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Contents

Aims and Scope

We, within Republic of Turkey Ministry of Forestry and Water Affairs General Directorate of Water Management, are committed to consistently provide access to the accurate, reliable and global information that are necessary for water education, research and public service regarding water management. We aim to become a well-known scientific journal, indexed and referred at both national and international level.
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Research Article

Invasive Macroinvertebrate Species Monitored in the Turkey Coasts between 2014 and 2015

2014 - 2015 Yılları Arasında Türkiye Kıyılarında İzlenen İstilacı Makroomurgasız Türler

Serdar KOYUN[1], Tahir ÖZCAN[2]

[1]*Ministry of Forestry and Water Affairs, General Directorate of Water Management, 06150, Yenimahalle-Ankara*
serdarkoyun@ormansu.gov.tr
[2]*İskenderun Technical University, Marine Sciences and Technology Faculty, 31200, Iskenderun-Hatay*
tahir.ozcan@iste.edu.tr

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Abstract

Invasive species has been accepted as one of the major threats to aquatic ecosystems. The biological invasion has resulted in significant ecological degradations including alteration of the structure of populations and changes in ecosystems processes and services. There are a variety of reasons why invaders have introduced to new aquatic areas, such as dense marine traffic, anthropogenic modifications, extreme human use of water bodies. To display the status of aquatic ecosystem in terms of the invasive species, benthic invertebrate communities are a very good indicator. A study was carried out in Turkish coasts during the *"Project on Establishment of the Water Quality Ecological Assessment System Specific for Turkey"* for biomonitoring studies between 2014 and 2015. In the scope of the project, 4 invasive species *Polydora cornuta* Bosc, 1802; *Prionospio saccifera* Mackie & Hartley, 1990; *Cerithium scabridum* Philippi, 1848 and *Rapana venosa* (Valenciennes,1846) were identified. Some geographical distribution data of these species are briefly examined.

Keywords: *Invasive species, benthic macroinvertebrate, biomonitoring, Mediterranean and Black Sea, Turkey*

Öz

İstilacı türler, su ekosistemleri için en büyük tehditlerden biri olarak kabul edilir. Biyolojik istila, popülasyon yapısının değişmesi ve ekosistem süreçleri ve hizmetlerindeki aksaklıklar dahil olmak üzere önemli ekolojik bozulmalara neden olur. Deniz taşımacılığı, antropojenik modifikasyonlar, su kütlelerinin aşırı kullanımı gibi faktörler, istilacı türlerin yeni sucul bölgelere giriş yapmasındaki nedenlerdir. İstilacı türler açısından sucul ekosistemlerin durumlarını göstermek için bentik omurgasız toplulukları çok iyi indikatördürler. 2014 ve 2015 yılları arasında "*Türkiye'ye Özgü Su Kalitesi Ekolojik Değerlendirme Sisteminin Kurulması Projesi*" kapsamında biyolojik izleme çalışmaları için Türkiye kıyılarında bir çalışma yürütülmüştür. Proje kapsamında 4 istilacı tür tespit edildi; *Polydora cornuta* Bosc, 1802; *Prionospio saccifera* Mackie & Hartley, 1990; *Cerithium scabridum* Philippi, 1848 ve *Rapana venosa* (Valenciennes,1846). Bu türlerin bazı coğrafik dağılım verileri kısaca incelenmiştir.

Anahtar sözcükler: *İstilacı türler, makroomurgasızlar, biyolojik izleme, Akdeniz ve Karadeniz, Türkiye.*

Introduction

Globally, invasive species has been regarded as one of the greatest threats to marine biodiversity (Simberloff et al., 2013). The rate of biological invasion has risen over the last century, is generating big concern due to the ecological and financial losses of invasion (Mack et al., 2000; Katsanevakis et al., 2013; Simberloff, 2014), and according to Pysek & Richardson (2010), this rate will possibly remain in the future. It is estimated that on indigenous populations invasive species have the most important pressures including that predominate over their assemblages and/or introduce different features to ecosystems (Shea & Chesson, 2002; Hall et al., 2006). It is responsible for alteration in the structure and composition of populations (e.g. diversity, spatial distribution, density) (Fritts & Rodda, 1998; O'Dowd et al., 2003) and changes in the ecosystem function (e.g. nitrogen cycling, light penetration) (Grosholz, 2002; Byrnes et al., 2007; Costello et al., 2010) which are important environmental damages.

Natural and anthropogenic global environmental changes influence the geographical and biological implications of invasions (Lapointe et al., 2012). Utilisation of rivers, lakes, and the coastal waters excessively by the human is usually joined by intentional or unintentional invader introductions. Invasive species dispersals in aquatic ecosystems have been occurring by human activities (Lockwood et al., 2013) such as aquaculture, canal building, recreational events, shipping (i.e. ballast water discharge), tourism and sports fisheries in the last few decades (Cohen & Carlton, 1998; Zenetos et al., 2012; Nunes et al., 2014). The structure of many aquatic ecosystems are being altered by anthropogenic modifications (Friberg, 2014) and ecological assessment for all water bodies is carried out through biomonitoring studies that have turned into a basic method for assessing and monitoring such impacts (Olenin et al., 2010; Buss, 2015).

According to the Marine Strategy Framework Directive (MSFD), the biological invasion is regarded highly in the biodiversity and marine ecosystem policies of EU (Directive, E.C., 2008; EU Commission, 2011). In the assessment of the environmental quality of marine waters, the richness and functional attributes of invasive species will be employed as criteria (European Commission, 2010), since that new alien species are entered European seas every year (Evagelopoulos et al., 2015; Katsanevakis et al., 2013). Determination of the ecological status of freshwaters and coastal waters are being done by using many biological quality elements including benthic macroinvertebrates, phytoplankton, macro algae, fish (Hellawell, 1986; Rosenberg & Resh, 1993; Carter et al., 2006; Boix & Batzer, 2016). Among these biological assemblages, benthic macroinvertebrates are the most common bio-indicator, are designated as one of the biological quality elements used in the implementation of the EU Water Framework Directive (WFD; EC, 2000). Benthic macroinvertebrate species in aquatic environment has strong trophic relations that could be intensely distressed by the introduction or the loss of species, therefore the development of a bio-monitoring instruments have been empowered via presence of indicative benthic invertebrate taxa and communities (Carpenter et al., 1985; Strong, 1992; Pace et al., 1999; Bonada et al., 2006). However, there is a lack of consensus on containing or given score values with regard to invasive species and biotic indices (Gabriel et al., 2005; Arndt et al., 2009; MacNeil et al., 2013).

The coasts of Turkey have different hydrodynamic systems and marine traffic characteristics. The Dardanel and Bosphorus Straits constitute the dense shipping activities in Turkey and invasive species have entered locations through these commercial ports being hotspots for invasive species. Also, intense populating of Lessepsian migrants has resulted from the Suez Canal along the Levantine coast of Turkey. (Çinar et al., 2006). In the country, the impacts of invasive species on ecosystems and their roles in the aquatic environment is becoming a subject of study (Çinar et al., 2016). This paper reviews the invasive species reported from the Turkish coasts during a project funded by Ministry of Forestry and Water Affairs, General Directorate of Water Management (*Project of Establishing Water Quality Ecological Evaluation System Specialized to Turkey, Project No: 2011K050400*) was conducted for bio-monitoring studies between 2014 and 2015.

Material and Methods

The benthic macroinvertebrate species were monitored at 46 stations along Turkish coasts, but invasive species were only recorded at 5 stations located in the Mediterranean (2), Levantine coasts (1) of Turkey and East Black Sea (2) (Fig. 1).

Figure 1: The location of 5 sampling stations where invasive species were found.

The coordinates of five stations are also represented in Table 1.

Table 1
The Coordinates of Five Stations

Station / Coordinates	**Longitude (X)**	**Latitude (Y)**
EDSBAKS01	55,3774	41,24024
EDSBAKS09	68,8656	40,58866
EDSDKKS02	41,0274	45,38094
EDSDKKS03	48,6718	45,40383
EDSCEGS02	37,154418	37,57956

Sampling process was conducted in summer, autumn, spring and summer seasons, respectively. Due to harsh winter conditions, the material was not sampled in winter period. The biodiversity and benthic community structures of the area were documented by performing qualitative and quantitative samplings at stations. At all monitoring stations, the sampling of soft substrate macrofauna was carried out between 2014 and 2015 with Van Veen Grab (0.1m^2 sampling area) as three replicates. Soft-bottom samples were filtered through a wash bucket with 0.5 mm mesh. The retained material was placed in separate boxes containing a 4%

formaldehyde solution. In the laboratory, the samples were rinsed in fresh water and identified to the species level under a stereomicroscope and protected in 70% ethanol.

The temperature and salinity values were measured in situ. All water quality parameters results of stations are presented in Table 2.

Table 2
Monthly Records of Mean Water Quality Parameters at the Five Sites

Test site	**Season**	**Temp. [ºC]**	**Sal. [µg/L]**	**pH**	**DO [mg/L]**	**TSS mg/L**	**Chl.-a [µg/L]**	**L.A [µg/L]**
EDSBAKS01								
	1	25,55	49,90	8,19	8,08	68,80	3,10	1,20
	2	19,00	28,53	7,99	7,08	61,20	3,10	4,00
	3	19,65	25,99	7,85	7,24	14,40	0,10	3,70
	4	29,30	33,30	8,25	8,87	17,60	0,10	2,50
EDSBAKS09								
	1	30,10	50,10	8,30	7,86	42,80	3,10	0,80
	2	21,25	36,75	8,35	9,51	33,20	3,10	3,00
	3	21,55	35,70	7,96	9,61	46,60	0,10	1,80
	4	28,45	40,75	8,32	8,61	46,20	0,10	4,00
EDSDKKS02								
	1	28,35	17,84	8,36	8,08	33,40	3,10	-
	2	-	-	-	-	-	-	-
	3	22,05	12,31	8,32	9,31	10,40	0,10	6,00
	4	25,05	15,95	8,56	8,19	30,20	0,10	1,70
EDSDKKS03								
	1	28,80	18,05	8,41	8,29	32,80	3,10	3,00
	2	-	-	-	-	-	-	-
	3	22,15	10,72	8,44	9,36	3,20	0,10	0,50
	4	27,00	17,59	8,59	8,06	28,40	0,10	6,00
EDSCEGS02								
	1	29,60	40,44	8,26	7,41	54,20	3,10	-
	2	22,55	41,15	8,40	8,91	9,40	3,10	0,90
	3	26,90	41,15	7,89	8,70	25,60	0,10	1,50
	4	28,25	41,45	8,32	8,26	55,40	0,10	1,00

Note.(1= summer 2014*, 2*=autumn 2014*, 3*= Spring 2015*, 4*= Summer 2015*)*
Temp=temperature, *Sal*= salinity, *DO*= dissolved oxygen, *TSS*=total suspended solid, *Chl.-a*= chlorophyll-a, *L.A*= light availability

Results and Discussion

During the project, 7 alien species, 4 invasive species presented in the following section from the Turkish coasts were identified.

Polydora cornuta Bosc, 1802 (Spionidae: Polychaeta)

Soft and hard bottom samples collected to examine from the station EDSBAKKS01 in summer, 2015 (Fig. 3) showed that invasive species, identified as *Polydora cornuta* Bosc, 1802 (Fig. 2), in the western Mediterranean coast of Turkey.

Figure 2: Polydora cornuta

Figure 3: EDSBAKS01 station

This species has been reported from different regions of the world oceans including the western Mediterranean Sea, is broadly dispersed from the Atlantic to the Pacific Ocean (Radashevsky & Hsieh, 2000). In the Mediterranean Sea, the spionid *P. cornuta* is considered to be one of the worst invasive alien species on benthic substrates (Streftaris & Zenetos, 2006). The first record in the Mediterranean Sea was reported by Tena et al., (1991) in organically enriched environments in the Spanish coast (Valencia Harbour). In Turkey, Çınar et al., (2005) encountered this species from the Alsancak Harbour in İzmir Bay, the Aegean Sea. The presence of *P. cornuta* in the Sea of Marmara and İzmir Bay (Aegean Sea) (Dağlı & Ergen, 2008), the Bosphorus Strait (Karhan et al., 2008) and the Greek waters (Simboura et al., 2008) provided that its distributional range increased within the Mediterranean and Black Sea. Although the routes of these species continue uncertain in the

Mediterranean (Radashevsky & Selifonova, 2013), shipping and aquaculture have been widely considered as pathways for the introduction of *P. cornuta* into the Mediterranean Sea, as the specimens were found in and around the busiest commercial harbours and mussel farm areas (Çınar et al., 2005, Simboura et al., 2008). In all these cases, *P. cornuta* was identified as an opportunistic species and also it has been commonly sampled in organically polluted sediments (Pearson & Rosenberg, 1978).

Prionospio saccifera **Mackie & Hartley, 1990 (Spionidae: Polychaeta)**

Specimens of *Prionospio saccifera* were collected in the station EDSBAKS09 in spring, 2015 (Fig. 4) in the Mediterranean Sea. It was firstly recorded from Hong Kong at 11-21 m depth and the Red Sea at 43-49 m depth by Mackie & Hartley (1990). Blake (1996) considered *P. saccifera* as very common in the western Pacific and the Indian Ocean. This species could have been introduced to the Mediterranean Sea from the Red Sea through the Suez Canal (Lessepsian migrants) (Dağlı & Çınar, 2010). The occurrence of this species in the Mediterranean Sea was first mentioned by Çınar and Ergen (1999). Çınar & Ergen (1999) mentioned that reporting this species in the western Mediterranean Sea extends its worldwide distribution, after Hong Kong and the Gulf of Suez (Red Sea), a phenomenon of Lessepsian migration may be hypothesized

Figure 4: EDSBAKS09 station

Cerithium scabridum **Philippi, 1848 (Cerithiidae: Gastropoda)**

The presence of an established population of *Cerithium scabridum* (Fig. 5) in the Mediterranean Sea was reported by Zenetos et al. (2009). In this study, these species were sampled from the EDSCEGS02 station in spring, 2015 (Fig. 6) in the

Levantine coast of Turkey. The presence *of C. scabridum* in the western Mediterranean is likely due to shipping from the eastern Mediterranean (Garilli & Caruso, 2004). On the contrary, other dispersion mechanism of this species can be with natural way via the Suez Canal along the Levantine Sea, it is called as Lessepsian migration (Zenetos et al., 2009). As the pattern is known for other Indo-Pacific species, *C. scabridum* from the Suez Canal recorded in Egypt, Israel, Lebanon, Syria, the southern coast of Turkey and Cyprus (Houbrick, 1992). It is supposed that the distribution pattern of *C. scabridum* has been explained with a double dispersal mechanism.

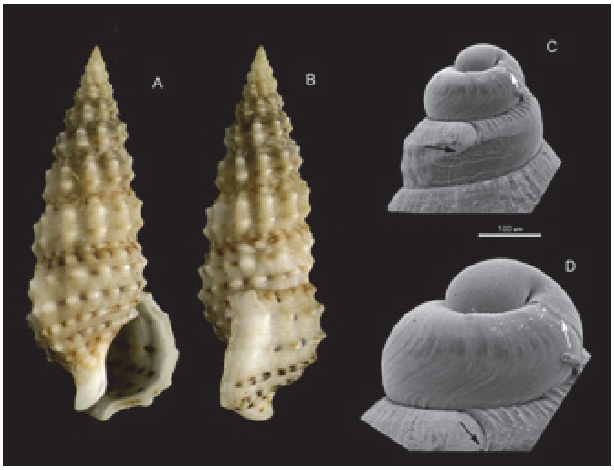


Figure 5: Cerithium scabridum adopted from WoRMS image, n d(a).

Figure 6: EDSCES02 station

***Rapana venosa* (Valenciennes, 1846) (Muricidae: Gastro[illegible]a)**

Rapana venosa species (Fig. 7) were collected from two stations (EDSDKKS02, Spring 2015 and EDSDKKS03, Summer 2014) (Fig. 8 & Fig. 9) in the eastern region of the Turkish coast of the Black Sea. *Rapana venosa* is a large predator originating from temperate Asian waters, such as the Sea of Japan, the Yellow Sea (Chung et al., 1993), the Bohai Gulf, and the east China Sea. It was first introduced to the Black Sea in 1947, has since spread into the Aegean Sea (Koutsoubas & Voultsiadou-Koukoura, 1991), the Adriatic Sea (Bombace et al., 1994). In the Black Sea, due to lack of major predators, *R. venosa* has become very abundant (Saglam & Duzgunes, 2007). In the late 1990s, the larvae of this species carried by ballast water from the Black Sea or from the Levantine Sea into the Chesapeake Bay (Atlantic basin). This successful invasion is supported by various factors such as appropriate sandy bottom areas and an abundant supply of bivalve prey (Saglam & Duzgunes, 2007).

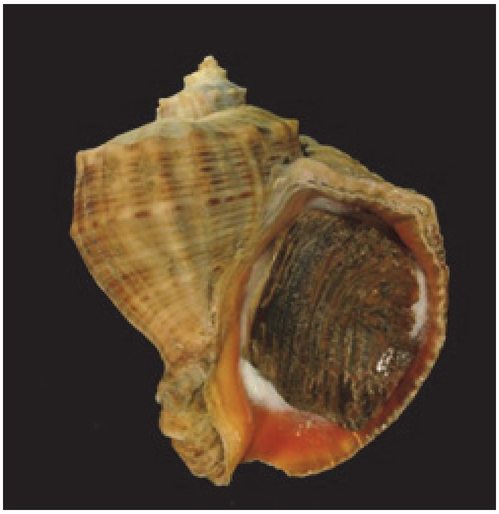
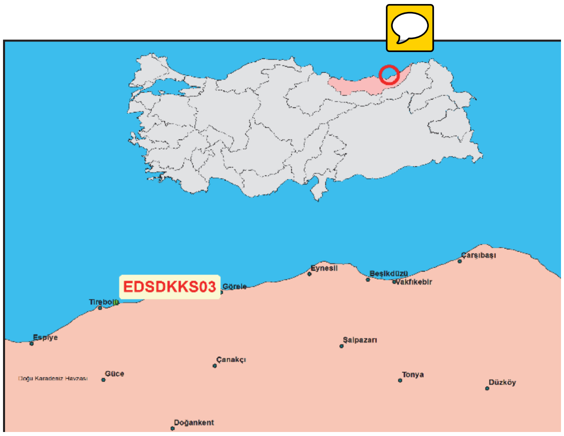


Figure 7: Rapana venosa adopted from WoRMS image, n d(b).



