Water quality of Danube Delta systems: ecological status and prediction using machine-learning algorithms

ABSTRACT

Environmental issues have a worldwide impact on water bodies, including the Danube Delta, the largest European wetland. The Water Framework Directive (2000/60/EC) implementation operates toward solving environmental issues from European and national level. As a consequence, the water quality and the biocenosis structure was altered, especially the composition of the macro invertebrate community which is closely related to habitat and substrate heterogeneity. This study aims to assess the ecological status of Southern Branch of the Danube Delta, Saint Gheorghe, using benthic fauna and a computational method as an alternative for monitoring the water quality in real time. The analysis of spatial and temporal variability of unicriterial and multicriterial indices were used to assess the current status of aquatic systems. In addition, chemical status was characterized. Coliform bacteria and several chemical parameters were used to feed machine-learning (ML) algorithms to simulate a real-time classification method. Overall, the assessment of the water bodies indicated a moderate ecological status based on the biological quality elements or a good ecological status based on chemical and ML algorithms criteria.

Key words | Danube Delta, machine learning, macro invertebrates, monitoring, water quality

INTRODUCTION

In the past decades, several anthropogenic activities such as hydrotechnical works, conversion of the natural ecosystems into arable lands, changes of riparian areas, industrial and municipal wastewater discharges, agricultural run-off, and introduction of alien species, affected the ecological integrity of worldwide lotic systems (Kwak & Freeman 2010; Ji et al. 2014; Liu et al. 2015). Unfortunately, the Danube Delta systems was an example of environmental degradation due to the above anthropogenic activities. In the early 1980s, the rectification works of the Southern Branch from the Danube Delta (Saint Gheorghe) facilitated navigation and strengthened the banks against coastal erosion, but unfortunately increased water and solid flows as well as meanders cut-off (Moldoveanu & Florescu 2010). Cutting the natural meanders caused biotope quality degradation by: (i) increasing the current velocity, the depth, and the organic deposit debris; the accumulation of nutrients and pollutants as well as the pathogenic bacterial load; and (ii) decreasing the transparency, and the structure of benthic fauna (Risnoveanu & Vadineanu 2000; Stoica et al. 2014).

Since the Water Framework Directive (WFD, 2000/60/EC) implementation, new approaches were established. The innovative contributions, aiming to achieve ‘good ecological status’, were accomplished at: (i) conceptual level, by introducing and explaining new concepts; and (ii) at the managerial level, by updating and developing the monitoring and the assessment of water bodies’ ecological status through physical, chemical, hydromorphological and biological integrated approach (EC 2000; Moldoveanu 2014; Poikane et al. 2014).

Thus, to assess the ecological status and to ensure a cohesion in terms of watershed management, the emphasis
is on ‘biological quality elements’. In this case, the macro invertebrates’ community composition was used as they are closely related to habitat and substrate heterogeneity. Moreover, ‘biological quality elements’ were more affected by anthropic and environmental pressure factors rather than ‘chemical quality elements’. Furthermore, results on monitoring the water quality allowed numerous researchers to develop a water quality index (WQI) useful to rapidly assess the water quality (Horton & Chase 1971; Horton 1965; Brown et al. 1970; Kumar & Alappat 2009; Nikoo et al. 2011). The method was applied not only for its ability to generate understandable classifications, but also for its potential to facilitate behavioral studies over time (Camejo et al. 2013). After the WQI computation, three different machine-learning (ML) algorithms were applied: partial decision tree (PART), artificial neural net (ANN); and k-nearest neighbor (k-NN). Lately, ML has become the main focus of many scientific fields, and it has been widely used in solving environmental problems, such as water resources modeling and management of problems (Rosly et al. 2015). Therefore, this study aimed to assess the ecological status of the major part of Southern Branch from the Danube Delta, Saint Gheorghe, through differentiation and testing of the proposed methods by structural and taxonomical composition of macro invertebrates as well as chemical elements. Furthermore, the water quality was assessed by a computational method as an alternative way for monitoring the water quality in real time based on water quality monitoring data from the studied area.

