

## **An Approach for Monitoring and Assessment of Hydromorphological Water Quality at Different Waterbody Types by Using Standard Method**

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### **ABSTRACT**

After publishing the Water Framework Directive, integrated water quality monitoring, including biological, chemical, physicochemical and hydromorphological quality elements, was gained special importance. Monitoring and assessment of hydromorphological quality elements are still challenged issue because of unstandardized applications in hydromorphological monitoring and assessment activities. In this study, hydromorphology are discussed as objective and scope. To monitor and assess hydromorphological feature of waterbodies, a new monitoring and assessment approach which takes into account the features affecting the hydromorphological parameters was addressed. A standard methodology which can be applied for different waterbody types and applied in different river basins characteristics was developed for monitoring and assessment of hydromorphological features of rivers and the methodology was applied at seven different river basins in Turkey. The method gave the expected assessment results for the waterbodies in all basins and provided sufficient consistency to be used as a standard method across the country.

**Keywords:** Hydromorphology, Water Framework Directive (WFD), Hydromorphological Monitoring, Hydromorphological Assessment, Hydromorphological Index, Hydromorphological Quality Elements.

### **1. INTRODUCTION**

In order to assess water quality, ecosystem-based approach was gained importance worldwide. In the scope of the integrated water quality monitoring, beyond the chemical quality elements, ecological quality elements including biological, physicochemical and hydromorphological quality elements needed to be monitored.

Hydromorphology is one of the important water quality elements for river ecosystem and after publishing the Water Framework Directive (WFD) (European Commission,

2000) its importance has increased even more for assessment of water quality of waterbodies.

According to the WFD, the term “hydromorphology” is the quality elements supporting the biological quality elements and it is the indicator of habitat quality, so a comprehensive evaluation of ecological water quality must always include a hydromorphological assessment (Meier et. al., 2013). Only in this way the information obtained from biological monitoring can be interpreted and ecological deficits from natural conditions can be recognized correctly (Verdonschot et al., 2012; Meier et. al., 2013). Therefore, methods that characterize the hydromorphological features of rivers and assess river habitat quality have arising importance as a decision-making tool in river basin management (Raven et al., 2002).

During recent decades, with notable differences in their aims, scales, and approaches, several hydromorphological monitoring and assessment methods have been developed in different countries (Belletti et. al., 2014; Azlak, 2015). Countries have developed different hydromorphological monitoring and assessment methods which suit their own country conditions. Although these methods are increasingly applied to support river management, the strengths and limitations have been insufficiently investigated (Belletti et. al., 2014; Azlak, 2015). Moreover, because there are a large number of methods, standardizing the hydromorphological assessments is challenging issue. In this study, to monitor and assess hydromorphological features of rivers with a standard method, an approach that can be applied for different waterbody types and at different basins has been put forward.

## 2. HYDROMORPHOLOGY

Hydromorphology has several conflicting definitions (Vogel, 2011), but after the WFD the term "hydromorphology" has been used widely and has gained a new special meaning (Azlak, 2015). In the WFD, with regard to hydromorphology, it is said that “hydromorphological quality elements which support biological quality elements”. Considering the boundaries drawn in the WFD, hydromorphology can be defined as the study area including the measurements which is made to monitor changes in water amount and flow, river channel, river bed, substrate, riverbank, riparian zone, aquatic and riparian habitat and also it can be defined as studies which are made to determine the ecological status. In this context, it can be said that hydromorphology is multi-disciplinary research area that examines and assesses the physical, hydrological and morphological characteristics of water bodies and the processes underlying these characteristics (Azlak, 2015).

In the WFD hydromorphological parameters are given (Table 1). River hydromorphology has three main hydromorphological parameters which are hydrological regime, continuity and morphological conditions. These three main hydromorphological parameters have a lot of sub hydromorphological monitoring and assessment parameters and these sub-parameters vary from method to method.

**Table 1:** Hydromorphological elements supporting the biological elements. Orange: Additional recommended sub quality parameters and tools which were identified by EU Member States for that particular water body type.

