Assessment of river water quality using an integrated hydro-morphological, physico-chemical and biological approach

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Abstract. River water bodies are being altered due to hydromorphological and chemical pressures. An integrated approach in the assessment of water quality was outlined more as a result of the EU water directives, especially the Water Framework Directive (WFD), which requires the development and harmonization of monitoring and assessment of water quality for all surface water bodies. As WFD addresses water quality in terms of "ecological status" respectively "ecological potential", the paper aims to discuss the analysis and the assessment of a "heavily modified river water body" in terms of hydro-morphological, physico-chemical and biological elements. The analyzed waterbody is in the same time the whole Hartibaciu River (110 km length) located within the central part of Romania. The study is based on monitoring data provided by the National Administration “Apele Romane” – The Olt River Basin Authority for three monitoring sections (one being a reference site). The 11th hydro-morphological indicators, the values of an 12th physico-chemical parameters and some values of two multimetric biotic indices (invertebrates and benthic algae) have been used to characterize the water quality. The heavily modified river water body showed a clear and pronounced gradient of pollution, from the unpolluted reference site to the site under anthropogenic pressure (located in the middle of the waterbody). Clear signs of organic pollution were found in the second monitoring section, such as low dissolved oxygen concentrations, high nutrient loads and also the highly tolerant macroinvertebrates species. Despite the evident signs of pollution in the middle part of the waterbody, the third monitoring section suggests an improvement of water quality. The hydro-morphological indicators of river continuity classify the water body in class 4 and most of the physico-chemical parameters classify the analyzed river water body in moderate ecological potential. Furthermore, the paper describes/explains the linkages among the physico-chemical and biological elements. Due to this integrated approach, the main conclusion is that the Hartibaciu water body could be spatially split into three parts/water bodies. This kind of integrated approach helps the re-designation of water bodies and could contribute to a more comprehensive assessment under the WFD for the effects of anthropogenic pressures on the quality status and functioning of aquatic ecosystems.
Key Words: ecological potential, heavily modified water body, hydro-morphological indicators, integrated approach.

Introduction. The analysis and assessment of rivers water quality are two important issues in water resources management. Monitoring water quality parameters was outlined more as a result of the EU water directives, especially the Water Framework Directive (WFD), which requires the development and harmonization of monitoring and assessment of water quality for all surface water bodies. In this context, the assessment of river status and the development of classification schemes have become a priority for the European scientific community.

The WFD addresses water quality in terms of "ecological status" defined as "an global expression of the quality of the structure and functioning of aquatic ecosystems" taking into account the abiotic factors (e.g. physiographic, geographical, climatic) including the physical and chemical parameters (natural or induces by human activities) (Oliveira & Cortes 2006). According to Oliveira & Cortes (2006) this approach is another expression of ecological integrity which can be defined as an unequal and dynamic overlapping between the three key components: physical, chemical and biological components. The importance of ensuring and/or maintaining the physical, chemical and biological integrity is fundamental to aquatic ecosystems (Barbour et al 2000; Oliveira & Cortes 2006) and it is tackled by WFD as "good ecological status" (GES). According to the Annex V of WFD "good ecological status" is defined by the biological, general physico-chemical and hydro-morphological elements as "supporting elements" for biota.

In the context of the Directive, the function of "support" refers to the fact that the values of abiotic parameters must be able to support biota classifying in a certain ecological status recognizing that the hydro-morphology and chemical parameters influence fundamentally the structure of biotic communities (Best et al 2007). Moreover, the aim of using these supporting elements in monitoring programs is not to substitute the biotic elements but to support the interpretation, assessment and classification of ecological status (Best et al 2007). Thus, the concept of "good ecological status" requires the identification, monitoring and control of anthropogenic pressure which disturbs the structure and functioning of aquatic ecosystems.

As many water bodies in Europe have been subject to major physical alterations another new concept of WFD is the "heavily modified water bodies" (HMWB). As the Directive mentions that HMWB "means a body of surface water which as a result of physical alterations by human activity is substantially changed in character", the identification of significant pressures in the river basins was crucial. Therefore, the designation the HMWB was an important step for the Member States which implies serious difficulties in the first planning cycle. Also, a real challenge for European countries (including Romania) have been defining GEP and the development of the methodologies for assessing GES.

According to Annex V of the WFD all Member States should assess ecological status of rivers respectively ecological potential by using the relevant quality elements as follows: biological, general physico-chemical and hydro-morphological elements. River water bodies should be classified in one of the five ecological status classes (high, good, moderate, poor or bad) or one of the three ecological potential classes (maximum, good, moderate). The status assigned will be determined by the worst case, this is also named the ‘one out - all out’ principle in the Guidance document no. 13 Overall approach to the classification of ecological status and ecological potential elaborated under Common Implementation Strategy of the WFD.

Taking into account the importance of integrated assessment of river status, the paper presents the analyses and assessment of the ecological potential based on the hydro-morphological, general physico-chemical and biological elements of a HMWB which is in the same time the whole Hartibaciu River. Therefore, the current national assessment methods updated or developed after first Romanian River Management have been applied.

Material and Method

Description of the study site. The Hartibaciu River is located in the central part of the country, belonging to the Olt River Basin (Figure 1). The Hartibaciu river originates in a wooded area of Rotbav Plateau, at an altitude of 670 m asl and the confluence point to the Cibin river being downstream Mohu Village, at an altitude of 383 m asl. The Hartibaciu River stretches over a length of 110 km, draining an area about 1025 km^2 (Cadastral Water Atlas of Romania 1992).

