Case Study

Determination of the Most Suitable Assessment Methods of River Hydromorphology for Turkey

Türkiye için En Uygun Nehir Hidromorfolojisini Değerlendirme Metotlarının Belirlenmesi

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Received Date: 19.06.2017, Accepted Date: 29.05.2018

Abstract

The physical structures and the habitat qualities of any rivers and degradation in rivers have become important elements of hydromorphological assessment because of recognising the influences of these variables in biotic structure that led to the development of more comprehensive assessments of rivers, including river habitat structure within the quality assessment. Accordingly, numerous hydromorphological assessment methods have been developed worldwide including Europe after the Water Framework Directive came into force. Turkey, as a European Union candidate country, has started to implement the Directive and has made some progress. In this context, Turkey needs to develop a national hydromorphological assessment method compliant with the. Two of Multi Criteria Decision Making (methods, which are Analytical Hierarchy Process and Simple Additive Weighting were applied to find the most suitable hydromorphological assessment method for Turkey. For this aim, we reviewed 25 non-European methods and 19 European methods, and determined the Slovenian method and the South African method as the most convenient ones.

Keywords: *hydromorphological-assessment, Multi Criteria Decision Making Method*

Öz

Nehirlerdeki fiziksel yapılar, habitat kalitesi ve bozulma, bunların sucul biyotik yapıya olan etkilerinin anlaşılmasıyla, kalite değerlendirilmesinde habitat yapısıda dahil nehirlerin daha kapsamlı değerlendirilmesine izin veren hidromorfolojik değerlendirmede önemli elemanları olmuşlardır. Bu nedenle birçok ülkede çok fazla sayıda hidromorfolojik değerlendirme metodları geliştirilmiştir. Bu metotlar amaç ve yaklaşım açısından farklılıklar göstermektedir. Bazı metotlar fiziksel habitat ve kıyı habitatı değerlendirmesini içerirken diğerleri morfolojik ve hidrolojik değişimin derecesini belirlemek için kullanılmaktadır. Fakat yaygın ve güncel metotlar multimetrik; morfolojik, hidrolojik, habitat kalitesini bir arada değerlendirmektedir. Avrupa'da ise Su Çerçeve Direktifi (SÇD)'nin yürürlüğe girmesinden sonra bu alandaki değerlendirme metotları hızla gelişmiştir. Türkiye Avrupa Birliği aday ülkesi olarak SÇD'yi uygulamaya başlamış ve bu konuda ilerleme kaydetmiştir. Ancak,Türkiye kendine özgü ve SÇD ile tam uyumlu ulusal hidromorfolojik değerlendirme metodunu geliştirmeye ihtiyaç duymaktadır. Türkiye için en uygun değerlendirme metodunun bulunması için bu çalışmada "Çok

Kriterli Karar Verme" yöntemlerinden ikisi, "Analitik Hiyerarşi Süreci" ile "Basit Ağırlık Ekleme" kullanılmıştır. Bu amaçla Avrupa Birliği ülkelerinden 19 adet ve diğer ülkelerden 25 adet metot değerlendirilmiştir. Çalışmanın sonucunda, Avrupa Birliği ülkelerinden Slovenya Metodu ve diğer ülkelerden Güney Afrika Metodunun Türkiye nehir hidromorfoloji değerlendirilmesinde kullnılabilecek en uygun metotlar olduğuna karar verilmiştir.
Anahtar kelimeler: *hidromorfolojik değerlendirme, Çok Kriterli Karar Verme Metodu,*

Introduction

During the last two decades, characterisation of river physical structure, assessment of river habitat quality and degradation has become important elements of hydromorphological assessment (Raven *et al*., 2002; Boon *et al*., 2010) because the importance of physical characterisation in ecological studies aiming to explain structure and composition of biotic systems has been widely recognised (Fernández *et al*., 2011). It has been noticed that river condition assessment is needed to achieve better understanding of river processes by considering interactions between pressures and response variables (Fryirs *et al*., 2008). All of these led to the development of more comprehensive assessments of rivers, including river habitat structure within the quality assessment, for example, River Habitat Survey by Raven *et al*. (1997), Boon *et al*. (2010). Within the Europe, this wider concept of quality assessment gained importance after the introduction of the EU Water Framework Directive (European Commission, 2000; Belletti *et al*., 2015; Boon *et al*., 2010). The WFD defines the quality elements used for classification of the ecological status of surface water bodies including obligatory hydromorphological elements (European Commission, 2000; Ferreira *et al*., 2011).

Hydromorphological quality components are namely (i) hydrological regime (quantity and dynamics of water flow and connection to ground waters) (ii) river continuity and (iii) morphological conditions (depth and width variation, substrate conditions and structure of riparian zone) (Annex V, 1.1.1 WFD). According to the WFD, river hydromorphological assessment requires the consideration of any alterations to flow regime, lateral and longitudinal continuity, river morphology and sediment transport (Rinaldi *et al*., 2013b). Additionally, the WFD has created the need for methods to determine type-specific reference conditions (Annex II, 1.3 WFD): to assess current status of hydromorphological pressures that could lead to a failure in achieving a water body's objectives (WFD Annex II, 1.4, 1.5); to classify different types of water bodies as a heavily modified or artificial (WFD Annex V, 1.1); and to determine maximum ecological potential of heavily modified water bodies (WFD Annex V, 1.2).

These WFD requirements reveal the necessity of a more comprehensive methodology, therefore river assessment must be changed from a single index system to multiple indices. In other words, there is an explicit need for a holistic approach (Feld, 2004) in addition to recognition of the necessity for a multidisciplinary (i.e. hydrology, geomorphology, biology, water quality and ecology) approach (Belletti *et al*., 2015).

Since the 1990s, several methods have been developed with the aim of characterising physical structure or river habitat quality assessment in order to meet various environmental objectives (Raven *et al*., 2002; Fernández *et al*., 2011). This development in Europe has gained pace following the introduction of the WFD with changes in purposes and content of methods (Ferreira *et al*., 2011). The approaches also differ in the number of hydromorphological elements considered, including the survey, survey method, spatial and temporal scale (Rinaldi *et al*., 2013b; Tavzes and Urbanic, 2009). However, in general two principles have been adopted for assessing river hydromorphological status, which are based on the evaluation of the diversity of habitat quality, and the assessment of the degree of hydromorphological modification (Tavzes and Urbanic, 2009; Raven et al., 2002).

In respect to methodology, the WFD generally defines ecological status and river habitat elements, so its guidance is limited (Weiß *et al*., 2008) but Annex V of the WFD explicitly suggests the use of guidance standards available from the European Committee for Standardisation (CEN) and the International Standards Organisations (ISO). Even though there is a remaining argument regarding the standardisation approach, the CEN has developed two appropriate standards for assessing river hydromorphology; EN 14614, '*Water Quality - Guidance standard for assessing the hydromorphological features of rivers*', provides a framework that Member States can use to develop their own national methods and EN 15843, '*Water Quality - Guidance standard of determining the degree of modification of river morphology*', which was designed for consistent characterisation of hydromorphological modification on river channels, river banks, the riparian zone and floodplains (Boon *et al*., 2010; EN 15843, 2010; EN 14614, 2004). However, there are several methods using the holistic approach and having all remarkable differences in their aims (e.g., spatial scale of application, reference condition, etc.). This wide range of methods occur when the limitations and strengths of the methods need to be investigated with greater emphasis (Rinaldi *et al*., 2013; Rinaldi *et al*., 2013b; Belletti *et al*., 2015). Considering all of the explanations above, the Member States have to assess the hydromorphological condition of rivers to designate their current status which is needed to meet WFD requirements either by maintaining good river status or by introducing action plans to achieve good status via a set of deadlines (Weiß *et al*., 2008; Raven *et al*., 2002).

Turkey is, as an EU candidate country, obliged to comply with WFD requirements by their date of accession (Moroglu and Yazgan, 2008; Sözen *et al*., 2003; Sumer and Muluk, 2011). The transposition of the WFD in Turkey was completed in 2011 with the intention to complete river basin management plans by the end of 2017, and achievement of good water status by the end of 2027 (Sumer and Muluk, 2011; Moroglu and Yazgan, 2008). In this context, the development of a specific method for national hydromorphological assessment of the rivers in Turkey has recently begun regarding the WFD requirements.

Two of Multi Criteria Decision Making (MCDM) methods, which are Analytical Hierarchy Process (AHP) and Simple Additive Weighting (SAW) were applied to find the most suitable hydromorphological assessment method for Turkey. The methods were chosen by considering accessibility of documents. Additionally, multiple methods were chosen from one country because of different approach of methods (e.g. Germany and Australia).

In this paper, the most suitable hydromorphological assessment methods (one from 19 European methods and the other from 25 non-European methods) have been determined for Turkey applying the MCDM process.

Methodology

To choose the most suitable hydromorphological assessment methods (HMAMs) for Turkey, 19 European methods, which were developed to implement the WFD, and 25 non-European methods were considered. A total of 44 HMAMs were examined in detail and 'presence and absence' tables were created. Methods that have been included in the evaluation are shown in Table 2-3. In order to determine the relative importance of each feature, Analytical Hierarchy Process (AHP) was applied, whilst to find the most suitable methods, the Simple Additive Weighting (SAW) procedure was used.