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### Hydrological regime

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- *Quantity and dynamics of water flow*
    - ✓ *Historical flows*
    - ✓ *Modeled flows*
    - ✓ *Real time flows*
  - *Connection to groundwater bodies*
    - ✓ *Water table height*
    - ✓ *Surface water discharge*
- 
- River continuity**
- 
- ✓ *Number and type of barrier*
  - ✓ *Provision for passage of aquatic organism*
- 
- Morphological conditions**
- 
- *River depth and width variation*
    - ✓ *River cross section*
    - ✓ *Flow*
  - *Structure and substrate of the river bed*
    - ✓ *Cross sections*
    - ✓ *Particle size*
    - ✓ *Presence / Location of CWD*
  - *Structure of the riparian zone*
    - ✓ *Length/Width*
    - ✓ *Species compositions*
    - ✓ *Continuity/ground cover*
  - *Current velocity*
  - *Channel Pattern*
- 

**Source:** (CIS No:7, 2003).

### 3. HYDROMORPHOLOGICAL MONITORING AND ASSESSMENT

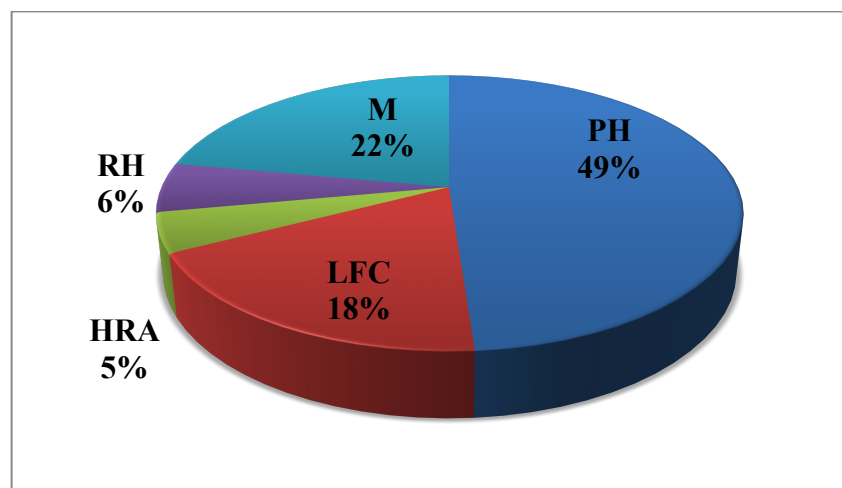
Hydromorphology is one of the main indicators of the ecosystem features. Determination of hydromorphological characteristic of waterbodies is important to understand waterbodies' ecological quality. Making hydromorphological monitoring is generally aimed at revealing the physical and hydrological interventions on the waterbodies and collecting information on physical, morphological, hydrological and qualitative aspects of the waterbodies. When assessing the status of waterbodies and aquatic life (biological quality elements), these collected information are used as supporting data.

The main idea behind the water quality monitoring and assessment activities is to determine the departure from the natural or non-intervened conditions and to achieve the waterbodies to good ecological status. In this scope, hydromorphological monitoring and assessment activities are carried out to determine physical, morphological and hydrological divergence from natural conditions. The other important idea behind the hydromorphological monitoring and assessment activities is to determine whether the hydromorphological features of waterbodies produce habitat diversity on waterbodies or not. Hence, towards the end of the 20th century, hydromorphological assessment mainly focused upon occurrence and spatial

configuration of physical habitats (e.g., Platts et al. 1983; Plafkin et al. 1989; Raven et al. 1997, 2002; Belletti et. al., 2014).

Hydromorphological assessments are usually carried out with data collection forms (indexes) including assessment criteria. For hydromorphological monitoring and assessment; a lot of forms (methods) have been developed specifically by different countries. Through these forms, physical, morphological, hydrological and qualitative features of the studied waterbodies can be collected and the hydromorphological status of the examined waterbodies can be assessed. While the contents of the forms vary, in general the survey forms are not holistic that will cover and can assess all of the hydromorphological features of waterbodies. The fact that there are many different methods on the basis of the countries leads to incomparability of the methods (Azlak, 2015).