The whole Hartibaciu River represents a heavily modified waterbody named within the Olt River Management Plan - “Hartibaciu-Cibin confluence”. For the purpose of this paper it will be named Hartibaciu waterbody.

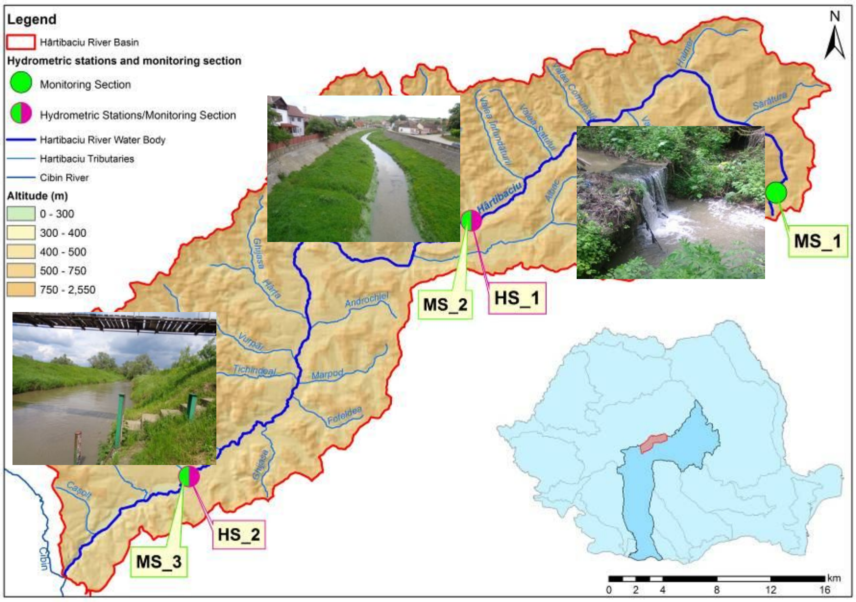

Figure 1. The Hârtibaciu river water body and the locations of the hydrometric stations (HS)/monitoring sections (MS).

The significant hydro-morphological pressures acting in the river basin led to the designation of Hartibaciu water body as "heavily-modified". Two temporary reservoirs, Retis and Benesti (Figure 2), located within the water body are functioning for water retention in case of floods, disturbing the longitudinal continuity of the river bed. The lateral connectivity of the Hartibaciu river with the riparian zone/floodplain is interrupted by dikes and regularization (over the 80 km length) made by hard and local materials, on one or both sides of the river.

Regarding the land cover, the riparian/floodplain zone is characterized by natural areas. The main point pollution source (municipal waste waters mainly originating from the Agnita town) is located in the middle part of the drainage basin.

Regarding the rivers typology (Table 1), the analyzed water body was classified as highland typology (RO 04). According to the National Management Plan (2015), the river bed substrate is represented by gravel and sand, thus providing habitat for a specific aquatic fauna. The multiannual average flow computed for the period 1959-2014 is 0.95 cm s^{-1} at Agnita hydrometric station (HS_1) respectively 2.96 cm s^{-1} at Cornatel hydrometric station (HS_2).

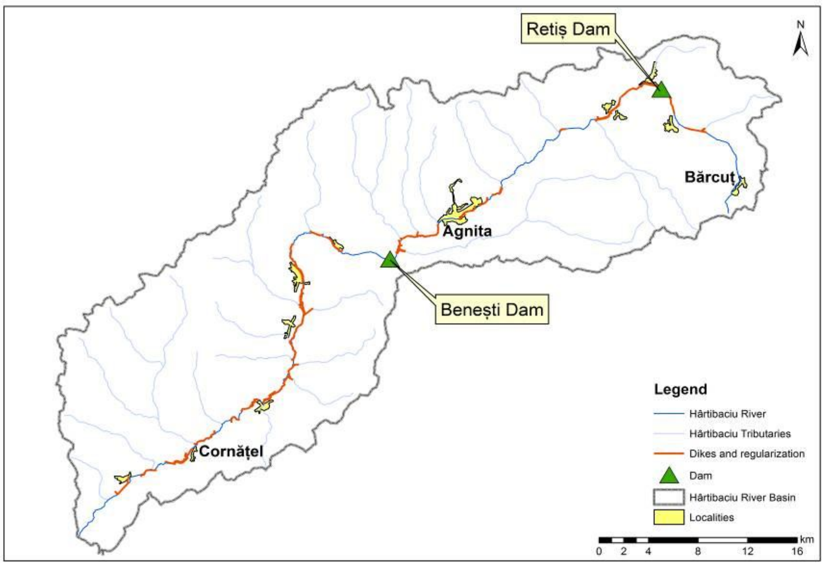

Figure 2. The Hârtibaciu river water body and the locations of the water works.

Table 1

The analyzed water body, its typology and the hydrometric stations (HS) and monitoring sections (MS) related to it

River name	*Water body name*	*Water body length (km)*	*Typology*	*HS name*	*HS code*	*MS name*	*MS site code*
Hartibaciu	Hartibaciu - Cibin confluence	110	RO04	-	-	Upstream Barcut	MS_1
				Agnita	HS_1	Downstream Agnita	MS_2
				Cornatel	HS_2	Cornatel	MS_3

Assessment of hydromorphological elements. The assessment of hydromorphological elements for the Hartibaciu river water body has been done using the Methodology for hydromorphological assessment of Romanian rivers (Moldoveanu et al 2015; Galie et al 2017). The methodology developed within National Institute of Hydrology and Water Management (Romania) is listed in the Annex 6.1.2.A. of Romanian River Management Plan (2015) and it is based on 11 hydromorphological indicators (listed in Table 2). Each indicator assesses the deviation from natural conditions in terms of hydrological regime, river continuity and morphological conditions.