Analytical Hierarchy Process (AHP)

AHP is one of the multi-criteria decision-making methods developed by Saaty (1980). This method enables subjective decision-making processes based on multiple attributes in a hierarchical structure (Triantaphyllou, 2000). The first stage of this structure designates the goal for the particular decision. In the second stage, the goal is decomposed into several criteria, and each criterion can then be further divided into sub-criteria (Tzeng and Huang, 2011). For this study, a hierarchical structure was formed as shown in Figure 1. The next step of AHP is the construction of an *m x n* matrix, where *m* is the number of alternatives and *n* is the number of criteria. This matrix is constructed using the relative importance of the weights between criteria (Tzeng and Huang, 2011; Triantaphyllou, 2000). Table 1 represents ratio scale employed to compare the importance of the various weights. This ratio scale enables decision makers to evaluate the contribution of each factor within the overall assessment methodology. The weighting of criteria was calculated by normalising the eigenvector and consisted of following steps: a) adding values in each column of the *m x n* matrix, b) normalisation by dividing each matrix by the sum of its column, c) calculation of the average of the elements in each row of the normalised matrix. The pair-wise comparison matrices have been created based completely on expert opinion.

To ensure the consistency of comparative weights, the right eigenvector which is calculated from the maximum eigenvalue (λmax), the consistency index (C.I.) and consistency ratio (C.R.) were calculated as suggested by Saaty (1980).

Table 1
Ratio Scale in the AHP (Saaty, 1980)

Intensify of Importance	**Definition**
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between two adjacent judgements
Reciprocals	Opposites

$$\lambda max = \frac{1}{n}\sum_{wi}^{n} \frac{(AW)i}{wi}, \quad (1)$$

$$AW = \begin{pmatrix} a11 & a12\ldots & a1n \\ a21 & a22\ldots & a2n \\ \ldots.. & \ldots.. & \ldots. \\ \ldots.. & \ldots.. & \ldots. \\ an1 & an2 & ann \end{pmatrix} \times \begin{pmatrix} w1 \\ w2 \\ \ldots \\ \ldots \\ wj \end{pmatrix}, \quad (2)$$

$$CI = \frac{(\lambda max - n)}{(n-1)}, \quad (3)$$

where λmax is the largest eigenvalue; wi is weight value; AW is comparison matrix and n represents number of criterions. C.R. is calculated as:

$$C.R. = \frac{C.I.}{R.I.}, \quad (4)$$

where *R.I.* refers to random consistency index which was generated by Saaty (1980). The *R.I.* in accordance with different size matrices is demonstrated in Table 4. As a general rule, the C.R. should be below 0.1 for consistent and reliable result, and 0.2 is designated as maximum tolerated level (Tzeng and Huang, 2011; Ẕarghāmī and Szidarovszky, 2011; Triantaphyllou, 2000).

Table 2

European Methods That Have Been Evaluated

	Methods from Europe for implementation of WFD ***Physical habitat assessment***								
	Name of Methods	**Country**	**Code**	**Used Reference**		**Name of Methods**	**Country**	**Code**	**Used Reference**
1	Eco-morphological classification of channels according to WERTH	Austria	Werth	Mc Ginnity et al. (2005)	11	Hydromorphological Assessment Protocol for the Slovak Republic	Slovakia	HAP-SR	NERI and SHMI (2004) Lehotský and Grešková (2007)
2	Danish Habitat Quality Index	Denmark	DHQI	NERI and SHMI (2004)	12	Index for the assessment of fluvial habitat in Mediterranean rivers	Spain	IHF	Barqu´n et al. (2011) Valero et al. (2015)
3	River Habitat Survey	England & Wales	RHS	Raven et al. (1997) Raven et al. (2002)		Methods from Europe for implementation of WFD ***Morphological assessment methods***			
4	CarHyCe–Hydromorphological characterization of rivers	France	CARHYCE	Gob et al. (2014) Rinaldi et al. (2013b)	13	Morphological Quality Index	Italy	MQI	Rinaldi et al. (2013) Rinaldi et al. (2011)
5	Stream habitat survey field survey method	Germany	LAWA-FS	Raven et al. (2002) Kamp et al. (2007) Sípek et al. (2010) Scheifhacken et al. (2012)	14	Methodology for the assessment of Hydromorphological changes	Latvia	MetHydro	Rinaldi et al. (2013b)
6	LAWA-OS - Stream habitat survey - overview survey method	Germany	LAWA-OS	Kamp et al. (2007) Sípek et al. (2010) Weiß et al. (2008)	15	Hydro ecological Monitoring method	Czech Republic	HEM	Langhammer (2008)
7	River Hydromorphology Assessment Technique	Ireland	RHAT	Murphy and Toland (2012)	16	Morphological Impact Assessment System	Scotland	MImAS	UKTAG (2008)
8	Core assessment of river habitat value and hydromorphological conditions	Italy	Caravaggio	Rinaldi et al. (2013b)	17	Hydromorphology auditing	France	SYRAH-CE	Chandesris et al. (2009) Rinaldi et al. (2013b)
9	River Hydromorphological Monitoring	Poland	MHR	Ilnicki et al. (2010)	18	Methodology for assessing hydromorphological status	Slovenia	SHIM	Tavzes and Urbanič (2009) Urbanič (2014)
10	Adaptation of RHS	Portugal		Ferreira et al. (2011)		Methods from Europe for implementation of WFD ***Riparian habitat assessment***			
					19	Riparian Forest Quality Index	Spain	QBR	Munn et al. (2003)

Table 3

Evaluated Non-European Methods

	Methods from Non-Europe for implementation of WFD ***Physical habitat assessment***					Methods from Europe for implementation of WFD ***Morphological assessment methods***			
	Name of Methods	**Country**	**Code**	**Used Reference**		**Name of Methods**	**Country**	**Code**	**Used Reference**
1	Index Stream Condition	Australia	ISC	Ladson et al. (1999)	15	Geomorphological Driver Assessment Index	South Africa	GAI	Kleynhans et al. (2005)
2	Habitat Predictive Modelling	Australia	HPM	Davies et al. (2000)	16	River Styles Framework	Australia	RSF	Brierley and Fryirs (2005)
3	AusRivAS Physical Assessment Protocol	Australia	AusRivAS	Parsons et al. (2004)	17	Rapid Geomorphic Assessment	USA	RGA	(Heeren et al., 2010) Langhammer (2008)
4	Urban Stream Morphology Index	China	USM	Xia et al. (2010)	18	Stream Corridor Survey-Rapid Geomorphic Assessment	USA	SCS-RGA	MDEP (2009)
5	Index of Habitat Integrity	South Africa	IHI	Kleynhans et al. (2008)	19	Stream Assessment Protocol	USA	SAP	Starr (2009)
6	Stream Habitat Assessment Protocol	New Zealand	SHAP	Murphy and Toland (2012)		Methods from Europe for implementation of WFD ***Riparian habitat assessment***			
7	Ukrainian Field Survey	Ukraine	UK-FS	Scheifhacken et al. (2012)	20	Rapid Appraisal of Riparian Condition	Australia	RARC	Munn et al. (2003)
8	Methods for Characterising Stream Habitat USGS	USA	MCSH	Mc Ginnity et al. (2005)	21	Riparian Vegetation Response Assessment Index	South Africa	VEGRAI	Kleynhans et al. (2007)
9	Rapid Stream Assessment Technique Field Methods	USA	RSAT	Somerville and Pruitt (2004) Clean Water Service (2000)	22	Visual Assessment of Riparian Health	USA	VARH	Ward et al. (2003)
10	Stream and Riparian Habitats Rapid Assessment Protocol	USA	SRHRAP	Somerville and Pruitt (2004)	23	Riparian /Wetlands Assessment	USA	RWA	Watershed Professionals Network (1999)
11	Subjective Evaluation of Aquatic Habitats	USA	SEvalAH	Rinaldi et al. (2013b) Fernández et al. (2011)	24	Stream Visual Assessment Protocol	USA	SVAP	USDA (2009)
12	Wadeable Stream Assessment Field Ops	USA	WSAss	USEPA (2013)	25	Watershed Condition Evaluation Network (1999)	USA	WCE	Watershed Professionals
13	Non-Wadeable Habitat Index	USA	NWHI	Wilhelm et al. (2005)					
14	Qualitative Habitat Evaluation Index	USA	QHEI	Rankin (1989)					

Table 4

Random Consistency Index (R.I.) for Different Size Matrices (Saaty, 1980)

n	RI	n	RI	n	RI
1	0	6	1.24	11	1.51
2	0	7	1.32	12	1.53
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

As a result of AHP, the weighting of individual feature was obtained. Afterwards, two most suitable hydromorphological assessment methods were derived using SAW.

Simple Additive Weighting (SAW)

The SAW method is well-known and widely used method for multi-attribute decision-making problems. Due to its simplicity, SAW is the most popular method to determine the best alternative, which is derived by the following equations (Tzeng and Huang, 2011).

$$A^*=\{Ui\ (x)|\max Ui\ (x)|\ i = 1, 2, \dots , n\}, \quad (5)$$

$$Ui(x) = \sum_{j=1}^{n} wj\ rij(x), \quad (6)$$

where $Ui(x)$ denotes the utility of the ith alternative; w_j denotes the weights of the jth criterion; $r_{ij}(x)$ is the grades of the ith alternative with respect to jth criterion.