The differences between purposes of methods and varying the focused hydromorphological elements have led to the necessity of classifying existing monitoring and assessment forms. In this context, a classification was made for river hydromorphology monitoring and assessment methods. With no clear distinction between classification characteristics, methods have been grouped into five categories, as physical habitat assessment (PH), riparian habitat assessment (RH), morphological assessment (M), hydrological regime alteration (HRA) and longitudinal fish continuity assessment (LFC) (Rinaldi, et. al., 2013).



**Figure 1:** Developed methods in Europe according to assessment purpose (%) (Azlak, 2015).

Most of the developed methods have been focused on one main hydromorphological quality parameter and its sub-parameters. This demonstrates that multiple method systems should be used or used methods should be supported with other complement tools like database, satellite images etc. for an integrated hydromorphological monitoring and assessment.

#### 4. HYDROMORPHOLOGICAL PROCESS OF RIVERS

Rivers pass different process from source to river mouth. River formation and development process starts at high altitudes where can be called as source and

finishes at low altitudes where the river discharged to one exit point (sea, lake etc.) and called as river mouth.

River streams characteristic changes from source to river mouth. At high altitude, rivers have more coarse substrates. Form of the valley at high altitude is deeper than lower altitude and generally U and V shaped valley forms are seen. This affects the flow types and flow velocity of rivers. Flow type is generally in form of riffle and pool combinations or cascade - step pool. Flow velocity is high. Depth of flow is low and width of river channels narrower than low altitudes. Erosion process generally occurs as vertically and gradient of rivers is high. Meandering process can't occur because of valley type in general, so sinuosity of river is very low. High-altitude rivers are generally in mountain area, so they aren't be affected from land use effects. These kind of rivers' riparian zones are covered by forest mostly. Because of forest covered riparian zone and narrow width, woody debris and tree roots can be seen in river channel and shading effect over rivers is high. Shading effect can also be caused by valley type at high altitude. Moreover, pressures which affect hydromorphological features of rivers like urbanization, agricultural and industrial activities, abstraction, discharge etc. are less than low-altitude rivers (Figure 2).

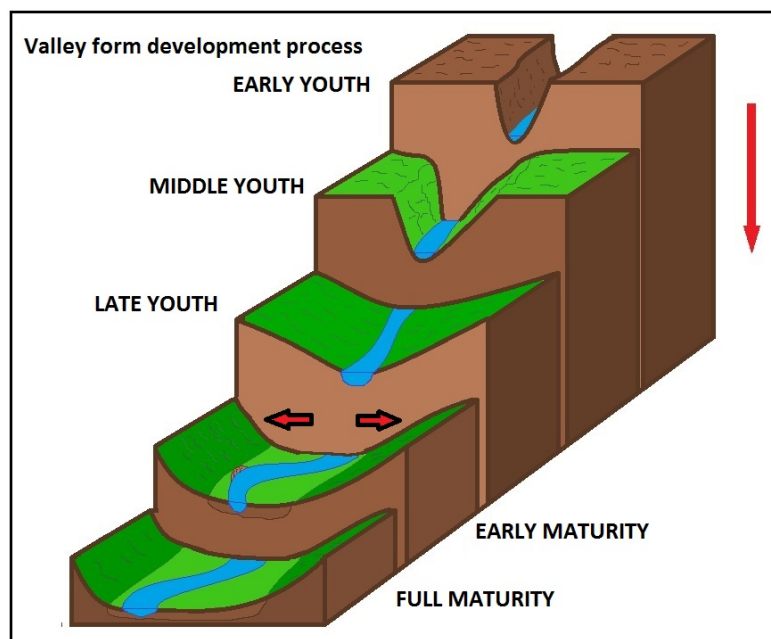


**Figure 2:** High-altitude rivers.

From high altitudes to mid altitudes, catchment area of river increase. As a result, amount of water in the rivers increases and the rivers get large. Width and depth of the rivers increase and this affects the flow types. Flow type changes from cascade-step pool to riffle-pool-glide combination. In contrast to the catchment area and water amount, gradient of stream decreases from higher to lower altitudes. Because of decreased gradient, flow velocity gets slow. The slowing of the rivers causes the suspended sediments to begin collapsing. Thus, substrate composition of river bed is

