ANALYSIS OF CORRELATION BETWEEN THE STATE OF GROUNDWATER AND THE STATE OF TERRESTRIAL ECOSYSTEMS INCLUDING WETLANDS

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Abstract

Analysis of correlation between the state of terrestrial ecosystems and groundwater aims the preservation of natural state of ecosystems in terms of sustainable exploitation of groundwater. The proposed analysis determines the intensity of dependence between ecosystems and groundwater based on two categories of criteria: *hydrogeological criteria* (**HC:** lithology of aquifer formations, vadose zone humidity, piezometric level depth and qroundwater quality) and *environmental criteria* (**EC:** the number of characteristic organisms, production function, role in cycling elements etc.).
The analysis contains two algorithms: one for identifying the potential ecosystems dependent on groundwater and one for estimating the intensity of interdependence on three levels: *high dependence* (**A: 100%**), *medium dependence* (**B: 50%**) and *nule dependence* (**C: 0%**).
Validation of the proposed analysis was conducted on a case study in Oltenia. In the selected area, the evaluation of dependence intensity for each Nature 2000 site was made using one criteria that maximizes the dependence and one that minimizes.
The proposed analysis uses GIS techniques and a database supplied with information from public monitoring systems of groundwater, SCIs-Nature2000 and habitats, Corine Land Cover databases.

Keywords*: environmental criteria, groundwater,* GIS, *hydrogeological criteria, SCI_Nature 2000.*

1. Introduction

Our analysis of correlation between the state of terrestrial ecosystems and groundwater is generated by the fact that one of the basic principles of groundwater protection policy against pollution and deterioration, included in EU Water Framework Directive 2000/60 EC and Directive 2006/118/EC, is: "If a groundwater resource or quality pressure is causing 'significant damage' to terrestrial ecosystems including wetlands, then the groundwater body will not be in "**good status**" [1], [2].
The difficulty of defining the correlation between terrestrial ecosystems and groundwater compel a maximum caution which aims to conserve the natural resources and use them in a sustainable manner [3].
The proposed methodology for analysis includes: criteria and algorithm for identification of dependence between ecosystems and groundwater and algorithm for assessing degree of dependence for each habitat and for entire studied area.

For the case study, conducted in Oltenia region, the main hydrogeological criteria used was the piezometric head of groundwater in correlation with some environmental criteria like: deep root system of plants, the number of characteristic organisms and in addition, the 44 classes/categories of land use (extracted from the Corine Land Cover database).
The result of our analysis is the average level of correlation for each SCI and habitat from the studied area, separated into three categories: *high dependence* (**A**), *medium dependence* (**B**) and *nule dependence* (**C**) (Table 3).

2. Materials and Methods (or Experimental)

Correlation between the state of terrestrial ecosystems and groundwater is made based on a ***new methodology*** which has three basic steps:

- identifying ***criteria*** for determining the correlation between ecosystems and groundwater
- accurate ***algorithm*** for identifying correlations between ecosystems and groundwater
- evaluating the ***intensity*** of correlation between ecosystems and groundwater

The ***criteria*** used to assess the correlation between ecosystems and groundwater was separated into two categories:

- ***hydrogeological criteria (HC)*** like: the recharge area of phreatic aquifer (***Fig.1***), hydrodynamic relationships between groundwater bodies and surface water (lakes, rivers and wetlands) [4]
- ***ecological criteria (EC)*** like: the number of characteristic organisms, production function, role in cycling elements etc. [3], [5], [6].