To determine the most suitable methods for Turkey, the following steps were applied:

Step 1: The essentiality scores of each feature for Turkey were identified.

Step 2: The weight of each feature was multiplied by its essentiality score by considering the characterisation of the methods (Tables 5 &6). The results were written in a column. If a feature is used by methods that are signed as “Y (Yes)” and “P (Potential)” it is counted, otherwise it is assigned “N (No)”.

Step 3: The sum of the column, which was created in Step 2, gives total SAW score of each assessment methods.

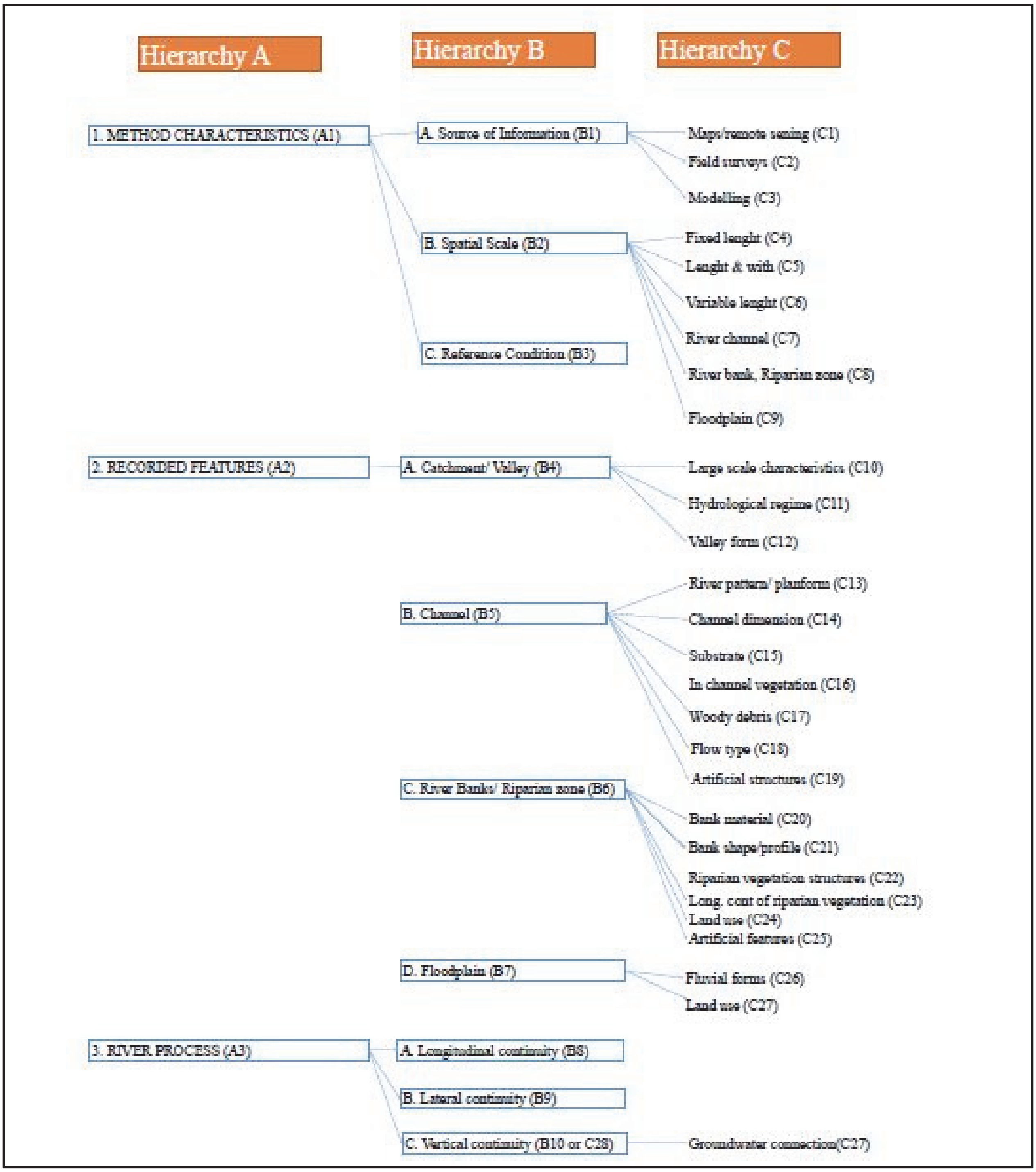


Figure 1. Hierarchical structure for AHP and a list of hydromorphological assessment features.

Table 5

Characterisation of European Hydromorphological Assessment Methods

			Werth	DHQI	RHS	CARHYCE	LAWA-FS	LAWA-OS	RHAT	Caravaggio	MHR	HAP-SR	IHF	RHS in Portugal	MQI	MetHydro	HEM	MImAS	SYRAH-CE	SHIM	QBR
1. Method Characteristics																					
A. SOURCE OF DATA		Maps/remote sensing	Y	Y	N	N	N	Y	Y	N	Y	Y	N	P	Y	NA	Y	Y	Y	Y	P
		Field Surveys	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	NA	Y	Y	N	Y	Y
		Modelling	N	N	N	N	N	N	N	N	N	N	N	N	N	NA	N	N	N	Y	N
B. SPATIAL SCALE	Longitudinal Scale	Fixed length	N	Y	Y	N	Y	Y	Y	Y	N	N	N	Y	N	NA	N	Y	N	Y	N
		Length & with	N	N	N	Y	N	N	N	N	N	Y	N	N	N	NA	Y	N	N	N	N
		Variable length	Y	N	N	N	N	N	N	N	Y	N	Y	N	Y	NA	Y	Y	Y	N	Y
	Lateral Scale	River channel	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		River banks Riparian zone	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
		Floodplain	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
C. REFERENCE CONDITIONS			Y	Y	Y	P	Y	Y	Y	Y	Y	Y	N	Y	Y	NA	Y	N	N	Y	Y
2. Recorded features																					
A. CATCHMENT VALLEY		Large scale characteristics	N	Y	N	N	N	Y	Y	N	P	Y	N	N	Y	Y	N	N	Y	Y	N
		Hydrological regime	Y	N	Y	Y	P	Y	N	Y	Y	Y	N	Y	Y	N	Y	N	Y	Y	N
		Valley form	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	N
B. CHANNEL		River pattern/planform	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	N
		Channel Dimension	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	P	P	Y	N
		Substrate	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
		In channel vegetation	N	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	N	N	N	Y	N	Y	N
		Woody debris	N	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	N	N	Y	Y	N	Y	N
		Flow type	Y	P	Y	N	Y	N	Y	Y	N	Y	P	Y	N	N	N	P	N	Y	N
		Artificial structures	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
C. RIVER BANKS/ RIPARIAN ZONE		Bank material	Y	N	Y	Y	Y	N	Y	Y	N	N	N	Y	N	N	N	Y	N	Y	Y
		Bank shape/profile	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y
		Riparian vegetation structure	Y	N	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
		Long. cont of rip. vegetation	P	N	Y	Y	P	P	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y
		Land use	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	P	N	Y	Y	Y	Y	Y
		Artificial features	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
D. FLOODPLAIN		Fluvial forms	N	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	N
		Land use	N	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	P	Y	Y	N	Y	Y	Y
3. River Process																					
A. Longitudinal Continuity			Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	P
B. Lateral Continuity			N	P	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	P
C. Vertical Continuity (Groundwater connection)			N	N	Y	N	N	N	N	P	Y	Y	N	Y	Y	Y	P	N	Y	Y	N