Conclusion

The biological invasion has resulted in significant ecological deteriorations including alteration of the population dynamics, biodiversity and ecosystem services. However, recognizing these alterations is not an easy task except where large, well-known species are of concern. There are especially two ways how invaders have introduced to new aquatic areas, natural ways such as carried by currents (e.g. larvae of invertebrates), attached to a piece of driftwood and human-based ways such as maritime transport, ballast waters and aquaculture. In Turkey, the marine invasive ecology has come into focus and spatial range of invasive species has expanded for coastal habitats in the last years. Having commercial ports take place in Turkey costal and opening Suez Canal in the Levantine coast of Turkey make a contribution to this situation. In this project, 4 invasive species recorded from different coasts indicate that invasive species has become a threat to the Turkey coasts. Although the impacts of invasive species on ecosystems and their roles in the aquatic environment have become subjects of study in Turkey, these studies are still mainly based on morphological examination and comparison of fixed specimens. The biogeographic origin of a species and its morphological variability can be the subject of future projects in biological monitoring studies in Turkey.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

2014 - 2015 Yılları Arasında Türkiye Kıyılarında İzlenen İstilacı Makroomurgasız Türler

İstilacı türler, denizel biyolojik çeşitliliğine yönelik en büyük küresel tehditlerden biri olarak görülmektedir. Denizel su kütlelerinde biyolojik istila oranı son yüzyılda artış göstermiş, ekolojik ve mali kayıpları yüzünden büyük endişe yaratmıştır. İstilacı türlerin, yerli topluluklar üzerinde de stres oluşturduğu ve/veya ekosistemlere farklı özellikler kazandırdığı tahmin edilmektedir. Ayrıca popülasyonların yapısında ve kompozisyonundaki değişiklikler ile ekosistem fonksiyonundaki bozulmalar (azot döngüsü, ışık geçirgenliği vb.) gibi çeşitli modifikasyonlardan sorumlu oldukları birçok araştırmacı tarafından dile getirilmektedir.

Doğal ve antropojenik kaynaklı küresel iklim değişiklikleri, istilaların coğrafi ve biyolojik sonuçlarını etkilemektedir. İstilacı türler su ürünleri yetiştiriciliği, kanal yapımı, kıyılardaki rekreasyonel faaliyetler, deniz taşımacılığı (balast sularının boşaltılması), turizm ve kültür balıkçılığı gibi son yıllarda artan insan faaliyetleri sonucu sucul ekosistemlere girmektedir. Tüm su kütlelerinde temel bir yöntem olan biyolojik izleme çalışmaları ile ekolojik değerlendirme ve antropojenik müdahalelerin etkileri ortaya konulmakla birlikte, istilacı tür varlığı da tespit edilmektedir.

Tatlı su ve kıyı-geçiş sularının ekolojik durumu, bentik makro omurgasızlar, fitoplanktonlar, makroalgler, balıklar gibi birçok biyolojik kalite unsuru kullanılarak belirlenmektedir. Bu biyolojik topluluklar arasında bentik makroomurgasızlar en yaygın kullanılan biyoindikatörler olup AB Su Çerçeve Direktifi'nin uygulanmasında kullanılan biyolojik kalite unsurlarından biridir. Sucul ortamdaki bentik makroomurgasız türlerinin bulunma durumu, yeni türlerin girişi gibi göstergeler ortamın trofik düzeyi ile ilişkilidir. Bu nedenle biyolojik izleme metotlarının gelişimi indikatör niteliğindeki bentik omurgasız takson ve toplulukların varlığı ile güçlendirilmiştir. İstilacı türler kıyı ve geçiş sularında ekolojik değerlendirmede kullanılan bir gösterge olmasına rağmen, tatlı sularda kullanımı konusunda henüz bir fikir birliğine varılamamıştır.

Türkiye'nin Karadeniz, Marmara, Ege ve Akdeniz sahillerinde farklı hidrodinamik sistemlerin varlığının yanı sıra deniz taşıma-nakliye faaliyetlerini içeren yoğun bir deniz trafiği yaşanmaktadır. Türkiye'deki ticari limanlar ve deniz trafiğinin yoğun olduğu Çanakkale ve İstanbul boğazları istilacı türlerin girişlerini sağlayan önemli noktalar olarak bilinmektedir. Ayrıca, Süveyş Kanalı'nın açılmasıyla birlikte Akdeniz'in doğu kıyılarından yoğun şekilde istilacı tür girişi olmaktadır (Lesepsiyen göç). İstilacı türlerin ekosistemler üzerindeki etkileri ve sucul çevredeki rolleri Türkiye'de çalışılan konulardan birisi olup, bu konuda bilimsel yayımlar son yıllarda artmaktadır.

Bu çalışmada tespit edilen istilacı bentik makroomurgasız türleri Batı Akdeniz (2 istasyon), Doğu Akdeniz (1 istasyon) ve Doğu Karadeniz (2 istasyon) kıyılarında bulunan 5 istasyonda izlenmiş ve kayıt edilmiştir. İzleme çalışması yapılan bölgelerin biyoçeşitlilik ve bentik topluluk yapıları, istasyonlarda niteliksel ve niceliksel örnekleme yapılarak değerlendirilmiştir. Tüm izleme istasyonlarında yumuşak substratumdan makrofauna örneği Van Veen Grab (0,1 m^2 örnekleme alanı) örnekleme ekipmanı ile üç tekrarlı (replikat) olarak gerçekleştirilmiştir. Yumuşak susbstratum örnekleri, 0,5 mm gözlü bir yıkama kovası boyunca filtrelenmiş ve % 4 formaldehit solüsyonu içeren ayrı kutulara yerleştirilmiştir. Laboratuvarda, numuneler tatlı suda durulanmış, bir stereomikroskop altında tür seviyesinde tespit edilmiş ve % 70 etanol içinde korunmuştur.

Proje kapsamında Türkiye kıyılarında, Batı Akdeniz, Doğu Akdeniz ve Doğu Karadeniz kıyılarında bulunan toplam 5 istasyonda 4 istilacı tür tespit edilmiştir.

Polydora cornuta **Bosc, 1802 (Spionidae: Polychaeta);** Batı Akdeniz havzası EDSBAKKS01 istasyonunda yaz döneminde örneklenmiştir. Akdeniz'de en tehlikeli istilacı türlerden biri olarak kabul edilmektedir. İspanya, Yunanistan, Atlantik-Pasifik arası ve Marmara denizi gibi çeşitli bölgelerde daha önce görüldüğüne dair kayıtlar bulunmaktadır. Literatürde nasıl yayıldığına dair kesin bir kanı olmamasına rağmen, gemicilik ve kültür balıkçılığı faaliyetlerinin *P. cornuta* türünün Akdeniz'de görülmesine sebep olduğu düşünülmektedir.

Prionospio saccifera **Mackie & Hartley, 1990 (Spionidae: Polychaeta);** Batı Akdeniz havzası EDSBAKKS09 istasyonunda ilkbahar döneminde örneklenmiştir. İlk olarak 1990 yılında Hong Kong'ta kaydı tutulmuş olan *P. saccifera*, batı Pasifik ve Hint Okyanusunda yaygın olarak görülmekte olup, Akdeniz'e girişinin Süveyş Kanalı vasıtasıyla olduğu düşünülmektedir. Akdeniz için ise ilk kayıt 1999 yılında Çınar ve Ergen tarafından tutulmuştur. Akdeniz'de görülmesi, dünya çapında dağılımının genişlediğinin bir göstergesidir.

Cerithium scabridum **Philippi, 1848 (Cerithiidae: Gastropoda);** Ceyhan havzası EDSCEGS02 istasyonunda ilkbahar döneminde örneklenmiştir. *P. saccifera* gibi yayılımında Lesepsiyen göç adı verilen ve Süveyş Kanalı aracılığıyla meydana gelen hareketliliğin rolü olduğu düşünülmektedir. Doğu Akdeniz'den batıya doğru yayılmasında gemicilik faaliyetlerinin de etken olduğu düşünülmektedir.

Rapana venosa **(Valenciennes, 1846) (Muricidae: Gastropoda) ;**Doğu Karadeniz havzası EDSDKKS02 istasyonunda ilkbahar ve EDSDKKS03 istasyonunda yaz döneminde örneklenmiştir. Asya kökenli büyük bir avcı tür olan *R. venosa,* Karadeniz'de ilk defa 1947'de kaydedilmiş olup buradan Ege ve Adriatik Denizi'ne yayılmıştır. Büyük avcı türlerin eksikliğinden dolayı Karadeniz'de hızlıca çoğalabilmektedir. Karadeniz'de ve Akdeniz'in doğusunda bulunan *R. venosa* türlerinin dünyanın çeşitli yerlerine gemilerin balast suları ile yayıldığı düşünülmektedir.

Bu çalışma, Orman ve Su İşleri Bakanlığı Su Yönetimi Genel Müdürlüğü tarafından finanse edilen biyolojik izleme projesi (*Proje No: 2011K050400, Türkiye'ye Özgü Su Kalitesi Ekolojik Değerlendirme Sisteminin Kurulması Projesi*) kapsamında Türkiye kıyılarından örneklenen istilacı türler hakkında yapılmış bir incelemedir. 2014 ve 2015 yılları arasında gerçekleştirilen izleme projesi boyunca, Türkiye kıyılarından 4 istilacı ve 7 yabancı tür tespit edilmiştir. Teşhisi yapılan istilacı türler; *Polydora cornuta* Bosc 1802; *Prionospio saccifera* Mackie & Hartley 1990; *Cerithium scabridum* Philippi 1848 ve *Rapana venosa* (Valenciennes, 1846). Bu türlerin bazı coğrafik dağılım verileri kısaca incelenmiştir.

Technical Note

How Syria Crisis Affects the Potable Water System Efficiency in Non-State Armed Group Controlled Areas

Suriye Krizi, Devlet Dışı Grupların Kontrolü Altındaki Bölgelerde İçme Suyu Verimliliğini Nasıl Etkiliyor

Abdullah SAGHIR

Syrian Engineers for Construction and Development Organization (SECD) Gaziantep- Turkey
a.saghir@secdo.org

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Abstract

The purpose of this study/technical assessment was understanding the effects of the crisis of Syria on water sector in the area out of the control of Syria regime (Non-State Armed Group controlled areas), and defined the worst communities, located in Daret Azza sub district/Aleppo governorate, which need urgent technical and financial assistance in the fields of water and sewage sectors. The study showed that 100% of wastewater was not be treated because of lack of wastewater treatment plants. There was no water distribution network and also 91% of the people in the community has not accessed to the public water network. The water-supply infrastructure was not efficient. Therefore, all water-supply infrastructure in Daret Azza subdistrict was needed to rehabilitate and maintenance. The people of Daret Azza subdistrict spent about 8-13% of their income for purchasing unsafe water while the people living in the Regime-controlled areas spent about 0.5-1% of their income for purchasing safe water. For this reason, the people of Non-State Armed Group controlled areas needed urgent and sustainable technical and financial supports, especially for obtaining potable water.

Keywords: *Water supply, Syria crisis, water system, Daret Azza*

Öz

Bu çalışmanın ya da teknik değerlendirmenin amacı, Suriye'de yaşanan krizin Suriye rejiminin kontrolünün dışında kalan alanlardaki (devlet dışı silahlı grupların kontrolündeki alanlar) su sektörü üstündeki etkilerini anlamaktır. Ayrıca, su ve kanalizayon sektörlerinde acil teknik ve mali yardıma ihtiyacı olan Halep Valiliğinin yönetimdeki Daret Azza nahiyesindeki en kötü durumda bulunan toplulukları belirlemek amaclanmaktadır. Bu çalışma ile ülkede arıtma tesisleri bulunmadığı için atıksuların tamamının arıtılmadığını gösterilmiştir. Aynı zamanda su dağıtım şebekesi de bulunmamakta ve nahiye nüfusunun %91'i kamu su şebekelerine erişememektedir. Su temin altyapısı yeterli değildir. Bundan dolayı, tüm su temin altyapısının rehabilite edilmesi ve bakımlarının yapılmasına ihtiyaç vardır. Daret Azza nahiyesindeki insanlar gelirlerinin %8-13 kadar kısmını güvenilmez su için harcarken rejimin kontrolü altındaki bölgelerde yaşayanlar gelirlerinin %0.5-1'ini harcamaktadırlar. Bu nedenle, devlet dışı silahlı grupların kontrolündeki alanlarda yaşayan insanlar, özellikle içme suyuna erişimde acil, sürdürülebilir teknik ve mali desteğe ihtiyaç duymaktadırlar.

Anahtar kelimeler: *Su arzı, Suriye krizi, su sistemi, Daret Azza*

Introduction

In recent years, water resources are under an increasing stress due to impacts of climate change, population increase and economic development (Selek et al.,2018).

Before the conflict of Syria at 2011, nearly 85% of the population in Syria accessed well-developed, state-owned, and centrally-managed water systems. Most of the water systems in rural Syria is defined as intermittent water supply on the contrary millions of people throughout worldwide have access to water consistently (Van den Berg et al, 2011). In the rural areas of Syria, piped water supply services are considered as intermittent water supply (IWS), that means the water is available only limited hours per a day (Ilaya-Ayza et al., 2017).

On the other hand, Syrian major cities only have sewage systems including treatment plants while other parts of the country relied on simpler technologies. The public institutions manage water systems in towns, cities and villages. About 85% of the population of towns and cities in Syria obtained their water needs form public water systems, on the other hand the others (about 20%) obtained potable water from other water resources such as private water well, water tracking etc. An average Syrian consumes drinking water about 100-200 liter/a day. The population in Daret Azza subdistrict obtains water from deep water wells which supply with Syrian standard on drinking water (SAOSM, 2007).

The Syrian conflict has enveloped the entire country and has led to socially, economically and civilly mass-scale destruction at all levels of society. The conflict has led to one of the worst humanitarian crises of modern history, leaving a particular impact on the most vulnerable populations of women and children. The water systems and wells have deteriorated drastically due to the conflict. Materials such as diesel for generators, chlorine etc. for operating water systems healthy and efficiently are extremely limited due to high prices and non-availability. Furthermore, during the 2014 and 2015 season, Syria has experienced one of the worst droughts affecting negatively all kinds of water systems of the last several years. Humanitarian intervention has thus far largely focused on emergency response including water trucking and the provision of bottled water.

It is estimated that 80% of water infrastructure in Syria is in need of rehabilitation and maintenance (UN-OCHA, 2018; HNO, 2017). As a consequence of the combined effect of infrastructure breakdown and scarce of water, an increasing proportion of the population nowadays depends on trucked water, provided by both the public and private sectors, which are not regulated or resorting to unprotected water sources, and have witnessed increases in prices.

Additionally, as a result of the lack of electricity in these cities, water stations do not work, it is need to have diesel/fuel oil to operate them. The number of displaced persons and communities in these cities and towns has increased day after day as a result of the lack of potable water. On the other hand, the poverty level is also rising and every family needs to have about 10-20$ monthly for purchasing unsafe water. This amount in general is not available to Syrian poor people, as 80 percent of its population live at or below the national poverty line in Syria. Moreover, the lack of electricity has had negative impacts across sectors, including health, and water, sanitation and hygiene (WASH). Indeed, 13 million of Syrian people have not chance to access permanently healthy water. The population, live in areas that are out of control of the regime, often depends on water tanks and other sources, supplied by private companies. This situation poses enormous financial burden on Syrian households (UN-OCHA, 2018; HNO, 2017).

Similar to several other systems in MENA (Middle East and North Africa) region, the water systems in Syria are characterized as being urban; modern and extensive. Water and sewage networks require increased support to continue providing a minimum level of services (UN-OCHA, 2017, HNO, 2016). The assessment objectives may be summarized as given below.

- Define the worst communities in water and sewage sector which need urgent technical and financial assistance.
- Drawing true picture about water infrastructure in the areas, out of the Syrian regime control.
- Understanding the negative effects of the war on the water sector in the areas out of Syrian regime control (UNICEF, 2017).

Methods

This research focused on Daret Azza subdistrict, located on Jebel Saman district in Syria, and managed by Aleppo governorate, Non-State Armed Group NSAG-controlled areas since the end of 2012 (Figure 1-2). Its population is about 109.612 people (47.637 internally displaced persons (IDPs), 61.975 local people) as showed in the table 1 (IOM, NPM, 2017).

Table 1

The Total Number of Population of Daret Azza Subdistrict Communities

Country	Governorate	District	Sub-district	Community	Number of population
Syria	Aleppo	Jebel Saman	Daret Azza	Hur	3474
Syria	Aleppo	Jebel Saman	Daret Azza	Tqad	8067
Syria	Aleppo	Jebel Saman	Daret Azza	Arhab	3359
Syria	Aleppo	Jebel Saman	Daret Azza	Majbineh	2674
Syria	Aleppo	Jebel Saman	Daret Azza	Bsartun	5500
Syria	Aleppo	Jebel Saman	Daret Azza	Anjara	12.754
Syria	Aleppo	Jebel Saman	Daret Azza	Zarzita	4030
Syria	Aleppo	Jebel Saman	Daret Azza	Hoteh	8384
Syria	Aleppo	Jebel Saman	Daret Azza	Bshantara	1265
Syria	Aleppo	Jebel Saman	Daret Azza	Bishqatine	1174
Syria	Aleppo	Jebel Saman	Daret Azza	Kafrantin	225
Syria	Aleppo	Jebel Saman	Daret Azza	Qabtan	4811
Syria	Aleppo	Jebel Saman	Daret Azza	Daret Azza	43.320
Syria	Aleppo	Jebel Saman	Daret Azza	Deir Saman	7000

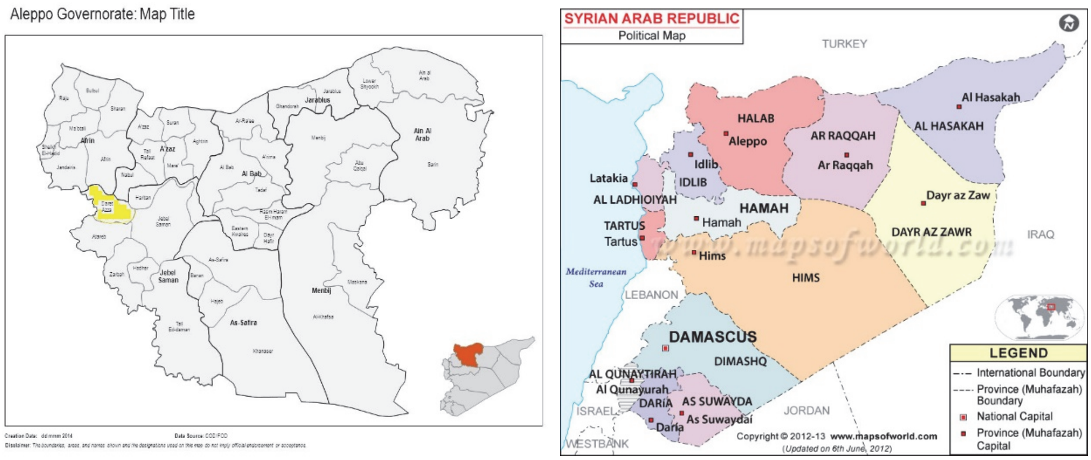

Figure 1-2. Syria map, Aleppo governorate and Daret Azza subdistrict location.

