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THE ASSESSMENT OF LOTIC ECOSYSTEMS DEGRADATION USING MULTI-CRITERIA ANALYSIS AND GIS TECHNIQUES

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Abstract: Proper assessments of degradation for lotic ecosystems are of a great importance, given that they provide essential ecosystem services and host some of the most endangered habitats. Currently, one of the most frequently used ways to assess lotic ecosystems integrity is the Water Framework Directive. It implies but important investments in material and human resources, while it is also time consuming. The implementation of a set of indicators, based on available public data, with the aim of assessing the lotic ecosystems integrity could be a good alternative, especially when focusing on large territories. The current study aims at creating a methodology to assess the degradation level of lotic ecosystems, by integrating the above-mentioned indicators into a GIS based multicriteria analysis. The proposed methodology was applied on a sector of one of the most important rivers in Romania, Mureș. The results we have achieved proved the efficacy of this method. In analyses of this kind, the accuracy of the output is directly related to the quality of input data (resolution, update and generalization level), thus a key element in our research was to process and compatibilize the available data to increase accuracy.

Key words: lotic ecosystem, habitat, degradation, indicators, methodology

1. INTRODUCTION

Lotic ecosystems are very sensitive and dynamic, being considered nowadays some of the most fragile and threatened habitats worldwide (MEA - Millennium Ecosystem Assessment, 2005). The term lotic refers to flowing water, river ecosystems being the most common lotic ecosystems. Lotic ecosystems range from small springs to large rivers. Because of intensive exploitation and human interventions on the river banks, lotic ecosystems suffered many transformations such as alteration of the flow regime, dam construction, riparian habitat desiccation, water storage and use, pollution and the introduction of invasive species (Ward & Stanford, 1995; Nilsson & Berggren, 2000; Allen & Ingram, 2002). The impact of these human activities seriously compromised the geographic distribution and the diversity of biological communities and hence of the ecosystem production (Rice et al., 2006; Winder et al., 2011; Lorenzo-Lacruz et al., 2012; Heath et al., 2014). The degradation of lotic ecosystems negatively affects their physical, chemical and biological components, with far-reaching ramifications on both living communities and on the ecosystem array of services (Ghazoul et al., 2015; Flint et al., 2017). Therefore, the degradation of ecosystems in general, and of rivers and streams in particular, represents a key element in the various implementation strategies related to climate change (e.g., IPCC - The Intergovernmental Panel on Climate Change, 2007; REDD+ - Reducing emissions from deforestation and forest degradation, 2008 or biodiversity conservation CBD - Convention on Biological Diversity, 1992).

The aims of this study were to: a) develop a GIS-based procedure in order to split water courses in sectors from the perspective of their degradation, as a close reflection of negative human activities on water basins, b) to identify suitable indicators for assessing the degree of lotic ecosystems degradation, c) to integrate the indicators through a multi-criteria analysis based on GIS techniques and finally d) to test this methodology on a case study in order to validate its efficiency. The current study aims at illustrating the degree of degradation of lotic ecosystems by some specific indicators (e.g. the level of landscape anthropization, the presence/absence of major pollution sources, the catchment slopes, the land use types, soil permeability or river banks anthropic transformation). Therefore, the resulting methodology will be a suitable tool for the assessment of lotic ecosystems degradation at regional, national or larger scale, which is also fast, reliable, implying a minimum investment of material and human resources. This study was undertaken using public database like ECRINS – European Catchments and River Network System, Copernicus Land Monitoring System (Corine Land Cover 2012, EU-DEM, EU-HYDRO, etc.), European Pollutant Release and Transfer Register (European Environment Agency).

2. THE CURRENT STATE OF THE ART

The ecological functions of riparian ecosystems have been assessed in many studies starting with 70's, as awareness of different types of habitat degradation and the need to preserve them increased. Currently, riparian ecosystems are considered key habitats in strategies for nature conservation and ecological restoration (CBD - Convention on Biological Diversity, 1992). The lotic ecosystems are relatively rarely given proper attention in the scientific literature, being usually obscured by the general water basin approach. These ecosystems are usually named and treated as riparian ecosystems (Wang et al., 2015). The quality of rivers and streams is massively influenced worldwide by the way the riparian ecosystems are used. Human interventions inevitably lead to the lotic ecosystem degradation. Extremely relevant for such a scientific approach is the study of Weissteiner et al., (2016), who used to automatically delimit riparian zones at European level through an interdisciplinary and stratified approach, based on soil, hydrology, Digital Elevation Model, vegetation and land use indicators. Therefore, the output of his study was an assessment of riparian areas, based on field observations and correlated with the hydrographical network Copernicus EU - Hydro dataset.