Each indicator is assessed in five classes, class I meaning the reference status/natural or a slight deviation and the other classes (II-V) indicate the severity of anthropogenic pressures compared to reference conditions. For some indicators that assess similar features (e.g. indicators 5 and 6 listed in Table 2), the methodology uses a multi-criteria indicators - McI for which the quality classes have been set equidistantly (Moldoveanu et al 2015; Galie et al 2017).

For the classification of each element the principle "one out, all out" (the worst status) was applied between some indicators. In order to have a final classification in terms of hydromorphological elements, the same principle was applied between the hydrological regime, river continuity and morphological conditions.

The assessment of hydro-morphology was done using the datasets from 2 hydrometric stations (HS_1 and HS_2) located on the Hartibaciu River water body. Some indicators (e.g. indicator 1, 2) are computed using measured values in hydrometric stations, while others (e.g. indicator 5) using criteria that reflect the severity of anthropogenic pressure at water body level. Generally, the lowest values (or percentage) of the indicators suggest maximum and good ecological potential (Table 2).

Table 2

The formulas and the values of hydromorphological indicators for each of the five classes

Indicator	*Formula/criteria*	*I/II*	*III*	*IV*	*V*
1. Average used/ consumed flow	$$\frac{\sum_{i=1}^{j} Q_{mean\_used} - \sum_{i=1}^{k} Q_{mean\_return}}{Q_{natural\_multiannual\_mean/reference\_condition}} * 100$$ Where: j = number of water intakes; k = number of users which return flows.	- If the value of *Average used/consumed flow* is ≤ 10% than $Q_{multiannual\ natural\ flow}$ the WB is in class I; - If the value of *Average used/consumed flow* is between 11% and 30% than $Q_{multiannual\ natural\ flow}$ the WB is in class II.	- If the value of *Average used/consumed flow* is between 31% and 50% than $Q_{multiannual\ natural\ flow}$ the WB is in class III.	- If the value of *Average used/consumed flow* is between 51% and 70% than $Q_{multiannual\ natural\ flow}$ the WB is in class IV.	- If the value of *Average used/consumed flow* is ≥ 71% than $Q_{multiannual\ natural\ flow}$ the WB is in class V.
2. Maximum flow abstraction	$$\frac{\underset{i=1}{\overset{j}{Max}} Q_{mean\_abstracted}}{Q_{natural\_multiannual\_mean/reference\_conditions}} * 100$$ Where: j = number of water intakes	- If the value of *Maximum flow abstraction* is ≤ 10% than $Q_{multiannual\ natural\ flow}$ the WB is in class I; - If the value of *Maximum flow abstraction* is between 11% and 30% than $Q_{multiannual\ natural\ flow}$ the WB is in class II.	- If the value of *Maximum flow abstraction* is > 30% than $Q_{multiannual\ natural\ flow}$ the WB is in class III.	- If the value of *Maximum flow abstraction* is 51% and 70% than $Q_{multiannual\ natural\ flow}$ the WB is in class IV.	- If the value of *Maximum flow abstraction* is ≥ 71% than $Q_{multiannual\ natural\ flow}$ the WB is in class V.
3. River connection to ground water bodies	$$\frac{\left(\frac{mean\_water\_level\_measured\_a.s.l.}{mean\_groundwater\_tabel\_measured\_a.s.l.}\right)^{natural}}{\left(\frac{mean\_water\_level\_measured\_a.s.l.}{mean\_groundwater\_tabel\_measured\_a.s.l.}\right)^{modified}}$$ Note: It is based on water level recorded in the river and in the closest wells. Will be considered approximately the same time period (both natural and modified conditions) for the groundwater table measurements in wells and the water level measurements in the river (at the hydrometric stations).	- If the value of *River connection to groundwater bodies indicator* is ≥ 0.9 the WB is in class I - If the value of *River connection to groundwater bodies indicator* is between 0.8 and 0.9 the WB is in class II.	- If the value of *River connection to groundwater bodies indicator* is between 0.7 and 0.79 the WB is in class III.	- If the value of *River connection to groundwater bodies indicator* is between 0.6 and 0.69 the WB is in class IV.	- If the value of *River connection to groundwater bodies indicator* is between 0.5 and 0.59 the WB is in class V.
4. Longitudinal continuity/ connectivity of the river bed	Number of dams or other transversal structures. The difference between upstream and downstream water level. Note: The indicator assesses the impact of dams or other transversal structures on the mobility of fish species.	- If the difference between upstream and downstream water level is: ≤ 30 cm (cyprinids zone) and there are < 0.33 barriers/km, 50 cm (salmonids zone) and there are < 0.33 barriers/km, the WB is in class I; If the difference between upstream and downstream water level is: ≤ 30 cm (cyprinids zone), 50 cm (salmonids zone) and there are > 0.33 barriers/km, the WB is in class II.	The difference between upstream and downstream water level is: between 30-50 cm (cyprinids zone), 50-70 cm (salmonids zone) and there are > 0.33 barriers/km, the WB is in class III.	The difference between upstream and downstream water level is: between 51-100 cm (cyprinids zone), 71-200 cm (salmonids zone) and there are > 0.33 barriers/km, the WB is in class IV.	The difference between upstream and downstream water level is: > 100 cm (cyprinids zone), > 200 cm (salmonids zone) and there are > 0.33 barriers/km, the WB is in class V.