Table 6

Characterisation of Non-European Hydromorphological Assessment Methods

			ISC	HPM	AusRivAS	USM	IHI	SHAP	UK-FS	MCSH	RSAT	SRHRAP	SEvalAH	WSAss	NWHI	QHEI	SVAP	WCE	GAI	RSF	RGA	SCS-RGA	SAP	RARC	VEGRAI	VARH	RWA
A. SOURCE OF DATA		Maps/remote sensing	Y	Y	Y	N	Y	Y	P	Y	N	N	Y	N	Y	N	Y	Y	N	Y	P	P	Y	N	N	N	Y
		Field Surveys	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		Modelling	Y	Y	Y	Y	N	N	N	N	N	N	N	N	Y	Y	P	N	N	N	N	N	P	N	N	N	N
B. SPATIAL SCALE	Longitudinal Scale	Fixed length	N	N	N	N	N	N	Y	N	Y	N	N	N	Y	Y	N	N	N	N	N	N	N	P	N	N	N
		Length & with	N	N	Y	N	N	Y	N	Y	N	N	N	Y	N	P	Y	N	N	N	N	N	N	N	N	N	N
		Variable length	Y	Y	N	P	Y	N	N	N	N	Y	Y	N	N	N	N	Y	Y	Y	P	Y	Y	Y	Y	P	Y
	Lateral Scale	River channel	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N
		River banks Riparian zone	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
		Floodplain	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
C. REFERENCE CONDITIONS			Y	Y	Y	P	Y	Y	Y	N	P	N	Y	Y	Y	N	Y	Y	Y	Y	P	P	Y	N	Y	N	Y
A. CATCHMENT VALLEY		Large scale characteristics	Y	Y	Y	N	P	Y	N	Y	N	N	Y	N	Y	P	Y	Y	Y	Y	N	N	Y	N	N	N	N
		Hydrological regime	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	P	N	N
		Valley form	N	Y	Y	N	N	Y	N	Y	Y	Y	N	P	N	N	N	Y	Y	Y	N	N	Y	N	N	N	N
B. CHANNEL		River pattern/planform	N	P	P	Y	N	Y	Y	N	N	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	N	N	N	N
		Channel Dimension	P	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	N	Y	N	N	N	N
		Substrate	N	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y	N
		In channel vegetation	N	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	N	N	Y	N	N	Y	N	N	N	N	N	Y	N
		Woody debris	Y	N	Y	Y	N	Y	Y	N	Y	Y	Y	Y	N	N	Y	P	N	Y	Y	Y	N	P	N	Y	N
		Flow type	N	Y	Y	N	N	Y	Y	P	Y	P	N	N	N	P	N	N	Y	Y	N	N	N	N	N	Y	N
		Artificial structures	Y	Y	Y	Y	Y	N	Y	Y	Y	P	Y	Y	P	Y	Y	Y	Y	N	P	P	Y	N	Y	N	N
C. RIVER BANKS/ RIPARIAN ZONE		Bank material	N	N	Y	Y	N	N	N	Y	Y	Y	N	N	N	N	N	Y	Y	Y	N	N	P	N	N	Y	Y
		Bank shape/profile	P	P	Y	Y	N	Y	Y	Y	P	Y	P	Y	N	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N
		Riparian vegetation structure	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	P	N	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y
		Long. cont of rip. vegetation	Y	N	Y	Y	Y	Y	N	P	Y	N	N	N	N	N	Y	Y	N	N	N	N	N	Y	P	Y	Y
		Land use	N	N	Y	P	Y	Y	N	N	P	Y	N	Y	Y	Y	Y	Y	P	N	N	N	Y	N	Y	Y	Y
		Artificial features	N	N	Y	Y	Y	N	Y	N	N	N	Y	Y	P	Y	Y	Y	Y	N	Y	P	P	N	Y	N	N
D. FLOODPLAIN		Fluvial forms	Y	N	P	Y	Y	P	N	N	N	N	N	N	P	P	Y	Y	N	Y	Y	N	N	N	N	N	Y
		Land use	N	N	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	Y	Y	N	N	N	P	Y	N	Y	Y	N
A. Longitudinal Continuity			P	N	Y	Y	Y	N	N	N	N	N	P	N	N	N	Y	Y	Y	Y	N	N	N	N	P	N	N
B. Lateral Continuity			N	N	Y	Y	Y	N	N	N	N	N	Y	Y	N	N	Y	Y	Y	Y	P	P	N	P	P	Y	Y
C. Vertical Continuity (Groundwater connection)			N	N	NA	NA	P	N	N	N	NA	NA	P	N	N	NA	NA	N	Y	Y	P	P	N	N	N	N	N

Note. *Y* = yes represents that features are considered by methods. *N* = no represents that features are not included in assessment. *NA* = not available represents that information is not available. *P* = potential represents that this method has a potential to incorporate features.

Results and Discussion

Calculating the Relative Importance (Weights) of Each Hydromorphological Feature

In order to find the relative importance of each hydromorphological feature, three different hydromorphologists from the British, Scottish and Irish Environment Agencies were asked to complete pair-wise comparisons that were constituted based on a hierarchal structure. Previous studies Rinaldi *et al*. (2013b) and Fernández *et al*. (2011), the European standard (EN 14614, 2004) and the WFD requirements were used to establish the elements within each stratum of the hierarchy. To ensure the consistency of the comparisons, consistency ratios (C.Rs) were calculated (Tables 7a-7k). The total weight of each feature was obtained by multiplying the weights of each hierarchy (Table 9).

Table 7a

Pairwise Comparison Main Goal- A1-3

Main Goal	A1	A2	A3	W
A1	1	1/5	1/3	**0.1149**
A2	5	1	2	**0.4795**
A3	3	1/2	1	**0.4054**

Note. CR=0.0379, *A1*= method characteristics, *A2*=recorded features, *A3*=river process.

Table 7b

Pairwise Comparison of A1-B1-3

A1	B1	B2	B3	W
B1	1	1/3	1/5	**0.1149**
B2	3	1	1	**0.4054**
B3	5	1	1	**0.4795**

Note. CR=0.0344, *B1*=source of information, *B2*=spatial scale, *B3*=reference condition.

Table 7c

Pairwise Comparison of A2-B4-7

A2	B4	B5	B6	B7	W
B4	1	1/3	1/3	1/2	**0.1093**
B5	3	1	1	2	**0.3507**
B6	3	1	1	2	**0.3507**
B7	2	1/2	1/2	1	**0.1892**

Note. CR=0.0053, *B4*=catchment/valley, *B5*=channel, *B6*=river banks/riparian, *B7*=floodplain.

Table 7d

Pairwise Comparison of A3-B8-10

A3	**B8**	**B9**	**B10**	**W**
B8	1	3	1	**0.4428**
B9	1/3	1	1/2	**0.1698**
B10	1	2	1	**0.3873**

Note.CR=0.0077, *B8*=longitudinal continuity, *B9*=lateral continuity, *B10*=vertical continuity (ground water connection).

Table 7e

Pairwise Comparison of B1-C1-3

B1	**C1**	**C2**	**C3**	**W**
C1	1	1/2	2	**0.3**
C2	2	1	2	**0.5**
C3	1/2	1/2	1	**0.2**

Note.CR=0.066, *C1*=maps/remote sensing, *C2*=field survey, *C3*=modelling.

Table 7f

Pairwise Comparison B2-C4-6

B2	**C4**	**C5**	**C6**	**W**
C4	1	2	2	**0.5**
C5	1/2	1	1	**0.25**
C6	1/2	1	1	**0.25**

Note.CR=0.00, *C4*=fixed length, *C5*=length & width, *C6*=variable length.

Table 7g

Pairwise Comparison B2-C7-9

B2	**C7**	**C8**	**C9**	**W**
C7	1	1	2	**0.4**
C8	1	1	2	**0.4**
C9	1/2	1/2	1	**0.2**

Note.CR=0.00, *C7*=river channel, *C8*=river banks/riparian zone, *C9*=floodplain.

Table 7h

Pairwise Comparison of B4-$C_{10\text{-}12}$

B4	**C10**	**C11**	**C12**	**W**
C10	1	1/3	2	**0.2394**
C11	3	1	4	**0.6232**
C12	1/2	1/4	1	**0.1372**

Note.CR=0.028, *C10*=large scale characteristics, *C11*=hydrological regime, *C12*=valley form.

Table 7i

Pairwise Comparison of B5-C13-19

B5	C13	C14	C15	C16	C17	C18	C19	W
C13	1	1	1/3	3	2	1/2	1/3	**0.0968**
C14	1	1	1/3	3	2	1/2	1/3	**0.0968**
C15	3	3	1	5	4	1	1/3	**0.2042**
C16	1/3	1/3	1/5	1	1/2	1/4	1/6	**0.0377**
C17	1/2	1/2	1/4	2	1	1/3	1/5	**0.0569**
C18	2	2	1	4	3	1	1/3	**0.1637**
C19	3	3	3	6	5	3	1	**0.3437**

Note.CR=0.049, *C13*= river pattern/planform, 14= channel dimension, *C15*= substrate, *C16*= In-channel vegetation, *C17*= woody debris, *C18*= flow type, *C19*= artificial structures.

Table 7j

Pairwise Comparison of B6-C20-25

B6	C20	C21	C22	C23	C24	C25	W
C20	1	1/4	1/5	1/5	1/3	1/6	**0.0391**
C21	4	1	1/2	1/2	2	1/3	**0.1237**
C22	5	2	1	1	3	1/2	**0.2047**
C23	5	2	1	1	3	1/2	**0.2047**
C24	3	1/2	1/3	1/3	1	1/5	**0.0764**
C25	6	3	2	2	5	1	**0.3511**

Note.CR=0.022, *C20*= bank material, *C21*=bank shape/profile *C22*= riparian vegetation structure, *C23*= long. cont of rip. vegetation, *C24*= land use, *C25*=artificial features.

Table7k

Pairwise Comparison of B7-C26-27

B7	C26	C27	W
C26	1	1/3	**0.25**
C27	3	1	**0.75**

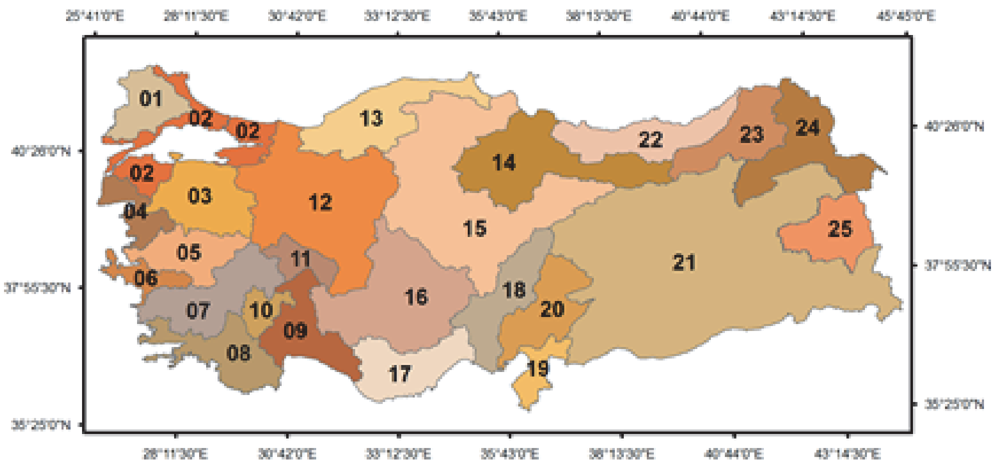
Note.CR=0.00, *C26*=fluvial flows*, C27*=fand use.