Besides the aesthetical, recreational (Lant & Tobin, 1989; Lant & Roberts, 1990) and ecological (Hunt, 1988) values of this ecotone, another major benefit of riparian ecosystems is to ensure the water cycle balance and water natural quality (Lant & Roberts, 1990). According to Malanson (1993), the most important benefits of riparian ecosystems are flood buffering, aquifers recharge, nutrients and pollutants retention, provision of natural habitat and ensuring habitats connections for some species. The scientific literature has already largely analysed the undesirable effects produced by the alteration of these ecosystem functions, with far-reaching direct and indirect ramifications on the aquatic ecosystems. Zube & Simcox (1987) investigated the effects of intensive grazing on riparian zones and Anderson (1985) the ones produced by intensive deforestation. Malanson (1993) mentioned that the human activities mostly responsible for the degradation of riparian ecosystems are agriculture, mining activities, industry, transport, urbanization and other human works (e.g. construction of canals and dams). From the many functions of riparian ecosystems, two stand out as major drivers in maintaining the quality of adjacent aquatic ecosystems: the control of sediments/ nutrients budget and river banks erosion (Malanson, 1993). GIS techniques for modeling the geomorphology of riparian areas is discussed in Avram et al., 2012 and Boengiu et al., 2009. With respect to the control of nutrients, nowadays it is fully accepted that the riparian zones regulate the nutrient budgets in rivers, acting as a buffer in the run-offs (and hence of dissolved nutrients) from land and therefore retaining most nutrients that otherwise would end up in the river (Elmqvist et al., 1991; Mayer et al., 2006; Moore et al., 2008; Sanchez-Perez et al., 1991). Most studies envisaging this crucial function have analyzed the nutrient input in rivers as a result of agricultural activities, but equally, there were studies that underlined the key-role played by riparian zones in regulating the input of sediments, mainly from heavily deforested regions (Malanson, 1993; Vigiak et al., 2016; Volk et al., 2016) or from the pollution with substances originating from residential areas (Osborne & Wiley, 1988; Tu, 2011). As such, the assessment of human activities within water basins, localized mainly in the riparian ecotone, becomes increasingly important in the attempt to evaluate the degradation of aquatic ecosystems and to identify certain measures designed to improve their functions and to establish the buffer zones in heavily human affected areas (Bentrup, 2008; Malanson, 1993).

At European Union level, the lotic ecosystems monitoring and conservation represent critical actions within the field of environmental sciences, especially since the implementation of certain regulations, action plans and strategies on this topic (FP7 - 7th Framework Programme for Research and Technological Development, EU Biodiversity Strategy up to 2020, WFD - Water Framework Directive, 2000). The Water Framework Directive (WFD - Water Framework Directive, 2000) compels member states to survey the ecological quality of aquatic ecosystems, whilst the European Strategy for Biodiversity (EU Biodiversity Strategy up to 2020) imposes that until 2020 the ecological status of 15% of degraded ecosystems at European level must be significantly improved. Once these directives were enacted, a series of scientific projects on these topics followed, envisaging the assessment of clear criteria to classify the quality of inland water bodies and to implement working methodologies at European Union level. The WFD methodology states that the status of a water body is assessed by considering the "*poorer of its ecological status and its chemical status*" (art. 2(17) - *Water Framework Directive,* 2000). *„The ecological status is an expresion of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified according to Annex V*" (art. 2(21) - *Water Framework Directive*, (2000). It is determined based on the general biological, hidromorphological, physico-chemical and specific pollutants (synthetic and non-synthetic) water quality classes, which in turn represent the functional framework for the very existence of biological communities. In order to assess the relevant indicators of water quality as the Directive provisions, it requires several sampling campaigns, well trained specialists and complex infrastructure. As these criteria are not always met, the need for implementing a more accessible alternative arose. That is, using some indicators based only on the available public databases, comprising human pressure sources and their impact on rivers. Following this rationale, Gabriels et al., (2010) discovered that the classification in classes of ecological quality is very subjective and prone to many errors. Moreover, Moss et al., (2003) underlined the fact that such classifications are solely based on the extremely subjective opinion of an expert, if reliable criteria to classify the water bodies as having a good, moderate, bad and very bad quality are not firmly established. Other researchers claimed the key role for other ecological indicators in assessing the water quality, focusing on the adjacent areas of influence (Brucet et al., 2013). Davies and Jackson (2006) have equally advised that a crucial direction for future analyses should take into account the relationship between pressure and response, underlining therefore that the degradation assessment should be based on the presence of detrimental sources in the immediate vicinity of these ecosystems, including the sensitivity and the resilience of these habitats. Therefore, all these aspects stress that the evaluation of rivers and streams integrity status based on a methodology that expresses the cause-response relationship of these geographic areas (water body-river bank-adjacent territory) is a necessary step forward.

3. METHODOLOGY

The river network used in this analysis was based on the database EU-Hydro River Network (Copernicus Land Monitoring Service), wich has specific geospatial information (geometry, coordinates, attributes). The last set of data, published in 2016, provides a significant increase of accuracy and detail, thanks to higher image resolution, up to 2.5 m (Very High-Resolution Image Data), but equally to the increasing number of type of objects represented. In order to facilitate the integration of river network within the automation processes, it is first necessary to divide it into sectors. The result will comprise the reference units of this study on which the calculation algorithm will be applied, attributing in the end a final degradation score to each of them. The main reason for splitting water courses into sectors is based on the idea that the dilution of any tributary after the confluence with a river would change the indices for water quality in the main course, so we considered the confluence points (the joining of tributaries with the parent river) as reliable for this division. In order for this process to be suitable, the discharge of both rivers must be comparable, therefore the splitting of different sectors is undertaken only on the confluence points with tributaries of similar order (e.g. a third order stream receives a tributary of the same order and the division will be applied for both of them) or maximum 3 orders smaller (e.g. a fifth order stream will be divided at the confluence points by its tributaries of fourth to second order, but not with one of first order).