Indicator	Formula/criteria	I/II	III	IV	V
5. River lateral continuity/ connectivity with the riparian zone/ floodplain (considering the length of water works)	$\frac{L_{ww}}{L_{wb} * 2} \cdot 100$ Where, L_{ww} – the length of the water works (dikes) L_{wb} - the length of the water body (dikes) Note: The indicator 5 analyses if the water works length varies in a certain percentage out of the double length of the water body.	- If the water works length are represented less than 20% out of the double length of the water body the the WB is in class I; - If the water works length are represented 21-30% out of the double length of the water body the WB is in class II.	If the water works length are represented 31-50% out of the double length of the water body the WB is in class III.	If the water works length are represented 51-70% out of the double length of the water body the WB is in class IV.	If the water works length are represented ≥ 71% out of the double length of the water body the WB is in class V.
6. River lateral continuity/ connectivity with the riparian zone/ floodplain (considering the reduction of the riparian zone width)	The location of the water works (dikes) at a certain distance from the minor river bed Note: The indicator 6 analyses the percentage of reduction for the floodplain's width caused by water works (dikes).	If the water works reducing the floodplain's width less than 20%, the WB is in class I; If the water works reducing the floodplain's width between 21 and 40%, the WB is in class II.	If the water works reducing the floodplain's width between 41-60%, the WB is in class III.	If the water works reducing the floodplain's width between 61-80%, the WB is in class IV.	If the water works reducing the floodplain's width ≥ 81%, the WB is in class V.
7. Mean depth corresponding to multiannual average flow	$\frac{h_{mm} - h_{mn}}{h_{mn}} \cdot 100$ Where: h_{mm} = mean water depth corresponding to the modified multiannual mean flow (current conditions); h_{mn} = mean water depth corresponding to the natural multiannual mean flow (reference/natural conditions).	- If the relative error/deviation of the mean water depth is less than 20%, the WB is in class I - If the relative; error/deviation of the mean water depth is between 21 and 40%, the WB is in class II.	- If the relative error/deviation of the mean water depth is between 41% and 60%, the WB is in class III.	- If the relative error/deviation of the mean water depth is between 61% and 80%, the WB is in class IV.	- If the relative error/deviation of the mean water depth is ≥ 81%, the WB is in class V.
8. Mean width corresponding to multiannual average flow	$\frac{B_{mm} - B_{mn}}{B_{mn}}$ Where: B_{mm} = mean water width corresponding to the modified multiannual mean flow (current conditions); B_{mn} = mean water width corresponding to the natural multiannual mean flow (reference/natural conditions).	- If the relative error/deviation of the mean water width is less than 20%, the WB is in class I; - If the relative error/deviation of the mean water width is between 21 and 40%, the WB is in class II.	- If the relative error/deviation of the mean water width is between 41% and 60%, the WB is in class III.	- If the relative error/deviation of the mean water width is between 61% and 80%, the WB is in class IV.	- If the relative error/deviation of the mean water width is ≥ 81%, the WB is in class V.

Indicator	Formula/criteria	I/II	III	IV	V
9. The sediment structure of the river bed	$$\frac{D_{50\%m} - D_{50\%n}}{D_{50\%n}} \cdot 100$$ Where: $D_{50\%m}$ = mean particle size fraction corresponding to current conditions; $D_{50\%n}$ = mean particle size fraction corresponding to reference/natural conditions.	If the relative error/deviation of the riverbed mean particle size fraction ($D_{50\%}$) is less than 20%, the WB is in class I; If the relative error/deviation of the riverbed mean particle size fraction ($D_{50\%}$) is between 21 and 50%, the WB is in class II.	If the relative error/deviation of the riverbed mean particle size fraction ($D_{50\%}$) is between 51 and 65 the WB is in class III.	If the relative error/deviation of the riverbed mean particle size fraction ($D_{50\%}$) is between 66 and 85%, the WB is in class IV.	If the relative error/deviation of the riverbed mean particle size fraction ($D_{50\%}$) is ≥ 86%, the WB is in class V.
10. Minor riverbed morpholog y and its lateral mobility	$$\frac{L_{ww}}{L_{wb} * 2} \cdot 100$$ Where: L_{ww} = length of the water works (regularization); L_{wb} = length of the water body (regularization). Indicator 10 analyses if the water works have changed the riverbed shape and its lateral mobility.	If the water works length is less than 10% out of the double length of the water body, the WB is in class I; If the water works length is between 11% and 30% out of the double length of the water body the WB is in class II.	If the water works length is between 31% and 50% out of the double length of the water body, the WB is in class III.	If the water works length is between 51% and 70% out of the double length of the water body, the WB is in class IV.	If the water works length is ≥ 71%, the WB is in class V.
11. Riparian zone	Natural, agricultural and artificial areas expressed in percentage (Corine Land Cover)	If the natural areas are more than 70% out of total surface of riparian zone, the WB is in class I If the natural areas are between 41% and 70% out of total surface of riparian zone, the WB is in class II	If the natural areas are between 21% and 40% out of total surface of riparian zone, the WB is in class III	If the natural areas are between 10% and 20% out of total surface of riparian zone, the WB is in class IV	If the natural areas are ≤ 10% out of total surface of riparian zone, the WB is in class V
McI1	Score ("one out, all out" between Indicator 1 and Indicator 2) *0.8 + Score (Indicator 3) * 0.2 Note: The value of McI1 gives the water body status in terms of hydrological regime	- If the value of McI is between [10.6 - 13], the WB is in class I - If the value of McI is between [8.2 - 10.6), the WB is in class II	- If the value of McI is between [5.8 - 8.2), the WB is in class III	- If the value of McI is between [3.4 - 5.8), the WB is in class IV	- If the value of McI is between (3.4 - 1], the WB is in class V
McI2	Score (Indicator 5) * 0.25 + Score (Indicator 6) * 0.75 Note: The value of McI1 gives the water body status in terms of lateral connectivity of river with the floodplain				
McI3	Score (Indicator 7) * 0.7 + Score (Indicator 8) * 0.3				
McI4	Score (Indicator 9) * 0.50 + Score (Indicator 10) * 0.50				

WB = water body.

