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Article

Using Pressure and Alteration Indicators to Assess River Morphological Quality: Case Study of the Prahova River (Romania)

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Abstract: River morphological quality assessment, derived from quantification of human pressures as well as river channel alteration, is a demand of the Water Framework Directive (WFD) in terms of integrating hydromorphological elements in defining ecological status. Our study's aim is to contribute to the hydromorphological evaluation by proposing indicators and separating classes, based on a revisited Morphological Quality Index (rMQI) protocol. The rMQI is based on 12 indicators of human pressures, 10 indicators of channel form adjustments, and 11 indicators of functionality. The rMQI scoring system allows for the quantification of changes when compared to reference conditions, be they undisturbed or nearly undisturbed by human interventions, with absent channel adjustments and a functioning natural river style. We used the lower, meandering sector of the Prahova River to demonstrate our assessment methodology. The Lower Prahova River suffers from a minor local intervention and a diminishing intensity of fluvial processes specific to a meandering style. Meanders geometry was affected by significant changes that included a decrease in the radius of curvature, width and width–to–mean–depth ratio. We concluded that the Lower Prahova River has a good morphological quality, which is rated as second class on a scale of five levels, from natural to severely modified. We recommend an improvement in the hydromorphological evaluation protocol in Romania by additional indicators for morphological alterations specific to each channel pattern.

Keywords: morphological quality index; hydromorphology; water framework directive; meanders

1. Introduction

Based on the Water Framework Directive (WFD), river morphology, hydrological regime, and river continuity are components of a hydromorphological quality evaluation, supporting the biological and physical quality of rivers [1]. Within hydromorphological assessment (HYMO), several morphological indicators were advanced by WFD for the assessment of a river's status: channel pattern, depth, width, flow velocity, structure, substrate of the riverbed, and the composition of the riparian zone. These indicators have to be analyzed by comparing them to conditions that are "totally or nearly totally undisturbed" by human pressures. Among man-made pressures altering a river's morphology, we include: means of water storage, transfers and distribution; cross-river-profile constructions (e.g., dams, weirs, locks/sluices, culverts, impoundments), longitudinal profile construction (e.g., dikes and levees); bank reinforcement and embankments, dredging and mineral extraction, channelization and straightening the flow, as well as land drainage and sealing [2]. These factors may contribute to the alteration of a river's morphology such as erosion and accumulation processes, river longitudinal and transverse profiles, and lateral connectivity with the floodplain [2].

A frequent question in the assessment of European river morphological quality is the degree of disturbance [3–5]. Within WFD, defining natural/reference conditions based on establishing indicators and, consequently, classes of disturbance becomes a scientific and administrative challenge in the European Union (EU) countries [3]. Natural/reference conditions are principally defined as a status lacking any artificial structures likely to affect the natural movement of sediment, water and its biota, either of which may impact or alter the hydromorphological processes, river planform and profile, riverbed and bank composition, or hydromorphological connection with the floodplain. Additionally, rivers should have adjoining natural vegetation appropriate to the river type and geographical location [6]. Numerous studies debate the definition of reference conditions, but a common vision is lacking [7]. In scientific terms, morphological reference conditions are viewed as evolutionary trajectories [8], highly dependent on water and sediment fluctuations [9] and, generally, on climatic variability and human factors [10]. For morphological pressure-alteration analysis, a simplified solution is adopted, and several definitions are available [11]: (1) in terms of pressures, reference conditions correspond to the absence or a minor presence of human interventions; (2) in terms of alterations, the reference channel form and processes correspond to a status prior to any major anthropogeomorphic interventions, in accordance with natural morphological typology (*i.e.*, a river style framework [8]) [7]. For restoration purposes, reference conditions may be framed as best or expected state given the human interventions context [8,12].

To assist countries in implementing a HYMO protocol, a number of tools were developed. Some of these tools deal principally with river morphological quality, with less emphasis on hydrological regime and river continuity. Rivers in Spain were assessed based on a hydromorphological assessment index [13], while rivers in France were investigated through the Relational System of Audit for Watercourses Hydromorphology [14] and Characterization of the Hydromorphology of Rivers [15]. Rivers in Poland were analyzed through the assessment of the River Hydromorphological Quality method [16], rivers in Scotland were evaluated based on the Morphological Impact Assessment System [17], and rivers in Italy were analyzed by the Morphological Quality Index [7,18]. Rivers in Belgium were assessed based on the Walphy method [19]. These HYMO-derived tools account for nationally specific physical conditions, history of human pressures, and data availability. As examples, the French methods assess the potential of river's alteration mostly based on systematic data about pressures and channel features, applied at a national scale. The Italian method relies mostly on non-systematic data integrating both remote sensing and field surveys, applied at a regional scale. The Belgium method is mostly field survey-oriented and applied at a regional scale.

A comprehensive methodology for the assessment of river morphological quality in Romania is lacking. To date, pressure and alteration specific indicators have been recommended in other methodologies. Şerban and Rădulescu [20] introduced five indicators for pressures (*i.e.*, transversal and longitudinal river works, reservoirs coupled with dams, channelization for navigation, and other interventions for water abstraction), that are then divided into three classes, and designated five Heavily Modified Water Bodies (*i.e.*, reaches of Danube, Prut, Argeş, Doftana, and Bârlad rivers). Gălie *et al.* [21] extracted from the Romanian HYMO protocol (RoHYMO) seven indicators (*i.e.*, channel depth and width in a natural *versus* an altered hydrological regime, plus five coefficients for dredging, damming, width diminishing by diking, banks consolidation, and stabilization of the riverbed), that are then grouped into five status classes (from very good to bad), but only the indicators using data from gauging stations were used to assess river status (*i.e.*, the Prut River). Tecuci and Moldoveanu [22] proposed several indicators to be used in the RoHYMO protocol but without applying classes of disturbance and case studies; these indicators reflect mostly longitudinal, lateral, and vertical continuity by quantifying human works, channel topography/shape, riverbed grain size, and adjacent vegetation.

