677.

Ionita I., Chelaru P., Niacsu L., Butelca D., Andrei A. (2014). Landslide distribution and their recent development within the Central Moldavian Plateau of Romania. *Carpathian Journal of Earth and Environmental Sciences*, 9 (3), 241–252.

Irimus I., Rosca Sanda, Rus Madalina-Ioana, Marian Flavia Luana, Bilașco Șt. (2017). landslide susceptibility assessment in Almas basin by means of the frequency rate and GIS techniques. *Geographia Technica,* Vol 12, Issue no. 2/2017, pp. 97-109. DOI: 10.21163/GT_2017.122.09

Moore I.D., Wilson J.P. (1992). Length-slope factors for the Revised Universal Soil Loss Equation-simplified method of estimation, *Journal of Soil and Water Conservation,* 47, 423-428.

Motoc M., (2002). Average erosion rate on the territory of Romania, *ASAS Newsletter*, 12, 11-17.

Niacsu L. (2012). Geomorphologic and pedologic restrictive parameters for agricultural land in the Pereschiv catchment of Eastern Romania, *Carpathian Journal of Earth and Environmental Sciences*, 7, 25–37.

Niacsu L., Ionita I., Curea D. (2015). Optimum agricultural land use in the hilly area of Eastern Romania. Case study: Pereschiv catchment. *Carpathian Journal of Earth and Environmental Sciences,* 10 (1), 195-204.

Nistor D., Hurjui C. (2010). *Sustainable utilization of soil and water resources on sloping land*, 2nd Edition, Ed. Alfa, Iasi, 535.

Popita G.E., Varga I., Gurzau A., Bence F., Yuzhakova T., Hategan R.M., Redey A., Popovici A., Marutoiu C. (2014). Environmental impact and risk assessment in the area of "Pata Rat" landfill site, Cluj–Napoca, Romania, *Environmental Engineering and Management Journal,* 13, 435-447.

Renard K.G., Foster G.R., Weesies D.K., Yader D.C. (1996). *Predict soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*, USDA - ARS, Agricultural Handbook, 703.

Williams J., Benson V., Jones A., Duke P., (1990). *EPIC - Erosion Productivity Impact Calculator. 1 - Model Documentation. 2 - User Manual, USDA - ARS*, Technical Bulletin No.1768.

Wischmeier W.H., Smith D.D. (1978). *A universal soil loss equation to guide conservation from planning,* Transactions of the 7th International Congress of Soil Science, Wisconsin, USA 7, 418-425.