Assessment of physico-chemical elements. The analysis and assessment of ecological potential in terms of physico-chemical elements have been done by applying the national methodologies listed in the Annex 6.1.3.A. of Romanian River Management Plan (2015) based on 12 physico-chemical parameters belonging to the five groups of elements as follows: thermal conditions (water temperature), oxygenation (dissolved oxygen - DO, biochemical oxygen demand - BOD_5, chemical oxygen demand - COD), salinity (conductivity - Cond), acidification (pH) and nutrients (ammonium - $N\text{-}NH_4$, nitrite - $N\text{-}NO_2$, nitrate - $N\text{-}NO_3$, total nitrogen - Nt, orthophosphates - $P\text{-}PO_4$, total phosphorus - Pt).

The assessment was based on the data sets obtained from the national monitoring system (N.A. "Apele Romane") for 3 monitoring sections located on the Hartibaciu waterbody. The data were collected generally monthly time step, for the period 2012-2015.

The methods are based on some percentiles computations. For some parameters (e.g. conductivity, COD) the methods were developed after 2013 (the 2013 datasets were used for developing the Second River Basin Management Plan) and within the paper the updated ecological potential assessment in terms of physico-chemical elements is presented.

The boundary values for the three quality classes of ecological potential namely, the boundary of the maximum/good ecological potential (MEP/GEP), the boundary of good/moderate ecological potential (GEP/MoEP) are presented in Tables 3 and 4.

Table 3

Boundary values* between the maximum and good ecological potential (MEP/GEP), respectively good and moderate ecological potential (GEP/MoEP) for RO 04 river typology

DO (mg O_2 L^{-1})		*BOD_5 (mg O_2 L^{-1})*		*COD (mg O_2 L^{-1})*		*pH*	*Cond*
MEP/GEP	GEP/MoEP	MEP/GEP	GEP/MoEP	MEP/GEP	GEP/MoEP	MEP and GEP	GEP/MoEP
9	7	3	6	10	25	6.5 – 8.5	1500 µS cm^{-1}

(Annex 6.1.3 A, Romanian River Management Plan 2015); *percentile values.

Table 4

Boundary values* between the maximum and good ecological potential (MEP/GEP), respectively good and moderate ecological potential (GEP/MoEP) for nutrients for RO 04 river typology

$N\text{-}NH_4$ (mg N_2 L^{-1})		*$N\text{-}NO_2$ (mg N_2 L^{-1})*		*$N\text{-}NO_3$ (mg N_2 L^{-1})*		*Nt (mg N L^{-1})*		*$P\text{-}PO_4$ (mg P L^{-1})*		*Pt (mg P L^{-1})*	
MEP/ GEP	GEP/ MoEP	MEP/ GEP	GEP/ MoEP	MEP/ GEP	GEP/ MoEP	MEP/ GEP	GEP/ MoEP	MEP/ GEP	GEP/ MoEP	MEP/ GEP	GEP/ MoEP
0.300	0.500	0.024	0.047	1.000	2.200	2.500	5.000	0.060	0.150	0.150	0.300

(Annex 6.1.3 A, Romanian River Management Plan 2015); *percentile values.

Based on datasets concerning the physico-chemical parameters the following percentiles has been computated: P98 for the water temperature, P90 for pH, nutrients, conductivity, BOD_5, COD and P10 for DO were computed for each monitoring section. The high values (percentile) of some parameters (e.g. DO) suggest maxim and good ecological potential whilst in case of other (BOD_5, COD and nutrients) the maxim and good ecological potential is given by the lowest values of parameters (Table 5).

The principle "one out, all out" (the worst status) have been applied for the classification of the ecological potential for some categories of parameters (oxygenation and nutrient conditions). In order to establish the final classification in terms of physico-chemical elements the principle previously mentioned have been applied once again between potential assessed under thermal conditions, acidification, salinity, oxygen and nutrient conditions.

Table 5

Basic steps for assessing ecological potential based on physico-chemical parameters

Physical and chemical parameters		*Assessment method*
pH	P90	- if the P90 value is inside the range mentioned in Table 3, the ecological potential is „maximum”; - if the P90 value is outside the range mentioned in Table 3, the ecological potential is „moderate”.
Dissolved oxygen (mgO_2 L^{-1})	P10	- if the P10 value is higher or equal to MEP/GEP boundary value, the ecological potential is „maximum”; - if the P10 value is lower than MEP/GEP boundary value, is compared with the GEP/MoEP boundary value; - if the P10 value is higher or equal to GEP/MoEP boundary value, the ecological potential is "good"; - if the P10 value is lower than GEP/MoEP boundary value, the ecological potential is "moderate".
BOD_5 (mg O_2 L^{-1}) COD (mg O_2 L^{-1}) N-NH_4 (mg N L^{-1}) N-NO_2 (mg N L^{-1}) N-NO_3 (mg N L^{-1}) P-PO_4 (mg L^{-1} P) Nt (mg N L^{-1}) Pt (mg P L^{-1})	P90 P90 P90 P90 P90 P90 P90 P90	- if the P90 value is lower or equal to MEP/GEP boundary value, the ecological potential is „maximum”; - if the P90 value is higher than MEP/GEP boundary, is compared with the GEP/MoEP boundary value; - if the P90 value is lower or equal to GEP/ MoEP boundary value, the ecological potential is "good"; - if the P90 value is higher than GEP/MoEP boundary, the ecological potential is "moderate".
Conductivity (µS cm^{-1})	P90	- if the P90 value is lower or equal to GEP/MoEP boundary value, the ecological potential is „good”; - if the P90 value is higher than GEP/MoEP boundary, the ecological potential is "moderate".