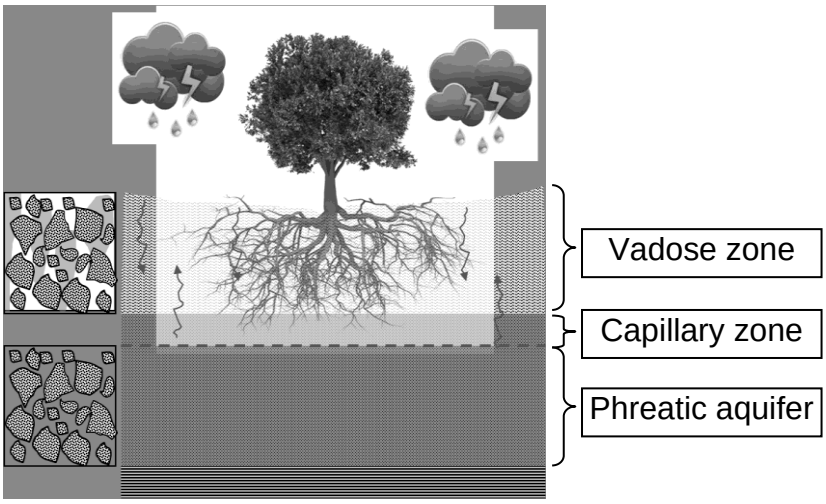

Fig. 1. *The recharge area for phreatic aquifer and the access area of groundwater to the root system of plants*

The algorithm for identifying correlations between ecosystems and groundwater bodies (***Fig. 2***) uses a ***database*** containing: areas of surface water bodies, areas of groundwater bodies (phreatic and confined), areas of ecosystems and types of hydrodinamic connections between water bodies.
The main steps of the algorithm are:

- mapping of water bodies
- specifying the types of connections between water bodies
- mapping of ecosystems
- intersection of water bodies and ecosystems
- framing the type of relationship between water bodies and ecosystems in two classes: ***dependent*** ecosystem and ***independent*** ecosystem (using hydrogeologicel criteria (***HA***) and ecological criteria (***EC***)