The water system in Daret Azza subdistrict consists of the following parts:

- Mechanical devices: Horizontal and vertical pumps, generators, pips, valves, chlorine dosing pumps.
- Civil infrastructure: ground water tank, high water tank, distribution rooms, control rooms.
- Electrical infrastructure: Cables, transformer and control panels.

SECD (Syrian Engineers for Construction and Development) organization team collaboration with United Nations Children's Emergency Fund (UNICEF) and Water, Sanitation and Hygiene (WASH) cluster/Turkey hub conducted a project for technical assessment of water stations in Daret Azza subdistrict, and also SECD team made a needs assessment for rehabilitation of its sewer system. The assessment of water stations at Daret Azza subdistrict was conducted by five technical engineers of SECD in the field.

SECD used the following simple equation which usually used by UNICEF (UNICIEF, 2017) for assessment of water stations. This method is familiar in Syria and most of water engineers use this equations for calculate the composite indicator.

$$I_C = W_1 \times I_1 + W_2 \times 1_2 + W_3 \times I_3 + \ldots + W_N \times I_N$$

Where W_N is a weight for the N^{th} component indicator (I_N), I_C is the composite indicator and $W_1 + W_2 + W_3 + \ldots + W_N = 100\%$ (UNICIEF, 2017).

For Daret Azza subdistrict, the water-supply infrastructure efficiency (WSIE) can be calculated by the equation given below.

WSIE = (55%) mechanical devices efficiency+ (30%) civil infrastructure + (15%) electrical infrastructure

The value of weight was calculated according to the cost and the importance of the indicator. In general, for water station of Daret Azza the average cost of rehabilitation of mechanical devices was about 55%, and the cost of rehabilitation civil infrastructure was about 30%, and the cost of electrical infrastructure related to water stations was about 15%. Each indicator consists of many sub indictors:

- Mechanical devices consist of many sub indictors: Is there a stand-by submersible pump(s) ready to use? The answer should be: yes or no.
    - Is there a stand-by horizontal pump(s) ready to use? The answer should be yes or no.
    - Is there a stand-by chlorine pump(s) ready to use? The answer should be yes or no.
    - Does the submersible pump(s) functions? The answer should be yes or no.
    - Does the Horizontal/vertical pump(s) functions? The answer should be yes or no.

  - Does the generators functions? The answer should be yes or no.
  - Do the pipes and valve(s) functions? The answer should be yes or no.
  - Does the Horizontal/vertical pump(s) functions? The answer should be yes or no.
  - Is there a submersible pump(s) ready to use? The answer should be yes or no.
  - Is there a horizontal pump(s) ready to use? The answer should be yes or no.
  - Is there a chlorine pump(s) ready to use? The answer should be yes or no.
  - Is there a generator pump(s) ready to use? The answer should be yes or no.

- Civil infrastructure consists of many sub indictors:
  - Does the ground water tank (s) functions? The answer should be yes or no.
  - Does the high-water tank functions? The answer should be yes or no.
  - Does the distribution room(s) functions? The answer should be yes or no.
  - Does the control room(s) functions? The answer should be yes or no.

- Electrical infrastructure consists of many sub indictors:
  - Is there a stand-by cables (s) ready to use? The answer should be yes or no.
  - Is there a stand-by transformer (s) ready to use? The answer should be yes or no.
  - Is there a stand-by control panels to use? The answer should be yes or no.
  - Does the cables (s) functions? The answer should be yes or no.
  - Does the transformer (s) functions? The answer should be yes or no.
  - Does the control panels s function? The answer should be yes or no.
  - Is there a sufficient cables (s) ready to use? The answer should be yes or no.
  - Is there a sufficient transformer (s) ready to use? The answer should be yes or no.
  - Is there a sufficient control panel? The answer should be yes or no.

- Water System Efficiency (WSE) = (45%) mechanical devices efficiency+(30%) civil infrastructure + (15%) electrical infrastructure + (10%) Availability of technical people at a water station

- Maximum Production Capacity of Water Stations (MPCoWS) (m^3/day): The amount of water produced by all water wells if the water pump work about 16 hours per a day (it is assumed that all water stations are function).

- Maximum Amount of Water for Per Person (MAoWP) (l/person, day) =Maximum production capacity ×1000× 0.8/number of population.

- The Actual Average Water Consumption for Per Person (AAWCP) (l/person, day) = the amount of water consumption per person per day. SECDO team consulted the families, selected randomly lived in the target location and reported the values about water uses. Before the crisis in Syria, each people consumed about 80-150 liter /day of drinkable water. However, after the Syrian crisis, the water consumption has been getting lower and lower because of the scarcity of water and the extreme high water prices.

- Actual Production Capacity of Water Station (APCoWS) (m^3/ day): According to the lack of public electricity and diesel for the generator in water station. In the water stations, water does not produced stably so the value of APCoWS is equal to 0 when there is not public electricity and diesel for the generator in water station, and sometime its value equal to MPCoWS.

Results

SECDO team during October and November of 2017 conducted the work for the understanding of sewerage and water system infrastructures that were located in Daret Azza district. The results of the assessment are shown in the tables 2, 3 and 4.

Table 2

The Technical Assessment Results for Sewer Network of Daret Azza Subdistrict Communities

Community	% of people served by public Sewer network	Amount of Wastewater (m^3/day)	Percent amount of treated wastewater (%)	Existence of WWTP (Yes/No)	Registered cutaneous leishmaniasis Cases during 2017 (ACU, EWARN 2017)
Hur	77%	133.4	0	NO	89
Tqad	82	374.3	0	NO	117
Arhab	72%	137.0	0	NO	
Majbineh	65%	109.1	0	NO	
Bsartun	82%	193.6	0	NO	
Anjara	83%	581.6	0	NO	183
Zarzita	0%	154.8	0	NO	
Hoteh	68%	288.4	0	NO	6 (1)
Bshantara	69%	52.6	0	NO	
Bishqatine	72%	49.8	0	NO	
Kafrantin	0%	8.8	0	NO	
Qabtan	83%	234.8	0	NO	205
Daret Azza	89%	2218.0	0	NO	371
Deir Saman	73%	274.4	0	NO	

Note. Amount of Wastewater (m^3/day)=0.8 ×number of population × the average water consumption (l/person. day)/1000, *WWTP*= wastewater treatment plant.

Note [1]. This value for only 11 weeks and the other value cover all 2017

Table 3

The Technical Assessment Results of WSIE Of Daret Azza Subdistrict Communities.

Community	The water network coverage WNC (%)	Number of Water Stations	WSIE (%)	MPCoWS (m³/day)	MAoWP (l/person. day)	Availability of public electricity (h/day)	AAWCP (l/person. day)	APCoWS (m³/day)	Total WDB during 2017 (Assistance coordination unit (ACU), EWARN 2017)
Hur	71%	2	48	1060	244.1	0	48	718	2401
Tqad	82	1	49	594	58.9	0	58	396	
Arhab	72%	1	64	360	85.7	0	51	0	
Majbineh	65%	1	63	450	134.6	0	51	0	
Bsartun	82%	3	57	792	115.2	0	44	429	
Anjara	87%	6	72	2484	155.8	0	57	0	121
Zarzita	0%	1	61	630	125	0	48	0	
Hoteh	68%	9	42	3996	381.3	0	49	0	1081 (2)
Bshantara	71%	1	62	540	341.5	0	52	361	
Bishqatine	72%	1	66	396	269.8	0	53	0	
Kafrantin	0%	0	0	0	0.0	0	49	0	
Qabtan Eliabal	81%	4	60	1638	272.4	0	61	0	247
Daret Azza	91%	4	77	8370	154.6	0	64	270	10234
Deir Saman	0%	1	59	360	41.1	0	49	215	

Note. The total WDB= ABD (Acute Bloody Diarrhea) + AWD (Acute Watery Diarrhea) + AD (Acute Diarrhea (i.e. all other diarrheal cases but AWD and ABD)) + STF (Suspected Typhoid Fever)

Note.[2] *This value for only 11 weeks and the other value cover all 2017*

Table 4

The Availability of Fuel and Chlorine of Daret Azza Subdistrict Communities Market and the Various Cost of 1 m^3 of Drinkable Water

Community	**Availability of fuel at water Station**	**Availability of fuel at the market**	**Availability of chlorine at water station**	**Availability of spare parts at water station (%)**	**Availability of technical people at water station (%)**	**Cost of buying 1 m^3 by water tracking**	**Cost of supplying (COS) 1m^3 by public water network**	**What percentage of income is used to buy water**
Hur	75%	100%	0	27%	51%	1.19	0.85	10 %
Tqad	67%	100%	0	17%	52%	1.25	1.08	12%
Arhab	0	100%	0	29%	59%	1.17	0.82	8%
Majbineh	0	100%	0	17%	62%	1.16	0.81	12%
Bsartun	0	100%	0	12%	52%	1.1	0.67	9%
Anjara	0	100%	70%	72%	79%	1.05	0.89	12%
Zarzita	37%	100%	0	0	0	0.92	0.48	11%
Hoteh	0	100%	40%	19%	52%	1.2	0.91	9%
Bshantara	68%	100%	0	31%	41%	1.13	0.75	9%
Bishqatine	0	100%	0	28%	43%	1.11	0.89	7%
Kafrantin	0	100%	0	0	0	1.2	N/A	13%
Qabtan Eljabal	0	100%	0	23%	73%	1.1	0.75	12%
Daret Azza	12%	100%	70%	63%	85%	1.4	1.09	8%
Deir Saman	71%	100%	100%	10%	62%	1	0.249	13%

1-100% of wastewater do not be treated because there is not a wastewater plant. Therefore, the cutaneous leishmaniasis is disseminated through country. Ground water are also polluted. According to ACU Reports, there were totally 14.536 patients with waterborne diseases and 971 patients with cutaneous leishmaniasis in Daret Azza subdistrict during 2017 . Local council and any nongovernmental organizations of NSAG-controlled areas do not have enough financial and technical resources for constructing wastewater treatment plant (ACU, EWARN 2017).

2-All sewer network is functioning, but there is a need to rehabilitate most of them. Additionally, Kafrantin and Zarzita communities do not have sewer network, so day by day, the water resources are getting polluted more and more.

3-The WNC values are about 0% (which mean there is not water network) and 91% of the houses of the communities have not access to the public water network. Zarzita, Deir Saman and Kafrantin communities till now (30.12.2017) did not have water supply network. Therefore, it is so important to construct new water systems in the locations which did not have any water supply networks or had dysfunctional networks, and also to extend to the areas that did not have this system.

4-WSIE is about 0% (which mean there is not water station because some communities in Syria do not have water station till now, and the people get obtain water from other communities) to 71%. Water-supply infrastructure in Daret Azza subdistrict should be rehabilitated and maintained, but the local authorities of Daret Azza do not have enough financial resources for making necessary rehabilitation. SECD, World Vision International (WVI), and other non- government organizations (NGOs) worked in Daret Azza for solution of water issues. Similarly, they also do not have enough financial resources to fix all the problems related to water system.

5-AAWCP (l/person.day) is about 44-64 liter/day. It is similar to the value in the export of WoS-WASH Clusters which the average number of water consumption of each person in Daret Azza subdistrict is explained as 61.73 liter /day.

6-MAoWP (l/person.day) values for Daret Azza communities are various among 0 (for the communities no having water stations) and the maximum value with 381.3 liter (l/person.day). This indicator is very important to determine their needs to establish new water stations. If MAoW value should be less than 50 liter/person, there will be a need to construct a new water station. Therefore, Deir Saman village urgently needs a new drinkable water resource. Most of water stations has not produced water because of lack of electricity and diesel for the generators replaced in water stations. In addition to, local councils and water units do not have enough financial resources for covering the operating costs of supplying water. On the other hand, a number of NGOs have supported certain local councils and water units such as Bsartun and Hur etc. By this way, they may provide potable water for their people, and the others such as Deir Saman, Daret Azza may conduct recovery costs, even if just drop. After all, water units and local councils in Daret Azza have needed uninterrupted support, as 85% of Syrian people has lived under the poverty line according to OCHA reports.

7-The cost of 1 m^3 by water trucking in Daret Azza communities is between 0.249-1 $ while in the regime-controlled areas, it is about 0-0.13 $/$m^3$ (MoWR, Order 894, 2014). Because the fee for water supplying service is determined by government. On the other hand, this water is not healthy, as it has not be disinfected. In parallel with this, the indicator of water disease born of Daret Azza is getting higher and higher according to reports of the [3]Early Warning Alert and Response Network Program (ACU, EWARN 2017).

8-COS of 1 m^3 of drinking water by public water network in Daret Azza communities is between 0.92-1.4 $. (Figure 5). Contrarily, this water is healthy depending on many factors: the depth of ground water table, the length of water networks etc. The maximum value of COS in Daret Azza and Tqad is shown as Figure 6. Because the ground water table level is too high, and the dynamic level in these communities is about -450 m.

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[3] Surveillance is a systematic and continuous collection of epidemiological health data within a specific time frame, and therefore the interpretation and dissemination of such information in the field of public health. Surveillance is essential in the planning, implementation and evaluation of public health practices. The Early Warning Alert and Response Network is a simplified disease surveillance system created in the affected north of Syria after the collapse of the health system in mid-2013.

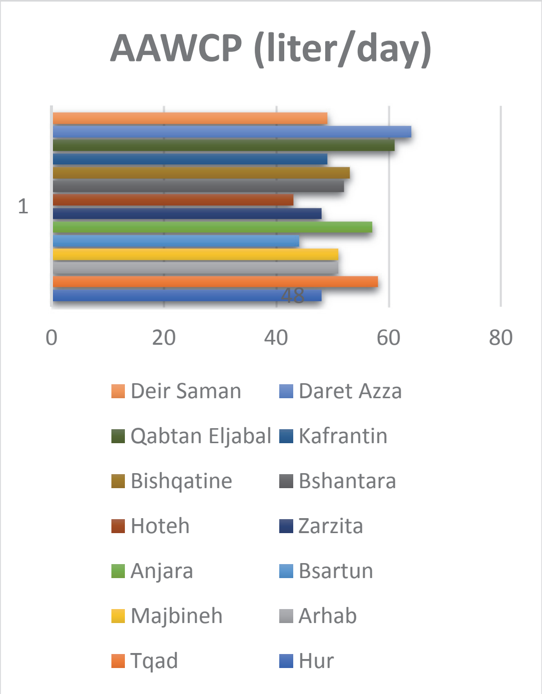

Figure 3. AAWCP (l/person.day) of Daret Azza subdistrict communities.

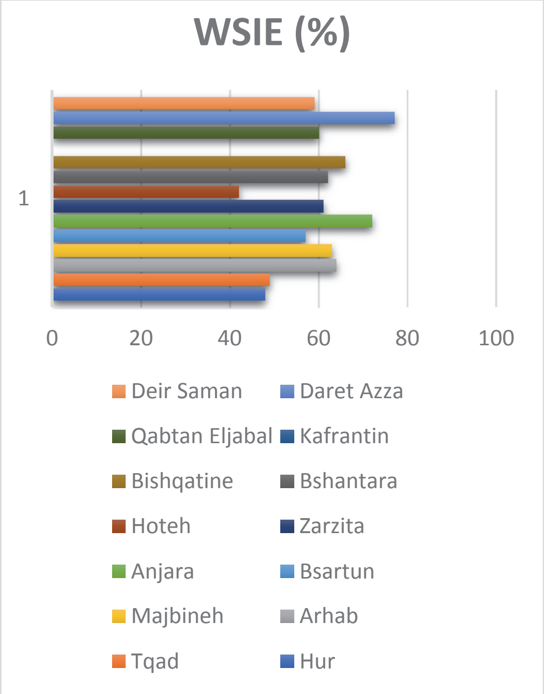

Figure 4. WSIE (%) of Daret Azza subdistrict communities.

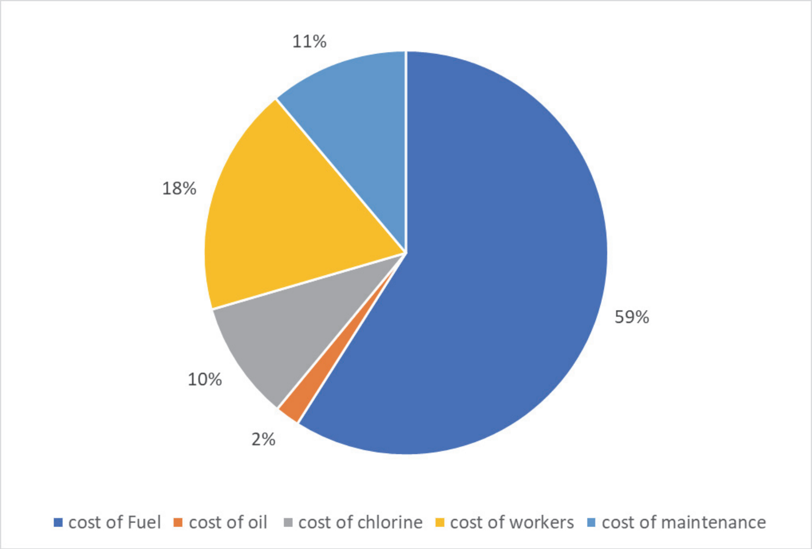

Figure 5. The cost segregation of supplying 1 m^3 of drinking water by public water network of Daret Azza communities.

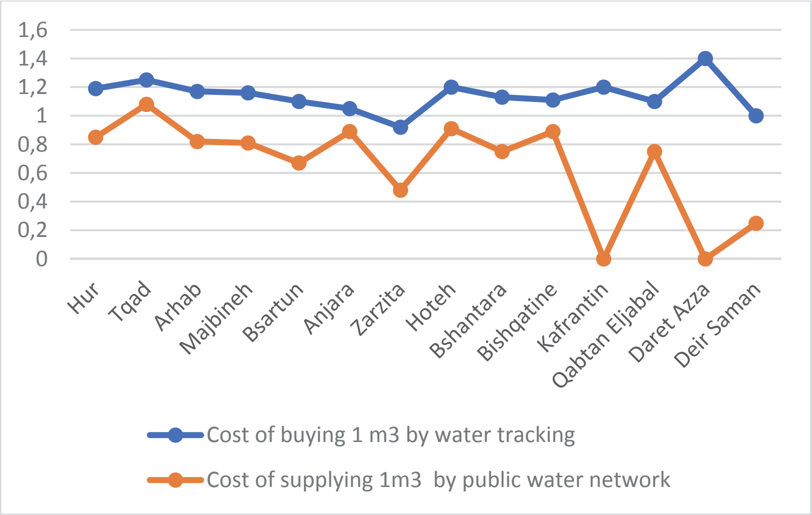

Figure 6. The cost of supplying 1 m^3 of drinking water by public water network and the cost of buying 1m^3 by water tracking.