Given that the scientific literature revealed that up to 90% of the most important processes in riparian zone takes place within the first 50 m of the river stretch (Siligardi, 2007; Siligardi & Maiolini, 1990; Siligardi & Maiolini, 1993), buffer zones of 50 m width situated on both sides of the river banks were delineated as territories to apply the present methodology. In particular, a more specific delimitation criteria were implemented for the most relevant type of rivers (beginning with third order streams, *sensu* Horton - Strahler) a European geospatial database for riparian zones being available (Copernicus Initial Operations, 2011-2013).

The riparian zones for the river network of at least third order together with above mentioned buffer zones (for the rest of the national hydrographical network) were divided based on the same principle as that applied to river networks. This way, we obtained the areas to be analyzed (Fig. 1), meaning the reference areas used to extract the parameters that were afterwards used to assess the degradation of river networks.

3.1. Indicators to assess the level of degradation of lotic ecosystems

For a complex analysis of river networks and assessement of their degradation, 12 relevant indicators were used, being grouped in four categories, as seen in table 1:

A. Indicators of the human pressure on riparian areas (7): the level of general anthropization, vegetation characteristics in riparian territories, the relationship with human settlements, the presence of sewage treatment plants associated with human settlements, the presence of major pollution sources, the proximity to roads and the presence of natural protected areas.

The anthropization (urbanisation being the most important form of land transformation) is considered a process with major negative effects on aquatic ecosystems (Shukla et al., 2013; Elmqvist et al., 2013, MEA - Millennium Ecosystem Assessment, 2005;

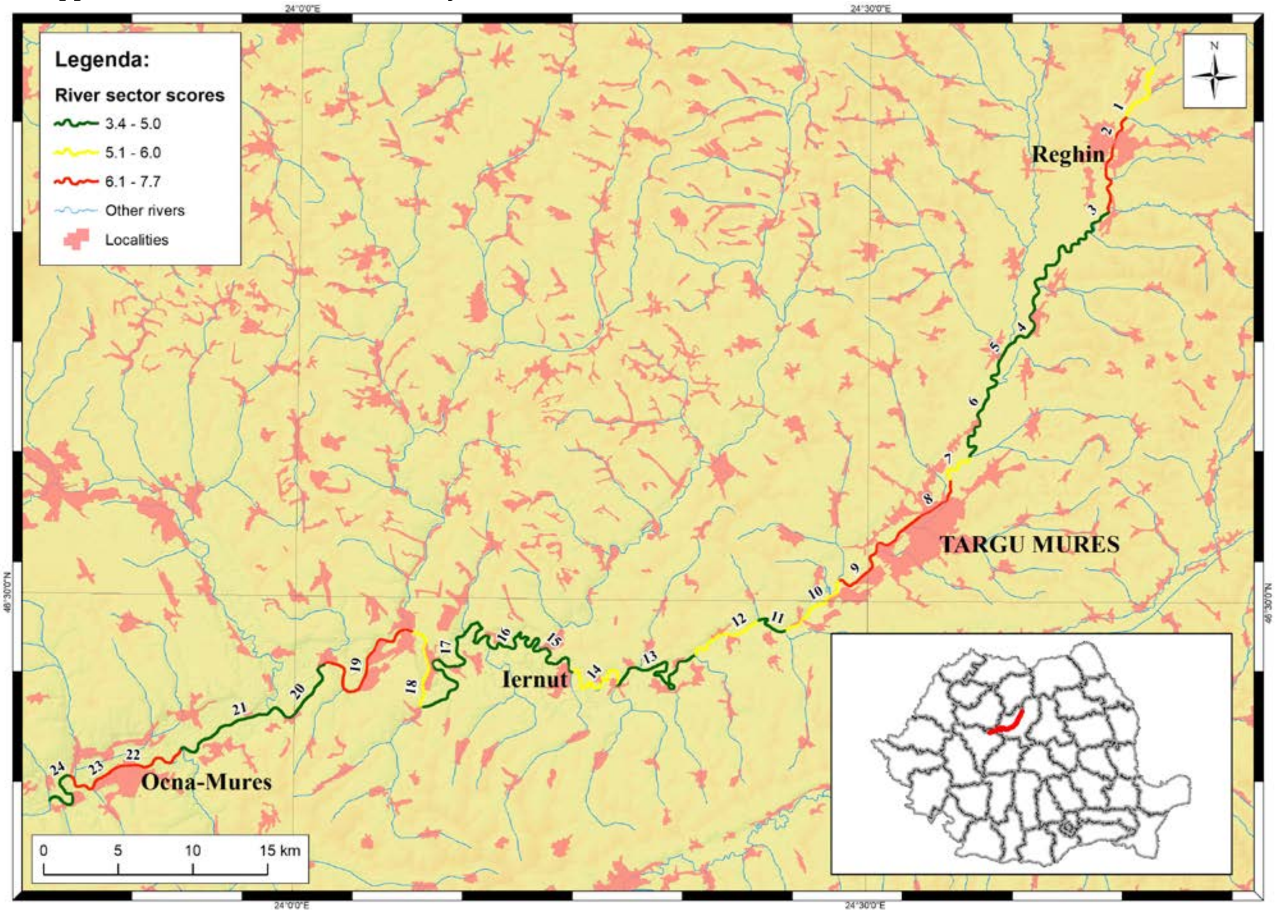

Figure 1. Degradation scores of the analysed river sectors (*labelling numbers represent the segment ID corresponding with table 4)