General Characteristics of Turkish Catchments

Turkey is a transcontinental country that lies between the Asian and European continents (36-42°N, 26-45°E) and has a total area of 779,452 km^2. The mean altitude is 1,250 m. While areas with more than 1000 m elevation generate 56% of the total country's land area, more than 15% slope generates 62% (Odemis and Evrendilek, 2007). Turkey has a subtropical, semi-arid climate with extremes in temperature (Kibaroglu and Tigrek, 2011). The temperature ranges from 45°C during summer in the eastern and southern region, to -40°C during winter in the east, with an average annual temperature of 19°C. Due to the diversity of its topology, the annual precipitation varies from 250 mm in the central and south eastern region to 2500 mm in the north eastern Black Sea region and annual average precipitation is about 574 mm. This seasonal precipitation and temperature change provides a range of low gradient streams in the plains and high gradient streams in the mountains (Odemis and Evrendilek, 2007). Turkey has 25 main catchments (Figure 3, Table 8) that range from 6,907 km^2 (Küçük Menderes) to 127,304 km^2 (Euphrates). In total, the mean annual run-off is approximately 186 billion cubic meters (BCM) of which 112 BCM can be exploited economically. A high variability of flows in large basins can be seen throughout the year, with a drought season that occurs with increasing frequency. Turkey hosts the world's largest rivers (Euphrates, Tigris) owing to the heavy snow it receives, and one of the world's fastest flowing rivers (Çoruh) due to steep mountainous regions (Odemis and Evrendilek, 2007; Kibaroglu and Tigrek, 2011).

Key Hydromorphological Pressures on Rivers in Turkey

A high growth rate, urbanisation, and increasing energy demand might require infrastructural development on water bodies. In Turkey, one of the most important water infrastructural developments is an extensive network of dams and reservoirs (Table 10) (Kibaroglu and Tigrek, 2011). It is expected that major constructions (i.e. dams) will have substantial impacts on longitudinal river continuum for biota, sediment, loss of ecological integrity (e.g. fish migration) and will cause serious river degradation at the downstream of the dam (e.g. channel incision).



Note. See Table 8 for legends.

Figure 3. Main 25 river basins of Turkey (Kibaroglu and Tigrek, 2011).

Table 8

General Characterisation of Main Catchments in Turkey
Adapted from Tockner et al. (2009); DSI (2015); Kibaroglu and Tigrek (2011); Odemis and Evrendilek (2007)

Catchment name	**Catchment area (km^2)**	**Average elevation (m)**	**Mean annual precipitation (mm)**	**Mean annual discharge (BCM)**	**Contribution to total (%)**	**Human population density ($people/km^2$)**
(01) Meric-Ergene	14,560	57	604	1.33	0.7	72.56
(02) Marmara	24,100	42	728.7	8.33	4.5	470.1
(03) Susurluk	22,399	202	711.6	5.43	2.9	119.4
(04) North Aegean	10,003	64	624	2.90	1.1	61.68
(05) Gediz	18,000	220	678	1.95	1.1	113
(06) Kucuk Menderes	6,907	4	710	1.19	0.6	253
(07) Buyuk Menderes	24,976	414	673	3.03	1.6	83
(08) West Mediterranean	20,953	383	875	8.93	4.8	42.5
(09) Antalya	19,577	249	1000	11.06	5.9	79.5
(10) Burdur Lakes	6,374	-	446.3	0.50	0.3	31.4
(11) Akarcay	7,605	1017	451.8	0.49	0.3	87.5
(12) Sakarya	58,160	509	514	6.40	3.4	97
(13) West Black Sea	29,598	326	811	9.93	5.3	63.95
(14) Yesilirmak	36,114	696	498	5.80	3.1	60
(15) Kizilirmak	78,180	748	547	6.48	3.5	58
(16) Konya	53,850	1139	416	4.52	2.4	45.14
(17) East Mediterranean	22,048	269	745	11.07	6.0	93.06
(18) Seyhan	20,450	750	545	8.01	4.3	92
(19) Orontes	7,796	159	714	1.17	0.6	182
(20) Ceyhan	21,982	685	619	7.18	3.9	91
(21) Tigris, Euphrates	184.95	1010	658, 559	52.94	28.5	65, 57
(22) East Black Sea	24,077	443	1198	14.90	14.90	103.61
(23) Coruh	19,872	757	690	6.30	3.4	37
(24) Kura-Aras	27,548	1653	527	4.63	2.5	74
(25) Lake Van	19,405	1829	474.3	2.39	1.3	51.8

Table 9
Weights of Each Hydromorphological Assessment Features Based on Analytical Hierarchy Process

Hierarchy A	**CR***	**W**	**Hierarchy B**	**CR***	**W**	**Hierarchy C**	**CR***	**W**	**∑W**
A1	0.0379*	0.1149	B1	0.0344*	0.1149	C1	0.066*	0.3	**0.003961**
						C2		0.5	**0.006601**
						C3		0.2	**0.002640**
			B2		0.4054	C4	0*	0.5	**0.023290**
						C5		0.25	**0.011645**
						C6		0.25	**0.011645**
						C7	0*	0.4	**0.018632**
						C8		0.4	**0.018632**
						C9		0.2	**0.009316**
			B3		0.4795	-			**0.055095**
A2		0.4795	B4	0.0053*	0.1093	C10	0.028*	0.2394	**0.012547**
						C11		0.6232	**0.032662**
						C12		0.1372	**0.007191**
			B5		0.3507	C13	0.049*	0.0968	**0.016278**
						C14		0.0968	**0.016278**
						C15		0.2042	**0.034338**
						C16		0.0377	**0.006340**
						C17		0.0569	**0.009568**
						C18		0.1637	**0.027528**
						C19		0.3437	**0.057797**
			B6		0.3507	C20	0.022*	0.0391	**0.006575**
						C21		0.1237	**0.020801**
						C22		0.2047	**0.034422**
						C23		0.2047	**0.034422**
						C24		0.0764	**0.012847**
						C25		0.3511	**0.059041**
			B7		0.1892	C26	0*	0.25	**0.022680**
						C27		0.75	**0.068041**
A3		0.4054	B8	0.0077*	0.4428	-			**0.179511**
			B9		0.1698	-			**0.068837**
			B10		0.3873	-			**0.157011**

Additionally, dams lead to an altered hydro-regime, especially downstream, that can be captured by measuring ecologically important smaller floods. Flow regime regulation for irrigation purposes leads to hydromorphological effects relation to sedimentation, discharge, flow velocity and depth. Other ongoing hydromorphological pressures can be listed as follows:

- Sediment exploitation,
- River regulation,
- Flood protection,
- Water abstraction,
- Irrigation and
- Land use development (agricultural, urbanisation, settlements)

Table 10.
Multi-Purposes Water Constructions in Turkey (Adapted from DSI, 2016 and DSI, 2017)

	In operation	**Under construction**	**In programme**
	1159	121	144
Dams	Large scale projects: 325	21	-
	Small scale projects: 834	101	-
Hydropower plants	596	83	639
• - Capacity	26.819 MW	5.424 MW	15.330 MW
• - Annual production	93.653 GWh	16.508 GWh	48.383 GWh
Irrigation (*million hectares*)	5.1		
Domestic water supply (*BCM*)	7.09		
Flood control (*million hectares*)	1.366 (more than 7.000 premises)		

Grading Each Hydromorphological Assessment Feature from 1 to 5 (least to most essential) for Turkey

The features of existing hydromorphological assessment methods were graded in terms of identifying the essentiality of each feature in the overall assessment process. To do this, a rating system out of 5 was introduced, as shown in Table 11. To grade features for Turkey, relevant literature and regulations, general catchment characteristics and key hydromorphological pressures on Turkish rivers were considered. The score of each feature is reported in Table 12.

Source of information/data collection (B1, C1-C3).

The data collection for HMAMs mainly consists of three different methods (maps/remote sensing, field survey and modelling). There is no precise study that has analysed the data collection methods of HMAMs. However, the majority of methods adopted the use of field surveys, as recommended by EN 14614 (2004) to collect data on field based features or those that can be found under water (e.g. woody debris, substrate, in-channel vegetation). Remote sensing technique is another common method that can yield valuable data on large-scale features (e.g., river planform, extent of river riparian zone). Turkey has diverse catchment characteristics from steep mountainous areas, especially in the northern region, to low gradient streams in the plains (Kibaroglu and Tigrek, 2011; Odemis and Evrendilek, 2007).