To fill the gaps in assessing river morphological quality in Romania as a tool for implementing the objective of WFD, our aim is to improve assessment tools in Europe by developing and testing a revisited Morphological Quality Index (rMQI). The specific objectives of our work are: (1) to propose indicators and classes for pressures and alterations that are based on existing applied methodologies and adapted to the physical, historical, and administrative context in Romania; (2) to assess human pressures and (3) to evaluate the alteration of a river as a case study. We used the Lower Prahova River to validate our assessment methodology.

2. Study Area

Our study area, the Prahova River, is located in the southern part of Romania (Figure 1a). The Prahova River is 193 km in length and entails a basin area of 3738 km^2 (Figure 1b), categorized as a second-order tributary of the Danube River. Due to its natural characteristics, it is a typical river for the Southern Romanian landscape, overlapping several natural units: the Carpathian Mountains at more than 800 m a.s.l., the Subcarpathians at 300–800 m a.s.l., and the lowlands at less than 300 m a.s.l. (Figure 1c). This region is covered mainly by forests, semi-natural areas, wetlands, and water bodies on

80.5% of the basin's area; the remaining 17.3% correspond to agricultural areas and 2.2% to artificial surfaces (Figure 1d).

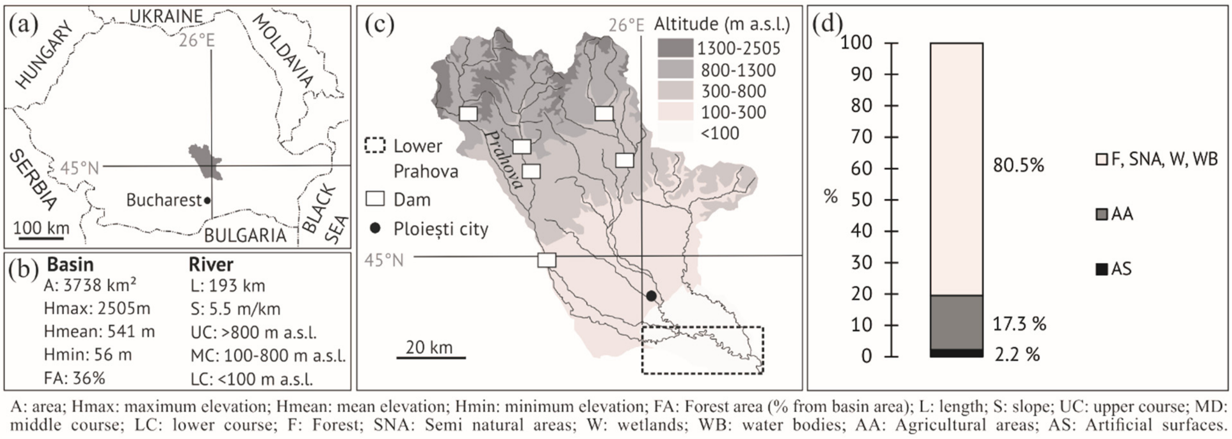

Figure 1. The study area and its features. (**a**) Location of the Prahova River basin in Romania; (**b**) Main morphometric characteristics of the Prahova River and basin [23]; (**c**) Location of the Lower Prahova River as studied river sector; (**d**) Land use in the Prahova River basin according to Corine Land Cover database [24].

We chose the Prahova River because it was affected by numerous anthropogenic pressures in the upstream part of the basin during the last half of the 20th century. On the upper Prahova course and on a part of the middle one (at >300 m a.s.l.), the most significant changes were: dam construction for hydropower generation, channel's embankment and bank protection for transport infrastructure, engineering works and reforestation for landslides and torrents stabilization, sediment mining of the riverbed and floodplain, limitation of the erosion corridor especially for industry expansion, urbanization, and extension of sealed surfaces [25,26]. Comparable man-made interventions exist on the upper courses of the river's tributaries [27]. In the middle part of the basin, the city of Ploiești (374,502 inhabitants) developed based on an industrial profile, as an important petroleum refining and petrochemical center [28].

Human pressures led to the alteration of the Prahova River's morphology. Braided channels from its middle course narrowed sufficiently until they underwent a fluvial metamorphosis [29] (*sensu*) and was transformed into a single channel of approximately one third of the prior braided river sector [25]. Some reaches of the newly formed single channel incurred a drastic incision process (up to 3–5 m, [30]). However, this evolution is characteristically on a local scale, because, in terms of hydrological variability, neither mean annual and seasonal discharges, nor suspended sediment loads registered statistically significant trends in the last half of the 20th century on both upper and middle Prahova River courses (analysis for 1975–2005 on water [31] and for 1961–1995 on sediments [25]).

In contrast to the upper and middle course of the Prahova River, on the lower course, the main river management solutions after 1950 consisted of local reforestation of the adjacent floodplain and levee construction [25]. This lower course is for the most part rural, with relatively small villages (between 1328 inhabitants in Brazii and 2723 inhabitants in Adâncata) and an agricultural profile [28].

Due to the longitudinal and lateral connectivity in fluvial systems [29,32], the lower course of the Prahova River might reflect changes in water flow characteristics and sediment loads from both the upstream and downstream parts of the basin. Therefore, it seems relevant to evaluate the morphological quality of this sector, by highlighting the impact of human activities on channel form and their associated processes.

The lower course of the Prahova River is less than 100 m a.s.l., within a lowland area, and it represents approximately half of the river's total length (*i.e.*, 90 km of 193 km) (Figure 1c). As a morphological characteristic, the Prahova forms a meandering planform style (sector slope 0.5 m/km; sector sinuosity index 2.2). As to water and sediment resources, the Prahova entails a mean annual discharge of 27 m^3/s, a specific stream power of 7 W/m^2, and a mean annual suspended sediment load of 107 kg/s at the Adâncata gauging station. Likewise, in the upper and middle courses, the Lower Prahova did not record statistically significant trends in mean annual discharge and suspended sediment loads in the last half of the 20th century (analysis for 1961–2002 on water and 1961–1995 on sediments [25]).