9-The people of Daret Azza communities spends about 8-13% of their income for buying unsafe water. The amount is so high for them as shown in Figure 7. The people living in the regime controlled areas spends about 0.5-1% of their income, as fee for water supplying services is determined as 0-0.13 $/$m^3$ by the government ·Before 2011, most of Syrian people spends about 0.3-1% $/$m^3$, so the people in NSAG and potable water sectors need uninterrupted financial and technical supports.

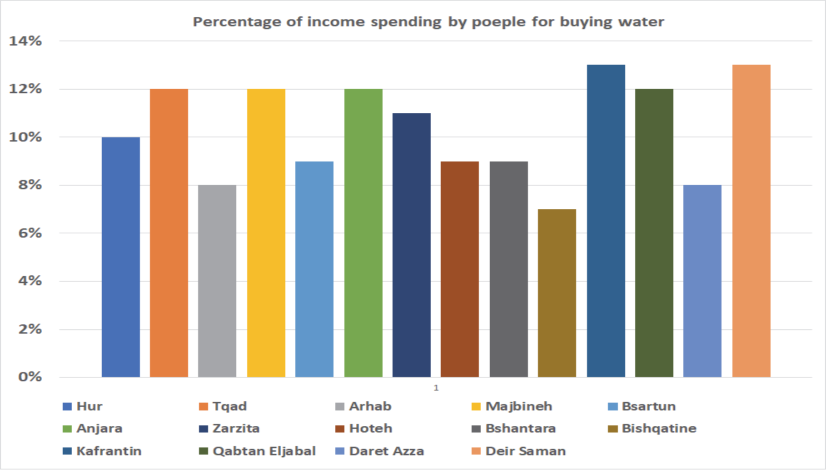

Figure 7. The percentage of income spending by people for buying water by track in Daret Azza subdistrict communities.

Conclusion

The assessment showed that the people in NSAG-controlled areas needs urgent and sustainable technical and financial supports, especially for obtaining drinking water. The unhealthy water which is supplied by water tracking is the root cause of high WDB during 2017. 14.536 patients with WDB was registered in 2017. Additionally the untreated wastewater of Daret Azza subdistrict is one of the cause of cutaneous leishmaniasis during 2017.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Suriye Krizi, Devlet Dışı Grupların Kontrolü Altındaki Bölgelerde İçme Suyu Verimliliğini Nasıl Etkiliyor

Suriye'deki savaş modern tarihin en kötü insani krizlerinden birine yol açmıştır.Tüm ülkeyi saran savaş toplumun her seviyesinde ve özellikle en savunmasız grup olan kadınlar ve çocuklar üzerinde en büyük olumsuz etkiyi yaparak sosyal ve ekonomik alanlar ile alt yapı sistemlerinde kitlesel ölçekte yıkıma yol açmıştır. Su sistemleri ve kuyular büyük ölçüde zarar görmüştür. Su temin sistemlerini işletmek için gerekli olan jeneratör, klor vb. gibi teçhizat ve kimyasalların fiyatlarının yüksek olması ve yeterince bulunamaması nedeniyle sağlıklı ve kesintisiz su arzı son derece sınırlıdır. Ayrıca, son birkaç yılda, Suriye'de, her türlü su sistemini olumsuz etkileyen en şiddetli kuraklıklar yaşanmıştır. Ülkeye yapılan insani yardımlar acil ihtiyaçlara odaklanmış, halkın su ihtiyacı tankerler ile taşınan veya şişelenmiş sularla karşılanmıştır. Bunun nedeni ise Suriye'deki su temin altyapısının %80'inin rehabilite ve bakıma ihtiyacı olduğunun düşünülmesidir (UN-OCHA, 2018; HNO, 2017). Ülke nüfusunun büyük çoğunluğu su temin altyapısının çökmüş olması ve su kıtlığı yaşanmasının birleşik etkisi sonucu günümüzde, kamu ve özel sektör tarafından kamyonlarla taşınan ve hijyenik olmayan suyu kullanmaktadır. Su ve kanalizasyon şebekelerinin, asgari düzeyde hizmet verebilmeleri için daha fazla teknik ve mali desteğe ihtiyaç duyulmaktadır (UN-OCHA, 2017, HNO, 2016). Suriyeli Mühendisler İnşaat ve Geliştirme Organizasyonu (SECD), UNICEF ve Su, Sanitasyon ve Hijyen (WASH) ekibi, Daret Azza alt bölgesinde su istasyonu teknik değerlendirmesi için bir proje yürütmüştür. Sözkonusu ihtiyaçları belirlemek amacıyla yürütülen bu projenin alt hedefleri aşağıda sıralanmaktadır:

1. Su ve kanalizasyon açısından acil teknik ve mali desteğe ihtiyaç duyulan bölgeleri belirlemek,
2. Suriye rejimi kontrolünde olmayan bölgelerin su ve kanalizasyon şebekelerinin gerçek tablolarını ortaya çıkarmak,
3. Suriye rejimi kontrolü dışındaki bölgelerde savaşın su sektörü üzerindeki olumsuz etkilerini anlamak (UNICEF, 2017).

SECD ekibi, kanalizasyon sisteminin rehabilitasyonu için bir ihtiyaç değerlendirmesi yapmıştır. Bu araştırma Suriye'nin Jebel Saman ilçesinde bulunan ve Halep Valiliği tarafından yönetilen Daret Azza alt bölgesine odaklanmıştır. Halep Valiliği'nin yönetimdeki Daret Azza nahiyesindeki en kötü durumda bulunan toplulukları belirlemiştir. Daret Azza alt bölgesinde yer alan su sistemi aşağıdaki kısımlardan oluşmaktadır:

1- Mekanik cihazlar: Yatay ve dikey pompalar, jeneratörler, borular, vanalar, klor dozaj pompaları
2- Sivil altyapı: yeraltı su deposu, yüksek su deposu, dağıtım odaları, kontrol odaları
3- Elektrik altyapısı: Kablolar, trafo ve kontrol panelleri

SECD ekibi, su istasyonlarının değerlendirilmesinde UNICEF (UNICIEF, 2017) tarafından kullanılan aşağıdaki basit denklemi kullanmıştır. Bu denklem Suriye'deki su mühendislerinin çoğu tarafından kompozit göstergeyi hesaplamak için kullanılmaktadır.

$$I_C = W_1\times I_1 + W_2\times 1_2 + W_3\times I_3 + \dots + W_N\times I_N,$$

(Ic) kompozit göstergesi= W1 + W2 + W3 +… + WN (WN): Nth'nin ağırlık değeri (In): bileşen göstergesi =% 100 (UNICEF, 2017).

Daret Azza alt bölgesi için Su tedarik altyapısı verimliliği (WSIE) şu şekilde hesaplanabilir:

WSIE = (% 55) mekanik cihazlar verimliliği + (% 30) sivil altyapı + (% 15) elektrik altyapısı.

Ağırlık değeri, maliyete ve göstergenin önemine göre hesaplanmıştır. Daret Azza su istasyonu için mekanik cihazların ortalama rehabilitasyon maliyeti yaklaşık %55, rehabilitasyon sivil altyapısının maliyeti yaklaşık %30, su istasyonları ile ilgili elektrik altyapısının maliyeti yaklaşık %15'dir. Her gösterge birçok alt göstergeden oluşmaktadır. Yapılan hesaplamalar ve çalışmalar neticesinde; aşağıdaki sonuçlara ulaşılmıştır.

1. Atık su tesisinin olmaması nedeniyle atık suyun %100'ü arıtılamamaktadır. Bu nedenle, kutanöz leishmaniasis hastalığı ülke çapında yayılmaktadır. ACU raporlarına göre, 2017 yılında Daret Azza alt bölgesinde, su kaynaklı hastalıkları olan toplam 14.536 hasta ve kutanöz leishmaniasisli 971 hasta kaydedilmiştir. Ayrıca, yeraltı suları da kirlenmiştir.
2. Tüm kanalizasyon şebekesi çalışmaktadır, ancak bunların çoğunun iyileştirilmeye ihtiyacı bulunmaktadır. Fakat Kafrantin ve Zarzita topluluklarının kanalizasyon şebekesi yoktur, bu yüzden her geçen gün su kaynakları giderek daha fazla kirlenmektedir.
3. WNC değerleri yaklaşık % 0'dır (yani su şebekesi yoktur) ve söz konusu toplulukların % 91'i kamu su şebekesine erişememektedir. 30.12.2017 tarihi itibarı ile Zarzita, Deir Saman ve Kafrantin topluluklarının su şebekesi yoktur. Bu nedenle, herhangi bir su şebekesi bulunmayan veya çalışmayan yerlerde yeni su sistemleri inşa etmek çok önemlidir.
4. WSIE %0 civarındadır (yani su istasyonu bulunmadığı için, Suriye'deki bazı topluluklar, diğer topluluklardan su temin etmektedir). Daret Azza alt bölgesindeki su temin altyapısının %71'nin iyileştirilmesi gerektiği halde, yerel yetkililerinin rehabilitasyon için yeterli mali kaynağı bulunmamaktadır.
5. AAWCP (1/insan*gün) yaklaşık 44-64 litre/gündür. WoS-WASH Kümelenmelerinin raporundaki değer ile örtüşmekte, Daret Azza nahiyesindeki her bir kişinin ortalama su tüketimi 61.73 litre/gün olarak açıklanmaktadır.
6. Dema Azza toplulukları için MAOWP (1/ insan*gün) değerleri en az 0 (su istasyonu bulunmayan topluluklar için) ve en çok 381,3 litre (1/insan*gün) arasındadır. Bu gösterge, yeni kurulacak su istasyonlarının ihtiyaçlarını belirlemek için çok önemlidir. MAOW değerinin 50 litreden az olması durumunda, yeni bir su istasyonu inşa edilmesine ihtiyaç olacaktır. Bu nedenle Deir Saman köyünün acilen yeni bir su istasyonuna ihtiyacı vardır.
7. Daret Azza topluluklarında 1 m^3'lük su temininin maliyeti, rejim kontrolü dışındaki bölgelerde 0.249-1 $ arasında iken, rejim kontrolü altındaki bölgelerde yaklaşık 0-0.13 $ / m^3'tür (MoWR, Order: 894, 2014). Diğer taraftan, rejim kontrolü dışındaki bölgelere temin edilen su dezenfekte edilmediği için sağlıklı değildir. Daret Azza'dan ortaya çıkan sudan kaynaklanan hastalık göstergesi, Erken Uyarı ve Müdahale Ağı Programı raporlarına göre daha yüksektir (ACU, EWARN 2017).
8. Daret Azza topluluklarında kamu su şebekesinden sağlanan 1 m^3 içme suyunun COS değeri 0.92-1.4 $ arasındadır. Su yeraltı suyu tablasının derinliği, su ağlarının uzunluğu vb. birçok faktöre bağlı olarak sağlıklıdır.
9. Daret Azza halkı gelirlerinin % 8-13'ünü güvensiz su satın almak için harcarken, rejime dayalı bölgelerde yaşayan insanlar ise gelirlerinin yaklaşık % 0,5-1'ini su için harcamaktadır.

Bu sonuçlardan da anlaşılacağı üzere, NSAG ve içme suyu sektörlerindeki insanlar kesintisiz mali ve teknik desteklere ihtiyaç duymaktadır. Bu nedenle, devlet dışı grupların kontrolündeki alanlarda yaşayan insanlar, özellikle içme suyuna erişimde acil, sürdürülebilir teknik ve mali olarak desteklenmelidir.

Research Article

Identifying Surface Runoff Distribution and Amount in Stream Basins: Ergene River Basin

Akarsu Havzalarında Yüzeysel Akış Dağılış ve Miktarının Belirlenmesi: Ergene Nehri Havzası

Atilla Karataş
Marmara University, Faculty of Science and Literature Geography Department, 34722 İstanbul, Turkey
atilla.karatas@marmara.edu.tr
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Abstract

The undisputable significance of water resources necessitates solving problems related to the amount and distribution of water. However, existing methods and the outcomes obtained via these methods are continuously criticized and do not meet the expectations in terms of reliability. On the other hand, increasing need to plan water resources and lack of alternative methods to determine the water potential in areas where flow measurement does not exist make it impossible to evade dependency on these methods. With this purpose generated flexible, comprehensive and reliable runoff distribution map was formed on the basis of weighted overlay in parallel to impact degrees of effective parameters. The calibration of the obtained map was done on the basis of pixels based on both theoretical and empirical data. As a result of the analyses, it was seen that an accurate runoff distribution model that fully reflects the characteristics of the field can only be developed by calibrating it based on the real flow data obtained from remote sub-basins that are free from external interventions. It would be impossible to free the theoretical approaches from errors since these approaches are related to amount of water which has an active nature and interacts with factors that are beyond measure. As a result of implementing the method on Ergene River Basin, the sample basin, a surface runoff volume of an average183,45mm/year/m², i.e. a total of 2100000000m³/year ±2% was obtained for the basin and this result has at least 27% difference from the results obtained with existing methods.

Keywords: *Surface runoff, runoff modeling, runoff distribution, water potential, Ergene River Basin*

Öz

Su kaynaklarının tartışmasız önemi bu maddenin miktar ve dağılışına dair problemlerin çözülmesini zorunlu kılmaktadır. Ancak mevcut yöntemler ve bu yöntemlerin verdikleri sonuçlar sürekli olarak tenkitlere maruz kalmakta, güvenilirlik açısından beklentiyi karşılayamamaktadır. Buna karşılık su kaynaklarının planlanması hususunda her geçen gün artan zaruret ve akım ölçümünün bulunmadığı alanların su potansiyelini belirlemenin başka bir yolunun olmayışı söz konusu yöntemlere bağımlılıktan kurtulmayı imkânsız hale getirmektedir. Dolayısıyla esnek, kuşatıcı ve güvenilir bir yüzeysel akış dağılış modeline olan ihtiyaç su kaynaklarının sevk ve idaresi konusundaki en temel meselelerden biridir. Bu amaçla öncelikle yüzeysel akışa etki eden parametreler üzerinden bir sayısal akış dağılış haritasının oluşturulması, ardından da bu haritanın en doğru sonuca ulaşacak şekilde kalibre edilmesi temelinde bir model geliştirilmeye çalışılmıştır. Akış dağılış haritası etken parametrelerin etki dereceleri parelelinde ağırlıklı çakıştırma eksenli olarak şekillendirilmiştir. Sonuçta elde edilen haritanın kalibrasyonu ise hem teorik hem de ampirik verilere göre piksel bazlı olarak yapılmıştır. Bütün analizlerin neticesi olarak doğru bir akış dağılış modelinin ancak sahanın özelliklerini tam olarak yansıtan bir akış dağılış haritasının dış müdahalelerden uzak alt havzalardan elde edilecek reel akış verilerine göre kalibre edilmesiyle şekillenebileceği anlaşılmıştır. Çünkü hareketli bir doğası olan ve sayılamayacak kadar çok faktörle etkileşim halinde bulunan suyun miktarına dair teorik yaklaşımların hatalardan arındırılması mümkün olmayacaktır. Metodun örnek havza olan Ergene Nehri Havzasında uygulanması sonucunda mevcut yöntemlerin verdikleri sonuçlar ile en az %27 oranında fark içerecek şekilde havza için ortalama 183,45mm/yıl/m² yani toplam 2100000000m³/yıl seviyesinde bir yüzeysel akış hacmine ulaşılmıştır.

Anahtar kelimeler: *Yüzeysel akış, akış modelleme, akış dağılışı, su potansiyeli, Ergene Nehir Havzası*

Introduction

It is crucial to plan and utilize water, which is one of the prerequisites for the existence of living creatures, in an extremely meticulous manner due to increased demands for its use, irregularities in its regional and seasonal distribution and its nature that is not unlimited. Supply and demand equilibrium is one of the prominent instruments that will guide this process. Therefore, existence and accuracy of the data for water distribution and amount which are the basic dynamics of water demand play a determinative role in taking well directed steps in water resources management. It is undisputable that errors and drawbacks in this regard will disrupt all the work in this area.

While it is possible to date the work in the field of hydrology way back to the history of humanity, the literature in the field started to shape with Halley's work (1694) in regards to measurement of evaporation from water surfaces and Dalton's (1802) work in measuring basin-based evaporation and permeability. During the first part of the 20th century, with Horton's works (1935; 1938; 1939), surface runoff calculations based on the relationship between infiltration capacity and surface runoff started to take place. Later, surface runoff modeling, that structurally matured with the works of Thornthwaite (1944; 1948), Penman (1948), Blaney and Criddle (1950; 1962), Thornthwaite and Mather (1955; 1957), presented an integrated outlook with the work and calculations on evapotranspiration for a long time (Makkink, 1957; Jensen and Haise, 1963; Baier and Robertson, 1965; Priestley and Taylor, 1972; Doorenbos and Pruitt, 1975; 1977; Hargreaves and Samani, 1982; 1985; Shuttleworth and Wallace, 1985; Jensen et al., 1990; Cohn et al., 1997; Alexandris et al., 2006). However, flow calculations and modeling were separated from one another as independent areas during the process. While studies by Jury and Tanner (1975), Allen and Pruitt (1986), Allen et al. (1998), Samani (2000), Irmak et al. (2003), Trajkovic

(2007), Jabulani (2008), Fooladmand and Ahmadi (2009), Jensen (2010), Lima et al. (2013), Rao et al. (2014) and Feng et al. (2017) aimed mainly to develop evapotranspiration calculation methods on one hand, flow data continued to be generated on the other. Evapotranspiration-surface runoff relationship, which indirectly continued to be taken into consideration in implementations, has been a medium through which science is generated in the framework of assessments in the form of continuous comparison of methods (Cruff and Thompson, 1967; Grace and Quick, 1988; Allen, 1993; McKenney and Rosenberg, 1993; Xu and Singh, 2000; 2002; Alexandris et al., 2008; Irmak et al., 2008; Weib and Menzel, 2008; Mohawesh, 2011; Sammis et al., 2011; Shahidian et. al., 2012; Tukimat et al., 2012; Lingling et al., 2013; Jensen, 2014; Callistus, 2015; Pereira et al., 2015; Çobaner et al., 2016). Studies towards narrowed targets increased in the name of protecting data integrity especially when Geographical Information Systems were started to be used and studies on evapotranspiration calculation started to become separate in the natural course of the process (Dockter, 1994; Zhou et al., 2006; Foolandmand, 2011; Diouf et al., 2016; Morales Salinas et al., 2017). Later, studies on determining water balance undertaken mainly to identify the need for agricultural water (Blaney and Criddle, 1950; 1962; ASCE, 1990; Baldwin et al., 2002; Neitsch, 2011) transformed into practices to calculate surface runoff distribution (Berry and Sailor, 1987; Drayton et al., 1992; Mattikalli et al., 1996; Gitika and Ranjan, 2014; Gajbhiye, 2015). While some of these practices gravitated towards analyses based on Lidar images (Pagh et al., 2005; Gonzalez Jorge et al., 2015), some presented new examples in the framework of methods such as existing Thornthwaite (1948) (Singh et al., 2004), Thornthwaite and Mather (1955; 1957) (Roy and Ophori, 2012) and USDA (1986) Curve Number (Sharma and Singh, 1992; Khatun, 2016; Vojtek and Vojtekova, 2016; Kaletova and Nemetova, 2017).