**MATERIALS AND METHODS**

**Geographical context**

Ten sampling sites (S2–S11) were established along the St. Gheorghe Branch (108 km, see Tiron Dutu et al. 2014) and one sampling site (S1) at 62 km upstream of the St. Gheorghe Branch on the Danube (total length 2,860 km while the last 1,075 km are in Romania) (Figure 1). The 11 sampling sites from this study belonged to two ‘water bodies’ from different typological categories: RO14 and RO15. The typology was defined considering the abiotic approaches (basin altitude, longitudinal outlining, lithological structure, flow, climatic features) and biotic approaches (potential biocenotic type). S1 belongs to the Danube – Calarasi – Isaccea (RO14) typological category and the other ten sites (S2–S11) located in the Danube Delta belong to the RO15 typological category according to Romanian River Basins Management Plan (RBMP 2010), the implementing tool of WFD. The South-East of the Danube Delta was chosen for this study due to the great socio-ecological role of this ecosystems complex at local, regional, national and international levels. The sampling sites location was selected based on St. Gheorghe Branch morphological changes as a result of the pressure from anthropic and environmental factors (Stoica et al. 2014). The water and sediment samples were monthly collected during 2013. Moreover, the methods were selected according to the legislation which requires the European Member States to develop and intercalibrate the assessment tools.

![Figure 1](https://iwaponline.com/wst/article-pdf/73/10/2413/461468/wst073102413.pdf)
Analytical methods

Physical and chemical analyses

Temperature (T), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (N-NH₄), nitrates (N-NO₃), nitrites (N-NO₂), orthophosphates (P-PO₄), total phosphorus (P) and total dissolved solids (TDS) were detected. The pump, then evaporated on a water bath, dried at 105 °C, and weighed. For the assessment of ecological status based on the Water Framework Directive (WFD), chemical and ecological water quality elements, the percentiles (P%) of pH, DO, Temperature (T), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (N-NH₄), nitrates (N-NO₃), nitrites (N-NO₂), orthophosphates (P-PO₄), total phosphorus (P) and total dissolved solids (TDS) were detected. The BOD was computed by oxygen determination during five days of incubation. For TDS analysis, the water sample (250 ml) was filtered through Filter-Lab glass microfiber filters (Ø = 47 mm; 1.2 μm pore size) using a vacuum pump, then evaporated on a water bath, dried at 105 °C and weighed. For the assessment of ecological status based on abiotic quality elements, the percentiles (P%) of pH, DO, N-NH₄, N-NO₃, N-NO₂, P-PO₄ and total P were analyzed according to EN ISO 7150-1 for N-NH₄, ISO 7890-3 for N-NO₃, EN 26777 for N-NO₂, EN ISO 6878 for P-PO₄ and total P) based on spectrophotometry. BOD was done using EN 1899 method. The BOD was computed by oxygen determination during five days of incubation. For TDS analysis, the water sample (250 ml) was filtered through Filter-Lab glass microfiber filters (Ø = 47 mm; 1.2 μm pore size) using a vacuum pump, then evaporated on a water bath, dried at 105 °C and weighed. For the assessment of ecological status based on abiotic quality elements, the percentiles (P%) of pH, DO, N-NH₄, N-NO₃, N-NO₂, P-PO₄ and total P were analyzed according to RBMP (2010).

Coliform bacteria analyses

Water samples were analyzed for total coliform (TC) bacteria using the most-probable-number (MPN) method that was assisted by incubation on disposable Quanti-Tray 2000. Colilert medium-18 contains a substrate solution that reacts with the galactosidase produced by coliforms. A single snap pack Colilert-18 medium was added to each 100 ml of sample. After 18–22 hours of incubation at 37 °C a TC positive reaction turns the medium yellow. The yellow wells were counted and the number was compared with the MPN according to EN ISO 9508-2.