A high number of catchments (25), their diverse characteristics and sizes make field surveys difficult. Consequently, using remote sensing technology for data collection would be a more practical than field surveys and modelling. In this sense, remote sensing, field survey, and modelling are assigned as significant, demonstrated, and strong essentiality for hydromorphological assessment, respectively.

Spatial scale (B2).

Longitudinal scale and lateral scale (C4-C9).

A river ecosystem represents a hierarchical spatial organisation (Fissell *et al*., 1986). The structure of each level characterisation is managed by physical process of its above levels. The importance of spatial scale has been largely underlined in relation to the assessment of habitat quality and biotic integrity (Allan *et al*., 1997; Allan and Johnson, 1997). Longitudinal scales are analysed under different lengths of unit survey that can change depending on the purpose of the assessment and the size of the river. These lengths are determined as fixed length, length and width ratio and variable length by each of the HMAMs. However, a fixed length survey unit is used by the vast majority of methods and recommended by EN 14614 (2004). In this respect, while the fixed length approach is assigned as having a demonstrated essentiality, others are assigned as having strong essentiality. Lateral scale is as important as longitudinal scale, and lateral scale boundaries need to include the river floodplain features suggested by EN 14614 (2004). Additionally, the WFD indicates that the structure and condition of the river channel and riparian zone need to include a hydromorphological assessment (Chave, 2001; ETC, 2012).

Table 11
Five Scale Rating and Its Definitions

Grading Scale	Definition
1	Limited essentiality of features for hydromorphological assessment
2	Weak essentiality of features for hydromorphological assessment
3	Strong essentiality of features for hydromorphological assessment
4	Demonstrated essentiality of features for hydromorphological assessment
5	Significant essentiality of features for hydromorphological assessment

Considering all the assessments above, river channels and banks/riparian zone have been assigned as having significant essentiality, whilst floodplains have been assigned as demonstrated essentiality for HMAMs.

Reference condition (B3).

The identification of hydromorphological reference condition is a critical pre-requisite in the evaluation of hydromorphological quality. Defining ‘high status’ type specific reference conditions in rivers is a requirement of the WFD that enables accurate, fair and meaningful comparison of river quality (ETC, 2012). A catchment first needs to be divided into river type(s) to obtain each river type’s reference condition, reflecting the total or nearly total undistributed condition (EN 14614, 2004). As Turkey has highly diverse river typology and catchment characteristics, the reference condition approach might be the best way of identifying a river’s target condition as “high status”. Therefore, the reference condition approach is determined as having significant essentiality in the assessment.

Catchment/Valley (B4).

Large-scale characteristics (C10).

It has been found that large-scale catchment features influence stream habitats (Davies *et al*., 2000). Large-scale variables enable a framework to be established for the characterisation of lower-scale variables and thus provide identifying the local physical characteristics that might be estimated to be found in vicinity of the river (Parsons *et al*., 2004; Fernández *et al*., 2011). In this respect, the characterisation of lower-scale habitat can be designated by river classifications that rely on large-scale variables (Fernández *et al*., 2011). There are several developed river typology methods based on large-scale variables such as the Rosgen Classification (Rosgen, 1994), River Styles (Brierley and Fryirs, 2005), whilst Orr *et al*. (2008) have developed a hierarchically-structured typology for British rivers. Large-scale characteristics are generally ignored in the characterisation of river habitats. However, these have important effects on river habitat characteristics at the reach scale (Benda *et al*., 2011).

Large-scale characteristics can be used to define local physical characteristics for large Turkish catchments (e.g., Euphrates). Consequently, this represents strong essentiality in the overall assessment.

Hydrological Regime (C11).

The hydrological regime, which is the quantity and dynamics of water flow and connection to ground waters, is one of the hydromorphological quality elements of the WFD (Belletti *et al*., 2015; Rinaldi *et al*., 2013b). River hydrology assessment is important because river hydrology and morphology provide a relationship between flowing water and the physical environment of rivers. The more precise hydrological character of a river can be best obtained by collecting flow variables from long-term data sets (Harding *et al*., 2009). In Turkey, there are a considerable number of dams and hydropower plants which are constructed, planned or are under construction (DSI, 2015). These directly influence the river hydrological regime (Harding *et al*., 2009), which in turn affects the abiotic and biotic characteristics of streams (Poff *et al*., 1997). Therefore, measuring hydrological regime changes is assigned as having significant essentiality.

Valley Form (C12).

It is important to monitor specific river landform in order to see how the river channel itself changes as it moves downstream. The river channel upstream is shallow and narrow, which is called a V-shaped valley form due to vertical erosion. Towards the downstream, however, velocity and discharge rise. Velocity increases due to decrease of channel roughness, while discharge increases because the catchment area of drainage basin and hence the number of feeding tributaries increases. Due to the increase in discharge, lateral erosion, widening and deepening all increase resulting in the formation of other river valley forms (e.g. U shape, box and wide shape) (The British Geographer, 2012). Turkey has a diverse topography, from high gradients in the eastern regions to the low gradient central Anatolia region (Odemis and Evrendilek, 2007) that results in a broad range of valley forms. Thus, assessing valley form would seem to be beneficial for Turkey’s hydromorphological assessment, and is accordingly allocated as a strong essentiality.

Channel (B5).

River pattern/planform (C13).

While river pattern refers to channel configuration (e.g., straight, meandering, braided), platform refers to other parameters (e.g., channel sinuosity, braided index, etc.). Therefore, channel straightening, widening changes and the general condition of the channel (e.g., naturalness and artificiality) are required to be examined (Rinaldi *et al*., 2013b). In this manner, river pattern/platform seems to have a direct impact on aquatic biota (Harding *et al*., 2009), and thus has demonstrated essentiality for the hydromorphological assessment.

Channel dimension (C14).

The most common recorded features are channel width and its variation, channel depth and its variation, wetted channel width and water depth, which is also one of the hydromorphological quality elements required by the WFD (Rinaldi *et al*., 2013b; Fernández *et al*., 2011).Wetted width and depth are key habitat descriptor parameters that can directly affect the available habitat for in-stream biota. Channel width and depth ratio (w/d) might indicate a suitable habitat for in stream biota. To illustrate, while a high w/d implies a wide shallow channel that is a good habitat for invertebrates, a low w/d implies a deep channel that can provide, for instance, a trout habitat. The measurement of channel width and depth offers flow independent measures of stream morphology that are unlikely to change over a short period of time. These parameters are also used to calculate maximum stream discharge (Harding *et al*., 2009). For this reason, channel dimensions have a demonstrable essentiality for any overall assessment.

Substrate (C15).

The WFD obliges the assessment of the river substrate condition as a survey unit (Weiß *et al*., 2008). The results of Star Project indicate that the channel substrate index has the second highest impact on the overall habitat quality assessment score (Szoszkiewicz *et al*., 2006). It can be seen that the size, distribution, and condition of the substrate affect the river habitat quality for aquatic organisms. The dominant particle size, the range of substrate size and compactness play important roles in the suitability of the substrate for different species (Harding *et al*., 2009). A large number of dam and hydropower constructions along the main rivers and tributaries could lead to the disruption of sediment transportation in Turkey. Thus, an assessment of the substrate is a significant essentiality for the hydromorphological survey in Turkey.

In-channel vegetation (C16).

Below-water vegetated banks and stream beds are defined as in-stream habitat. The stream bed is home to various aquatic species, an area for deposition and incubation of their eggs, their food source and, more importantly, a refuge against their predators, droughts and floods (Harding *et al*., 2009). In-stream and riparian vegetation have been established as important aspects of any description of the variability of the species composition of invertebrates within the site (Sandin and Johnson, 2004). The

Star Project concluded that in-channel vegetation has the third highest impact on the Habitat Quality Assessment (HQA) score (Szoszkiewicz *et al*., 2006). In that sense, in-channel vegetation also has a demonstrable essentiality for the hydromorphological assessment.

Table 12

The Essentiality Score and Weight for Each of the Features

Features	**Weights***	**Essentiality Scores**
(B1) Source of Information/ Data Collection		
(C1) Maps/remote sensing	0.003961	**5**
(C2) Field Surveys	0.006601	**4**
(C3) Modelling	0.002640	**3**
(B2) Spatial Scale		
(C4) Fixed length	0.023290	**4**
(C5) Length & with	0.011645	**3**
(C6) Variable length	0.011645	**3**
(C7) River channel	0.018632	**5**
(C8) River banks Riparian zone	0.018632	**5**
(C9) Floodplain	0.009316	**4**
(B3) Reference Condition	0.055095	**5**
(B4) Catchment /Valley		
(C10) Large scale characteristics	0.012547	**3**
(C11) Hydrological regime	0.032662	**5**
(C12) Valley form	0.007191	**3**
(B5) Channel		
(C13) River pattern/planform	0.016278	**4**
(C14) Channel Dimension	0.016278	**4**
(C15) Substrate	0.034338	**5**
(C16) In channel vegetation	0.006340	**4**
(C17) Woody debris	0.009568	**3**
(C18) Flow type	0.027528	**4**
(C19) Artificial structures	0.057797	**5**
(B6) River Banks/ Riparian Zone		
(C20) Bank material	0.006575	**3**
(C21) Bank shape/profile	0.020801	**4**
(C22) Riparian vegetation structure	0.034422	**4**
(C23) Long. Cont. of rip. vegetation	0.034422	**4**
(C24) Land use	0.012847	**4**
(C25) Artificial features	0.059041	**5**
(B7) Floodplain		
(C26) Fluvial forms	0.022680	**2**
(C27) Land use	0.068041	**4**
(B8) Longitudinal Continuity	0.179511	**5**
(B9) Lateral Continuity	0.068837	**5**
(B10) Vertical Continuity	0.157011	**5**

Note. Weights were taken from Table 9.