IPCC - Intergovernmental Panel on Climate Change, 2007; Grimm et al., 2008; Marinescu et al., 2012), disrupting the water cycle by eradicating vegetation with a crucial role in buffering lateral run-offs, intensifying of soil erosion and increasing water turbidity, the increasing of impermeable surfaces, the intensifying of watercourse pollution by blocking the self-cleaning capacity normally assured by vegetation and soil, increasing pollution phenomena etc. The presence of agricultural lands implies the degradation of rivers, extremely cumbersome when it comes to fertilisers and pesticides (Cherry et al., 2008; Withers et al., 2014, McKenzie & Williams, 2015). Reducing the vegetation surface, the degradation of vegetation, changes in species distribution disrupts the normal functionality of ecosystems (Gurnell, 2014). The buffer zones created by riparian vegetation between the river and adjacent areas is beneficial for the aquatic ecosystems by reducing the nitrogen and phosphorous loads and biodiversity conservation, to name only a few (Klatt et al., 2017).

Industrial units are considered factors exerting high pressure on aquatic ecosystems, directly, as it is the case of hydroenergetic industry and indirectly, as in the case of chemical pollution (Dyson et al., 2003; Melnyk et al., 2014). Airborne suspended particles (particulate matter) generated by traffic can contain cadmium, lead, zinc, substances extremely dangerous for the aquatic environment (Shorshani et al., 2014). The influence of the natural protected areas on the quality of water bodies is discussed in Niculae et al., 2014.

B. Indicators for substrate in envisaged riparian areas (2): slope (in order to express the intensity of surface water runoff from adjacent territory to rivers and streams - a higher slope indicates a higher pressure on the river) and the soil permeability (a complementary indicator for the slope for deriving the runoff, but adding supplementary information such as the soil capacity to retain pollutants);

C. Indicators associated to rivers (2): the human interventions in the river banks expressed as presence/absence of impoundments, dams and other hydrotechnical works (The impoundments limit the capacity of running waters to create adjacent areas, functionally important, such as to overcome floods overflow, to filter surface waters or as reproduction sites for several aquatic species) and the ecological status of water bodies (A synthesis of hydromorphological, chemical, physico-chemical and biological status of streams and rivers available in Annex 5 - 2000/60/CE - Water Framework Directive (2000));

D. Indicators of morphological complexity of watercourses (1): the river sinuosity, comprising the ratio between the length of a rivers sector to the straight line between the point of start and the end of that sector; sinuosity reflects the morphological complexity of river banks (meandering status, reflected in the alternation between deposition and erosion sectors), important factor in revealing the diversity of river ecosystems.

These indicators have been analysed in detail in Avram et al. (2018). The reason for choosing them resides in their contribution towards showing the level of ecosystem degradation for riparian designated areas.

3.2. The calculation of indicators of degradation level of lotic ecosystems

Using the aforementioned twelve indicators, a complex metric was used to calculate a value for indicating the relative level of rivers degradation (the higher the value, the less affected the watercourse by human pressure). The metric was based on the idea of river functionality, the most relevant indices to show that being used from the current databases open to public. The indicators' values were calculated for each river sector. As we mentioned when presenting the methodology, where riparian zones were not already delineated in existing databases, areas with a width of 100 m (50 m on each side of the river bank) were analysed with the aid of *Create Buffer* function in ArcGIS. The buffer was created by selecting *EndType,* characteristic *Flat,* in such a way that the adjacent sector buffer ends do not overlap. By proximity analysis, the elements of the study area were evaluated and recorded in specific data layers (the numbers correspond to tables 1 and 4): land use (A1), riparian vegetation (A2), special protected areas (A7), proximity to roads (A6) and the presence/absence of certain parameters in the study area (human settlements of various sizes - A3 -, the proximity of sewage treatment plants to human settlements - A4 -, major sources of pollution - A5- , human interventions in the river banks - C1 -). The resulting data was used to rank all river sectors by the chosen indicators (Table 1) and the values were afterwards summed up with the aid of multi-criteria analysis. The sinuosity (D1) of each river stretch was calculated using the extension ArcHydro, the slope (B1) was derived from the altitude model of the terrain and the soil permeability (B2) was based on different types of soil textures situated in the analysed areas. The ecological status of water bodies (C2) was derived from the official data available at "Romanian Waters" National Administration. The databases we used for creating those layers were as follows: a)

Corine Land Cover 2012 and Copernicus Land Monitoring System for delineation of riparian zones, b) land use categories within riparian zones or human settlements, c) National Institute of Statistics for the population of human settlements, d) Urban Waste Water Treatment Agglomeration (European Environment Agency) for sewage treatment plants, e) European Pollutant Release and Transfer Register (E-PRTR) (EEA) for pollution sources, f) Open Street Map for the transportation network, g) European Environment Agency and Romanian Ministry of Environment for the limits of IUCN and Natura 2000 protected areas, h) EU-DEM and Copernicus Land Monitoring System for the slope map, i) Pedological maps of Romania, scale 1:200.000, realised by ICPA, for soil textures map, j) ECRINS (EEA) and *Geospatial.org* for the presence of impoundments and dams on rivers, k) National Management Plans ("Romanian Waters" National Administration) for the ecological state of water bodies and l) Copernicus Land Monitoring System – EU Hydro for calculating sinuosity.