3. Materials and Methods

To assess a river's morphological quality, we quantified pressures and alterations following the baseline protocol of the Morphological Quality Index (MQI) [7,18]. MQI is a tool to assess the deviation from undisturbed or nearly undisturbed conditions by human interventions, with active processes specific to local natural river style, in terms of degree and mode of change.

Due to the pressure-alteration dimension of our assessment, reference conditions were applied to the study area within the river style framework [8] (*sensu*, *i.e.*, spatial scale) and local history of human impact (*i.e.*, temporal scale). River style had been determined previously for the Lower Prahova River; within a largely unconfined valley setting, it forms a meandering planform sector, with meanders partially confined in fine-grain sediments [25,33] (*sensu*). Within this study, we considered the lower course of the Prahova River as a sector-scale, meanders as extended geomorphic units, and the river cross-section as an extended hydraulic unit. Human pressures were compared to conditions undisturbed or nearly undisturbed by human interventions, on the entire basin and the sector-scale. Human pressures were evaluated for the present timeline. Alterations resulted from the analysis of channel adjustments on sector, geomorphic and hydraulic units scale, and by extrapolation of the intensity of processes, *i.e.*, functionality, that are specific to the meandering river style. Channel form adjustments were evaluated for the studied period with significant human interventions (*i.e.*, the last half of the 20th century) and the functionality for the present timeline.

In addition to the degree of change, to highlight the particularities of the Lower Prahova River in terms of deviation from undisturbed or nearly undisturbed conditions, we completed the analysis with a qualitative approach of pressures and alterations (e.g., types of channel adjustments).

3.1. Data

To evaluate human pressures and river functionality, we used orthophotoplans of 2010 (scale 1/5000) and field surveys. Orthophotoplans are available for consultation on the Romanian INSPIRE Geoportal [34]; the 2010 edition is the most recently available for the studied region. Field surveys occurred in March–October 2005–2010.

To evaluate alterations on planform sector and geomorphic unit, we compared topographic maps from 1954 (scale 1/25,000) against orthophotoplans from 2005 (scale 1/5000). For comparison purposes, the maps were converted from the initial Gauss-Krüger projection to the Stereo 70 projection. We used

ERDAS for data georeferencing and conversion, and QGIS for digitization (ERDAS IMAGINE® Intergraph; Quantum GIS). The lateral errors of these documents, resulting from the scanning, georeferencing, digitization, and water level variations, were ± 9 m for topographic maps and ± 4.5 m for orthophotoplans [35].

Alterations of hydraulic unit forms were evaluated using cross-sectional profiles from the Adâncata gauging station for the 1966–2010 timeline, provided by the Romanian National Institute of Hydrology and Water Management. These profiles were surveyed in relation to the most important phases of the flow regime, from 1 to 4–5 times per year; therefore, some profiles corresponded to high or low water levels and others to recorded flood events. Due to a lack of systematic records for statistical sampling, we randomly selected 1 cross-sectional profile per year. To evaluate the occurrence of any hydrological phenomena, we used the maximum annual discharges from the same Adâncata gauging station for the 1961–2010 timeline.

3.2. Revisited Morphological Quality Index

To analyze the morphological quality of the Lower Prahova River, we followed a multi-phase protocol adapted to available data (Figure 2). We initially selected relevant indicators for pressures and alterations; then, for each selected indicator, we defined 2–4 classes of changes and match them against undisturbed conditions and to an expert opinion baseline [7] reflecting absence of changes, moderate changes, and significant changes. Finally, we evaluated the level of pressure and alteration by assigning a score to each class of change (*i.e.*, 0 for the absence of change and the maximum score for a significant change).

To determine the degree of change, we used three indexes: index of the level of pressure, index of the level of alteration, and an index of global river morphological quality (*i.e.*, revisited MQI, namely rMQI). The pressure index is based on pressure indicators. The alteration index is based on indicators for channel adjustments and functionality. Each index is calculated as the sum of the scores per indicator obtained for the case study divided by the sum of the highest potential scores per indicator (*i.e.*, total score of changes), expressed as a percentage. The resulted rMQI global index represents the mean of the two indexes, *i.e.*, pressure index and alteration index.

The rMQI corresponds to one of the five classes of morphological quality (adapted from [7]): [0–14%) a very good morphological quality reflecting a natural status; [15%–29%) a good morphological quality; [30%–49%) a moderate morphological quality; [50%–69%) a poor morphological quality; [70%–100%] an extremely poor morphological quality reflecting a severely modified status.

3.2.1. Human Pressure Indicators Linked to Disturbed River Morphology

To assess the likelihood of human pressures for the 2010 time outlook, we grouped indicators based on their spatial impact: on longitudinal continuity, on lateral continuity and on the riverbed substrate.

On a river's longitudinal continuity, we calculated four indicators: on a basin scale, (1) basin area associated with reservoirs and dams located upstream of the analyzed reach and (2) the level of interventions in the upstream part of the basin; on sector scale; (3) the number of weirs/check dams and (4) the number of bridges. On river lateral continuity at a local scale, we determined three indicators: (1) length of bank protection; (2) length of reforested banks; and (3) length of levees in proximity of the river banks. On the substrate, at a local scale, we calculated two indicators: (1) the length of quasi-impermeable revetments and (2) the length of rectifications. Other activities with impact on river functioning were evaluated in terms of their intensity and measured by three indicators: (1) local sediment mining activity (from the riverbed and the floodplain); (2) wood removal; and (3) removal of riparian vegetation.