While today runoff calculations based on direct precipitation-runoff relationship are conducted (Nash and Sutcliffe, 1970; Lane, 1984; Ranzi et al., 2003; Reintjes, 2004; Liebe et al., 2009; Tedela, 2012; Poullain, 2012; Idowu et al., 2013; Kellagher, 2013) surface runoff and water balance modeling (Thornthwaite, 1948; Thornthwaite and Mather, 1955; 1957; SCS; 1986; Xu et al., 1996) are still in practice. These models and calculations are often used in various fields and for varying purposes such as effects of climate change (Gleick, 1986; 1987; Schaake and Liu, 1989; Arnall, 1992), underground water balance and flow (Sauer and Ries, 2002; Tstsumi et al., 2004; Stanton et al., 2013), amount of permeability (Zimmermann, 2006), erosion (Knisel, 1980), basic flow (Santhi et al., 2008), soil moisture (Pastor and Post, 1984), flood risk (Hewlett and Hibbert, 1966; Borga, 2002; Tayfur and Moramarco, 2008) and drought risk (Majumder and Sivaramakrishan, 2016). However, a great deal of work which criticizes, critiques and corrects the existing water balance identification methods is noteworthy (Lane, 1984; Calvo, 1986; Klemes, 1986; Steenhuis and Van der Molen, 1986; Wilcox et al., 1990; Xu and Vanderwiele, 1994; Ponce et al., 1996; Xu and Singh, 1998; Xu, 1999a; Beven, 2000; Xu and Singh, 2005; Black, 2007). This observation points to nonexistence of a single model that can perfectly explain runoff (Harssema, 2005) and at the same time clearly shows that existing methods and models are not satisfactory. The fact that even the SCS-CN model, the most commonly and often used method is far from solving problems (Rallison and Miller, 1982) since it does not have the ability to keep pace with the variables to solve hydrologic problems in wide and heterogeneous areas due to its simplicity shows that this issue is yet to be solved.

Problem Statement

Runooff models can roughly be categorized into two as lumped or distributed or deterministic or stochastic (Harssema, 2005). The opposite of lumped model that treats the whole basin as a single unit and presents it with a single average value is the distributed model that represents the basin with the value of grid based variables. Along the same lines, the opposite of the stochastic model that addresses the probable range of input-output balance is the deterministic model which is used in many runoff models and refers to the constant value that corresponds to a variable (Ward and Robinson, 1990; Beven, 2000; Rientjes, 2004; Harssema, 2005). Although it is systematically possible to make such an assessment, it should be remembered that this is problematic with many aspects from the parameters taken as basis to the period of calculation, from the dimensions of the study area to variability of calibration.

The first issue that should be emphasized in relation to the inadequacy of existing methods is the issue of what calculation methods or models actually aim. At this point, the models that aim to determine agricultural water necessity and the models to determine underground water irrigation or models that set out to present water balance with flood risk after precipitation will not reach the same conclusions by identifying the same route and methods and therefore they will not be able to solve the same problem and use it for the same purpose. Along the same lines, difference of period in models or calculations is another area which causes separation of techniques. The runoff that occurs after the precipitation that is sought in precipitation-runoff equations is a completely specific event and it is only relevant for the time and location for which the calculation is undertaken. Generalizing such data will cause serious errors. The same can be observed between models that depend on daily climactic data which make it impossible to study in wide areas and models that depend on monthly data. There can be very distinct anomalies between daily and monthly data and the core of planning is the monthly data, i.e. the regime of annular average.

Similar to differences in results in data due to differences in periods, there are differences in results in data resulting from the differences in area. The main reason for this is the lack of homogenous distribution of runoff in almost any of the basins. It is a dire error to interpret the data obtained at the level of points to include the whole area or whole basin by putting aside the fact that each point and each pixel in the model has unique conditions. Each point has its own conditions in terms of the parameters in the model and reflects a different level of relationship with surface runoff based on the impact level of the parameters. Hence, accurately identifying the runoff distribution design that demonstrates heterogeneous conditions almost everywhere will make it possible to present the specific runoff dynamics for the whole basin or area or its sections or sub units. At this point, it is crucial to determine effective parameters and compare their impact values.

The process of identifying the parameters in the model starts with eliminating the confusion in relation to goals and period. Although very different parameters such as infiltration capacity and permeability values (Horton, 1935; 1938; 1939; Brakensiek, 1955), precipitation (Snyder, 1963; Fiering, 1967; Tuffuor and Labadie, 1973; Kuczera, 1982; Gabos and Gasparri, 1983), precipitation and temperature (Thornthwaite and Mather, 1955; Palmer, 1965; Thomas, 1981; Alley, 1984), monthly precipitation and potential evapotranspiration (Pitman, 1973; 1978; Van der Beken and Byloos, 1977; Roberts, 1978; 1979; Krzystofowicz and Diskin, 1978; Hughes, 1982), daily precipitation and potential evapotranspiration (Haan, 1972; Kuczera, 1983), interception (Mulder, 1985), land use (Bultot et al., 1990; Bhaduri et al., 1997; 2000; Krause, 2002), land use and soil texture (Lane, 1984; Liang et al., 1994), lithology, land use and soil texture (Westenbroek et al., 2010) and geographical and geological characteristics, land use and climactic characteristics (Nielsen et al., 1973; Ries, 1990; Neitsch et al., 2011) are taken as basis for calculations and model development in various studies; comprehensive and satisfactory results have not been achieved. It was expressed that all runoff models, even the models that include nine (Langford et al., 1978) or eleven (Salas et al., 1986) parameters are full of errors (Cowen, 1957; Mockus, 1964; Kent, 1966; 1973; Rallison and Miller, 1982; Harssema, 2005; Tayfur and Singh, 2011).

It is possible to classify the parameters that affect precipitation primarily as meteorological factors such as type, amount, density, distribution and duration of precipitation, storm destination, soil moisture based on precipitation, temperature, wind, relative humidity and seasons and physical factors such as land use, flora, soil type, drainage area, basin geometry, elevation, slope, topography, aspect, drainage network and reservoirs (Arnold et. al., 1999; USGS, 2017). Data related to special conditions such as soil texture, underground water table and underground water depth (Batelaan and Smedt, 2007) and snowfall, cumulative snow, snow melt and actual evapotranspiration (Xu, 1999b) can be added to these conditions. All these climactic and surface data can be assessed in conjunction with each other with the help of Geographical Information Systems to identify the distribution characteristics of precipitation that presents a complex design at the surface (Batelaan and Smedt, 2007; Gajbhiye, 2015). Despite problems of all types, some reasons increase dependency for these models such as abundance of basins for which no flow measurements are taken and the fact that runoff models generate more accurate data compared to river flow measurements in regards to surface runoff, changes in soil moisture, evapotranspiration and underground water irrigation-discharge values (Gleick, 1987). As a result, in addition to increasing the number of observation stations; various alternatives such as creating computer software to develop existing models and calculations, produce new models and facilitate the use of existing models continue to be presented and attract attention (Stone, 1988; Birsoy and Ölgen, 1992; Westenbroek et. al., 2010; Doğdu, 2011).

Method

Generally, all modeling based on empirical and/or physical data is composed of hypotheses expressed as mathematical estimates of effective elements (Beven, 2000). However, the existence of factors -the numbers of which are difficult even to specify- that affects water potential shows the fact that assumptions or generalizations in such models are inevitable. Considering the essentiality that each assumption should be recognized or based on knowledge to ensure that the theory will be taken into consideration, it is crucial to prove that results are produced in a specific confidence interval. Therefore, forming a methodological framework depends on a delicate balance among many issues each of which is significant enough to affect results, from identifying data that will form the basis of theory or model to establishing an accurate relationship among them, from ensuring the ability to revise the mode based on conditions to producing field specific results that fit a definitive confidence interval. At this point, the first step in the study was the identification of the basic components that affected the distribution design regarded as the foundation.

Without doubt, basins that should be regarded as unique hydrological units in terms of runoff dynamics include many characteristics that shape the runoff distribution design in their own conditions. While some of them are more dominant and determinative of the basic pattern, some others have relatively lower impact capacity. For instance, it would be unnecessary to take the lithological data of the field into consideration while identifying the runoff design in a basin composed of homogeneous alluvial deposition areas in terms of lithology. Hence, parameters that direct the runoff design in terms of study area will demonstrate differences based on field conditions.

For this study; precipitation and potential evapotranspiration values in mms., hydro-geological structure, land use, soil types, slope and soil texture data were obtained from the sample field site Ergene River Basin (NW Turkey) (Table 1). ASTER GDEM V2 with 15m resolution digital elevation model (METI&NASA) was utilized in relief based analyses. Filed conditions played a direct and complete role in identifying which parameters to be taken into consideration. On the other hand, the rate of parameter impact on runoff and impact coefficients of units included on the database of parameters on runoff distribution design were determined based on reference work in literature related to the field and units (Horton, 1932; 1945; Langbein, 1947; 1949; 1980; Strahler, 1952; 1957; Ardel, 1957; 1965; Melton, 1957; Kurter, 1963; Yalçınlar, 1968; Eagleson, 1970; Fleming, 1975; Warnick and Nielsen, 1980; Verstappen, 1983; Atalay, 1986; Chow et al., 1988; Miller, 1990; Özer, 1990; Bayazıt et al., 1991; Dumlu et al., 2006; Hoşgören, 2012; Karataş and Korkmaz, 2012) in addition to expert views focused on determining the relative relationship among units (Table 1). The obtained multiplier values were transformed into a quantitative surface runoff distribution map with the help of weighted overlay method (Clerici et al., 2002; Saha et al., 2002; Esri, 2017) based on conditions related to identifying impact factor levels with theoretical classification of effective elements. At this point, it is evident that abundance of units as multipliers will reduce error amplitude and enhance reliability of results. However, since impact values assigned while generating the afore-mentioned digital map did not have real numerical equivalents, it should be remembered that the obtained map is a relative digital runoff distribution design map in need of calibration.

Data included in the table in relation to precipitation and potential evapotranspiration were compiled from the records at the meteorology stations in the study area (Turkish State Meteorological Service, 2016) and their equivalents reproduced by spreading the elevations of these records to specific benchmarks (Schreiber, 1904). Thornthwaite (Thornthwaite and Mather, 1957) method was utilized to obtain potential evapotranspiration data. Data from the enlarged climactic data points in the basin were taken as basis to determine potential evapotranspiration values for each point. Later, both precipitation and potential evapotranspiration data in point based form were interpolated to obtain weighted distribution maps for both climactic parameters. ArcMap Geostatistical Wizard-CoKrigging (Esri, 2013) device was used for interpolation process by taking both point based climactic data and areal climactic data zones divided according to elevation levels into consideration. As a result, quantities in the obtained maps were classified to generate five impact classes and each was assigned a value of coefficient “3” by observing that precipitation and potential evapotranspiration were the dominant parameters that affected runoff in the study area (Table 1).

Table 1

Classes and Impact Values Used in Weighted Overlay Method

Parameter	Classification	Coefficient	Impact Value	Multiplier Effect
Precipitation (mm)	861-932	3	5	15
	781-860		4	12
	701-780		3	9
	621-700		2	6
	540-620		1	3
Potential Evapotranspiration (mm)	450-550	3	5	15
	550-650		4	12
	650-750		3	9
	750-850		2	6
	850-950		1	3
Hydrogeology	Gneiss, Schist, Meta-granite	2	5	10
	Granite, Marble, Schist		4	8
	Undifferented Terrestrial Clastics		3	6
	Clastics and Basalts		2	4
	Alluvium		1	2
Land Use	Irrigated Areas	2	5	10
	Grassland and Pastures		4	8
	Forest, Shrubbery, Vineyard-Orchard		3	6
	Urban Areas		2	4
	Dry Farming Areas		1	2
Soil Type	Alfisols	2	5	10
	Vertisols		4	8
	Mollisols		3	6
	Urban Areas		2	4
	Entisols		1	2
Slope (%)	20 +	1	5	5
	15-20		4	4
	10-15		3	3
	5-10		2	2
	0-5		1	1
Soil Texture	Rocky	1	5	5
	Very shallow (0-20cm)		4	4
	Shallow (20-50cm)		3	3
	Medium depth (50-90cm)		2	2
	Deep (90+ cm)		1	1

Hydro-geological units in the field were classified into five relative classes among themselves based on their porosity and permeability characteristics and their support for surface runoff. Similarly, land use design and distribution of soil types in the basin were classified into five classes each based on their relative contribution to surface runoff and “2” was assigned as coefficient for each of these three parameters (Table 1). When basin conditions are taken into consideration, the impact of these three parameters on surface runoff in the basin is lower than that of precipitation and potential evapotranspiration but higher than that of slope characteristics and soil texture. Slope values and soil texture classified into five among themselves were assigned a coefficient of “1” and it was ensured that they were determinant corresponding to the level of their impact while generating the surface runoff distribution map (Table 1). Since characteristics related to precipitation, potential evapotranspiration, slope values and soil texture were divided into equal or equivalent numerical categories, the impact values of units in these parameters were assigned in accordance with their quantities. Units for hydro-geology, land use and soil types were assigned impact values based on their characteristics emphasized in literature related to the field (Ardel, 1957; 1965; Kurter, 1963; Yalçınlar, 1976; Ardos, 1995; Pelen et al., 2003; Horvat and Rubinic, 2006; General Directorate of Mineral Research and Exploration, 2006; Aksoy, 2007; Aksoy et al., 2007) and their relative impact rates on surface runoff based on the relationships among these characteristics.

During the last phase of the study, weighted overlay procedure (Esri, 2017) was undertaken in conformity with Table 1 with the help of “Raster Calculator” module of ArcMap 10.3 application included in ArcGIS package program and the runoff distribution model of the basin was presented. While a numerical value existed for each pixel in the obtained digital map, these numbers were only unitless expressions that were the results of multiplication conducted during the implementation of weighted overlay. In order to transform these expressions to numeral values represented by actual units, the map was calibrated according to indicators such as annual average precipitation depth, average flow value of the main river at the mouth and flow data in sub basins with wild flow with the methods of Langbein et al., (1949), Turc (1954), Thornthwaite (1957) and USDA (1986). Correlation of intermediate values with maximum and minimum values provided intermediate values in calibrations.

Results

The methodology proposed in this study was conducted in an applied manner in Ergene River Basin which was selected for implementation. The basin is situated in northwest Turkey and is composed of 11036 km² wide water catchment area that includes Ergene River and its branches, the sub basin of Meriç River Basin (Figure 1).

The main factors that played determinant roles in basin selection were the variable but not too complex structure of components that affect runoff -mentioned beforehand in relation to methodology-, existence of various surface and climactic areas and abundance of data that allow the control and validation of implementation output.

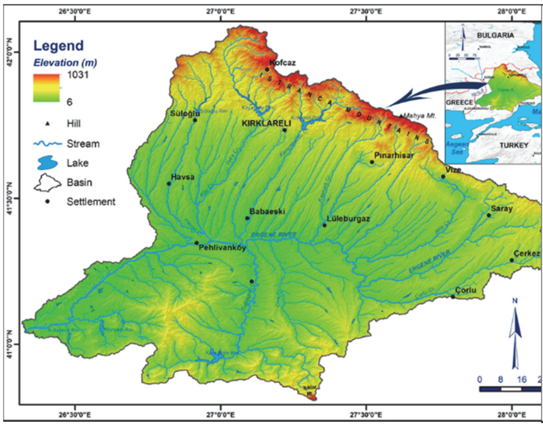

Figure 1. Location and topography map of Ergene River Basin.

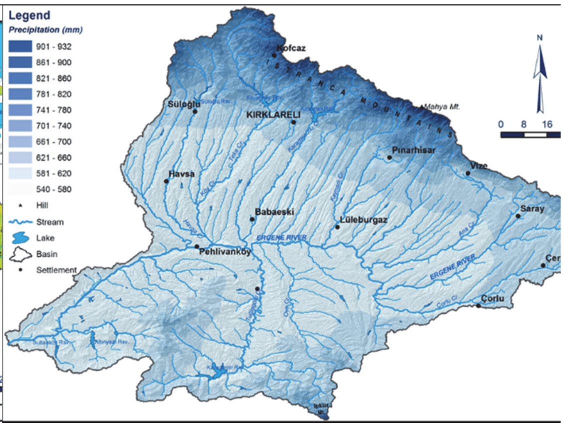

Figure 2. Distribution of average annual precipitation distribution in Ergene River Basin.

The first component to determine surface runoff distribution design of Ergene River Basin was the precipitation distribution map of the field (Figure 2). Instead of direct interpolation of the points with climactic data in the basin, CoKrigging (Esri, 2013) multi parameter interpolation -in which changes in precipitation according to elevation levels were included in the equation- was preferred and precipitation data were mapped in a manner to form a numerical surface. At this point, increase in the amount of precipitation from basin floor to higher areas which can be roughly defined as the increase from center to periphery was clearly observed. Precipitation depth that changes between annual averages of 540–932mm is congruent with meteorology station data and real climactic indicators observed in the basin in terms of amount and distribution. According to existing table, compared to central parts of the basin, meteoric water input that supported surface runoff was higher in Istranca (Yıldız) Mountains that covered the northern section of the basin and relatively in the southern section that was close to Işıklar Mountain. Especially the southern slopes of Istranca Mountains appeared as the most prominent potential meteoric water reservoir in the basin. Therefore, it was expected that these sections would provide higher values in the surface runoff distribution obtained at the end of the analysis process.