Given the spatial characteristics of the analysed criteria, some of them were calculated directly for each river segment, whereas others were derived from the proximity of the former. Therefore, after obtaining all values, the data was transferred as attributes of lines representing the watercourse. The function *Spatial Join* was used, with the option *Join_one_to_one* (to each river sector corresponds only one riparian/ buffer zone) and the spatial function *Within* (each river sector is situated entirely within the riparian / buffer zone).

Table 1. Indicators used for lotic ecosystem classification in quality classes.

Criteria	Value	
	Interval	Mark
A – Indicators of the human pressure on riparian areas		
A1. The anthropization of the adjacent territory of a watercourse		
A1a. Anthropic areas, with a high impact on river degradation (e.g., dense urban areas, exploitation areas, industrial areas)	0 - 5 % 5 - 10 % 10 - 30 % 30 - 50 % > 50 %	1 2 3 4 5
A1b. Anthropic areas with an average impact on watercourse degradation (e.g., urban zones with reduced density, irrigated agricultural fields)	0 – 10 % 10 – 25 % 25 – 50 % 50 – 75 % > 75 %	1 2 3 4 5
A1c. Anthropic areas with low impact on watercourse degradation (e.g., barren agricultural lands, orchards, vineyards, vegetation influenced by man)	0 – 20 % 20 - 40 % 40 – 60 % 60 – 80 % > 80 %	1 2 3 4 5
A2. Vegetation cover in riparian areas	0 – 10 % 10 – 25 % 25 – 50 % 50 – 75 % > 75 %	5 4 3 2 1
A3. Relationship with human settlements - *settlements with a population are envisaged >10.000 (Council Directive 91/271/EE)*	Does not overlap Overlaps with cities with a population < 10.000 inh. Overlaps with cities with a population btw. 10.000-150.000 inh. Overlaps with cities with a population > 150.000 inh.	0 1 3 5
A4. The presence of sewage treatment plants in relation to human settlements	No treatment plants, but human settlements Primary processing of sewage, with human settlements Secondary processing of sewage, with human settlements Tertiary processing of sewage, with human settlements No treatment plants, no human settlements	5 4 3 2 1
A5. The presence of major pollution sources (industrial, dairy farms, wastelands, mining exploitation)	Presence Absence	5 0
A6. The length of transport network (intervals and marks allotted for each of the following categories)		

A6a. Highways and European roads A6b. National and regional roads A6c. Local roads	Depending on the values recorded by indicators at national level (Natural breaks categories in ArcGIS) Do not overlap	1-5 0
A7. Natural protected areas	Does not overlap or < 10 % 10 – 25 % 25 – 50 % 50 – 75 % > 75 %	5 4 3 2 1
B – Indicators of substrate of the land adjacent to the watercourse		
B1. Slope (correction coefficient) *(slope categories after Florea et al., 1987)*	< 5 degrees 5.1° – 10° 10.1° – 25° 25.1° – 50° > 50°	1 1.1 1.2 1.3 1.4
B2. Soil permeability (correction coefficient)	Coarse texture Average texture Fine texture	0.7 0.8 0.9
C – Indicators associated with rivers		
C1. The human interventions in the river banks	Impoundments present < 30 % of river sector Impoundments present between 30 - 60 % of river sector Impoundments present > 60 % river sector No impoundments	1 3 5 0
C2. Ecological status of water bodies	I II III IV V	1 2 3 4 5
D – Indicators of morphological complexity of water courses		
D1. Sinuosity (correction coefficient) (categories after Brierley & Fryirs, 2005, p. 119)	1 - 1.05 1.06 – 1.30 1.31 – 3.0	1.2 1.1 1

3.3. The aggregation through multi-criteria analysis

The multi-criteria analysis represents an evaluation method used for the classification of a set of objects (in this case the river sectors) based on several indicators. It proves especially adequate when using it for assessing the progress recorded in the implementation of certain objectives (Munier, 2014). All multi-criteria analyses follow a common procedure: (a) definition of objects that must be ranked (i.e. river sectors and their adjacent areas), (b) identification of the criteria that will be used to calculate the final output (first column in Table 1), (c) designation of indicators' relative importance – criteria weights - (Tables 2 and 3), (d) values normalization – classification and conversion into marks (according to Table 1, column 2 – values' classes – and column 3 – assigned marks -) and (e) final output (Convertino et al., 2013, Iojă et al., 2014, Onose et al., 2015) (Fig. 2).