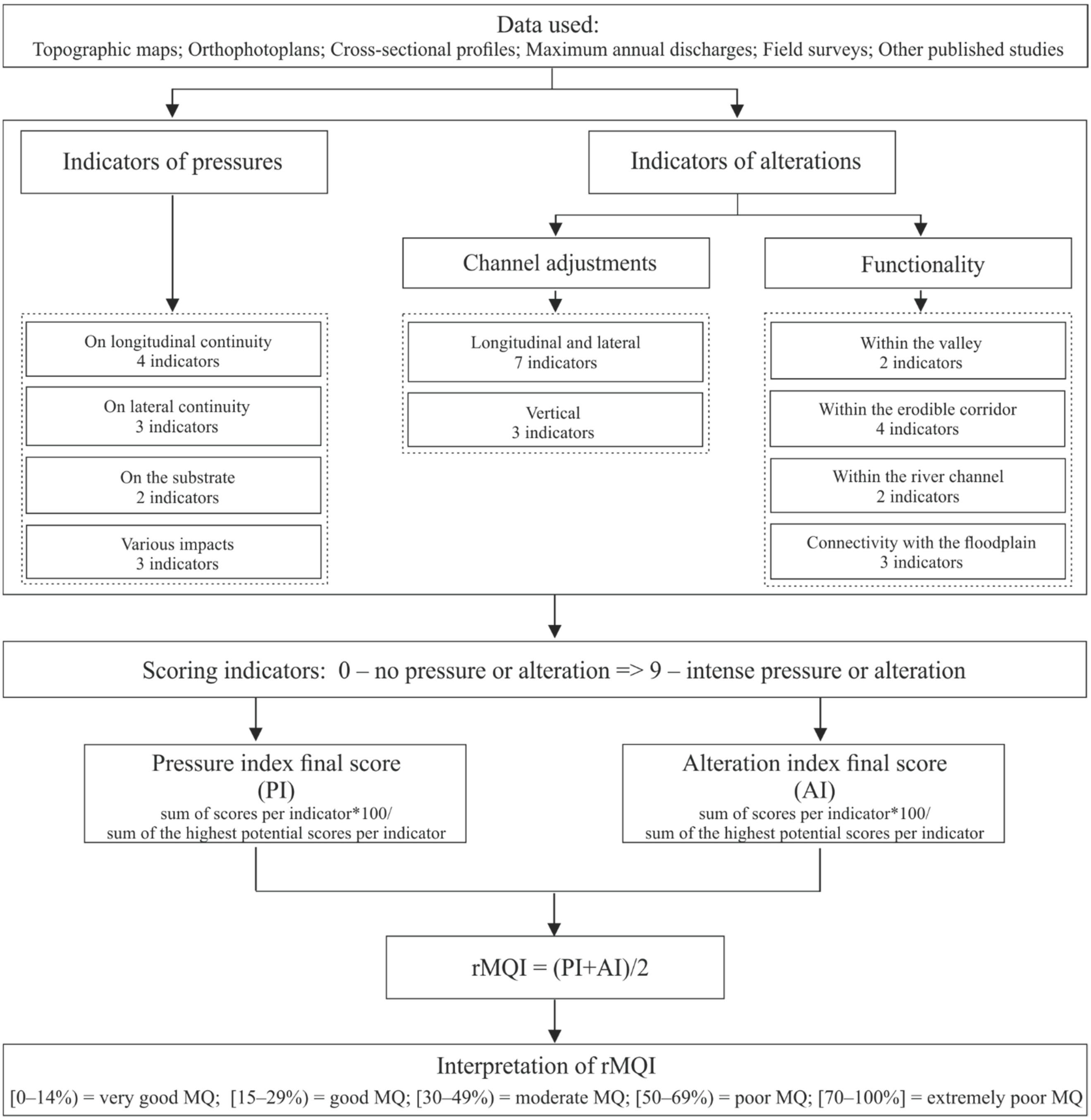

Figure 2. Flowchart of a methodological protocol of the revisited Morphological Quality Index (rMQI); data and scoring for each indicator are in Supplementary File.

For each human pressure on river morphology indicator, we, generally, followed the classes and scores of the original MQI (Table S1 in Supplementary File). We divided them into several classes; a score of 0 indicates an absence of human pressure; a score of 3–4 highlights a moderate human pressure; a score of

6 indicates an intense human pressure; and a score of 9 demonstrates a very intense human pressure on water flow and sediment loads that results in a probable local erosion/accumulation processes.

3.2.2. Change/Trend of Channel Adjustment Indicators

To assess changes among the present and a past timeline (reference conditions), we used the diachronic approach of channel form adjustment. Indicators were based on the 3D dimensions of the river channel (longitudinal, lateral, and vertical).

Longitudinal and lateral adjustments were assessed by comparing meander geometry. We considered meanders with sinuosity index greater than 1.4 [36] and wavelengths greater than 0.25 km (value adapted to the scale of the topographic maps used). We calculated their wavelengths, streamwise lengths, sinuosity indexes, amplitudes, radii of curvature, and channel widths.

Vertical adjustments were assessed by computing area, maximum depth, and width–to–mean–depth ratio at the bankfull stage based on cross-sectional profiles. The bankfull stage was established based on the most recent profile of discontinuities in the transverse channel bank slope as well as for the lowest bank stage level. An elevation numerical value was determined for the bankfull stage, and all older cross-sectional profiles were analyzed against this value.

For each indicator, we defined 2 classes of changes: absence of a significant statistical change/trend based on non-parametric tests (score = 0, the river is in a status of natural equilibrium) and a significant statistical change/trend (score = 6, a long-term change within the hydrosystem) (Table S2 in Supplementary File). Each score was attributed by comparison to scores within the original MQI.

3.2.3. Indicators for Meandering Functionality

To evaluate the functionality of a river's meandering style, we analyzed indicators by spatial scale: fluvial valley, erodible corridor, and the river's channel. In addition, we analyzed the connectivity with the floodplain.