The second parameter in the basin related to surface runoff distribution design was the amount and distribution of potential evapotranspiration. Since no regular and common evaporation measurement existed in the basin, Thornthwaite (1957) water balance measurement method was utilized to present the amount and distribution of this parameter in the basin. Thornthwaite adjusted potential evapotranspiration values were taken into consideration in order to remove dry spell effects. While generating the map; the same path was followed as the precipitation distribution map and evapotranspiration change zones formed by taking into consideration the changes in temperature and precipitation based on climactic data points and elevation were operationalized via compound CoKrigging (Esri, 2013) method. Annual average potential evapotranspiration values of Ergene River Basin were found to change between 450-950mm according to numerical potential evapotranspiration map obtained in this process (Figure 3). Especially the middle sections closer to the valley floor in the central part of the basin and the west-southwest sections towards Ergene River downstream were found as the areas with increased potential evapotranspiration. Severity of evapotranspiration was determined to decrease towards Istranca Mountains, supporting the assumption that surface runoff would present higher flows in these mountainous areas where precipitation was higher.

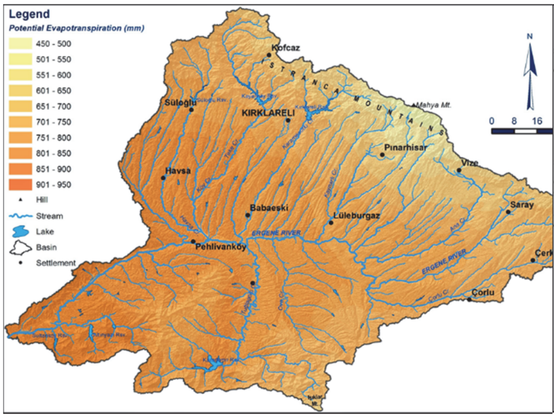

Figure 3. Distribution of average annual pot. evapotranspiration in Ergene River Basin.

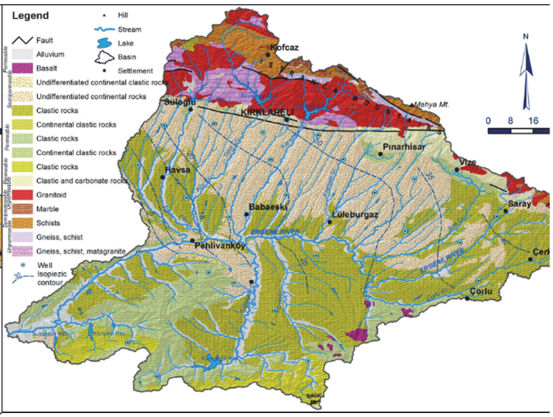

Figure 4. Hydrogeological structure of Ergene River Basin.

One of the compounds with significant effects on basin surface runoff distribution design -albeit not as much as precipitation and potential evapotranspiration- is the lithological characteristics of the ground. The main lithological structure of the basin includes metamorphites and clastics (Figure 4).

Metamorphites (gneiss, schist, marble), older than clastics, are generally known with their low permeability. It can be argued that fissured or jointed texture of sporadic marble, schist and granitoid units increase porosity albeit in low amounts and therefore form semi-permeable areas. Clastics in the basin are composed of permeable units generally called terrestrial clastics. However, the clayish-marly levels observed in younger and unsegmented elements among these units decrease permeability. Basalt crops found in the southeastern part of the basin in the form of holms and alluvium found in valley floors can be cited as units prominent with their high permeability. In this case, while non-permeable units and units with low permeability surfacing especially in Istranca mass support surface runoff, units with permeability that cover the center and south parts provide conditions for a weaker surface runoff. In addition, tectonic lines found in north and northeast are estimated to affect surface runoff. However, it was difficult to reach a definitive conclusion as to whether this effect had a negative direction in the form of increased permeability or positive direction via springs along fault.

Land use and flora are significant factors that affect surface runoff. Ergene River Basin has wide-spread dry farming areas that support permeability (Figure 5). Indeed, dry farming areas which are dominant in the basin make negative surface runoff conditions especially in middle and southern parts more apparent. In addition, forest areas, second largest after dry farming areas are relatively disadvantageous in terms of surface runoff. It should be remembered that interception plays an important part in this. On the other hand, porosity decreases and surface runoff is supported in irrigated agricultural fields mostly found in valley floors largely based on to the fact that they are water logged. Just like urban areas, meadows and orchards that are less observed on the basin scale provide less support for surface runoff compared to irrigated agricultural areas but give more support compared to dry farming areas. As a result, contribution to surface runoff in terms of land use is lower in slopes in the inner parts of the basin and in interflow zones; medium along Istranca mass and hilly areas in south-southwest sections and high in valley floors. This finding gives Istranca mountainous mass an advantageous position in terms of surface runoff.

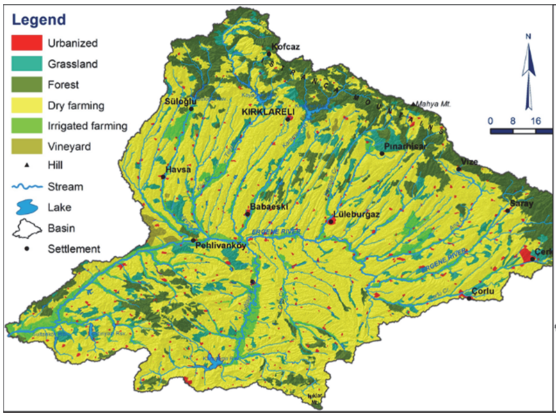

Figure 5. Current land use in Ergene River Basin.

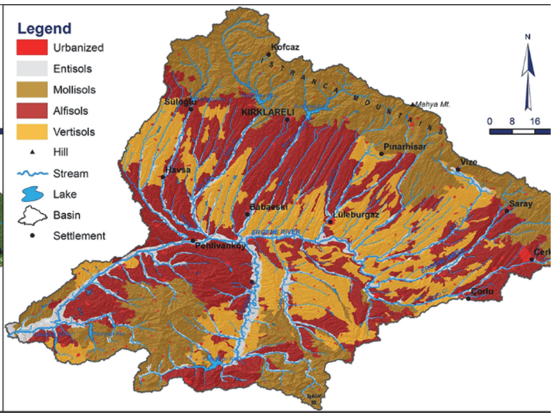

Figure 6. Distribution of soil types in Ergene River Basin.

As in land use design, distribution of soil types have a determinant role in regards to surface runoff. Due to abundance of clay content in Ergene River Basin, soil in alfisol group prevents permeation. Spreading on the low slopes of mountainous areas and downstream of Ergene River, this soil supports surface runoff in these areas (Figure 6). A similar situation is valid for vertisols that cover large areas towards the upstream of Ergene River. Mollisols that completely cover mountainous areas and entisols found in valley floors also establish the foundation that allows permeability with their soft texture and porous structures. This situation creates a relative disadvantage for areas such as Istranca Mountains and Işıklar Mountain slope which host favorable conditions for the increase of surface runoff. However, as it will be discussed later, shallow soil strata in these parts and the fact that they are limited with impermeable units that are located right below decrease the negative impact of this disadvantage.

The fact that slope directly affects runoff velocity and runoff velocity affects amount of permeation makes the distribution and degree of topographic slope significant in the study area. Ergene River, which separates Istranca range in the north and Işıklar range in the south, is surrounded by slopes from both mountainous areas with decreasing attitude towards the river bed (Figure 7). The slope of these mountain hillside is directly proportional to elevation. Especially the areas to the north of Kırklareli-Vize that correspond with the core of Istranca Mountains consist of the sections where slope values reach the highest levels due to abrasion resistance and abrasion types of resistant lithological units at basin scale on the floor. Slope levels that also increase towards the high areas in the vicinity of Işıklar Mountain present a softer, plainer and still relief in conformity with the abrasion of Neogene deposits composed of detritic material in a manner that cannot present sharp lines and decreased energy of the rivers in the areas in central parts of the basin. Slope values of Ergene River Basin are classified as 5% segments. Accordingly, the most available conditions for surface runoff are found in high mountainous areas and the most negative unfavorable can be observed in valley floors and interflow areas. Therefore, higher parts of the basin strengthen the expectations that with their structure that allows them to flow before finding an opportunity to permeate, meteoric water that reach the surface would increase surface runoff potential in these areas.

Another factor that affects the surface runoff distribution design of Ergene River Basin is soil texture. Depths of soil that cover the ground and the type of soil directly affect amount of permeation and period of saturation. Since soil is the decomposed state of the bedrock, its porosity is relatively higher and when its depth increases, the amount of water that it permeates and stores also increases. In terms of texture, the soil in the study area is classified in five classes as rocky and devoid of soil, very shallow (0-20cm), shallow (20-50cm), medium depth (50-90) and deep (90cm +) (Figure 8). While deep soil is mostly found in the central parts of the basin, shallow soil and rocky surfaces are generally observed in high mountainous areas and slopes where slope value is higher. Valley slopes located especially in the upstream of rivers, tectonic lines and valley floors overwhelmed by current alluviums can be defined as unfavorable areas for the formation of deep soil texture. In this sense, since soil texture becomes shallow in areas where elevation and incline increases for Ergene River, the shallow soil texture will have less water holding capacity and therefore surface runoff will increase.

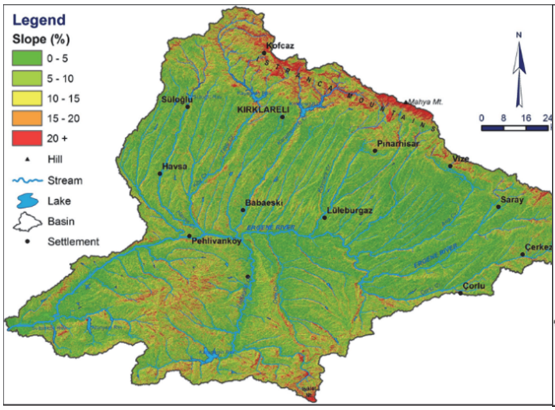

Figure 7. View of Ergene River Basin in terms of slope values.

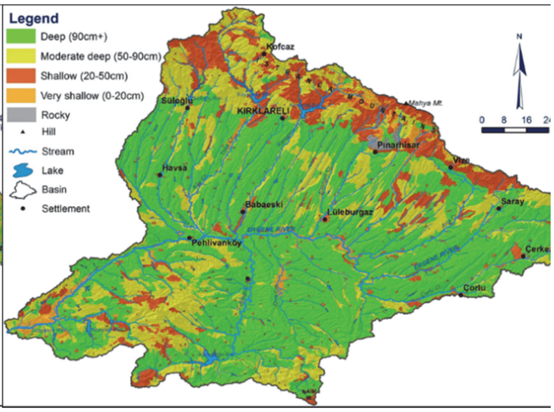

Figure 8. Ergene River Basin soil texture map.

Seven main parameters listed above which shaped the surface runoff distribution design in Ergene River Basin were composed of units revised with multiplier coefficients based on their impact rates. These units corresponded to pixel based numerical expressions and were analyzed to present the digital surface runoff distribution design map of the basin determined according to all these factors by applying the weighted overlay method (Esri, 2017). The map obtained as a result established a surface runoff distribution design that reflected the foreseen impact of each unit in initial interpretations (Figure 9). The digital surface runoff distribution map, the output, included pixel based values that changed between 144 and 414720. These values were visualized as quantities between 1 and 5 via reclassification. However, in order to save sensitivity in calibration procedures that would follow, minimum value, intermediate value and maximum value were assigned as 144, 207288 and 414720 respectively. At this point, although the mentioned map was not calibrated yet, it presented a clear view of surface runoff distribution design. As expected, it can be observed that surface runoff was stronger along Istranca mountainous mass and in areas closer to Işıklar Mountain and on the other hand it weakened in areas towards the valley floor. Since this view was designed by taking all specific conditions of each point in the basin into consideration and did not rely on generalizations, it corresponded to a distribution model that expressed separate realities for each pixel. Therefore, values that will be obtained after calibration are also specific for each point.

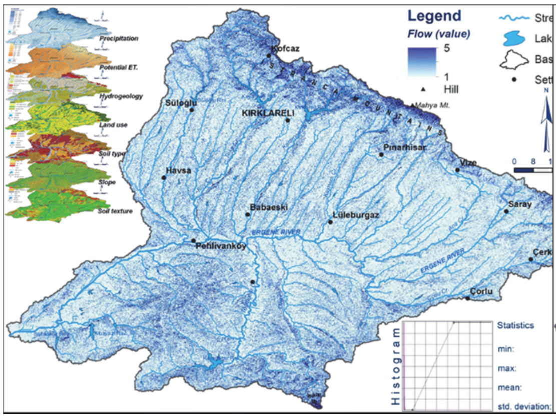

Figure 9. Compounds that affect surface runoff distribution in Ergene River Basin and surface runoff distribution design.

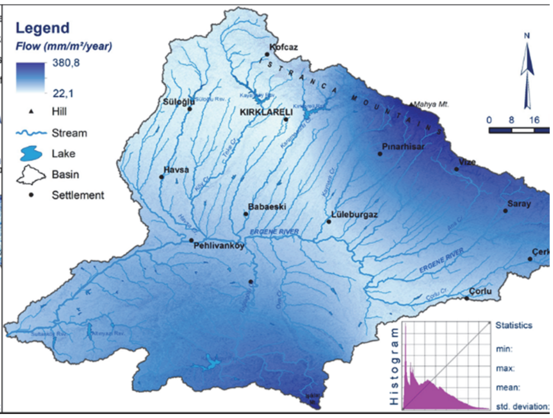

Figure 10. Surface runoff distribution map of Ergene River Basin generetaed according to Thornthwaite method and interpolation of climatic data points.

In order to comprehend the level of compatibility between surface runoff distribution map of Ergene River Basin and the real land conditions and how far the findings were from generalization, it would be useful to make comparisons with the runoff distribution map interpolated according to Thornthwaite water balance measurement. Thornthwaite runoff accounting based on the relationship between precipitation and potential evapotranspiration is listed at the top of the methods widely used today since it provides rather realistic results with almost 90% confidence interval at some areas (Calvo, 1986). However, whether results obtained for climactic data points can be representative for areas with no data or not and the results obtained after evaluating surface runoff based only on these point data can clearly be observed in runoff distribution map generated in this framework (Figure 10). It is evident that amount of surface runoff observed in rather low values especially to the north of Kırklareli-Süloğlu line does not correspond with the data obtained from the parameters that affect surface runoff in the basin. Also, as befitting the logic of interpolation, an imaginary transition occurs between Istranca and Işıklar ranges that represent high values and the central parts of the basin that correspond to relatively lower values. Therefore, areas outside of climactic data points are completely represented according to homogeneous surface and based on only estimated and generalized data. In this sense, the usability of data obtained according to this method will be ruled out for sub basins where especially climactic data is very few or nonexistent. Despite the fact that the design that is presented offers an unrealistic design in terms of surface runoff distribution; minimum (22.1mm), maximum (380.8mm) and intermediate (128mm) flow depth are important data that can be used to calibrate digital runoff distribution map devoid of the units generated in this study.

Intermediate surface runoff values (128mm) obtained for the basin via Thornthwaite method were used for the calibration of the map generated in this study and obtained the following values after reclassification: maximum 5, minimum 1 and intermediate 1.57 unit values. Maximum, minimum and intermediate runoff values (mm) obtained via Thornthwaite method were assigned for the maximum, minimum and intermediate values in the unitless digital surface runoff distribution map in this study. The calibration provided a surface runoff distribution model with actual units that reflected maximum 400mm, minimum 80mm and intermediate 126.5mm surface runoff values (Figure 11). Compared to the imaginary distribution mode obtained via Thornthwaite method, this model is more realistic and free from generalizations. Also, it can ensure 90% confidence interval for each point of the basin while Thornthwaite method can present this rate only on the basis of climactic data points.

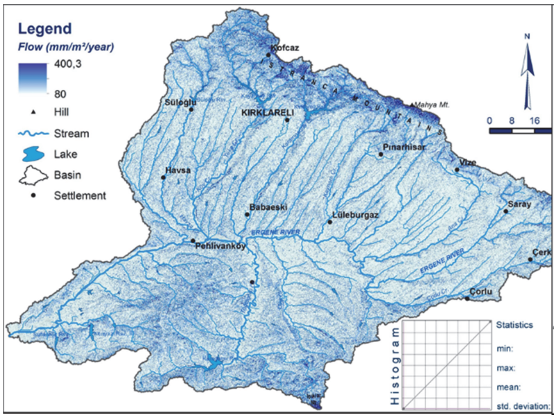

Figure 11. Surface runoff distribution map of Ergene River Basin calibrated according to Thornthwaite (Thornthwaite and Mather, 1957) method.

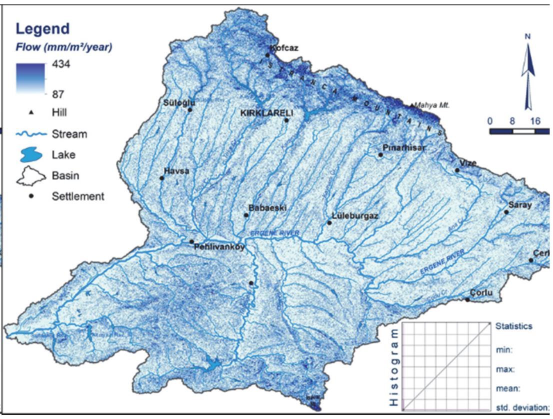

Figure 12. Surface runoff distribution map of Ergene River Basin calibrated according to Turc (1954) method.

Calibration similar to the one used in Thornthwaite method can be undertaken with the results of other methods with the potential to provide the most appropriate and realistic results. Thus, it would be possible to ensure flexibility and independency from the outcomes of only one method. In this framework, another calibration was implemented by using 139mm intermediate runoff value obtained via Turc (1954) method with extensive use (Figure 12). The maximum 434mm, minimum 87mm and intermediate 137.6mm values obtained via reference runoff of the Turc method are quite close to values obtained via Thornthwaite method. In this respect, Thornthwaite and Turc methods can be used to corroborate and verify one another. An imaginary surface runoff distribution design similar to the design in Figure 10 is obtained In Turc method, as in other methods using climactic data points as the basis. Hence, the disadvantages expressed for the distribution design obtained via Thornthwaite method are also valid for Turc method as well as other point data abased methods.