Woody debris (C17).

The method mainly collects information about branches, trees, roots, and woody debris, which is also recommended by EN 14614 (2004). Wood accumulation in rivers frequently provides a refuge for fish. Besides, both wood accumulation and leaf packs are commonly used as substrate by invertebrates (Raven *et al*., 1997). Additionally, large woody debris can lead to a change in river depth and velocity (Harding *et al*., 2009). For these reasons, this assessment is assigned as a strong essentiality for the hydromorphological assessment.

Flow type (C18).

Flow types are often assessed by choosing the most dominant attributes from pools, riffles, glides, and runs (Harding *et al*., 2009; EN 14614, 2004). This is also suggested by EN 14614 to assess hydromorphological quality. Flow type has been identified as the greatest influence on overall Habitat Quality Assessment score (Szoszkiewicz *et al*., 2006). Almost half of methods include as this as an attribute of hydromorphological assessment (Rinaldi *et al*., 2013b). Consequently, including a flow type assessment in the overall hydromorphological assessment might have demonstrated essentiality.

Artificial structures (C19).

In-channel artificial structures need to be included in any assessment (e.g., dams, weirs, culverts, deflectors, etc). These structures can potentially alter continuity of flow, sediment transport, and migration of biota (Rinaldi *et al*., 2013b). River continuity is one of the WFD hydromorphological quality elements that requires undistributed fish migration and sediment transport by anthropogenic activities (Weiß *et al*., 2008). It plays an important role in determining river hydromorphological quality in Turkey because of the construction of dams, hydropower plants, and flood defences. Thus, it has significant essentiality for overall hydromorphological assessment.

River banks/ riparian zone (B6).

Bank material (C20).

The assessment of gravel, sand, clay, and artificial bank material is suggested in EN 14616. This might identify any artificiality of river banks in terms of the extent to which they are affected by bank material (Ulrich, 2014). This feature could be essential for river surveys that indicate, for example, modification for flood prevention. However, it is more precise to assess riverbank artificiality by directly including the presence absence or length of flood defences in the assessment. Consequently, it has weak essentiality because of the fact that it is not an indispensable feature for hydromorphological assessment.

Bank shape/profile (C21).

This can indicate the naturalness and artificiality of riverbanks by way of assessing point bars, side bars, eroding and stable cliffs, re-sectioning and reinforcing. Artificial bank modifications will clearly have an adverse effect on biodiversity (Raven *et al*., 1997). Armitage *et al*. (2001) found that riverbank sites are dynamic environments in which living communities differ due to the growth of side vegetation and their impact on flow, in addition to bank structure, which has a direct effect on invertebrate abundance and number of taxa. Including this feature in the assessment has been assigned as demonstrated essentiality.

Riparian vegetation structure and its continuity (C22-C23).

Riparian habitats play a crucial role in determining ecosystem functioning (Tabacchi *et al*., 1998). In-stream and riparian vegetation were established as important aspects of any description of variability in invertebrate species composition within the site (Sandin and Johnson, 2004). Riparian zones have a disproportionately large effect on stream habitat and water quality; however, another function of riparian zones is the reduction of contaminant inputs from the broader landscape. Therefore, river restoration processes worldwide mainly focus on management of riparian areas (Palmer *et al*., 2007). Basic riparian management includes fencing to exclude livestock, creating buffers by planting native trees and shrubs, etc. Moreover, the WFD requires inclusion of riparian zones as a component of spatial scale (Chave, 2001; Weiß *et al*., 2008). Consequently, riparian zones have a demonstrated essentiality because HMAMs needs to consider the influence of the riparian zone and the presence of riparian buffers.

Riparian land use (C24).

The overall aim to record the 'naturalness' of the vegetation in the riparian zone is based on land cover. Basic non-natural land covers includes recreational and agricultural areas, pasture, cultivated land, urban areas, etc. Classes of near-natural land cover include natural wetland, alluvial forest/natural woodlands, moorland (Hrvatske Vode, 2013). There is no significant correlation between land use features and river morphology (Szoszkiewicz *et al*., 2006). However, Raven *et al*. (1998) suggest that different land use in a similar site can have a considerable effect on a habitat quality assessment score, whilst Feld (2004) claims that land use features often indirectly indicate alterations in stream morphology. Subsequently, this has a demonstrated essentiality for hydromorphological assessment.

Riparian zone artificial features (C25).

This refers to any artificial features located in a riparian zone such as embankments, re-sectioning, dikes, stabilisation, channelization, levees, etc. (Rinaldi *et al*., 2013b). It is clear that such artificial modifications directly affect river morphology and have an adverse impact on river habitat quality (Raven *et al*., 1998). Considering the increasing modification of Turkish rivers, including this feature in the assessment is of significant essentiality.

Floodplain (B7).

Fluvial forms (C26).

The WFD is relatively limited in terms of requiring any assessment of floodplain features; however, CEN standards suggest recording this (Belletti *et al*., 2015; EN 14614, 2004). This records specific information on fluvial forms in the floodplain (e.g., presence of oxbow lakes, wetlands, backwaters, side arms, springs, natural lakes, natural terraces, etc.). A weak essentiality is stated for including fluvial forms in the assessment.

Land use (C27).

This index mainly records type of land use (e.g., floodplain forest, agriculture, pasture, meadow, urban development) and the extent of development (Rinaldi *et al*., 2013b; EN 14614, 2004). Kail *et al*. (2009) indicate that land use on a floodplain has greater hydromorphological effect than land use in a riparian zone. Therefore, land use might have at least demonstrated essentiality in terms of hydromorphological assessment.

Longitudinal continuity (B8).

Longitudinal connectivity is crucial to the optimal functioning of river ecosystems. The presence of transverse constructions in rivers has serious ecological consequences because of blocking natural water flow, sediment and wood debris transportation, and finally aquatic organism migration (Hrvatske Vode, 2013). Artificial barriers have considerable adverse impact on aquatic life and flow regime. The main influence of artificial barriers is fish migration disturbance which should be captured by the index (Ladson *et al*., 1999). Longitudinal continuity is mainly affected by artificial structures. The WFD requires methods to assess the risk to sediment flux and flow regime alteration in terms of barrier construction and water storage (e.g., dams, weirs) as well as undistributed fish migration as part of river continuity (Weiß *et al*., 2008; Chave, 2001; EN 14614, 2004). In case of Turkish hydromorphological assessment, longitudinal continuity has high substantial effects, and thus is assigned as having significant essentiality.

Lateral continuity (B9).

This consists of lateral hydraulic connections between the river channel and its riparian zone/floodplain and sediment delivered by bank erosion and wood continuity (Rinaldi *et al*., 2013b). The degree of lateral connectivity is directly affected by construction of levers, channel incision and aggradations; this connectivity is indirectly related to flood frequency (Kleynhans *et al*., 2005). It is stated that lateral connectivity is a considerable factor in terms of river functioning as it regulates nutrient and organic matter transport between the channel and the floodplain (Elosegi *et al*., 2010). It is also important for in-stream biodiversity especially in large rivers (Paillex *et al*., 2007), because species spend a part of their lifecycle in the floodplain (Elosegi *et al*., 2010). Assessment of lateral continuity is essential in terms of indicating channelized streams (Harding *et al*., 2009) as well as the naturalness of a river bank, and thus needs to be included in bio-monitoring tasks (Erba *et al*., 2006). The grading of lateral continuity has significant essentiality for the hydromorphological assessment of rivers.

Vertical continuity (B10).

Vertical continuity considers the connection between a river and groundwater. The groundwater is an essential element of maintaining flow, quality, and surface water ecology. It is obvious that the disconnection of groundwater can affect the hydrological regime and, consequently, the river ecosystem (Hrvatske Vode, 2013). One of the WFD hydromorphological quality elements is hydrological regime that requires an assessment of connection to groundwater (Weiß *et al*., 2008; ETC, 2012). Vertical connectivity also occurs through the *hyporheic zone* - a dynamic ecotone between surface water and shallow groundwater aquifers (Gibert *et al*., 1990) where both waters mix (White, 1993). This water exchange happens by way of hyporheic pores, which significantly contributes to stream biodiversity (Elosegi *et al*., 2010). Additionally, this zone is a temporary habitat for the pupae of invertebrates and the embryos of various species of fish (Malcolm *et al*., 2005). Consequently, vertical continuity is considered to be of significant essentiality.