Within the fluvial valley, we estimated (1) the presence of a continuous floodplain and (2) the connectivity with local terraces for water and, especially, sediments supply. Within the erodible corridor, defined conventionally as the distance on each river side that matches the channel width, we estimated: (1) the intensity of lateral migration processes recorded between 1954 and 2005; (2) the intensity of cut-off process by comparing recorded data between periods 1900–1954 and 1954–2005; (3) the intensity of meandering processes reflected in accumulation forms in the 2010 timeline (*i.e.*, above-water bars devoid of vegetation that are to be found in the vicinity of convex river banks of the analyzed meanders); and (4) the length of the erodible corridor in the 2010 timeline. Within the river channel, we evaluated (1) the changes in substrate composition and (2) the presence of large woods. For connectivity between river flow and floodplain, we evaluated (1) the presence of oxbow wetlands and we estimated (2) the frequency of flooding (exceeding the bankfull discharge Q_b) and (3) the frequency of geomorphologically efficient floods (exceeding the 10 years return period Q_{10}).

Each indicator falls into 2–3 classes, generally corresponding to the initial MQI (Table S3 in Supplementary File). A score of 0 indicates a quasi-natural functionality of a meandering planform; an intermediary score of 2–3 denotes a moderately disturbed hydrosystem; and a score of 5–6 indicates a disturbed hydrosystem.

4. Results: Level of Pressure and Alteration of Lower Prahova River

The Lower Prahova River has a good morphological quality (rMQI value = 24.4%; Figure 3). This value is resulting from a pressure index of 20.3%, and an alteration index of 28.4%. The pressure index value is derived from an intense (*i.e.*, dams and reservoirs construction) and three moderate human pressures (*i.e.*, other river management solutions upstream, bridges, and reforestation of banks on local scale), and the alteration index value is based on four intense changes (*i.e.*, radius of curvature, width, width–to–mean–depth ratio, and less intense cut-off process) and four moderate changes (*i.e.*, moderate intensity of lateral migrations and erosion/accumulation processes, a moderate change in the substrate composition, and the diminishing of the Q_b frequency). Scores attributed to each indicator are explained in Supplementary File.

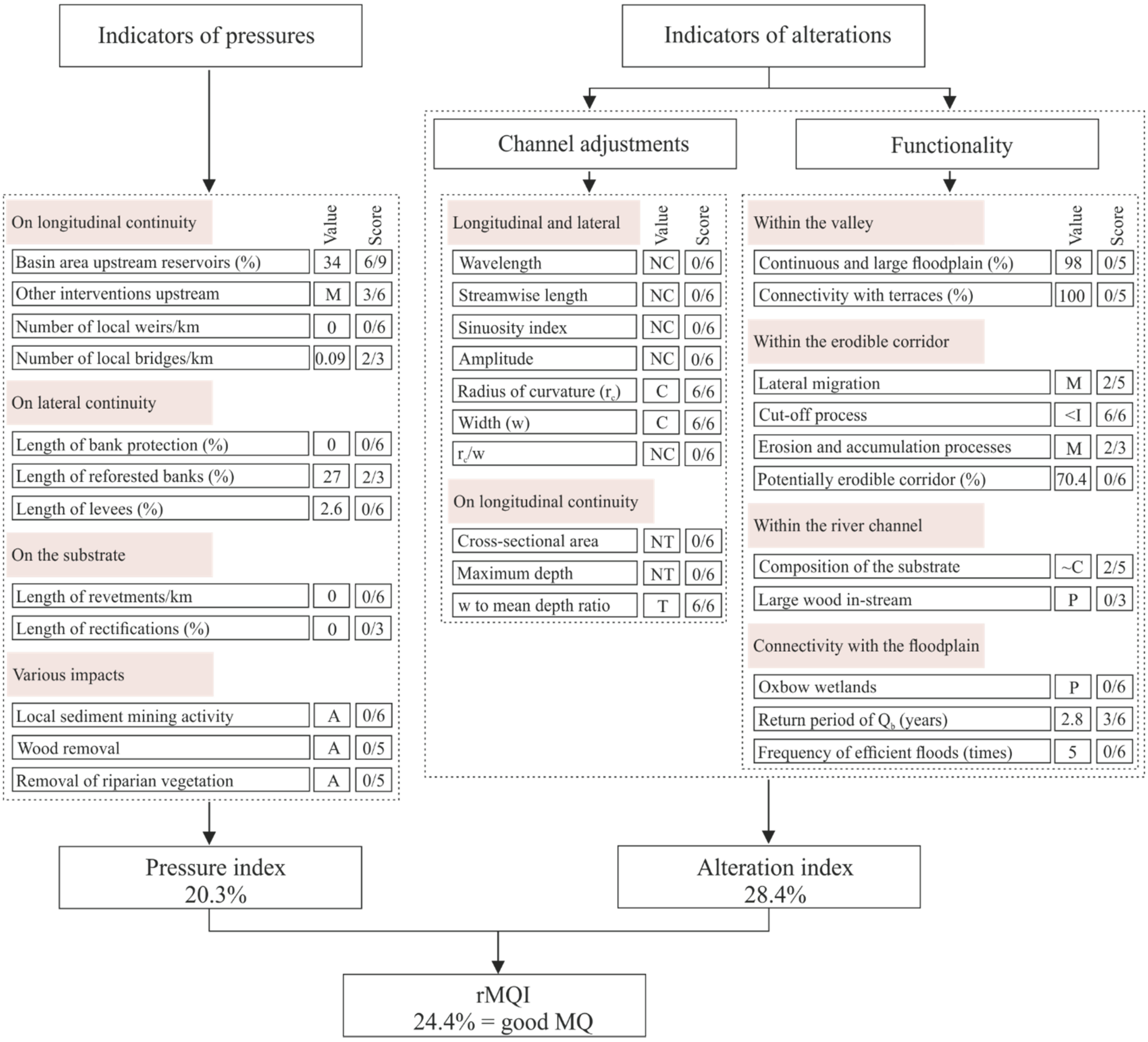

Figure 3. Results of Revisited Morphological Quality Index (rMQI) protocol for the Lower Prahova River; a list of acronyms for values are provided in Supplementary File.