Assessment of biological elements. The assessment of ecological potential in terms of biological elements have been done using two biological elements: benthic invertebrates and benthic algae. The multimetric indices have been computed by the Olt River Basin Authority for the period 2012-2015 using the monitoring data from the three monitoring sections. The multimetric indices for benthic invertebrates (biMI) and benthic algae (baMI) have been calculated based on a wide range of biotic indices (Risnoveanu et al 2017) using the formulas provided by the Romanian National River Basin Management Plan (2015). The range of multimetric index is between 0 and 1, the ecological potential being maximum and good as the values are closer to 1 (Table 6).

Table 6

The formulas, boundary values between the maximum and good ecological potential (MEP/GEP), respectively good and moderate ecological potential (GEP/MoEP) for multimetric index of benthic invertebrates (biMI) and benthic algae (baMI) and the basic steps of the assessment method

Multimetric index	*Formulas*	*MEP/GEP*	*GEP/MoEP*	*Assessment method*
biMI	$0.3*EQR_{biSI}+0.1*EQR_{EPT}+0.2*EQR_{biSW}+0.1*EQR_{NF}+0.1*EQR_{OCH}+0.1*EQR_{FG}+0.1*EQR_{REO}$	0.75	0.58	- if the index value is higher or equal to MEP/GEP boundary, the ecological potential is „maximum”; - if the index value is higher or equal to GEP/MoEP boundary value, the ecological potential is "good"; - if the index value is lower than GEP/MoEP boundary value, the ecological potential is "moderate".
baMI	$0.3*EQR_{baSI}+0.15*EQR_{NT}+0.3*EQR_{baSW}+0.25*EQR_{BI}$	0.78	0.62	

SI - Saprobic Index; EPT - Ephemeroptera-Plecoptera-Thricoptera Index; SW - Shanon Wienner Index; NF - Number of Family Index; OCH - Oligochaeta - Chironomidae Index; FG - Functional Groups Index; REO - Rheophilic Index; NT - Number of taxa; BI - Biological Index; EQR are the ecological quality ratio = index value in investigated site/index value in reference site.

Results and Discussion

Classification for hydromorphological elements. Regarding the hydrological regime, due to the fact that there are no water uses within the Hartibaciu water body, the quantity and dynamics of flow have been considered natural and the Hartibaciu water body has been classified in class I (indicators 1 and 2). Therefore, the flow status has been classified in class I.

Another element which influences the hydrological regime is the connection of the river to groundwater bodies (indicator 3). According to the instructions mentioned in the methodology (Moldoveanu et al 2015; Galie et al 2017), the indicator 3 was computed only for Agnita hydrometric station (HS_1) based on water level recorded in the river and in the closest wells. The result ($1.655 \geq 0.9$) classifies the Hartibaciu water body in class I.

According to the formula of Multi-criteria indicator 1 (McI 1) and the boundary values (see Table 2), the hydrological regime of Hartibaciu water body is in class I.

River continuity assessment has been done using three indicators: one indicator for longitudinal continuity – indicator 4 and two indicators for lateral continuity – indicator 5 and indicator 6.

Taking into account the two transversal structures (dams) located within the Hartibaciu water body that interrupt the minor river bed continuity and the movement and migration of fish fauna, the indicator 4 classifies the water body in class IV (Table 7).

Table 7

Hydromorphological classification for the Hartibaciu water body

Hidromorphological elements																		
Hydrological regime					*River continuity*					*Morphological conditions*								*"one out, all out"* between *Hydrological regime*, *River continuity* and *Morphological conditions*
1	2	*"one out, all out"* between 1 and 2	3	McI 1	4	5	6	McI 2	*"one out, all out"* Indicator 4 and McI 2	7	8	McI 3	9	10	McI 4	11	*"one out, all out"* McI 3, McI 4 and indicator 11	
I	I	I	I	I	IV	III	IV	IV	IV	II	I	I	I	II	I	II	II	IV

The lateral continuity of the river with the riparian zone/floodplain is described using the length of water works (dikes) (indicator 5), and the location of these works (dikes) at a certain distance from the minor river bed (indicator 6). Due to the fact that the Hartibaciu water body length is 110 km, and the dikes are 39% out of the double length of the water body, the indicator 5 classifies the water body in class III. Also, the percentage of reduction for the floodplain's width caused by water works (dikes) was considerable (more than 60%), therefore the indicator 6 classifies the water body in class IV.

In terms of morphological conditions, the assessment have been done using the five indicators and the formulas listed in Table 2. Therefore, all indicators (including the multicriteria indicators) classify the water body in class I and II and the final morphological status of the water body was class II. This result is explained by the fact that, the water is flowing in normal regime through the Retis and Benesti temporary reservoirs. The two reservoirs are storing the water in case of floods.