The Most Suitable Hydromorphological Assessment Methods for Turkey

The two most suitable methods were obtained from the European and non-European methods by application of the SAW procedure. The Slovenian method (SHIM) and the Index of Habitat Integrity from South Africa (IHI) received the highest scores among the European and non-European methods, respectively (Table 13). The scores of non-the European methods were considerably lower than those of the European methods; eight European methods scored higher than the highest non-European score. This might be due to the weighting of features only being obtained using European experts' opinions and the fact that WFD requirements are considered as paramount to grading the essentiality of features. The result might also be indicative of the wider concept of river assessment introduced by the WFD. RHS and its variations received the highest scores (SHIM, RHS in Portugal and RHS), which favours the functionality of RHS for application of hydromorphological assessment. Determination of the most suitable methods do not mean these can properly use in Turkey's rivers. The most suitable European (SHIM) and non-European (IHI) methods should be investigated in detail. It is obvious that the strengths and weaknesses of these methods should be identified. Considering these results, Turkey's hydromorphological assessment method could be developed in order to comply with WFD requirements.

Table 13

Simple Additive Weighting (SAW) Score of the Each Method from Highest to Lowest

	Non-EU Methods	**Country**	**SAW Scores***		**EU Methods**	**Country**	**SAW Score**
1	IHI (P)	South Africa	**4.233**	**1**	SHIM (M)	Slovenia	**4.693**
2	SEvalAH (P)	USA	4.078	2	RHS in Portugal (P)	Portugal	4.647
3	GAI (M)	South Africa	3.960	3	RHS (P)	England & Wales	4.627
4	AusRivAS (P)	Australia	3.849	4	Caravaggio (P)	Italy	4.627
5	SVAP (P)	USA	3.698	5	HAP-SR (P)	Slovakia	4.581
6	RSF (M)	Australia	3.581	6	MHR (P)	Poland	4.497
7	WCE (P)	USA	3.451	7	MQI (M)	Italy	4.443
8	USM (P)	China	3.294	8	HEM (M)	Czech Republic	4.402
9	VEGRAI (R)	South Africa	3.148	9	SYRAH-CE (M)	France	3.886
10	RGA (M)	USA	3.053	10	MetHydro (M)	Latvia	3.877
11	SCS-RGA (M)	USA	2.914	11	LAWA-FS (P)	Germany	3.842
12	ISC (P)	Australia	2.473	12	RHAT (P)	Ireland	3.736
13	UK-FS (P)	Ukraine	2.307	13	LAWA-OS (P)	Germany	3.380
14	WSAss (P)	USA	2.264	14	QBR (R)	Spain	3.279
15	NWHI (P)	USA	2.240	15	MImAS (M)	Scotland	3.119
16	SAP (M)	USA	2.123	16	Werth (P)	Austria	2.958
17	SHAP (P)	New Zealand	1.996	17	CARHYCE (P)	France	2.957
18	RSAT (P)	USA	1.860	18	DHQI (P)	Denmark	1.863
19	QHEI (P)	USA	1.788	19	IHF (P)	Spain	0.461
20	HPM (P)	Australia	1.757				
21	VARH (R)	USA	1.583				
22	MCSH (P)	USA	1.504				
23	SRHRAP (P)	USA	1.316				
24	RWA (R)	USA	1.223				
25	RARC (R)	Australia	0.895				

Note. Highest results represent the most suitable methods for Turkey

Conclusion

Hydromorphological assessment has gained significant support for its ability to allow for understanding the influence of physical habitat and hydromorphological characteristics of rivers; accordingly, numerous assessment methods have been developed worldwide. Raid development has been seen in Europe explicitly after the introduction of WFD to fulfil its requirements. Turkey, as a European Union candidate country, has started to implement the WFD and some progress has been made. Turkey needs to develop a specific national hydromorphological assessment method that is compliant with WFD. In this paper, to obtain a wider geographical perspective, 25 methods from non-European and 19 methods from European countries have been evaluated in order to choose the most appropriate hydromorphological assessment methods for Turkey. At first, AHP was applied to find the weights of each assessment feature by only including expert opinions, and SAW was applied to find the most suitable methods for Turkey with due consideration for Turkish catchment characteristics, and the main hydromorphological pressures on its rivers. As a result, the Slovenian (SHIM) method has been found to be the most suitable method among the European methods considered, and the South African IHI method as the most suitable non-European method.

Acknowledgements

This article was adapted from the master dissertation titled *"Development of Recommendations For Turkey's Assessment Method Of River Hydromorphology: An Application Of Multicriteria Decision Making Process For Finding The Most Suitable Hydromorphological Assessment Methods For Turkey",* at University of Leeds, School Geography, MSc in River Basin Dynamics and Management with GIS. I would like to express my gratitude to my supervisor Dr. Paul Kay for the useful comments, remarks and contributions through the learning process of this master programme. Furthermore, I would like to thank the participants in my survey, who have willingly shared their precious opinion and time.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye için En Uygun Nehir Hidromorfolojisini Değerlendirme Metotlarının Belirlenmesi

Nehirlerin hidromorfolojik açıdan kapsamlı değerlendirilmesi son zamanlarda oldukça önemli hale gelmiştir. Bunun temel nedeni ise nehirlerin fiziksel yapılarının karakterize edilmesi, habitat kalitesi ve bozulmasının değerlendirilmesi ve bunların sucul biyotik yapıya olan etkisinin anlaşılmasıdır. Hidromorfolojik değerlendirme yapmak için dünya çapında çok sayıda metot geliştirilmiştir. Avrupa'da ise Su Çerçeve Direktifi'nin (SÇD) yürürlüğe girmesinden sonra metot geliştirme süreci hızlanmıştır. SÇD'ye göre nehir hidromorfolojik kalite bileşenleri üç elementten (hidrolojik rejim, nehir devamlılığı ve morfolojik durum) oluşmaktadır. Hidromorfolojik değerlendirme ise akış rejimindeki değişimler, enlemsel ve boylamsal değişimler, nehir morfolojinde meydana gelen değişimler kıyı habitatında meydana gelen değişimler ve sedimantasyon değişimlerinin incelenmesini gerektirmektedir. Bu gereklilikler daha kapsamlı değerlendirme metotlarının geliştirilmesine ve çoklu indeks sistemine geçilmesine sebep olmuştur. Türkiye de Avrupa Birliği (AB) aday ülkesi olarak SÇD'yi uygulamaya başlamış ve bu alanda bazı ilerlemeler kaydetmiştir. SÇD'nin ilgili yükümlülükleri doğrultusunda Türkiye için ülkenin gerçekleri göz önünde bulundurularak hidromorfolojik değerlendirme metodu geliştirilmesine ihtiyaç duyulmuştur.

Bu çalışmada; Türkiye'nin ulusal nehir hidromorfolojik değerlendirme metoduna temel oluşturması için en uygun hidromorfolojik değerlendirme metotları belirlenmiştir. Bu amaçla 14 AB ülkesinden 19 adet ve AB üyesi olmayan diğer 6 ülkeden 25 adet metot seçilmiş ve incelenmiştir. Hidromorfolojik değerlendirme metotlarının içerdiği parametrelerin bağıl önemlilik dereceleri Analitik Hiyerarşi Prosesi uygulanarak ve İngiltere, İskoçya ve İrlanda Çevre Ajanslarında çalışan hidromorfoloji uzmanlarının görüşleri alınarak belirlenmiştir. Türkiye için en uygun iki metot ise basit ağırlıklandırma yöntemi ile seçilmiştir. Bu kapsamda bütün hidromorfolojik değerlendirme metotlarındaki parametrelerin Türkiye özelinde, gereklilik dereceleri hesaplanmıştır. AB üye ülkelerinde, SÇD kapsamında geliştirilen metotlar içerisinden Slovenya Metodu (SHIM) ve diğer ülkelerden Güney Afrika Metodu (IHI) Türkiye'ye uyarlanabilecek en uygun metotlardır. Bunlara ek olarak, Türkiye'nin havza karakteristikleri ile nehirler üzerindeki temel hidromorfolojik baskılar göz önünde bulundurulmuş ve ulusal nehir hidromorfolojik değerlendirme metoduna yönelik temel çıkış noktası belirlenmiştir. Türkiye'de nehirler üzerindeki temel hidromorfolojik baskılardan en önemlisi yoğun bir şekilde farklı amaçlar (sulama, hidroelektrik, taşkın kontrol ve su temimi) için yapılan baraj ve rezervuarlardır. Bu yapıların boylamsal nehir devamlığına, akış rejimine, biyolojik kalite unsurlarına, sedimantasyona ve nehir hidrolojisine negatif etkisi olduğu açıktır. Başlıca diğer baskılar ise sediman çekimi, nehir düzenlemeleri, taşkın koruma yapıları, su çekimi, sulama, arazi kullanımında değişiklikler olarak sayılabilir. Türkiye'de nehirlerin hidromorfolojik değerlendirilmesi için ulusal değerlendirme indeksi geliştirilmelidir. Bu çalışmanın sonucunda Türkiye için belirlenen en uygun metotların (SHIM ve IHI) doğrudan kullanılması hidromorfolojik değerlendirmede doğru sonuç vermeyeceği düşünülmektedir. Öte yandan belirlenen metotların SÇD kapsamında ulusal hidromorfolojik değerlendirme indeksi oluşturulmasında temel teşkil edeceği düşünülmektedir. Bu bağlamda, SHIM ve IHI metotlarının güçlü ve zayıf yönlerinin belirlenmesi, Türkiye'ye uyarlanarak yeni bir indeks geliştirilmesi gelecek çalışmalar için önerilmektedir.