In terms of human pressures, 33.3% of the pressure indicators were associated with impact on river channel and floodplain morphology of the lower course of the Prahova River. On the basin scale, we identified two types of pressures: (1) upstream dams and reservoirs comprising 34% of the area were determined as significant pressure contributors (score 6); and (2) other human interventions (e.g., bridges and weirs located upstream) were evaluated as moderate pressure contributors (score 3). On a local scale, we identified two types of pressures (Figure 4a): (1) reforestation of river banks amounting to 27% of both banks length (score 2); and (2) a bridge density of 0.09 bridges/km (score 2). The remaining 66.7% of pressure indicators were considered irrelevant on river channel and floodplain morphology. As an example, on a local scale, levees built as defense against floods on only 2.6% of both banks length were estimated as an insignificant pressure (score 0).

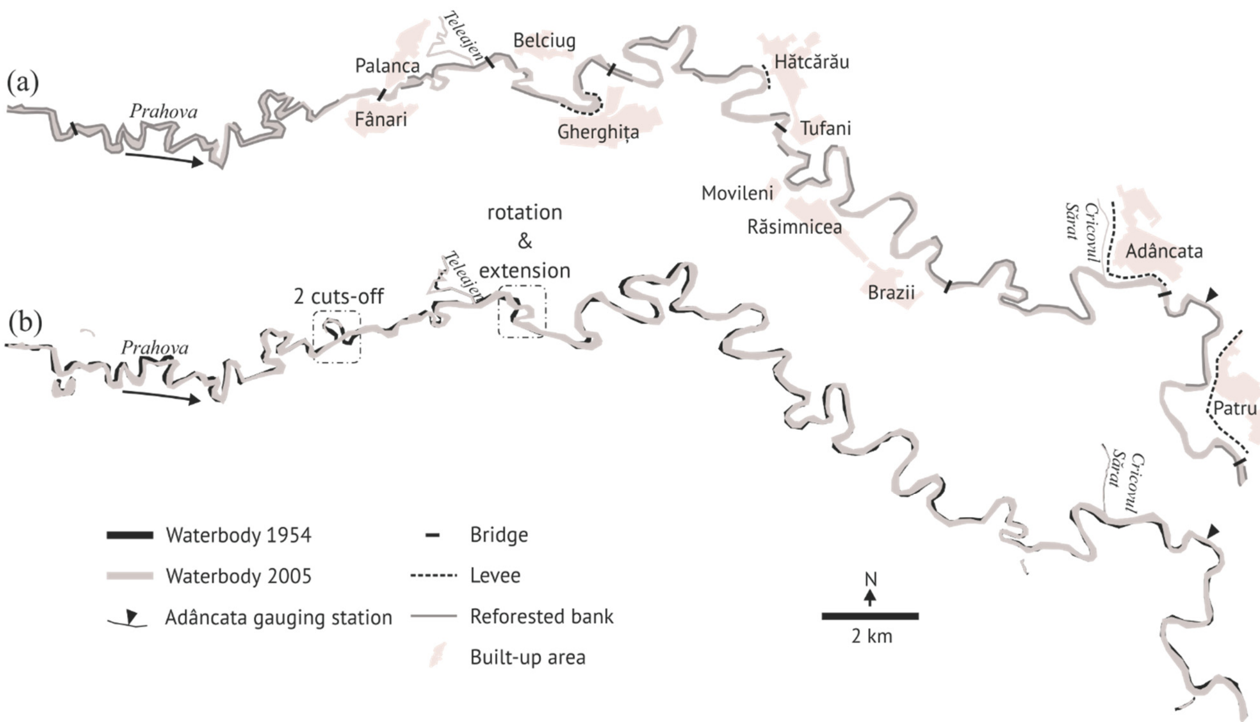

Figure 4. Particularities of the Lower Prahova River. (**a**) Local human pressures; (**b**) Lateral dynamics of river channel during the 1954–2005 timeline.

In terms of alteration associated with channel adjustments, 30% of all indicators registered some changes/trends (score 6). Radius of curvature of meanders, width and width–to–mean–depth ratio registered decreasing values: radius of curvature median fluctuated between 164 m in 1954 to 124 m in 2005; width median ranged between 50 m in 1954 to 42 m in 2005; width–to–mean–depth ratio decreased from 42.6 in 1966 to 19.2 in 2010 (Table 1). Most indicators of meanders geometry did not register statistically significant changes/trends (score 0), *i.e.*, wavelength, streamwise length, sinuosity index, amplitude, cross-sectional area and maximum depth. As an example, sinuosity index is maintained at 2.4 for a streamwise length of 1200 m; maximum depth was in the order of 3.2 m; cross-sectional area was approximately 150 m^2 (Table 1). In terms of alteration observed in the functionality of meanders, 45% of the indicators revealed a disturbed hydrosystem. As to alterations, we determined a moderate functionality or a diminishing of processes intensity specific to meanders (scores 2 or 6): (1) moderate intensity of lateral migration processes of meanders (*i.e.*, one expansion and one rotation during the 1954–2005 timeline) (Figure 4b); (2) moderate intensity of erosion/accumulation processes (in 2010); (3) decrease of cuts-off (*i.e.*, 2 cuts-off between 1954–2005 compared to 12 cuts-off between 1900–1954); (4) reduction of substrate grain-size from gravel and sand to only sand exclusively. Another moderate alteration was identified by a longer return period of Q_b – 2.8 years—indicating less frequent flooding compared to ideal undisturbed conditions (score 2). The balance of 55% of indicators suggested a natural functionality of meanders. As an example, on a floodplain scale, existent oxbows (Figure 4b) and the occurrence of five geomorphologically efficient floods within the past 50 years revealed undisturbed conditions (Table 1).

Table 1. Alteration indicators of the Lower Prahova River (statistically significant changes/trends in bold).