In order to establish the share of each indicator to an integrated result (i.e. to decide how important is to indicate the rivers' degradation in relation to others), the pairwise comparison was applied. That means that all the indicators used as criteria for classification were compared two by two by all the authors of the paper, in the case of the categories A (one comparison) and C (another similar comparison). A scale from 1 to 9 of relative importance of each pair of indicators was used, 1 meaning that both indicators are equally important for showing rivers degradation and 9 suggesting that one criterion is definitively more important than its pair. The result of multiplying the paired indicators should be always 1, so if one is noted with 1, then its pair should be noted with 1/1, if one is noted with 2, its pair should be noted with ½ and so on. For the categories B and D, this procedure is not needed, thus not being applied, these indicators (slope, soil permeability, river sinuosity) being used just as correction factors, diminishing or increasing the effects of those in categories A and C. After assessing the relative importance for each pair of indicators, for each indicator a geometric mean is calculated on the assigned notes in order to diminish the initial differences between values; then, the so obtained geometric mean is used in the calculation of the final score as percentage from the sum of geometric means for all indicators, in each category (A and C). In this way, two independent multi-criteria analyses were undertaken - one for the category A of indicators - Indicators of the human pressure on riparian areas and one for category C - Indicators associated with rivers (with results in Tables 2 and 3). For the criteria for which the indicator was split into subcategories (criteria 1 and 6), a second multi-criteria analysis was undertaken, similar to the aforementioned ones, in order to assess the weight of these indicators in the final calculation rank.

After setting the weights of each indicator (i.e. the abovedescribed percentages), the correction indicators in categories B and D were used to multiply the weights.

The calculated values of all indicators that define the criteria categories A and C were classified as shown in table 1, column Interval, then transformed into marks using a standard scale ranging from 0-5 (the column Mark in Table 1). The partial score for each indicator for each river sector was obtained by multiplying its weight by its 0-5 value (e.g. columns 2-12 in Table 4 for criteria in A category and 15-16 for criteria in C). For criteria categories B and D, the calculated value was transformed into a correction coefficient that ranges from 1 (reduced transfer) to 1.4 (increased transfer) in the case of slope, from 0.7 (reduced transfer) to 0.9 (increased transfer) in case of soil and from 1 (more complex river channel) to 1.2 (less complex river channel) in case of sinuosity. The correction coefficients corresponding to category B were used to correct the partial scores (by multiplication) of indicators A1, A2, A3, A5, and A6 from category A (the values of indicators A4 and A7 were not corrected as they are not influenced by slope and soil permeability) and the criterion from category D for the correction of the indicator's partial score in category C.

The specific score of each river segment was obtained by summing the corrected scores of indicators A1, A2, A3, A5 and A6 from category A (column 19 in Table 4) with the corrected scores for indicators C1 and C2 from category C (column 21 in Table 4) and the uncorrected scores of indicators A4 and A7 from category A. The final scores for each river sector mirrors in this way the degradation level of the lotic ecosystem. The lower the value, the closer to a natural, unaltered state the river sector is.

4. RESULTS

In order to apply and test the proposed methodology, we have chosen as a case study a segment of the Mureș River, from Reghin to Ocna Mureș. 24 river sectors resulted through the segmentation process, further used in the segmentation of the riparian zones. The calculation algorithm described in section 1.3 of the present study generated the values used to rank each sector, as shown in Table 1. The marks assigned, as well as their aggregation into a final score, are listed in Table 4 for some relevant sectors, for illustrative purposes. The values of the final scores have no significance as absolute values, they should be interpreted only in relation to one another. Thus, the higher the score, the more degraded the lotic ecosystem is. To allow a visual representation of results and to facilitate results' interpretation, final scores values were grouped arbitrarily into three categories considering the major gaps within the distribution of the calculated values and a balanced grouping into categories (Fig. 1). Thus, the thresholds were set to values 5 and 6, with 12 sectors in the first category, 6 in the second and 6 in the third. The extreme scores obtained were 3.4 and 7.7. This categorization has no other relevance except offering a visual overview of the degradation state along the analyzed river.

Table 2. The weights of indicators used in the multi-criteria analysis for indicators in category A - Indicators of the human pressure on riparian areas.

No.	Indicator	Weight
A1	The anthropization of the adjacent territory of a watercourse	0.338982
A2	Vegetation cover in riparian areas	0.121906
A3	Relationship with human settlements	0.133307
A4	The presence of sewage treatment plants in relation to human settlements	0.134022
A5	The presence of major pollution sources	0.207464
A6	The length of transport network	0.035873
A7	Natural protected areas	0.028446

Table 3. The weights of indicators used in the multi-criteria analysis for category C of indicators – Indicators associated with rivers.

No.	Indicator	Weight
C1	The human interventions in the river banks	0.248
C2	The ecological status of water bodies	0.752