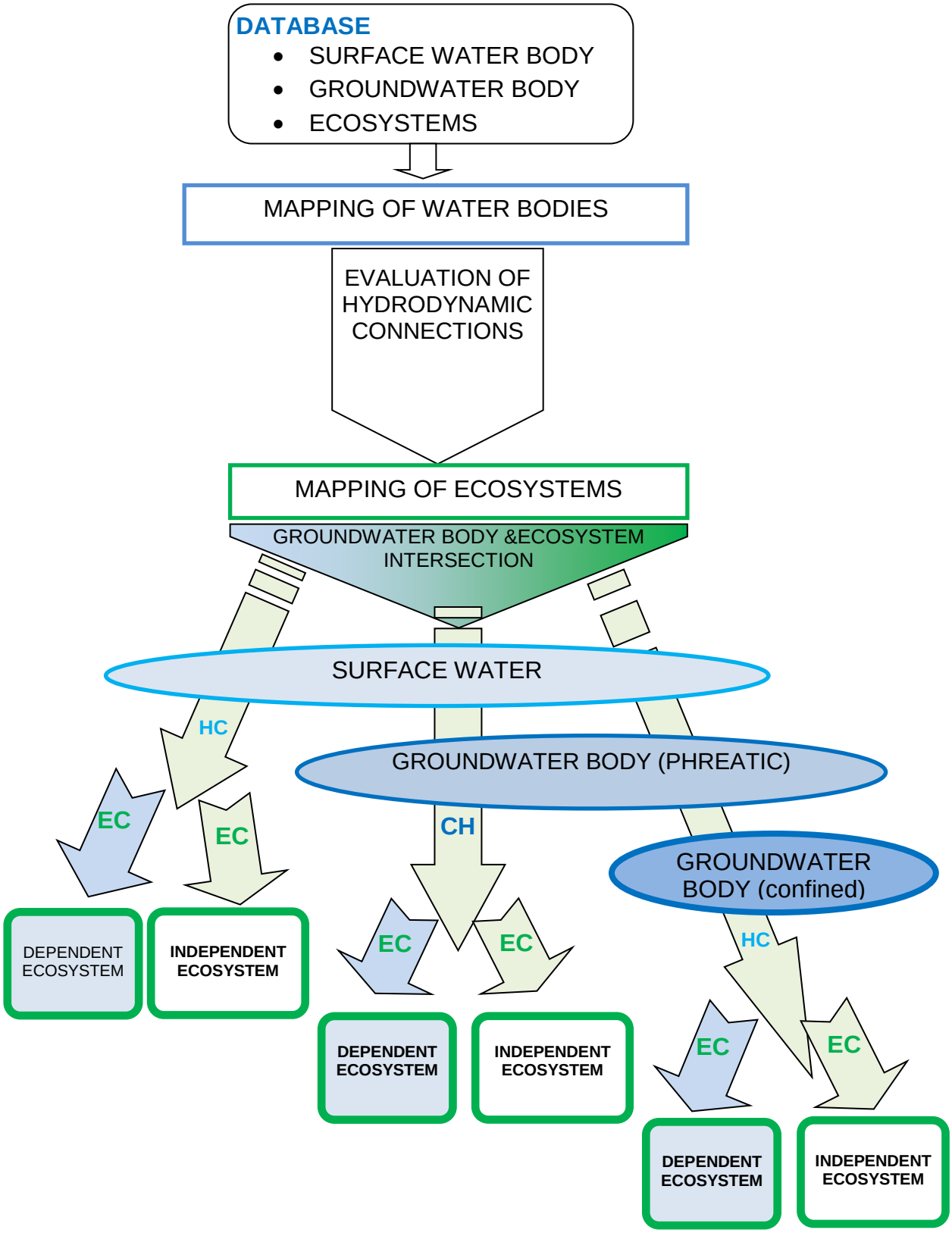

Fig. 2. Algorithm for identifying correlations between ecosystems and groundwater bodies (surface water, groundwater body (phreatic/confined)

The algorithm for evaluation of the ***intensity*** of correlation between ecosystems and groundwater (***Fig. 3***) applies only to ecosystems dependent on groundwater potential identified in the second stage of the methodology.
Applying the two categories of criteria (hydrogeological criteria: CH and ecological criteria: EC) leads to two series of assessments for the corresponding dependency. All the criteria may generate, depending on the conditions of the land, three dependency levels:

- high dependence: A: 100%
- medium dependence: B: 50%
- nule dependence: C: 0%

It follows that an ecosystem dependent on groundwater potential will have after applying the algorithm, a number of indices (A / B / C) equal to the number of hydrogeological criteria (HC) and ecological criteria (EC). Establishing the degree of dependence for a studied area, with several ecosystems, is proposed to be quantified by two indices [7]:

- ***maximum dependency index*** (**C1**) - equal to the maximum dependency level identified for all ecosystems from studied area.

$$C1 = MAX\,(DEP_{E_1}, DEP_{E_2}, ..., DEP_{E_n}) \qquad [1]$$

where
DEP_{E_1} - level of dependency for E_1 ecosystem (A=100%, B=50% and C=0%)
n - total number of ecosystems in the studied area.

- ***medium dependency index*** (**C2**) - calculated as a average of dependency levels weight with the surface of each ecosystem identified in the studied area only for level of dependency A or B.

$$C2 = \frac{\sum_{i=1}^{i-n} DEP_{E_i} \cdot S_{E_i}}{\sum_{i=1}^{i=n} S_{E_i}} \text{ with values: } \begin{cases} A & if \quad C2 \geq 75\% \\ B & if \quad C2 < 75\% \end{cases} \qquad [2]$$

where
S_{E_i} - the area of ecosystem „i"

C2 is not calculated in areas with independent ecosystems (level of dependency is C=0%).
Acording to the ***principle of minimum precaution*** for any area where there is a dependent ecosystem is given a level of dependency B. If C2>75% the level of dependency is increased to A.