Macro invertebrate analyses

The benthic invertebrates were characterized in terms of both taxonomic (qualitatively) and structural composition (quantitatively). Sample collection of benthic invertebrates followed by preservation and processing steps were performed according to Stoica et al. (2014). The quantitative structure was expressed in terms of frequency of occurrence (C), dominance (D) and significance ecological index (W). For the assessment of aquatic systems ecological status, taxonomic composition of macro invertebrates and numerical density values were used. Moreover, unicriterial indices such as Shannon-Wiener Index (SWI), Oligochaeta-Chironomidae Index (O/CHI), family number (FAM), Functional Group Index (FGI), water flow preference index: fast (REO) and slow (LIM) and/or multicriterial indices such as Multimetric Index (MI) were calculated (RBMP 2010). Both indexes Ephemeroptera-Plecoptera-Trichoptera Index (EPT_I) and Saprobic Index were not calculated because of the absence of EPT species and lack of identification of Oligochaeta, Nematoda, Dipera at species level, respectively. The ‘one-out, all-out’ principle (EC 2000) was applied for the ecological status final classification.

ML algorithms

To accomplish the ML method for real-time monitoring purposes, a WQI was determined in the first place as an initial reference for the classifiers algorithms. The WQI was computed based on a multiplicative form of the (US) National Sanitation Foundation (NSF) method (Kumar & Alappat 2009). The parameters used were: DO, TC, pH, BOD, T, total P, N-NO₃ and TDS. As feature selection, a VarSelRF algorithm, based on ‘Random Forest’ was used. Following the VarSelRF results, only three of the eight parameters were selected in this study: DO, N-NO₃ and pH. The selected parameters and Kumar classification fed the ML algorithms. The classification step, as shown in Figure 2, implemented two cross-validation methods. The second method was used for validating every iteration from the first cross-validation method. The 80% of these data were applied to train the model, 10% to validate it and the remaining 10% were used for a final test of the model generated by ML algorithms. Moreover, the PART algorithm classifier was selected with 95% confidence. The PART algorithm is known as Induction Algorithm Decision Lists and is based on a ‘divide-and-conquer’ strategy.

The other two candidates were a k-NN algorithm based on the Bregman Divergences and Mahalanobis distance and ANN back propagation algorithm with three hidden layers: three and one neurons, respectively.

RESULTS AND DISCUSSION

Assessment of the water bodies’ ecological status using chemical quality elements

As required by the WFD, chemical and ecological water bodies’ status was assessed. The analysis of abiotic quality
elements and the macro invertebrates' community allowed the assessment of Danube (RO14) and Danube Delta (RO15) water bodies during 2013. For the assessment of chemical status, P$_{90}$ of raw indicators values were applied (Table 1). The values were compared with the established threshold values for 'very good/good' (FB/B) and 'good/moderate' (B/M) ecological status (RBMP Annex 6.1.3A, 2010).

The pH (P$_{90}$) measurements were calculated for each sampling site and ranged between the pH of 6.65 at S6 and 8.23 at S3. The pH values were within 6.5 and 8.5 range, characteristic interval for a very good and good ecological status, respectively.

P$_{10}$ were calculated for the DO, measured in terms of concentrations. The DO P$_{10}$ values at S1 were lower than the FB/B limit but higher than B/M limit, which indicated 'good' ecological status for RO14 water body. Concerning RO15 water body, the DO percentiles values showed 'good' ecological status at S2, S3, S5, S7, S8 and 'very good' ecological status at S4, S6, S9, S10 and S11.

The P$_{90}$ applied to nutrient concentrations were lower than FB/B limit for RO14 typology, thus the water body showed 'very good' ecological status. In the case of RO15 typology, the P$_{90}$ values of N-NH$_4$, N-NO$_2$, P-PO$_4$ and total P were lower than the FB/B limit in all sampling sites, nutrients which indicated 'very good' ecological status. The P$_{90}$ applied for N-NO$_3$ concentration were below the FB/B limit in all stations, except S3, S7, S8 and S11 where the N-NO$_3$ exceeded FB/B limit.