One of the reference values used in the calibration of surface runoff distribution map generated in this study for Ergene River Basin is the intermediate runoff volume of 118,5mm obtained via Langbein (Langbein et al., 1949) method. Maximum 370mm, minimum 74mm and intermediate 117mm flow depth for m²/year were observed in the calibration undertaken for Ergene River Basin based on this value (Figure 13). As in Thornthwaite and Turc methods, close but lower values were obtained in this surface runoff model which focuses directly and solely on climactic parameters. It can be argued that Langbein's disregard for sheetflow and his sole focus on rivers that provide on river channel included runoff while calibrating his own method played a role in this outcome (Langbein et al., 1949). Even so, it is clear that his model correspond to a rather consistent surface runoff amount from the angle of the two previously mentioned methods. In this case, it is observed that methods that aim to calculate surface runoff based on similar parameters arrive at approximate conclusions and therefore they are similar in regards to successful aspects as well as errors. However, it should be remembered that what is calculated in the framework of these theoretical methods is the surface runoff fed with meteoric water. Hence, underground water and sources, composed of water that do not permeate surface runoff, should be added to the amount of surface runoff while calculating the total basin discharge. On the other hand, it should also be remembered that while theoretical methods include sheetflow, empirical methods are more attuned to the flow that arrive at the river bed.

Different from the Thornthwaite, Turc and Langbein methods, it would be wise to address the revised and developed SCS-CN (Soil Conservation Services-Curve Number) (USDA, 1986) method which adopted the view that ground parameters should be taken into consideration while calculating surface runoff. Due to its simplicity, this method which evaluates the characteristics related to the ground such as hydrologic soil groups and flora along with climactic data together has become prominent as one of the most widely used methods to determine surface runoff. When calibration was undertaken via 339,1mm intermediate runoff value obtained with SCS-CN method, the amount of surface runoff in Ergene River Basin was calculated as maximum 1085mm, minimum 217mm and intermediate 343,1mm (Figure 14). Compared with models designed only with climactic data, these values are equivalent to three times more runoff volume and reflect the fact that evapotranspiration is not given enough space in the equation. These values are also clear indicators that differences in methods can create such significant differences in the calculation of the amount of surface runoff.

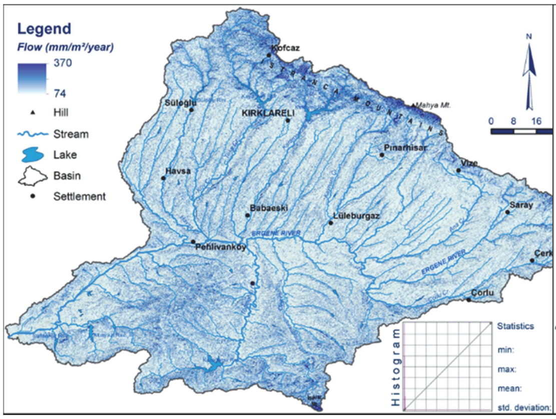

Figure 13. Surface runoff distribution map of Ergene River Basin calibrated according to Langbein (Langbein et al., 1949) method.

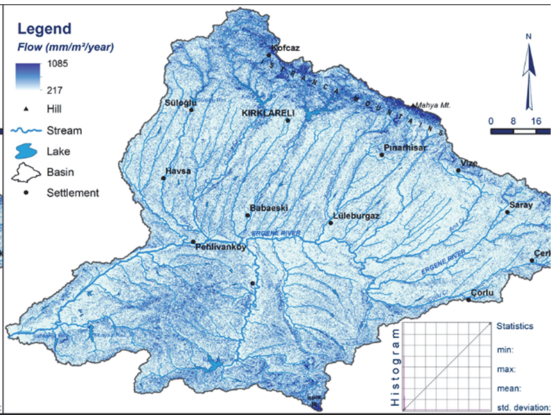

Figure 14. Surface runoff distribution map of Ergene River Basin calibrated according to SCS-CN (USDA, 1986) method.

In addition to previously mentioned methods that should be regarded as theoretical although they have some empirical foundations, use of more data obtained according to outcomes of measurement and observation during calibration will pave the way to make interpretations with wider perspectives by presenting differences. In this framework, in order to present more systematized work and generate a confidence interval, this study selected the empirical data used as the basis of calibration in a manner that would determine the lower and upper limits of the surface runoff amount in Ergene River Basin. Without doubt, the upper limit is defined via calibration based on average precipitation depth of the basin because such a calibration means that the entirety of the meteoric water transforms into surface runoff., i.e. possible maximum surface runoff value can be reached in this manner. The following values were obtained for Ergene River Basin as a result of the calibration by taking 581,4mm intermediate flow depth as reference according to precipitation distribution map of the study area: maximum 1817mm, minimum 363mm and intermediate 574,1mm volume surface runoff values (Figure 15). While these values are far from the real runoff volume of the basin, they are significant since they express the maximum runoff volume. As a result, it cannot be expected for annual surface runoff amount in Ergene River Basin to surpass 574,1mm/m² level.

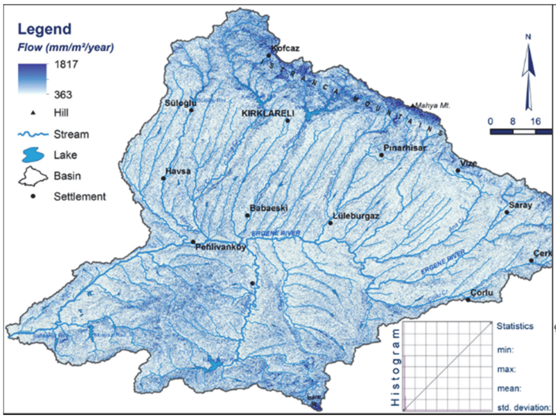

Figure 15. Surface runoff distribution map of Ergene River Basin calibrated according to annual intermediate precipitation depth.

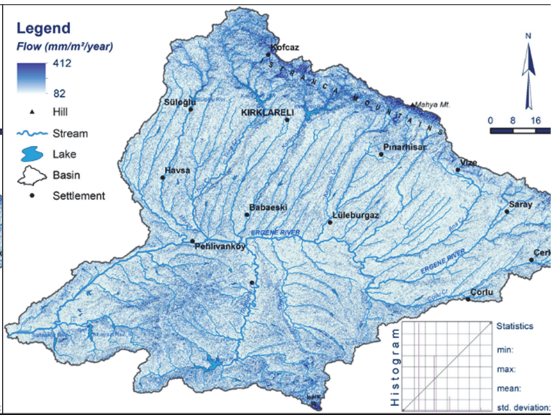

Figure 16. Surface runoff distribution map of Ergene River Basin calibrated according to flow of Ergene River at the mouth.

Another data that can be addressed in terms of empirical data is related to flow data of the main river provided by the stream gauging stations. It is already known that amount of flow presented by surface data can be compared with data obtained by flow observation stations at the basin estuary to look for compatibility (Arnold et.al., 2000). At this point, calibration that will be undertaken based on the average of flow observations conducted at the mouth of the main river in the basin will reflect minimum values for the basin since it is based on the amount of water that leaves the basin after all losses. Ergene River's surface runoff distribution map calibrated over 132mm (EİE, 2008; DSİ, 2017) of annual average runoff based on flow values obtained from No. 12 SGS (Stream Gauging Station) just before the discharges Meriç River provided the following values: maximum 412mm, minimum 82mm and intermediate 130,1mm (Figure 16). These values are average minimum surface runoff values that reach the river channel in Ergene River.

Flow observation data for some sub basins that may be exposed to human intervention at lower levels compared to flow at the main river downstream were also used during the calibration of Ergene River Basin surface runoff distribution map. In this framework, in different parts of the basin, according to surface runoff distribution map with 1.57 average pixel value, a separate calibration was done for each of these sub basins and only included these sub basins-titled SGS 108 with 2,13 average pixel value; SGS 110 with 1,81 average pixel value and SGS 111 with 1,45 average pixel value. Average runoffs calculated as 138mm, for SGS 108, 109mm for SGS 110 and 102mm for SGS 111 (EİE, 2008) were taken as reference and surface runoff distribution maps whose average pixel values were calibrated provided the following results: maximum 323mm, minimum 64mm, intermediate 141,9mm for SGS 108; maximum 301mm, minimum 60mm, intermediate 109,4mm for SGS 110 and maximum 351mm, minimum 70mm, intermediate 102,6mm for SGS 111 (Figure 17). These volumes are unique to these specific sub basins, but they can also be regarded as reference values for flow data based flow depth for relatively small areas in different parts of Ergene River Basin.

As expressed, it is possible to generalize the flow observation data obtained from some streams in different parts of the basin to represent the entirety of the Ergene River basin. The runoff volume in the digital surface runoff distribution map calibrated by taking 118m flow depth, the product of average runoff of the three sub basins that were mentioned, as reference, were found for the whole basin as maximum 375mm, minimum 75mm and intermediate 118,6mm (Figure 18). Compared to the map (Figure 16) calibrated according to mouth discharge of Ergene River, these values correspond to lower values. Therefore, the fact that average flow values are lower in the sub basins -which are thought to be exposed to less human interventions- than the average flow level at the mouth level points to high level of water losses as a result of storage and use of the water for irrigation in these areas which are expected to have higher runoff volumes since they are positioned relatively at the upper course. This situation can be regarded as an indication that higher volumes are possible in areas with completely wild flows. However, the fact that these results represent volumes under actual values since they do not include sheetflow water that does not reach the main channel support the view that flow depth that should be valid for the basin corresponds to higher volumes.

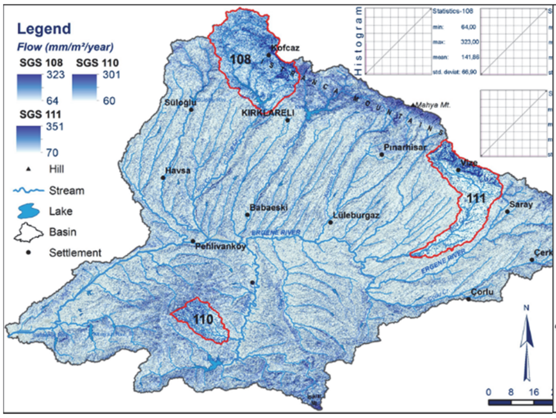

Figure 17. Surface runoff distribution map of Ergene River Basin calibrated according to flow rates recorded in basin estuaries of some sub basins.

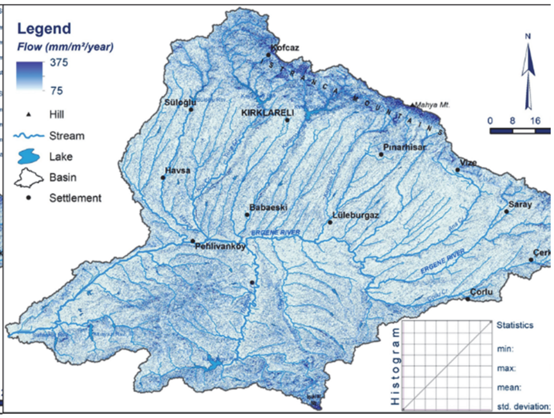

Figure 18. Surface runoff distribution map of Ergene River Basin calibrated according to the average flow depth in No. SGS 108, SGS 110 ve SGS 111 sub basins.

Almost nonexistent human intervention in Ergene River Basin and the existence of at least 15-year flow observation data for some of the sub basins that can be defined as wild flowing makes it possible to undertake calibration based on empirical data free from anthropogenic impact. At areas where such opportunities do not exist, it is still possible t arrive at base data by conducting flow observations for at least a year and correlating these records with the long term records found in nearby observation stations.

The average flow records that were taken as reference for the calibration based on flow observations in the basins that correspond to drainage areas of No.13, 52 and 69 SGS's in different parts of the Ergene River Basin where human intervention to natural conditions is almost nonexistent were as follows: 216mm for SGS 13, 215mm for SGS 52 and 351mm for SGS 69 (DSİ, 2017). Relevant basins were removed from the digital runoff distribution map with 1,57 average pixel used as distribution map for all three basins in question and the following average pixel values were calculated in the next weighted pixel distribution: 2,31 for SGS 13, 1,69 for SGS 52 and 2,74 for SGS 69. Representative results for basins were obtained as a result of calibrating these values with the average flow data measured in each basin. Accordingly, the runoff volumes obtained are as follows: maximum 467mm, minimum 93mm, intermediate 223,4mm for SGS 13; maximum 636mm, minimum 127mm, intermediate 218,4mm; for SGS 52 and maximum 640mm, minimum 128mm and intermediate 383,3mm for SGS 69 (Figure 19). Coordination with the total basin was ensured in this manner and average pixel based surface runoff distribution weighted value was obtained from any part of the basin by averting the mistake of generalizing the regional conditions to the whole basin with the help of flow measurement average assigned according to average pixel value in the basin whose calibration was undertaken. Hence, it was possible to obtain runoff data directed towards the general. Therefore, it was possible to attain the position where it was sufficient to take the average value as reference by only using the accurate runoff distribution map regardless of which part of the basin was used for calibration.

In addition, the fact that average runoff volumes in SGS 52 and SGS 69 were very close as if to confirm one another and higher than that of SGS 13 indicated that surface runoff was much higher in the northern sector of the basin. It is possible that this result is related to the factors such as abundance of rain received on the slopes of Işıklar Mountain that face the north, impact of fohn winds and lack of moisture in the air masses that come over Marmara compared to air masses coming over Black Sea. On the other hand, these flow depths calculated according to flow that arrive the river at the mouth of each sub basin ignore flows with sheetflow character that do not reach the river channel even though they are very small basins. Hence, while it is possible to reach the most realistic volumes with the help of this calibration done according to flow data obtained from areas that are isolated from direct anthropogenic impact to a large extent, it can be argued that the surface runoff that is discussed may be a little bit under the actual value.

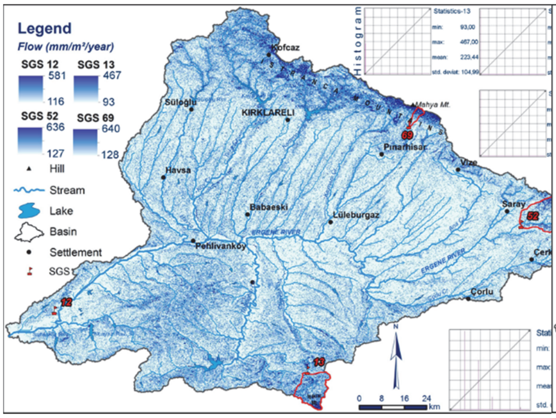

Figure 19. Surface runoff distribution map of Ergene River Basin calibrated according to the amount of average precipitation in sub basins with wild flow.

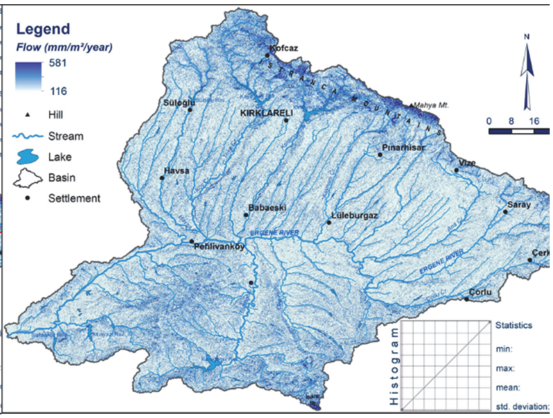

Figure 20. Surface runoff distribution map of Ergene River Basin calibrated according to average flow depth product in sub basins with wild flow.

The digital surface runoff distribution map of Ergene River Basin with 1.57 average pixel value calibrated during the last phase of calibration process by taking 182,55mm average runoff value as reference which was the product value of average runoff volume in the three basins with wild flows provides the following values for the entirety of the basin: maximum 581mm, minimum 116mm and intermediate 183,45mm flow depth (Figure 20).

This value corresponds to a runoff where error margin based on basin sector is decreased by taking different parts of the basin into consideration and which is comprehensive enough to represent the whole basin. Therefore, it is possible to claim that the amount of surface runoff in Ergene River Basin whose natural course is minimally disrupted is an average of 183,45mm and final surface runoff volume including the direct and indirect impact of the calculable and incalculable stakeholders and factors takes place at a higher level with an option between 2% and 5%.

The calibrations with different characteristics that were applied in the study clearly demonstrate that surface runoff amount in Ergene River Basin can be calculated in a manner that will correspond to highly various values. At this point, it can be argued that a serious conflict exists as to which expression is more accurate. However, when all data are evaluated in conjunction with each other, it can be clearly understood that some expressions related to flow depths cannot be accurate (Table 2). A comparison is necessary and even compulsory to reach a definitive conclusion as to the degree of accuracy of the results for Ergene River Basin obtained by different methods. However, it is certain that assessments that will be undertaken in this regard will be specific to Ergene River Basin and very different conditions may apply for another basin because degree of proximity to accuracy in each method can show differences from basin to basin.

Table 2

Some Values Obtained For the Runoff in Ergene River Basin as a Result Of Calibrations Conducted in Digital Runoff Distribution Maps Based on Different References

Calibration	**Max. Runoff** *(mm/year/m²)*	**Min. Runoff** *(mm/year/m²)*	**Intermediate Runoff** *(mm/year/m²)*	**Average Output** *(l/sn/km²)*	**Average Flow** *(m³/year)*	**Ratio to Precipitation** *(%)*	**Ratio to Flow** *(±%)*
Thornthwaite	400	80	126,50	4,01	1395605497	21,75	-2,91
Turc	434	87	137,56	4,36	1517416451	23,64	+5,57
Langbein	370	74	117,02	3,71	1291196108	20,12	-10,17
SCS-CN	1085	217	343,14	10,88	3786580500	59,00	+163,44
Precipitation	1817	363	574,13	18,21	6337649900	98,76	+340,92
Flow	412	82	130,13	4,13	1437369252	22,40	0
Sub basin average	375	75	118,60	3,76	1308869600	20,65	-8,93
Mini SGS Average	581	116	183,45	5,82	2024554200	31,94	+40,85

Note.Total amount of precipitation for Ergene River Basin 6417544360m³/year (Turkish State Meteorological Service, 2016), basin area 11036km² and Ergene River mouth discharge 132mm/m²/year (EİE, 2008; DSİ, 2017).

First of all, all “flow” referenced output that corresponds to flow values measured at the mouth of Ergene River channel should be regarded as having the lowest volumes that can represent the whole basin since they take the water existence in the river channel as the basis despite all anthropogenic impact and water losses due to consumption. On the other hand, the fact that calibration conducted according to sub basin averages stays under this value is a result of low flow measured in the sub basins especially located in the east and south and it points to the reality that intervention to surface water in these regions is above basin average and/or water used for irrigation, industry and daily use are recharged to the channel as recycled water from the downstream of Ergene River. This once again reminds us that any generalization for the basin cannot be representative for many sub basins even though they are located in the same main basin. Although it is an agreed matter that there is contributions form groundwater existence, and as explained before, there is no problem to cite these type of contributions while calculating the amount of surface runoff. However, these empirical references that ignore water included in the surface runoff but does not reach the main channel due to their sheetflow character will definitely correspond to higher volumes once sheetflow water is included. Hence, there will be no inconveniency in using volume obtained as a result of calibration conducted according to flow values as surface runoff ground values. At this point, the fact that methods such as the widely used Thornthwaite method, Langbein method and calibrations conducted according to sub basin averages due to the reason cited above generate volumes that are under referenced runoff values show that these methods produce misleading results for Ergene River Basin and are far from usability. It is once again comprehended that while methods with wide use such as Thornthwaite and Langbein methods provide very reliable outputs in different parts of the world, they will not produce the best results everywhere every time.