Indicator	Mean		Standard Deviation		Median		Change Mann-Whitney Test α = 0.05	
	1954	2005	1954	2005	1954	2005	Two-Tailed (*p*-value)	Upper-Tailed (*p*-value)
Wavelength (m)	540	544	261	296	516	492	0.759	--
Length (m)	1209	1203	558	626	1011	1049	0.736	--
Sinuosity index	2.4	2.4	1.0	0.9	2.1	2.3	0.871	--
Amplitude (m)	506	483	244	268	427	409	0.434	--
Radius of curvature (r_c) (m)	178	151	83	78	164	124	**0.029**	**0.007**
Width (w) (m)	53	44	19	15	50	42	**0.014**	**0.015**
r_c/w	3.4	3.5	1.3	1.7	3.1	3.1	0.781	--
Indicator	**Mean**		**Standard Deviation**		**Median**		**Trend Mann-Kendall Test α = 0.05**	
			1966–2010				**Two-Tailed (*p*-value)**	**Lower-Tailed (*p*-value)**
Cross-sectional area (m^2)	152		11.6		149		0.088	--
Maximum depth (m)	3.2		0.2		3.2		0.544	--
Width–to–mean–depth ratio	28.6		6		28		**<0.001**	**<0.001**
Indicator	**Value (m^3/s)**				**Return period (Log Pearson III, 1961–2010)**			
Q_b (m^3/s)	280				2.8 years			
Q_{10} (m^3/s)	550				1966, 1972, 1975, 1997, 2005			

5. Discussion

Applying the rMQI methodology, we concluded that the Lower Prahova River has a good morphological quality, with only slight human pressures, and a low alteration of river morphology. The rMQI protocol proved to be a useful tool for assessing river morphological quality in the frame of WFD by employing the available data in Romania.

5.1. Interpretation of Morphological Quality of the Lower Prahova River

When analyzing the influence of human pressures on the Lower Prahova River, we found three significant driving forces susceptible to impacting on river morphology: reservoir dam construction for a variety of uses, river management for defense against flooding by the construction of levees and for protection against lateral erosion by river bank reforestation, and other specific interventions such as consolidation of bridges. Our conclusions are consistent with prior studies since these forms of pressures appear to be common characteristics within the EU, where the majority of human pressures are associated with the water flow regulation by means of reservoir dam construction, local river management, and water abstraction [2].

As to the spatial scale of human pressures, the Lower Prahova River appears to be influenced principally by activities from the upstream part of the basin (*i.e.*, two indicators scoring 9/12) as compared to local pressures (*i.e.*, ten indicators scoring 4/49). However, the role of human pressures at the basin scale remains difficult to analyze and forecast due to unknown other simultaneous changes in (dis)connectivity between river compartments [37]. Additionally, in an overriding human impact framework on fluvial systems in the past centuries [38], the majority of studies indicate the difficulty in separating the role of each factor, human or natural, in river dynamics due to synchronous and simultaneous events [10,39–41] and, generally, in assessing rigorously physical processes especially in such morphological conditions assessment methodologies [11].

Concerning to the temporal scale of human pressures, the Prahova River experienced two phases of river management. The first phase (1950–1990) was characterized by extreme structural engineering measures: the construction of dams for hydropower, flow regulation and water extraction due to intense demand for water in a developing society—industry, urbanization, and intensive agriculture [42,43]; construction of levees for defense against flooding after their dramatic damages in the 1970s [42]. The second phase (1990–2010) was marked by softer legal norms in river management [44]. Law enforcement at the local level was lessened with the economic objectives overriding all river management norms. This led to the river's environmental degradation as exemplified by expanded sediment mining [45]. The Romanian example demonstrates that the transition from engineering to environmentally responsive vision in river management is challenging and complex when economic objectives are present and prevail. These evolutionary stages are common in river management as adopted by other European countries (Netherlands [46]; France [47]). Significant human pressures related to river management were adopted prior to the 1980s [46,47] and river management assumed a softer approach in relation to changes in the perception of the environment as a whole after 1990 [48]. The transition issues are becoming universal for Eastern European countries. In a flood risk domain, while the shift towards natural solutions in flood defense is well reflected at a national level, traditional engineered approaches favoring "grey" infrastructures still prevail at the regional level, as in the case of the Czech Republic [49].

In terms of qualitative alteration, the meandering Prahova River underwent a reduction of channel width, a lessening of its radius of curvature and width–to–mean–depth ratio. These consequences suggest a decreasing fluvial resources, in both water and sediment discharges [29,50] and in diminished frequency/duration of floods [51]. Nonetheless, high values of radius of curvature to width ratio (>2) and of width–to–mean–depth ratio (>20) prove that meanders are still functioning on each side by erosion and deposition [52,53]. Most likely, the Prahova River is an example of a passive meandering [54,55] (*sensu*), characterized by fine-grained alluvia and low evidence of active erosion/deposition forms. Similar channel narrowing were recorded for the Tisza River (Hungary, [56]), the Ebro River (Spain, [57,58], the Hernád River (Hungary, [51]) and the Aragon River (Spain, [59]). Over time, the Tisza and Ebro rivers metamorphosed into passive meandering, each with a relative lateral stability after 1950 in relation to human pressures (e.g., artificial bank stabilization works, revetments, and increase in reforestation).

The good morphological quality of the lower course of the Prahova River is probably due to the result of the absence of major human river management pressures on its local scale. However, the change from active to passive meandering indicates some disturbances within the hydrosystem. Even if the Prahova River complies with the demands of WFD for achieving a good ecological status, at least in terms of morphological components, questions should be posed concerning the further evolution of the river especially in the framework of a transition towards less-restrictive river management approaches at the national level.