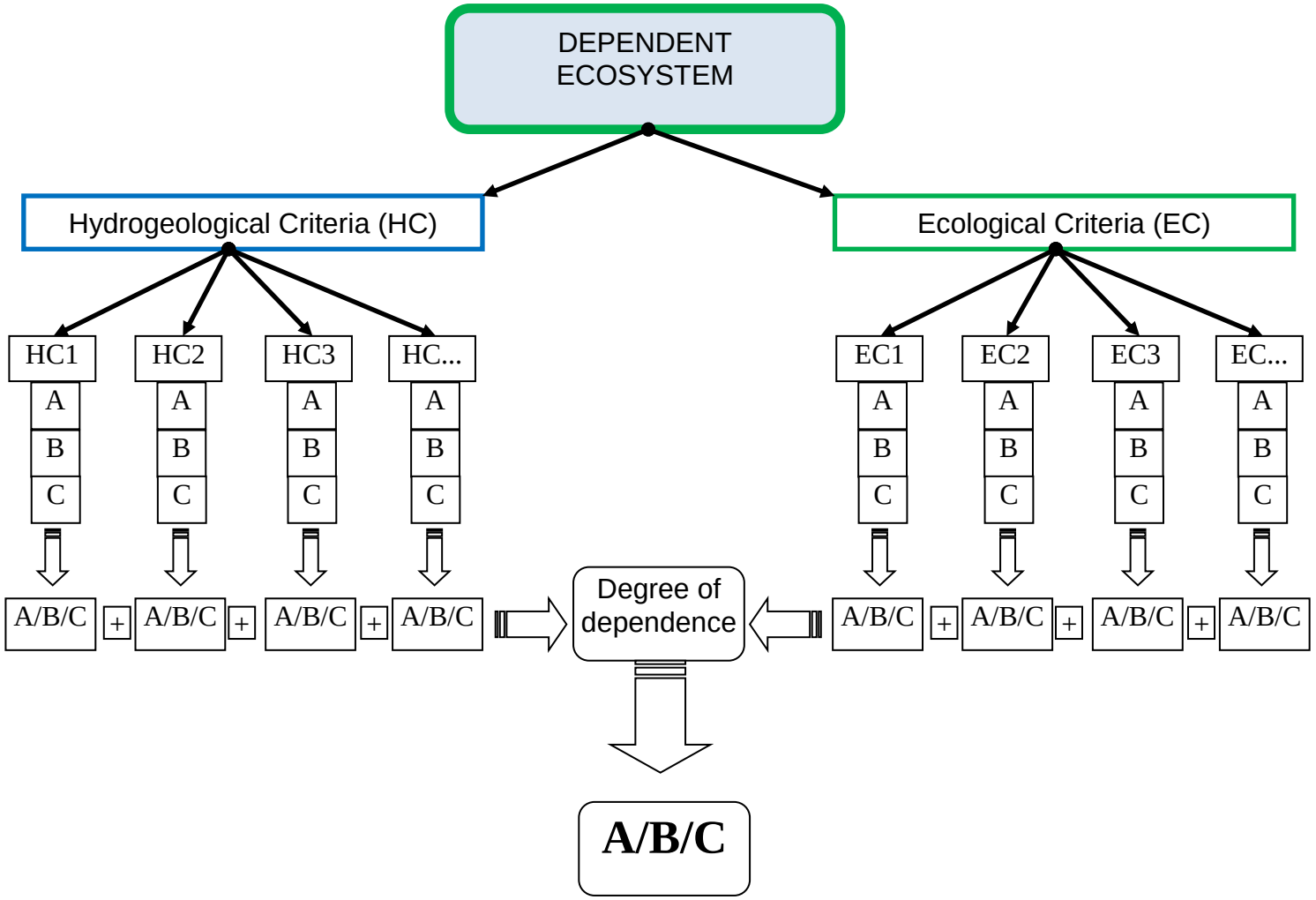

Fig. 3. The algorithm for evaluation of the ***intensity*** of correlation between ecosystems and groundwater

3. Results and Discussion

The case study applies the methodology developed for the analysis of correlation between groundwater bodies and terrestrial ecosystems in the Oltenia region placed in southwestern Romania (***Fig. 4***) with a complex hydrostructure and a wide variety of Nature 2000 sites.

The areas where the dependency between terrestrial ecosystems and groundwater aquifers becomes possible are:

- phreatic aquifers
- natural emergency of aquifers like wetlands and surface waters (lake and rivers) recharged from groundwater.

Database needed to analyse the correlation between ecosystems and groundwater, in the studied area, consists in:

- water bodies of regional hydrostructure Oltenia [8]:
  - preatic aquifers: ROJI05, ROJI06, ROOT08 (***Fig. 5a***)
  - deep aquifers: ROOT13, ROJI07
- ecosystems from the network Nature 2000 (SPA & SCI) in the same area [9]:
  - ROSPA: 0011, 0046, 0013, 0023, 0196, 0024, 0137
  - ROSCI: 0039,0202, 0045, 0306, 0173, 0403, 0296, 0299, 0376, 0166, 0168, 0183, 0174, 0011, 0266, 0359, 0362, 0366 (***Fig. 5b***)
- habitats from nationat network (10x10km) in the studied area:
  - 6510, 6120, 91IO, 2190, 92A0, 91M0, 3260, 6440, 9170, 91Y0 (***Fig.5c***)
  - dependency/depth of piezometric level (***Table 1***) [10]
- land use categories (Corine Land Cover; [11]):
  - 311, 312, 313, 321, 324 (***Fig. 5d***)
  - dependency/depth of piezometric level (***Table 2***)