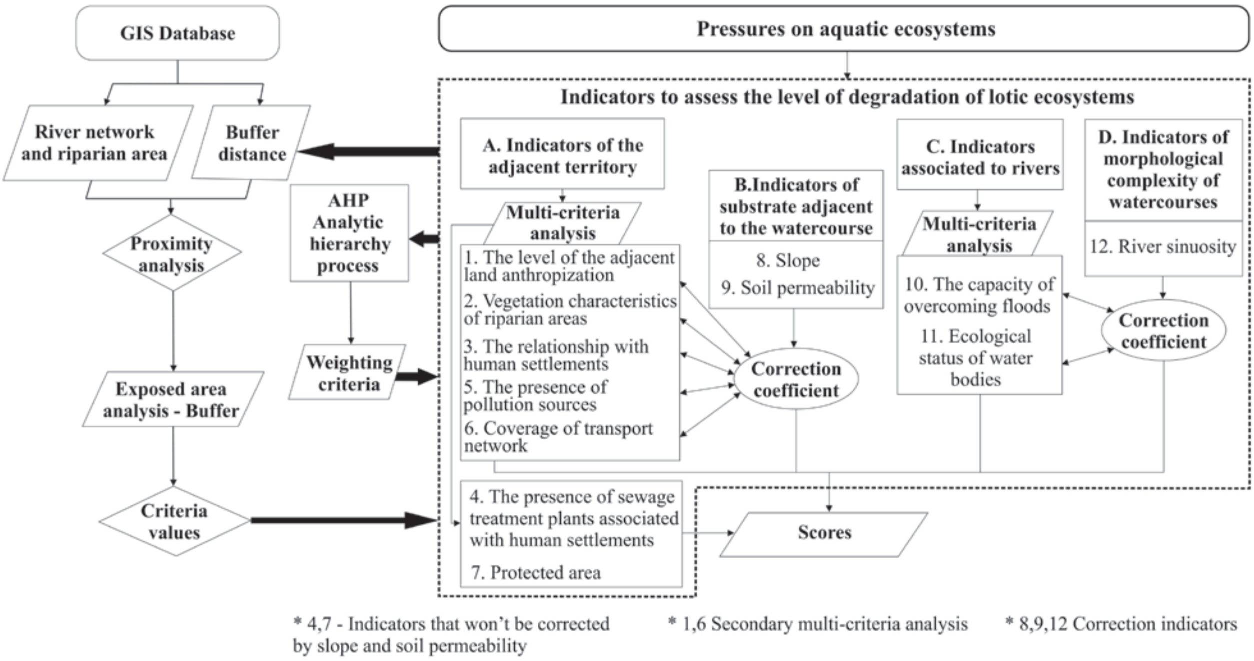

Figure 2. The methodological flow in use to evaluate the degradation level of river ecosystems.

Table 4. Example of indicator's values and attributed marks for some sectors in the studied area.

ID	A1a	A1b	A1c	A2	A3	A4	A5	A6a	A6b	A6c	A7	B1	B2	C1	C2	D	A 1,2,3,5,6	A correc.	C	C correct.	Total
3	2	4	1	4	1	5	0	0	1	2	4	1	0.9	1	2	1	1.3	1.2	1.8	1.8	3.6
8	4	3	1	4	5	5	5	0	2	3	5	1	0.9	5	3	1.1	3.5	3.1	3.5	3.8	7.7
9	3	3	2	4	5	5	5	0	1	3	5	1	0.9	5	3	1.1	3.3	3.0	3.5	3.8	7.5
2	4	3	1	4	3	3	5	0	2	3	5	1	0.9	5	2	1.1	3.2	2.9	2.7	3.0	6.4
14	3	3	1	3	1	5	5	2	1	2	3	1	0.9	1	3	1	2.7	2.4	2.5	2.5	5.6
19	4	3	1	4	3	3	5	1	1	1	5	1	0.9	5	3	1	3.2	2.9	3.5	3.5	6.9
21	1	4	1	4	1	5	0	0	0	2	5	1	0.9	0	2	1.1	1.1	1.0	1.5	1.7	3.4
22	1	1	1	5	3	5	0	0	0	0	5	1	0.9	0	3	0	3.1	2.8	3.0	3.3	6.8
23	1	1	1	5	3	5	0	0	0	0	5	1	0.9	0	2	0	2.9	2.6	2.7	2.7	6.1
24	1	1	1	5	1	5	0	0	0	0	5	1	0.9	0	2	0	1.5	1.3	1.5	1.5	3.6

As a general rule, the human presence increases the level of degradation of lotic ecosystems, the sectors that have obtained the highest scores - corresponding thus to the most degraded ecosystems - are those whose flowing channel or riparian zones intersect the main inhabited areas. This is the case of segments 2 (Reghin) with a score of 6.4, 8 (Târgu Mureș) with the highest score of 7,7, 9 (Târgu Mureș) with 7.5, 19 (Luduș) with 6.9, 22 (Ocna Mureș) with 6.8 and 23 (Ocna Mureș) with 6.1. The highest 2 final scores correspond with the only 2 records with value 5 for indicator A3 (the overlapping with localities, classified in relation to their population). The anthropization expressed as the degree of human transformation of natural surfaces, with the first category being the most relevant (dense urban areas, exploitation or industrial ones) shows a less correlation with the final score comparing to the population. Thus, the highest value for the first anthropization indicator (A1a), which is 4 in the studied area, corresponds with the first, the third and the fifth of the final scores.

In these populated areas, some major pollution sources (indicator A5) were also identified along the same sectors, as well as for 14 (near Iernut) and 10 (downstream Târgu Mureș). A wood processing plant in Reghin (Kastamonu Romania SA), a mineral fertilizers plant in Târgu Mureș (Azomureș SA), a sugar beet processing plant in Luduș (Tereos Romania SA), a chemical plant in Ocna Mureș (GHCL Upsom Romania SA) or agricultural large activities near Iernut or Târgu Mureș are the reasons for giving mark 5 for this indicator in thevabove mentioned river sectors. As an overall image, the highest 8 final scores have all value 5 for indicator A5, for the rest, major pollution sources being absent. On the other hand, the lowest value obtained for the final score (sector 21) corresponds with the only situation in which a value of 1 was awarded to indicator A1 (reduced presence of anthropic areas).