combination of fine and coarse materials. Valley type at mid altitude changes according to high altitude and gets shallower. Depending on this, the rivers swing from side to side. Meandering formation process begins. Erosional and depositional effects start. The river channels start to fill with sediment and lateral erosional processes occur. Pressures which affect hydromorphological features of rivers like urbanization, agricultural and industrial activities, abstraction, discharge etc. are more than high-altitude rivers.

When rivers enter into low altitude, the amount of the rivers achieves the maximum values. Depth and width of the rivers increase. Gradient of the rivers becomes minimum, so velocity of the flow decreases. Flow type converts into run which has medium or low speed and is flat, non-turbulent flow. Decreased velocity flow increases deposition of sediment. Substrate of river channel becomes fine material like silt, clay and sand dominantly and because of this, embeddedness increases. The water gets turbid and color of water changes, become denser. Valley type gets shallower, it is almost flat (Figure 3). As a result of this, rivers swings a lot and constitute huge loops. It can also possible to see braided river structures which are possible result of widening and ox-bow lakes which are possible result of huge loops. Flat valley type affects the land use at riparian zone. Land use at riparian zone is generally agricultural. Beyond the agricultural land use, anthropogenic activities like industrial pressures, urbanization, abstraction and discharge, channelization etc. affect the low-altitude waterbodies more than upper-altitude waterbodies as hydromorphological pressures.



**Figure 3:** Valley form development process.

## 5. METHODOLOGY

Numerous researchers emphasize that the river quality assessment requires knowledge about the hydrological regime, geological formation, and geomorphological processes of the stream, as well as about impacts of natural and anthropogenic origin both in the past and present (Riis and Biggs, 2003; Tremp, 2007; Jēkabsone and Uzule, 2014). As mentioned at former title, hydromorphological process of rivers

changes from source to mouth. Therefore, when assess the hydromorphological features of waterbodies; this issue should be taken into account. In this scope, most important qualifications which hydromorphological monitoring and assessment methods should carry are that they have a holistic viewpoint and they take into account the hydromorphological processes which change from source to mouth and are affected from geographical and climatological conditions. In this context, it is necessary to give selectable assessment with the concept of "different assessment at different types". This situation is actually identified with the classification concept of river waterbodies such as the WFD compliant typology studies, Rosgen Stream Classification (RSC) (Rosgen, 1994, 1996) etc.. The term "Selectable assessment" is the assessment that carries out by taking into account the conditions which affect the hydromorphological parameters. In addition to parameters of selectable assessment, there are also parameters that don't affect from hydromorphological processes of rivers. This kind of parameters can be called as "Type-independent parameter" and can use for all water bodies at all river basins (Azlak, 2015)

In this study, in order to use standard method for all waterbodies and for all river basins that have different characteristic, standard parameter list was determined. After determining parameter list, features which affect the some of the determined parameters (parameters of selectable assessment) were identified. The identified features are intended to assist in providing a holistic assessment of the hydromorphology which is sensitive to the dynamic behavior of river channels; the upstream, downstream and lateral connectivity of channels; and the relationship between physical and biotic characteristics.

### **5.1. SELECTED FEATURES AFFECTING PARAMETERS**

In the scope of the study, six features are identified to develop standard method. These are altitude, upper forest level (UFL), climate zone, flow type (seasonality of flow / perennial, ephemeral), valley type and river width.

#### **Altitude:**

Altitude is the most critical feature to monitor and assess hydromorphological characteristic of rivers. As mentioned at former title (3), hydromorphological characteristic of rivers change with altitude. Most of the hydromorphological monitoring and assessment parameters like; hydrological parameters, flow type assessment parameters, substrate parameters, riparian zone assessment parameters, habitat diversity parameters etc. are affected by altitude directly. Therefore, altitude was used as high, middle and low to develop assessment criteria.