5.2. Usefulness of rMQI for River Morphological Quality Assessment in Romania

The rMQI protocol uses 33 indicators, favoring indicators of alteration (21) instead of indicators of pressures (12). It places an emphasis on channel forms analysis using a diachronic approach that is consistent with classic fluvial geomorphology case studies on channel adjustments and may result in data practical to test and develop anthropogeomorphic theories [60]. To support this idea, we emphasize that, among the confirmation of alteration to the river's morphology, seven indicators were derived using the diachronic approach and one from the functionality verification within present timeline. Moreover, rMQI encouraged the usage of systematic gauging records that provided the only source of a continuous, long-term streamflow and channel-geometry databases [61]. In comparison to other attempts to use the MQI protocol, rMQI suggests more complexity in terms of variety of indicators and methods. Previous studies using MQI relied principally on GIS tools, lacking updated administrative databases [62] or analyzed only indicators for vertical dimension of 3D river channel [63]. Moreover, including additional data within hydromorphological assessments suggests an improvement in the significance of the results [64].

In terms of quantitative attributes, the degree of alteration of river's morphology seems to be more intense than the level of detected human pressures for our case study (28.4% for the alteration index *versus* 20.3% for the pressure index) compared to a quasi-natural status; it suggests a degree of alteration higher than the degree of human pressures, caused by various feedback loops in river landscape-human system, currently insufficiently known [65]. According to the WISE WFD database relying on the River Basin Management Plans [66], in most EU member countries, the reported state seem to be contrary: a greater number of river bodies is affected by pressures than by alteration of the habitat (e.g., among classified rivers, 66.1% suffered hydromorphological pressures and 31.4% registered altered riparian habitats in EU, as a mean value for member countries which reported both pressures and alterations). Romania reported that, among classified river bodies, 46.6% were affected by hydromorphological pressures and 16.5% by altered habitats. Two rationales account for this contradictory situation: (1) these results are not representative for rivers across Europe given that they tally only the classified water bodies and some Member States have reported only provisional data [66]; (2) in the case of Romania, the minimal number of indicators used for river morphology alteration (*i.e.*, channel depth and width) might impact on the results, pointing to the necessity of enhancing the national methodology before making any further decisions on river management policy.

The rMQI is an enhanced protocol in comparison to morphological pressure-alteration indicators used in RoHYMO: (1) rMQI is generally status-oriented [67] and includes 12 pressure indicators and 21 alteration indicators (10 for channel adjustments and 11 for functionality); (2) RoHYMO is mostly pressure-oriented [67] and includes 5 pressure indicators, and 2 alteration indicators (for channel adjustments). For these pressure indicators, two are comparable if we take into account their purpose (*i.e.*, damming, levees). Indicators for channel adjustments are equally comparable and exhibit vertical (depth) and lateral (width) changes during a given timeline. To expand morphological pressure-alteration assessment for Romanian rivers, we suggest the following improvements. Within RoHYMO, firstly, indicators should be added based on available data. In addition to the current ones, other indicators for pressures may be included and calculated from available recent orthophotoplans and existent administrative databases. For channel form adjustments, indicators should be adapted to a river's national hydromorphological typology [68]; they must include at a minimum one indicator for each dimension within a 3D model (*i.e.*, length revealed by sinuosity index, width and depth); yet, a higher number of indicators may confirm the results; these parameters may be computed on long-term data, available for gauging stations. Indicators for functionality are the most sensitive ones and must be based on multiple data types and approaches such as orthophotoplans interpretation, gauging station records, and field surveys. This protocol may have been applied since 1950, corresponding to important human interventions in Romanian river basins and also to systematic gauging records in Romania [69]. Secondly, the weighting process intensity by a scoring system proved to be an efficient approach developed within HYMO [5] by integrating a robust multi-criteria assessment [70]. However, the outcome of an rMQI protocol must be cautiously interpreted, due to a certain degree of subjectivity; nearly a quarter of the indicators depend on the experience of the evaluator of river management (e.g., absent, moderate, or intense sediment mining activity). Therefore, fluvial geomorphologists should be integrated into existing research teams [3,60,71] and field crews should be trained in fluvial morphology [7,72].

The rMQI protocol contributes to a morphological pressure-alteration analysis by expanding the number of indicators for alteration, which seem to be useful in the context of under-evaluated river alteration as compared to pressures in both RoHYMO conclusions and reports submitted to the EU. This indicates that, despite the central position taken by channel changes in recent studies of human impact on rivers [60], the integration of alteration indicators in quantification methodologies is deferred. When analyzing alteration of the Prahova River, we emphasized the need for integrating types of alterations; the quantification of changes should be associated to their features (*i.e.*, long-term increasing or decreasing values of an indicator). Therefore, in respect to James and Marcus [60], the fundamental goal remains to deepen the understanding of how humans alter rivers, which is a justification for greater participation of river scientists in decision making process.

6. Conclusions

Overall, the MQI protocol, based on indicators of pressure and alteration, was revisited for adaptation to the Romanian context and validated for the Lower Prahova River case study. The advantages of an rMQI tool are: (1) it is a standardized approach, allowing supplementary comparisons among rivers in EU countries; (2) it uses a variety of indicators based on diverse types of data, improving the significance of results; (3) it is adaptable to various spatial scales, from sector to geomorphic and hydraulic units; (4) the morphological indicators are analyzed independently from hydrological regime, that is sufficient for both rivers with or without altered, regularized flow. Therefore, the rMQI protocol may serve as a model to improve the assessment of morphological components within RoHYMO. On this basis, we recommend the adoption of indicators to the specificity of fluvial dynamics (*i.e.*, form, processes) for each type of river within a Romanian hydromorphological typology. Likewise, we propose an administrative bottom-up approach in morphological quality assessment by using local expert opinions in integrating results into classes of disturbance.

Besides the administrative purpose of rMQI, this tool may serve to expand further researches. The synthesis of the results would identify key issues in morphological quality of Romanian rivers and foster the detection of major issues that would assist in setting priorities for river management in terms of elaborating strategies to improve a river's ecological status.

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Author Contributions

Gabriela Ioana-Toroimac and Liliana Zaharia conceived the manuscript; Gabriela Ioana-Toroimac performed data analysis; Gabriel Minea collected and processed data; all the authors wrote the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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