The extent of impounding river channels represents another important indicator with a high impact on lotic ecosystem degradation, substantially reducing its functionality. The highest value for this specific indicator (value 5 for C1) corresponds with the highest 3 final scores (river sectors 8, 9 and 19), then with the fifth and sixth (river sectors 2 and 22), at the same time fitting pretty well with the highest values of indicators A1a and A3. There is only one situation in which the highest value for indicator C1 corresponds to a final score lower than 6, but in that case, major sources of pollution are absent (river sector 1).

There are other situations in which other indicators trigger differentiation between sectors, as in case of indicator A4 (sewage treatment plants). Thus, when comparing sectors 2 and 22 (Reghin and Ocna Mureș), they have final scores of 6.4, respectively 6.8, in conditions of similar values for high impact indicators as A3 (overlapping localities by population) and A5 (major pollution sources). The other very important indicators mentioned in the previous analyses, A1a (dense urban and industrial areas) and C1 (human interventions in river banks) have higher values for sector 2 (worse situation), but cause a lower impact on the total score comparing to indicator A4, which has a higher value for indicator 22 (a worse situation).

5. DISCUSSION

The present paper proposes a method useful in large scale assessments, where direct analyses on the lotic ecosystem are not possible (e.g. regional or national reports on ecosystems' state).

The criteria chosen in this analysis were based initially on literature sources, but the available data for the area envisaged – which are, in fact, also available for the entire territory of Romania – determined us to make some adjustments compared to reference works. For example, specific data on habitats and species are essential for this kind of analysis, but in lack of them, we focused on data issued by the National Administration "Apele Române" (NAAR) related to water bodies ecological status, expressed in five classes, as well as other relevant indirect indicators. Water bodies ecological status is assessed taking into account mostly physico-chemical and biological indicators. The indirect indicators we used refer both to water channels (e.g. presence of dams, impoundments, and sinuosity) or to adjacent areas connected functionally to the water courses – riparian zones -, sometimes strongly influenced by human activities.

All the data that this methodology relied upon was obtained from public sources, mostly centralised and available at different instituitions at European (European Environment Agency) or national level (National Institute of Statistics, Romanian Ministry of Environment). These datasets were sometimes not extremely precise (e.g. type of the vector data representing major pollution sources or the resolution of raster data), causing less accuracy in representation. In case of major pollution sources, the geographic features used in representation were points, not polygons, determining in some cases that the riparian areas din not intersect the representation point, but in reality, if represented as polygon, it would intersect the real surface of a pollution unit (a plant, a farm etc.). This means that some pollution sources would be excluded from analysis, so we decided for this study to create a buffer of 300 m around the points, in order to catch them all inside the riparian areas. We applied a 300-m buffer by measuring in Google Earth the footprint of some pollution units, randomly chosen, but for the future, these areas should be vectorised, creating polygons instead of points.

Another key aspect of our study was to split the riparian corridor – at first a unique polygon - into polygons related with rivers segments obtained as described in the methodology, in order to delineate the areas for calculating the indicators in categories A and B. For this, two delineation methods were tested: (1) cutting the riparian corridor by perpendicular lines on each end point of a river segment and (2) creating buffers wider than riparian corridor on each river segment, then intersecting them with the riparian corridor. In both cases, a lot of intersection conflicts have appeared at confluences, determining us to use Thiessen polygons in order to avoid them. This technique means that from the source polygon – the riparian corridor – surfaces that contain all the points that are closer to a specific vertex in a line – all rivers' segments – than to any other vertex in that dataset are selected. This technique produced the best results, eliminating the intersection conflicts previously met. In order to improve the riparian corridor splitting process, it could be first splitted by the watershed, further being applied the above-mentioned technique. This wasn't the case of our study, because we used the 25 meters EU-DEM, being thus not smoother enough for this purpose.

The indicators were included in a multicriterial analysis, their individual weight being decided by using the pairwise method. Although the method is based on awarding scores in a rather subjective manner (experts' opinion), it succeeds in objectizing results by the large number of indicators used and the in depth relative analyses which enables multiple correlations between indicators. All indicators that were chosen are relevant for the final purpose (e.g. presence of major source of impact, presence of treatment plants, density of road network etc.), each of them mirroring to a certain extent the way human activities influenced the analyzed ecosystem. Anyway, the results could be further improved by increasing the objectivity level in assigning the weights for each indicator used. That means to apply the pairwise comparison to a large number of specialists in the field.

6. CONCLUSIONS

The methodology used to evaluate the degree of degradation of lotic ecosystems based on a multi-criteria analysis and GIS techniques is an extremely useful tool in the attempt to cover large areas of analysis, its important advantadges standing in the reduced human and time resources and the usage of existing GIS data. It could be successfully integrated within a European assessment of the same type. By covering a large number of criteria that comprise different forms of anthropic influence, directly and indirectly, on the lotic ecosystems, the present methodology is based on cause-effect relationship that characterizes the complex rivers-riparian zones, modified by human activities in various ways. This method included not only the potential human impacts on rivers but also the terrain characteristics (slope and soil permeability) that buffer these effects. Some aspects of this methodology were based on expert opinions (e.g., the classification and marking system, the assessment of the importance of each indicator), therefore, in order to be improved, its validation will probably require further testing. Still, the increased number of indicators used and their selection was based on a thorough literature review, hence conferring the required objectivity for its implementation.

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