Taking into account the 'one-out, all-out' principle, during 2013 the assessment of chemical quality elements indicated

### Table 1

<table>
<thead>
<tr>
<th>Water body</th>
<th>Sampling sites code/ limit values</th>
<th>Chemical quality elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danube (Calarasi-Isaccea)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>7.82</td>
<td>6.95</td>
</tr>
<tr>
<td>FB/B</td>
<td>6.5–8.5</td>
<td>8</td>
</tr>
<tr>
<td>B/M</td>
<td>6</td>
<td>1.4</td>
</tr>
<tr>
<td>Danube Delta (St. Gheorghe Branch)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>7.83</td>
<td>7.01</td>
</tr>
<tr>
<td>S3</td>
<td>8.23</td>
<td>7.56</td>
</tr>
<tr>
<td>S4</td>
<td>7.92</td>
<td>8.49</td>
</tr>
<tr>
<td>S5</td>
<td>7.80</td>
<td>7.95</td>
</tr>
<tr>
<td>S6</td>
<td>6.65</td>
<td>8.11</td>
</tr>
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<td>S7</td>
<td>7.67</td>
<td>7.76</td>
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<td>S8</td>
<td>8.01</td>
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<tr>
<td>S9</td>
<td>7.85</td>
<td>8.41</td>
</tr>
<tr>
<td>S10</td>
<td>7.81</td>
<td>8.11</td>
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<td>8</td>
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<tr>
<td>B/M</td>
<td>6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Ecological status (Quality class): 'good' (II).
'good' ecological status for both the Danube water body (RO14) and St. Gheorghe Branch (RO15), respectively. In spite of a slow decrease of total suspended solids and turbidity, as reported during the past century (Gastescu & Tuchiu 2012), due to particular hydrological regime and morphological conditions, the DO values were low at S1 (Isaccea) on Danube, S2 (Upstream Tulcea) and S3 (Downstream Tulcea). Low DO concentrations were also recorded along St. Gheorghe Branch especially due to a high organic load generated by biodegradation processes that occur in the lotic system. Moreover, they were amplified by high temperatures, low flow rate and wastewater discharges. At the same time, the DO decreased might be caused by TDS increase, which could be correlated with the organic debris generated by microbial communities (Catrangiu et al. 2015). Moreover, increased levels of nutrients (in this case, N-NO₃) were associated with the decrease of DO concentration at S3 (Downstream Tulcea), S5 (Baltenii de Sus), S7 (Murighiol), S8 (Uzlina), and S10 (St. Gheorghe) as a result of nitrification process and inputs caused by anthropogenic activities from downstream Tulcea county (unpublished data).

Assessment of the water bodies ecological status using macro invertebrates

In addition, to draw a better picture of the water quality, we used macro invertebrates as an assessment tool, because they have the potential to point out – through population structure and composition changes – the effects of various environmental pressures, such as chemical pollution or hydromorphological changes (Hering et al. 2004; Ismail et al. 2014). The analysis of the macro invertebrates' composition allowed in 2013 the identification of ten taxa of which six were phylum (Nematoda), class (Oligochaeta) and family (Psychodidae, Ceratopogonidae, Tipulidae, Chironomidae) level as well as 41 at species level. The main species which recorded the highest frequency of occurrence (100%) along the Danube and St. Gheorghe Branch, were: Oligochaeta, Chironomidae, Bivalvia (Dreissena polymorpha, Corbicula fluminea) and Gasteropoda (Lithoglyphus naticoides, Theodoxus danubialis), except for Amphipoda (Corophium curvispinum) with 81.8% frequency of occurrence (Figure 3(a)). In terms of dominance over the entire populations the Oligochaeta reached 14, 8%, Amphipoda (C. curvispinum (9, 28%)), Bivalvia (D. polymorpha (5, 35%), and Gasteropoda (L. naticoides (10, 6%)) (Figure 3(b)).

In terms of significance ecological index (W%), the worms, crustaceans of Ponto-Caspian origin C. curvispinum, non-native D. polymorpha species, as well as L. naticoides snails were ranked as the highest species in the studied area (Figure 3(b)). The results were comparable with the studies conducted by Litéathy et al. (2002), Sommerwerk et al. (2010), Martinović-Vitanović et al. (2013), and Liška et al. (2015).

Based on the structure and composition of benthic invertebrates, several indices (Table 2) were proposed to evaluate the ecological status of water bodies’ (RBMP 2010).