#### **Upper Forest Level (UFL):**

Upper forest level is the border where the forest and trees presence is ended. This feature is important to assess riparian vegetation parameters (buffer riparian zone) and riparian forest assessment. Above the UFL, there is also no woody debris occurrence and shading effect. Therefore UFL was used in this study.

#### **Climate Zone:**

Climate zone is the other important features which affects the hydromorphological characteristics of rivers. Hydrological regime is directly linked to climatic conditions, but the assessment of hydrological parameter is done by using gauge stations' data. For assessment of hydrological regime parameters, reference time series of representative gauge stations can be used and departure from natural condition can be determined correctly. Thus, there is no need to take climate zone feature into consideration in hydrological regime assessment, but climate zone features is important for standardizing the assessment of riparian habitat parameters. Because of local climatic conditions; riparian land vegetation, riparian buffer zone vegetation and riparian forest cover can be poor or lack. Hence, climate zone feature was used to take into account this features and to make correct assessment.

### Flow Type:

Flow type is important to assess ground water interaction parameter and flow characteristics parameters correctly, so flow type was used in the study as perennial and ephemeral.

### Valley Type:

Valley type is important for the assessment of sinuosity parameter. Valley type was used in the study as deep, shallow and flat (Figure 3).

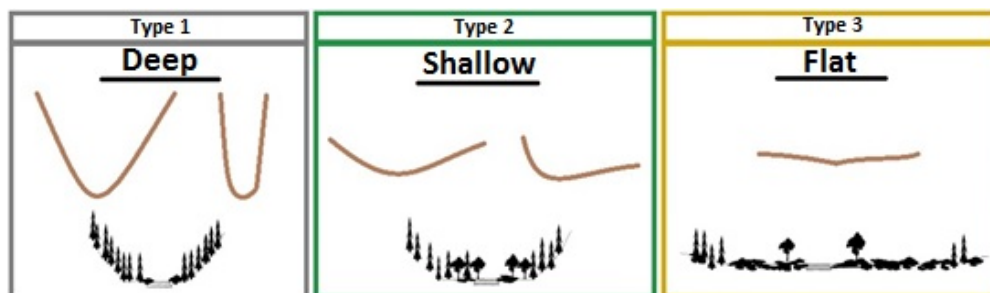


Figure 4: Valley types used in methodology.

### River Width:

River width is important for assessment of shading effects. Over large rivers, shading effect is less according to thin rivers. In this scope, river width was used for assessment of shading parameters as  $>10$  m and  $\leq 10$  m.

Although it can be possible the diversify selection features affecting hydromorphological parameters and selection features' options, to avoid complexity in application, the number of selection feature and their options were determined in reasonable number (Table 2).

Table 2: Selected Features Affecting Parameters and Determined Options.

Altitude	Upper Forest Level (UFL)	Climate Zone	Flow Type	Valley Type	River Width
High	Yes	Steppe	Perennial	Deep	$> 10$ m
Middle	No	Non-Steppe	Ephemeral	Shallow	$\leq 10$ m
Low				Flat	



## 5.2. APPLICATION OF METHODOLOGY

In the scope of the study, first standard hydromorphological parameters were determined as forty three parameters. Then, features affecting hydromorphological parameters were identified (4.1.). In order to assess different hydromorphological characteristic correctly, selectable assessment criteria and their scores are developed according to identified features. After that, developed methodology applied at different waterbodies which have different characteristic and which are at seven different river basins of Turkey. Scores for all water bodies were obtained by using developed standard method with same parameters.