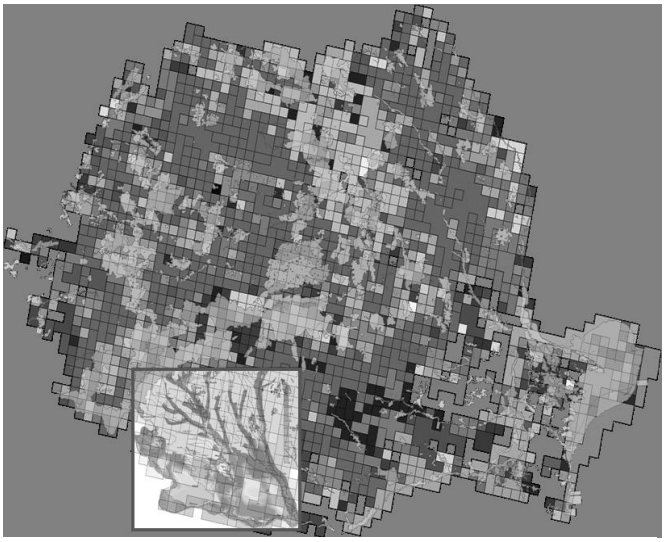

Fig. 4. *Case study location on the Romanian map with habitats in the network 10x10km*

Table 1. Correlation between dependency level and piezometric level depth

Code habitat	Dependency level Piezometric level depth
2190	A
3260	A
6120	A 0-2 m, B 2-4 m, C > 4m
6440	A
6510	A 0-2 m, B 2-4 m, C > 4m
9170	A 0-10 m, B 10-20 m, C > 20 m
91M0	A 0-10 m, B 10-20 m, C > 20 m
91I0	A 0-10 m, B 10-20 m, C > 20 m
91Y0	A 0-10 m, B 10-20 m, C > 20 m
92ª0	A

Table 2. Correlation between dependency level and piezometric level depth

Code CLC	Dependency
311	A 0-10 m, B 10-20 m, C > 20 m
312	A 0-10 m, B 10-20 m, C > 20 m
313	A 0-10 m, B 10-20 m, C > 20 m
321	A 0-2 m, B 2-4 m, C > 4m
324	A 0-4 m, B 4-8 m, C > 8 m