The analysis of unicriterial indices revealed the following aspects: SWI values characterized RO14 and RO15 water bodies as having a good and moderate ecological status; the O/CHI values pictured the Danube water body for very good ecological status and the Danube Delta (St. Gheorghe Branch) for good ecological status due to the values recorded at S6 (Mahmudia) and S7 (Murighiol). The FAM value at S1 (Isaccea) characterized the RO14 typology for good ecological status. The lowest and highest FAM values were recorded at S3 (Downstream Tulcea) and S10 (St. Gheorghe), respectively. Thus, for RO15 typology, the FAM values indicated both moderate and very good ecological status. The FAM values determined for the other

![Figure 3](https://iwaponline.com/wst/article-pdf/73/10/2413/461468/wst073102413.pdf)
sampling sites situated along St. Gheorghe Branch showed good ecological status. All FGI values were greater than the ‘good’ threshold value, thus the FGI values indicated very good ecological status for RO14 and RO15 typologies.

The water flow preference index values, for REO were characteristic for bad ecological status for the two studied water bodies. Based on LIM values a good ecological status for RO14 typology was assigned, but a bad one was determined for RO15 typology.

The unicriterial indices from 2013 allowed a heterogeneous classification of Danube (RO14) and Danube Delta (RO15) water bodies. Moreover, they showed high variability at both temporal and spatial levels. The lowest correlation between sampling sites was observed for OCH/O ($R^2 = 0.0326$) and SWI ($R^2 = 0.0344$), while FAM presented a good correlation ($R^2 = 0.5164$). Therefore, the multicriterial indices developed for benthic invertebrates’ community allowed the classification of water bodies’ ecological status as a single value (Moldoveanu et al. 2013) (Table 2). The final classification of Danube and Danube Delta (St. Gheorghe Branch) ecological status based on macro invertebrates and MI values indicated a moderate ecological status (Figure 4(b)). In this case, the hypothesis confirmed in which benthic invertebrates integrated into

<table>
<thead>
<tr>
<th>Water body</th>
<th>Water body typology</th>
<th>Sampling sites code</th>
<th>SWI O/CHI (%)</th>
<th>FAM (%)</th>
<th>FGI (%)</th>
<th>REO (%)</th>
<th>LIM (%)</th>
<th>MI</th>
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<tbody>
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<td>RO14</td>
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<td>6</td>
<td>77</td>
<td>7</td>
<td>70</td>
</tr>
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<td>10</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>Danube Delta (St. Gheorghe Branch)</td>
<td>RO15</td>
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<td>8</td>
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<td></td>
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<td>34</td>
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<td>5</td>
<td>60</td>
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<td>S10</td>
<td>1.93</td>
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<td>11</td>
<td>54</td>
<td>9</td>
<td>45</td>
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<tr>
<td></td>
<td>'good'</td>
<td></td>
<td>1.3</td>
<td>60</td>
<td>6</td>
<td>10</td>
<td>20</td>
<td>70</td>
</tr>
</tbody>
</table>

Ecological status (Quality class): 'moderate' (III).

SWI: Shannon-Wiener Index; O/CHI: Oligochaeta-Chironomidae Index; FAM: family number; FGI: Functional Group Index; REO (fast) – LIM (slow): water flow preference index; MI: Multimetric Index.

**Figure 4** | WQI average values applied on 2013 datasets along Danube and Danube Delta using Kumar & Alappat (2009) methods (a) and the correlation between ecological status and prediction using ML algorithms (b).
their structure the effects of environmental pressures, such as chemical pollution or hydromorphological changes.

Overall, the 2013 unicritical indices dynamics revealed a strong substrate type dependence; highest FAM values were recorded at S8 (Uzlina) and S10 (St. Gheorghe) where organic substrate abounded. The reoife species prevailed at S4 (Nufaru) and S5 (Baltenii de Sus) where the water velocities allowed a better oxygenation of the substrate.

Nevertheless, a series of limits should be refined in Europe with regards to harmonization of ecological status assessment methods (Poikane et al. 2014; Reyjol et al. 2014) especially for large rivers such as the Danube.

Classification system using ML algorithms

The real-time classification system was developed as a chain of three different blocks with specific functionalities as previously described. The water quality monitoring data from 2013 were applied to the system. After the initial WQI classification based on NSF improved method (Kumar & Alappat 2009), 48 samples were classified in Class II (good) and 16 samples in Class III (medium), according to Brown et al. (1970) (Table 3).