The final class of the Hartibaciu water body in terms of hydromorphological elements applying the "one-out, all-out" principle (between the hydrological regime, river continuity and morphological conditions) was class IV (Table 8).

This classification for the Hartibaciu water body was influenced by the indicators of "river continuity".

Table 8

Ecological potential* for the Hartibaciu river water body in terms of physico-chemical elements

Monitoring section code	Year	Thermical conditions	Acidification	Oxygenation			Ecological potential Oxygenation	Salinity	Nutrients						Ecological potential nutrients	Ecological potential in terms of general physico-chemical elements
		T (^0C)	pH	O_2 (mg L^{-1})	CBO_5 (mg O_2 L^{-1})	CCO-Cr (mg O_2 L^{-1})		Cond. (µS cm^{-1})	N-NH_4 (mg N L^{-1})	N-NO_2 (mg N L^{-1})	N-NO_3 (mg N L^{-1})	Nt (mg N L^{-1})	P-PO_4 (mg P L^{-1})	Pt (mg P L^{-1})		
MS_1	2012	16.8	8.02	8.92	1.52	5	II	836	0.703	0.04	1.716	2.539	0.069	0.108	III	III
	2013	15.64	7.62	9.37	1.16	7.5	I	720.2	0.020	0.005	0.787	1.077	0.015	0.024	I	I
	2014	20.46	7.69	7.22	2.45	16.48	II	1049.2	0.019	0.008	0.791	1.405	0.021	0.044	I	II
	2015	18.88	7.95	7.92	1.9	13.08	I	676.4	0.039	0.009	0.603	0.889	0.015	0.034	I	II
MS_2	2012	23	7.89	1.18	15.79	127.62	III	816.2	16.359	0.087	0.857	19.257	1.681	2.922	III	III
	2013	23.3	7.75	2.07	17.03	64.81	III	922.25	10.999	0.374	0.987	12.632	1.273	1.407	III	III
	2014	21	7.73	3.4	14.07	67.31	III	914.6	8.239	0.143	1.151	10.027	0.812	1.602	III	III
	2015	23.79	8.02	4.58	9.77	53.6	III	1036.6	5.622	0.200	0.832	7.455	0.715	0.836	III	III
MS_3	2012	22.58	8.21	7.63	2.5	2.5	II	781.8	0.743	0.090	1.163	2.156	0.100	0.124	III	III
	2013	20.31	7.93	8.95	2.7	2.7	II	829.3	0.328	0.026	1.256	2.217	0.163	0.13	III	III
	2014	18.52	7.8	8.38	3.09	3.09	II	818.6	0.206	0.036	1.335	2.606	0.081	0.093	II	II
	2015	20.88	8	6.5	3.34	3.34	III	871.2	0.140	0.024	1.399	2.153	0.075	0.099	II	III

*assessment of ecological potential was done according to national methods listed in Annex 6.1.3.A. of Romanian River Management Plan (2015); the values within the table are the values of the percentiles as following: P90 (pH, nutrients and conductivity) and P10 (DO, BOD5, COD).

■ - MEP - maximum ecological potential (class 1); ■ - GEP - good ecological potential (class 2); □ - MoEP - moderate ecological potential (class3)

Ecological potential - physico-chemical elements. High variations of the physico-chemical water quality in the Hartibaciu water body were recorded during the study period. The percentile values computated based on raw data for each physico-chemical parameter are very heterogeneous, most of them (parameters of oxygenations and nutrients category) covering the entire range from maximum to moderate ecological potential (see Table 8).

In 58% of the total cases (sampling time for all monitoring sections) DO, BOD_5, COD and parameters of nutrients category (except $N\text{-}NO_3$) caused not achieving the environmental objective (good ecological potential) as WFD requires. On the contrary, the temperature, pH and conductivity classify in all cases in maximum and good ecological potential (Table 9).

At the reference site (MS_1), a headwater highland stream with low anthropogenic pressure, the percentile values of all physico-chemical parameters were within the maximum and good ecological potential, except for $N\text{-}NH_4$ in 2012 which indicated a moderate ecological potential (Table 8).

The downstream Agnita monitoring section (MS_2) can be considered a special case due to specific values of the chemical parameters: the values of DO declined significantly as BOD_5 and COD are increasing. The values of P10 computed for DO are below 7, the boundary value between good (GEP) and moderate status (MoEP) (Table 9) during the entire study period. Also the P90 values for the most of nutrients ($N\text{-}NH_4$, $N\text{-}NO_2$, $P\text{-}PO_4$, Pt) are high, above the boundary GEP/MoEP (Table 4) classifying in moderate ecological potential (Table 8). Signs of organic enrichment, i.e. low DO concentrations as well as high BOD_5 and nutrients levels, were most likely as a result of pronounced anthropogenic pressures from urban area (Agnita town) namely wastewater discharged into the Hârtibaciu waterbody in combination with low stream flows.

However, a strong improvement in water quality has been observed in case of MS_3 due to the increase of water flow (water dilution effect). The percentile values of physico-chemical parameters classify in maximum and good ecological potential, except for $N\text{-}NH_4$ and $N\text{-}NO_2$ in 2012, $P\text{-}PO_4$ in 2013 and O_2 in 2015, which indicated a moderate ecological potential (Table 8).