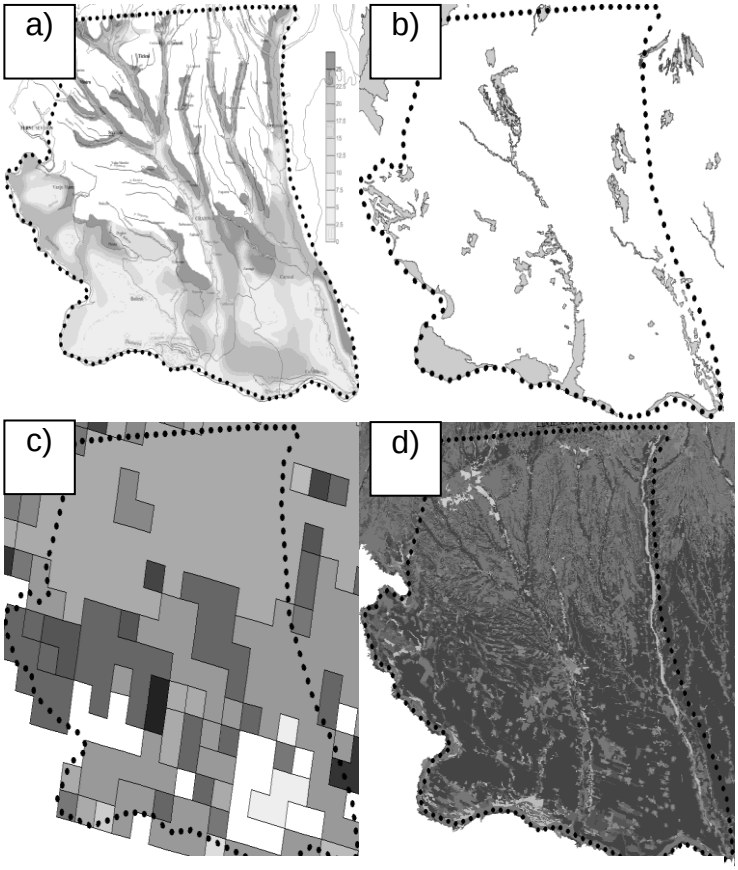

Fig. 5*. Database for case study: a) depth of piezometric level; b) the 18 SCI; c) habitats (10x10km); d) the land use categories.*

Table 3. *Synthesis of case study results*

ROSCI				HABITAT		
No	Code	DEP		Code	DEP	
		C 1	C2		C1	C2
1	0366	C	C	9170	C	C
2	0362	C	C	9170	C	C
3	0045	A	B	6440	A	A
				9170	C	C
				92A0	A	A
				6510	C	C
				3270	C	C
4	0039	A	B	6510	C	C
				6120	B	B
				91I0	A	A
				2190	A	A
				92A0	B	B
5	0202	C	C	91M0	C	C
6	0306	A	B	91M0	B	B
				92A0	A	A
7	0173	A	A	92A0	A	A
8	0403	C	C	91Y0	C	C
9	0296	C	C	9170	C	C
10	0376	A	A	92A0	A	A
11	0168	C	C	92A0	C	C
				9170	C	C
12	0166	C	C	92A0	C	C
13	0183	C	C	91I0	C	C
14	0174	C	C	91I0	C	C
15	0011	C	C	91I0	C	C
16	0266	A	A	92A0	A	A
17	0359	C	C	9170	C	C

The results of methodology conducted in Oltenia with both criteria (C1 and C2) are included in ***Table 3***. It follows that the two criteria (C1 and C2) lead to different results only in large areas (***Table 4***).

The relevance of these results obtained by applying the proposed methodology depends on [12]:

- accuracy spatial delimitation of groundwater bodies, ecosystems and habitats
- representativeness of the data used to assess the depth of piezometric level of groundwater bodies and hydrodynamic relations.

The two recommended criteria for assessing the degree of dependence of ecosystems to groundwater bodies should be selected according to:

- protecting biodiversity without taking any risk of deterioration (criteria C1);
- reducing the number of representative habitat types according to the percentage of the surface in the studied area (criteria C2).

4. Conclusions

The proposed methodology allows a satisfactory identification and ranking of ecosystems dependent on groundwater according to the depth of piezometric level of aquifers.

We appreciate that the correct identification of groundwater dependent ecosystems is possible in special cases where there are studies based on mathematical models of coupled flow of surface water, groundwater and ecological processes.
Such studies are recommended for protecting ecosystems of special importance where they can be affected by irrational exploitation of groundwater bodies.

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***Table 4**. Areas (S) of SCI and habitats in studied area*

No	SCI		Habitat	
	Code	S [km2]	Code	S [km2]
1	ROSCI0366	19.2	9170	19.2
2	ROSCI0362	4.4	9170	4.4
3	ROSCI0045	714.5	6440	0.0
			9170	200.0
			92A0	0.0
			6510	23.0
			3270	20.0
4	ROSCI0039	398.0	6510	44.0
			6120	79.0
			91I0	0.0
			2190	0.0
			92A0	77.0
5	ROSCI0202	31.0	91M0	31.0
6	ROSCI0306	134.0	91M0	0.0
			92A0	0.0
7	ROSCI0173	12.0	92A0	5.0
8	ROSCI0403	7.0	91Y0	7.0
9	ROSCI0296	7.0	9170	7.0
10	ROSCI0376	59.0	92A0	0.0
11	ROSCI0168	68.0	92A0	58.0
			9170	15.0
12	ROSCI0183	4.0	92A0	15.0
13	ROSCI0166	16.0	92A0	0.0
14	ROSCI0174	0.7	91I0	4.0
15	ROSCI0011	3.0	91I0	0.7
16	ROSCI0266	15.0	91I0	3.0
17	ROSCI0359	24.0	92A0	0.0
18	ROSCI0299	46.0	9170	24.0

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