The WQI values calculated for Danube and St. Gheorghe Branch reached Class III water quality class (medium) for S4 (Nufaru) and S6 (Mahmudia) and Class II water quality class (good) for the other nine sampling sites (Figure 4(a)).

Moreover, the VarSelRF algorithm showed good performance when selecting relevant subsets of features. The relevant outputs were: TC, DO, N-NO3 and pH. However, due to the difficulty of TC real-time monitoring, this parameter was removed from the classification process. Although, different ML algorithms (PART, ANN, k-NN) showed similar tendencies when considering the three parameters that could be measured in real time (DO, N-NO3 and pH), the optimum results were obtained by the PART algorithm. The final classification accuracy reached 94.85% for ‘medium’ class and 96.73% for the ‘good’ class.

The results based on the chemical, biological ecological status assessment and prediction emphasized that ML algorithms could be a feasible tool for classification in real time. A good DO and N-NO3 indicators correlation was recorded between ML algorithms and chemical element assessments. Overall results showed that the macro invertebrate community is the appropriate tool for the long-term ecological status assessment (Figure 4(b)).

CONCLUSIONS

In the present study, three types of methods, based on biological and chemical quality elements as well as ML algorithms, were tested with the purpose of water quality assessment of the Danube Delta (St. Gheorghe) and of 62 km area upstream of the Danube.

The data from 2013 water quality monitoring were applied for detecting the chemical status and for prediction using the ML algorithms.

The assessment of water bodies’ ecological status by chemical quality elements showed that DO and N-NO3 were the main defining indicators for the RBMP tested method.

Moreover, based on field results and ML algorithms, it is recommended that the organic load such as chemical oxygen demand, BOD and salinity indicators (electrical conductivity) as well as TDS should be taken into consideration as possible new parameters for the ecological status assessment.

Considering the ‘one-out, all-out’ principle the chemical quality elements indicated ‘good’ ecological status from both Danube (RO14) and Danube Delta (RO15).

The WQI prediction using ML algorithms, showed good accuracy with NSF method and could be a feasible tool for real-time classification.

The combination between VarSelRF (as feature selection) and PART (as classifier) showed a close correlation with NSF modified method. Moreover, the overall water quality from this study was classified as ‘good’ according to the NSF method. Thus, a close correlation was observed between the two tested methods – chemical status and prediction using ML algorithms.

Concerning the benthic invertebrates’ analysis, the unicritical indices allowed a heterogeneous classification of Danube and Danube Delta water bodies from spatial and temporal perspective. However, the MI values indicated the final ecological status of the studied water bodies. The classification of the studied water bodies’ ecological status

Table 3 | WQI ranges (Brown et al. 1970)

<table>
<thead>
<tr>
<th>Range</th>
<th>Categories</th>
</tr>
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<tbody>
<tr>
<td>90–100</td>
<td>Excellent</td>
</tr>
<tr>
<td>70–90</td>
<td>Good</td>
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<tr>
<td>50–70</td>
<td>Medium</td>
</tr>
<tr>
<td>25–50</td>
<td>Bad</td>
</tr>
<tr>
<td>0–25</td>
<td>Very bad</td>
</tr>
</tbody>
</table>
based on macro invertebrates predicted a moderate ecological status. Even though the water quality assessment based on chemical elements and ML algorithms provided a rapid response, the biological elements gave an accurate answer.

Nevertheless, future research is needed to integrate long-term monitoring data to ensure high levels of confidence and precision in assessing the status of water bodies.

ACKNOWLEDGEMENTS

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REFERENCES


EN 1899 2003 Water quality – Determination of biochemical oxygen demand after n days (BODn) – Part 1: Dilution and seeding method with aldehydihemoglobin addition.


Moldoveanu, M. 2014 The development and testing of ecological indexes set for monitoring and evaluating the lotic systems integrity, PhD Thesis, University of Bucharest, Bucharest, Romania, 213 (in Romanian).


River Basins Management Plan (RBMP) 2010 (in Romanian).