Ecological potential - biological elements. In most cases (sampling time for all monitoring sections) the values of the multimetric index of benthic invertebrates (biMI) classify in maximum and good ecological potential except MS_2 which has a moderate ecological potential (Table 9). On the contrary the values of the multimetric index of benthic algae (baMI) reveals in all cases maximum and good ecological potential. According to the "one out, all out" principle between the two multimetric indices, the baMI established the final ecological potential in terms of biological elements in 75% out of the total cases. Therefore, due to the values resulted, in Agnita monitoring section (MS_2), the Hartibaciu water body has been classified in moderate ecological potential in terms of biological elements in 2012, 2014 and 2015 (Table 9).

As variation in the water chemistry plays a fundamental role in driving variation community structure across river basin (Risnoveanu et al 2017), the waste water discharges of Agnita town (human agglomeration) into the Hartibaciu River have been leading to significant changes regarding benthic invertebrates communities in the three monitoring sections.

In MS_1 (reference site) more than 50% of benthic invertebrates species are belonging to EPT, Gastropods, Amphipods and Unionidae groups known as indicators of clean water (de la Ossa-Carretero et al 2012). As geomorphological variables explain the variation of invertebrates species along rivers (Bernadet et al 2013) in case of our case study (especially the reference site) the EPT species may be associated with geology and coarse substrate (gravel), which allows the optimal (Timm et al 2008), stable (Pan et al 2012) and a high quality habitat (Duan et al 2009).

On the contrary, in MS_2 the EPT taxa are lacking and Chironomidae and Tubificidae species are dominant, which typically tolerate a broad range of environmental conditions (Beyene et al 2009; Goretti et al 2014). The absence of EPT taxa is explained by low dissolved oxygen levels and high organic load (Czerniawska-Kusza 2005). The presence of Ephemeroptera and Thricoptera taxa in MS_3 could be explained by the improvement of water quality in terms of oxygenation and nutrients.

Table 9

Ecological potential of the Hartibaciu river water body in terms of biological elements

Monitoring section	*Sampling campaign/year*	*Benthic invertebrates* biMI	*Ecological potential*	*Benthic algae* baMI	*Ecological potential*	*Ecological potential in terms of biological elements ("all out, one out")*
MS_1	April/2012	0.68	2	0.98	1	GEP
	October/2012	0.55	2	0.98	1	GEP
	April/2013	0.70	2	0.96	1	GEP
	October /2013	0.75	1	0.99	1	MEP
	April/2014	0.83	1	0.99	1	MEP
	October /2014	0.70	2	0.95	1	GEP
	June/2015	0.58	2	0.99	1	GEP
	August/2015	0.59	2	0.99	1	GEP
MS_2	April/2012	0.73	2	0.86	1	GEP
	October /2012	0.49	3	0.78	1	MoEP
	April/2013	0.60	2	0.73	2	GEP
	October /2013	0.55	2	0.80	1	GEP
	April/2014	0.54	3	0.83	1	MoEP
	October/2014	0.33	3	0.87	1	MoEP
	June/2015	0.59	2	0.88	1	GEP
	August/2015	0.33	3	0.78	1	MoEP
MS_3	April/2012	0.83	1	0.99	1	MEP
	October/2012	0.66	2	0.89	1	GEP
	April/2013	0.69	2	0.98	1	GEP
	October/2013	0.79	1	0.90	1	MEP
	April/2014	0.72	2	0.96	1	GEP
	October/2014	0.73	2	0.94	1	GEP
	June/2015	0.66	2	0.92	1	GEP
	August/2015	0.75	1	0.87	1	MEP

MEP - maximum ecological potential (class 1); GEP - good ecological potential (class 2); MoEP - moderate ecological potential (class 3).

Conclusions. An integrated approach of river quality assessment is an important step for the WFD implementation in Romania.

Based on the combined results of the physico-chemical, hydromorphological and biological approaches, the three monitoring sections located on the Hartibaciu water body classified in good to moderate ecological potential for biological and physico-chemical elements and in class IV for hydromorphological elements.

The hydromorphological status was assessed by 11th indicators which show the severity of anthropogenic (hydromorphological) pressures. The Retis and Benesti reservoirs that functioning for water storage in case of floods, combined with dikes and regularizations are the hydro morphological pressures that influence the final hydro morphological classification for the Hartibaciu water body. Therefore, the indicators of "river continuity" classify the water body in class III and IV.

The wastewater discharge into the river (in the area of Agnita town) caused not achieving the environmental objective (good ecological potential) in terms of physico-chemical parameters in MS_2 and also generally it influenced the final classification of physico-chemical status of the Hartibaciu water body.

One has noted that the physico-chemical elements have influenced the biological status in each monitoring section. The results of the assessment of the physico-chemical elements served to explain the variability of invertebrates community structures across the three monitoring sections. The benthic invertebrate seems to be more sensitive to organic pollution than benthic algae, as the latter classifies the water body in high ecological potential.

The results suggest that the Hartibaciu water body could be spatially split into three parts/water bodies according to pollution levels and hydromorphological pressures. One is the Hartibaciu River from the springs to Retis reservoir where the water quality in terms of biological, chemical elements is good and low anthropogenic pressures are noticed. Another one includes the middle part of the river, downstream Retis reservoir to Benesti reservoir, where has been identified a serious water pollution and also the water works are made by hard materials. The last part is downstream Benesti reservoir - confluence with the Cibin River.

The paper suggests a need for an in-depth analysis in order to re-define the water bodies and to establish if the new ones should be natural or heavily modified water bodies.

An integrated physico-chemical, hydromorphological and biological approach for the assessment and classification of water quality should include other relevant biological elements as fish fauna and macrophytes. This integrated approach supports the re-designation of the water bodies.

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