During the field works, to make assessment of methods, expert judgement for waterbodies was also determined. For all waterbodies expert judgments carried out by three experts. In order to avoid human-based assessment divergence, assessments were made by same experts for all waterbodies. For expert judgements;

- 1) Hydrological departure from natural conditions,
- 2) Longitudinal continuity of water bodies (transportation of sediment and fish)
- 3) Habitat diversity of waterbodies (in channel)
- 4) Quality of buffer riparian and riparian zone
- 5) Qualification of water (color, turbidity, odor etc.) and land use (agricultural, urbanization etc.)

were assessed and all five criteria were scored as 0 / 0,5 / 1. Total score of these five criteria was assessed according to table 3 and water bodies were categorized in five status classes by experts as high, good, moderate, poor and bad.

**Table 3:** Determination of Expert Judgement. The mean of three expert judgment scores was used for final decision.

EXPERT JUDGEMENT	CLASS BOUNDARY SKORS
High	$\geq 4,5$
Good	$\geq 3,5 - <4,5$
Modarate	$\geq 2,5 - < 3,5$
Poor	$\geq 1,5 - <2,5$
Bad	$<1,5$

After obtaining the scores of developed methodology and experts judgment for all water bodies, expert judgement and method results were evaluated.

## 6. RESULTS

Hydromorphological monitoring is important for holistic water quality assessment. Characterization of the physical structure and assessment of the habitat quality of rivers are gaining importance in the context of environmental planning, appraisal, and impact assessment (Jēkabsone and Uzule, 2014). Hydromorphological quality assessment also plays a crucial role in the WFD because it is used to determine undisturbed□ and □heavily modified□ conditions of rivers (Raven et al., 2002; Jēkabsone and Uzule, 2014). Especially in the last two decades many

hydromorphological methods have been developed for monitoring and assessment of hydromorphological features of rivers and most of them are country-specific methodologies. The development of many methods related to hydromorphological monitoring and assessment has hampered the standardization and comparison of methods. In addition to this, rivers pass different processes from source to mouth and hydromorphological features of rivers changes depending of this process. This situation makes the works more complicated. Because of the necessity of making different assessment for different waterbody types, using same methods at different waterbody types needs reference conditions' results or ends up with unreliable assessment. Most of the time finding result of reference conditions is not possible. In this scope, with this study it is aimed that, developing an approach to monitor and assess hydromorphological features of rivers at different waterbody types by using standard method. For this aim, standard parameter list was determined which will be applied for all waterbodies firstly. Then, features affecting these parameters were identified and assessment scores are set according to these features. Identifying these features and setting the score system according to these features made the developed methodology usable for all waterbodies. As a result of applying this methodology at different river basins and different waterbodies, assessments which are consistent with expert judgement were obtained (Table 4).

**Table 4:** Application result of the method according to river basins.

River Basins	Number of Monitoring Points	Compatible with Expert Judgement	Incompatible with Expert Judgement
Batı Akdeniz River Basin	22	19	3
Kuzey Ege River Basin	18	15	3
Doğu Karadeniz River Basin	24	21	3
Büyük Menderes River Basin	43	39	4
Susurluk River Basin	19	17	2
Konya River Basin	24	21	3
Meriç - Ergene River Basin	16	14	2
<b>TOTAL</b>	<b>166</b>	<b>146 (%88)</b>	<b>20 (%12)</b>

The methodology was applied at seven river basins and one hundred sixty six waterbodies. %88 of the assessments were in line with the expert judgements. The remaining incompatible results deviated only one status class from expert judgements. This results shows that this approach is useful to monitor and assess hydromorphological features at different river bodies and at different river basins.

## 7. DISCUSSION

In order to compare the results, it is important that using standardized one method in all waterbody types and in all river basins. For assessment, each waterbody has different features or hydromorphological process (WFD: typology), so these must be taken into account in methods for more confidential results. In this scope, to make method available for using in different waterbody types or in different river basins, development of criteria for features affecting the hydromorphological parameters and development of score system according to these features are important solution. In

this study this solution is addressed and successful results were obtained. On the other hand, this study was carried out depending on expert judgements. Beyond this study, relationship must be established between biological data and hydromorphological features. In this way, the reliability and limitations of the method can be determined by using a correct and scientific approach.

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