On the other side of the issue lays the impossibility of expecting meteoric water runoff to exceed the 50% rate in Ergene River Basin that can be defined as a subhumid steppe field where high evapotranspiration values prevail (Koçman, 1993; MGM, 2017) and where high permeability is experienced with a plain relief. Also, since calibrations conducted based on flow observation data take into account the flow that reaches the stream gauging station rather than the river channel itself, it is believed that surface runoff that cannot reach the stream gauging station constitutes a significant ratio considering many reservoirs, agricultural fields that cover wide areas and the population that is close to 1 million (Çevre ve Şehircilik Bakanlığı, 2017) (Figure 21). Also, releasing an annual 255 million m^3 discharge water, from domestic an industrial sources, 20% of which consists of groundwater, to Ergene River (DSİ, 2016) and the existence of reservoir volume exceeding a total of 500 million m^3/year, out of which only the reservoirs built in the last five years is close to 100 million m^3/year volume

(Çevre ve Şehircilik Bakanlığı, 2017) provides some ideas as to the degree of representation of basin surface water in flow observations. In addition to all this, it is known that the amount of water discharged with surface runoff in 37,12% as average in Turkey (DSİ, 2018). Hence, it is clearly seen that SCS-CN method is far from usability in Ergene River Basin while it is designed according to the assumption that meteoric water will flow at the rate of 98,76% and points to 59% surface runoff even though it is highly below the precipitation-referenced calibration that expresses maximum runoff volume for the basin. On the other hand, it should be remembered that contributions from groundwater that is not included in the amount of surface runoff support just the opposite. Possible contributions from the sources that will be reflected in the observations of the main channel have the effect to carry the value obtained as a result of calibration to a higher level than the real amount of surface runoff. While it is probable to calculate major sources to subtract them from the total flow, it is not possible to calculate groundwater transitions such as feeding from the river bed. Actually, the most accurate approach to be adopted at this point, as mentioned before, is to assess contributions from groundwater along with surface water because even though underground water is part of underground flow for a while, it eventually comes to surface and can be used as surface water. Therefore, increase in volume based on feeding from underground water in the river bed will directly cause an increase in surface water potential and it will be a part of surface runoff. Hence, calibrations that take flow observation data into consideration attain a different dimension as calculations that pay regard to the water in this scope.

In the light of all this information, it can be claimed that the surface runoff volume that is realized in Ergene River Basin is between the minimum value of 1437369252m^3/year and maximum value of 2535059960m^3/year which corresponds to 40% of meteoric water. None of the results obtained with existing surface runoff calculation methods are included in this range. So, improbable results will be obtained and the risk of miscalculating the water potential will increase regardless of the method used to calculate surface runoff in Ergene River Basin. Since this case can be replicated in other basins in different manners, the road will be paved for dire errors unless calibration and confidence interval are not identified similar to the one presented in this study. Following these assessments, it is possible to cite a rather high value based on information obtained in terms of Ergene River Basin, impressions and expert views on the field. This value is about 2100000000m^3/year ±2% level as the volumetric expression of average surface runoff amount in Ergene River basin. Therefore, it is possible for a flow to materialize in the basin, a runoff other than the ones foreseen by other methods.

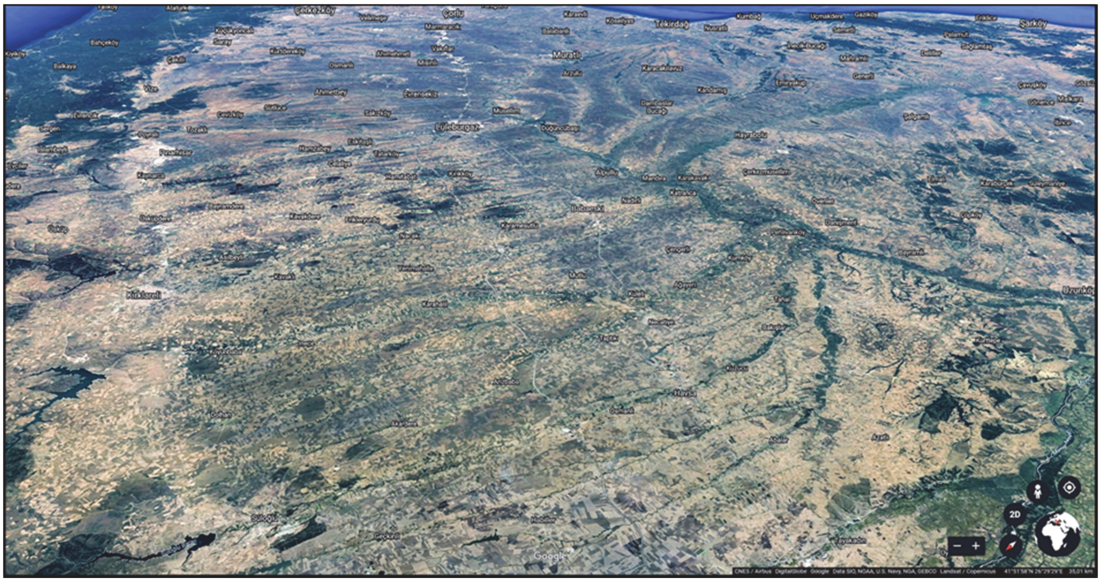

Figure 21. Google Earth image demonstrating the density of agricultural areas and distribution of reservoirs in Ergene River Basin.

The different surface runoff models led by commonly used SCS-CN and Thornthwaite methods, which can be defined as rather reliable methods when evaluated separately, provide such different results when assessed together that it is probable some of these results are inaccurate. This situation should be regarded in a manner that one should not regard these methods as wholly erroneous but take it as the variance in success based on the existence of different conditions that affect the method. Hence, as it was initially expressed, defining existing methods in a manner far from flexibility and comprehensiveness that is necessary for adaptation to all conditions is anything but a reality found in the results of this study. All analyses and comparisons undertaken in the framework of this study have strengthened the opinion that modeling a surface runoff distribution calculation method and calibrating it with the appropriate reference values based on the necessary conditions of the field will create a useful route to obtain data with fewer errors.

Discussion and Conclusion

The fact that small differences in the calculation process of the methods that are used can generate significant fluctuations in the obtained ruoff volume was clearly observed in the results attained from the methods utilized for Ergene River basin. At the same time, another interesting finding is the fact that none of the results were found similar to the results obtained as a result of calculations according to direct flow measurements and they even pointed to volumes much higher or lower values with significant differences. The point that should be strictly emphasized here is the fact that it is not possible to express surface runoff amount which is shaped under the impact of many variables -that may or may not be calculated- as a precise numerical value but at the same time, a sound volume value robust enough to be used in planning can only be obtained by preparing a surface runoff distribution map well with a narrow range and by calibrating it based on real flow data obtained from parts of the filed far from interventions. There is at least a 27% (Turc) or more difference in the runoff volume obtained in this manner and by using other methods in Ergene River Basin. Such a high error margin is outside of acceptable limits. Hence, there is no doubt that existing methods provide erroneous results that cannot be tolerated and there is a dire need for a more reliable and consistent surface runoff calculation method.

The model proposed in this study adopted a new approach that supported benefiting from advantageous aspects of all categorical approaches and sorting out the disadvantageous aspects related to the issue. As a result of the efforts to develop a surface runoff distribution map, a model was created that is flexible enough to include specific parameters such as frost period, interception and water infrastructures in the equation and comprehensive enough to take into consideration the impact values of many variables that are impossible to calculate via calibration conducted according to real flow values. As a matter of fact, it is a reality that let alone calculating the factors that affect hydrodynamic process; we do not even know their names. Hence, while it was possible to present a statement broadly at the end, it was decided that the only way to obtain the closest value to real runoff was to interpret the accurate runoff distribution design based on real field data in their natural forms. Also, with the help of the model, it was possible to make alternative selections in a manner that the final goal would pay a determinant role in calibration and it became possible to separate different runoff characteristics such as sheetflow and channel flow. Calibrations based on flow observation data facilitated this separation.

Even when an average value comprehensive of the total basin was identified at the final point, pixel-based detailed data were used. In this way, it was possible to reflect the data of more than one variable on each pixel and average expressions were opened to specific assessment and analyses through the parts of a whole. Also, while a distinct expression was highlighted as an average value at the end of all analyses, possible lower and upper limit values were identified with the confidence interval of this numerical expression narrowed as much as possible. Hence, representative weakness that would be caused by a single numerical expression was discarded and average flow data were supported by determining maximum and minimum flows over the maximum and minimum values of hydro-meteorological input. In addition, calibration was undertaken according to both empirical and theoretical data sets and in a manner, verification of outputs obtained via different methods was ensured. At this point, it was once again observed that the success rate of models may change under different conditions and each specific variable may cause a model to generate reliable or unrealistic results. Therefore, following the route of identifying the maximum and minimum runoff range by developing the runoff distribution model of the area instead of following a single model or method and therefore getting rid of models that present unrealistic results was regarded as an undoubtedly accurate preference.

In the framework of the results obtained about the study area, total surface runoff volume of Ergene River Basin was calculated as 2100000000m³/year ±2%. This is a reliable value that can be used to express the general condition of the basin and none of the methods implemented in this study generated a result that would correspond to this value. Hence, the current methods widely used for Ergene River Basin are far from generating reliable results. This finding points to the reality that it is inevitable to face different versions when the basin and conditions change. Therefore, without doubt, the route followed in this study will maximize the chance of success in obtaining the most reliable runoff value. Also, it is evident that runoffs that are lower and higher than the values identified for Ergene River Basin occur in the sub basins of different parts of the basin and it should be regarded as a natural phenomenon. That's the reason why this model becomes more significant with its ability to enable identification the surface runoff amount for of all desired points as specific to this point or area by allowing separate runoff values for all pixels at the rate of data resolution used in the map that represents the surface runoff distribution model.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Akarsu Havzalarında Yüzeysel Akış Dağılış ve Miktarının Belirlenmesi: Ergene Nehri Havzası

Akışa etki eden parametreleri temelde yağışın tipi, yoğunluğu, miktarı, dağılışı, süresi, fırtına istikameti, yağışa bağlı toprak nemi, sıcaklık, rüzgâr, bağıl nem ve mevsim gibi meteorolojik faktörler ile arazi kullanımı, bitki örtüsü, toprak türü, drenaj alanı, havza şekli, yükselti, eğim, topografya, bakı, drenaj şebekesi ve rezervuarlar gibi fiziksel faktörler olarak sınıflandırmak mümkündür. Bunlara toprak tekstürü, yeraltı su tablası ve yeraltı suyu derinliği ile kar yağışı, biriken kar, kar erimesi ve gerçek evapotranspirasyon gibi özel koşullara ait verilerin de eklenmesi mümkündür. Bütün bu klimatik ve yüzeysel verilerin coğrafi bilgi sistemleri marifetiyle bir arada değerlendirilmesi sayesinde, yüzeyde karmaşık bir desen ortaya koyan akışın dağılış özelliklerini belirleme imkânı söz konusu olabilecektir. Her türden problemin varlığına rağmen üzerinde akım ölçümü yapılmayan havzaların çokluğu ile birlikte akış modellerinin yüzeysel akış, toprak nemindeki değişiklikler, evapotranspirasyon ve yeraltı suyu beslenim-boşalım değerleri gibi birçok konuda akarsu akım ölçümlerine göre daha isabetli veriler üretmesi şeklinde sıralanabilecek sebepler bu modellere bağımlılığı artırmaktadır. Sonuçta akım gözlem istasyonlarının sayısını çoğaltmanın yanında mevcut model ve hesaplamaların geliştirilmesi, yenilerinin üretlmesi ve var olan modellerin uygulamalarının kolaylaştırılması amacıyla bilgisayar yazılımlarının oluşturulması gibi birçok alternatif ortaya konulmaya ve ilgi görmeye devam etmektedir.

Mevcut yüzeysel akış belirleme yöntemlerinin yetersizliği konusunda vurgulanması gereken ilk başlık hesaplama yöntemlerinin veya modellerin neyi amaçladıkları meselesidir. Bu noktada tarımsal su ihtiyacını belirlemeye yönelik modeller ile yeraltı suyu beslenimini tespite yönelik olanlar veya yağış sonrası taşkın riski ile su bilançosu ortaya koymayı hedefleyenler aynı yol ve yöntemleri belirleyip aynı sonuçlara ulaşamayacaklar, dolayısıyla da aynı problemi çözerek aynı amaç için kullanılamayacaklardır. Aynı şekilde model veya hesaplamalarda dikkate alınan periyodun farklı oluşu da çalışmaların ayrışmasına sebep olan bir diğer alandır. Yağış-akış denklemlerinde araştırılan yağışın akabinde ortaya çıkan akış tamamen spesifik bir hadise olup, sadece hesaplamanın yapıldığı zaman ve yer için geçerlidir. Böyle bir verinin genellenmesi ciddi hataları da beraberinde getirecektir. Bu durumu, iş yükünü artırarak geniş alanlarda çalışmayı olanaksız kılan günlük klimatik verilere dayanan modeller ile aylık verilere dayanan modeller arasında da gözlemlemek mümkündür. Günlük veriler ile aylık veriler arasında çok belirgin anomaliler olabileceği gibi, planlama çalışmalarında esas olan da aylık veriler yani yıllık ortalamaların rejimidir.

Verilerin süre bakımından farklılıklarına dair sonuçları alansal farklılıklarda da görmek mümkündür. Bu durumun en önemli sebebi neredeyse hiçbir havzada akışın homojen dağılmamasıdır. Modele konu her noktanın, her pikselin benzersiz koşulları olduğu bir kenara bırakılarak, noktasal boyutta elde edilen verilerinin bütün alanı veya havzayı kapsıyormuşçasına yorumlanması vahim bir yanılgıdır. Çünkü her bir nokta modele konu parametreler bakımından kendi koşullarını haiz olup parametrelerin etki değerleri ölçeğinde yüzeysel akış ile farklı bir ilişki seviyesini yansıtmaktadır. Dolayısıyla hemen her yerde heterojen koşullar sergileyen akış dağılış deseninin doğru tespit edilmesi havza ya da alanın hem geneli için hem de bölüm veya alt birimleri için spesifik akış dinamiklerinin ortaya konulmasına imkân sağlayacaktır. Bu noktada etken parametrelerin belirlenmesi ve etki değerlerinin kararlaştırılması hayati öneme sahiptir.

Şüphesiz akış dinamikleri açısından benzersiz hidrolojik birimler olarak kabul edilmesi gereken havzalar, kendi özel koşulları içerisinde akış dağılış desenine şekil veren birçok özelliği barındırırlar. Bunların bazıları daha baskın ve ana paterni belirleyici nitelikte iken bazıları nispeten düşük etki kapasitesine sahiptirler. Örneğin litolojik açıdan homojen alüvyal dolgu sahasından ibaret olan bir havzada akış desenini belirlerken sahanın litoloji verilerini dikkate almak gereksiz bir işlem olacaktır. Dolayısıyla her çalışma alanı açısından akış desenine yön veren parametreler arazi koşullarına göre farklıklar arz edecektir. Bu çalışmada ortaya konan metodoloji örnek havza olarak belirlenen Ergene Nehri Havzasında uygulamalı bir şekilde açıklanmıştır. Ergene Nehri Havzasında yüzeysel akış dağılış desenine şekil veren yedi ana parametre (yağış, potansiyel evaotranspirasyon, hidrojeolojik yapı, arazi örtüsü, toprak türü, eğim ve toprak dokusu) etki oranları nispetinde çarpan katsayılarla revize edilen birimlerden oluşmaktadır. Bu birimler piksel bazlı sayısal ifadelere karşılık gelmekte olup, ağırlıklı çakıştırma işlemi uygulanarak havzanın bütün bu faktörlere göre şekillenen sayısal yüzeysel akış dağılış deseni haritasını ortaya çıkaracak şekilde analize tabi tutulmuşlardır. Sonuçta elde edilen harita herbir birimin ilk yorumlamalarında öngörülen etkisini yansıtacak şekilde bir yüzeysel akış dağılış deseni teşekkül ettirmiştir. Çıktı niteliğindeki sayısal yüzeysel akış dağılış haritasında piksel bazlı değerler 144 ila 414720 arasında değişen değerler arz etmektedirler. Bu değerler yeniden sınıflandırılarak 1 ila 5 arasında değişen nicelikler şeklinde görselleştirilmişlerdir. Ancak daha sonra yapılacak kalibrasyon işlemlerinde verilerdeki hassasiyetin azalmaması için taban değer 144, ortaç değer 207288 ve tavan değer de 414720 olacak şekilde işlem görmüştür. Bu noktada sayısal akış dağılış haritası henüz kalibre edilmemiş olsa da yüzeysel akış dağılış deseni açısından net bir görüntü ortaya koymaktadır. Beklendiği gibi yüzeysel akışın Istranca dağlık kütlesi boyunca ve Işıklar Dağı'na yaklaşılan kesimlerde güçlendiği, buna karşılık havza tabanına doğru olan kesimlerde zayıfladığı net bir şekilde izlenebilmektedir. Bu görüntü aynı zamanda bir genellemeden ibaret olmayan ve havzadaki herbir noktanın bütün özel koşulları gözetilerek dizayn edildiği için her piksel için ayrı ayrı gerçeklik ifade eden bir dağılış modeline karşılık gelmektedir. Dolayısıyla kalibrasyon sonrasında elde edilecek değerler de her nokta için özel olan değerlerdir.

Ergene Nehri Havzasının bu çalışma kapsamında elde edilen yüzeysel akış dağılış haritasının arazinin reel koşulları ile ne derece uyumlu olduğu ve genellemeden uzak bulunduğunu anlamak için Thornthwaite su bilançosu hesaplaması, Turc, Langbein ve Soil Conservation Services-Curve Number gibi teorik yöntemlerin yanı sıra; akış yüksekliği, ortalama ana akarsu akımı, alt havzalar bazlı ortalama akım ve vahşi akışa sahip akarsu havzaları ortalama akımı gibi ampirik veriler, bu çalışmada üretilen ve yeniden sınıflandırıldıktan sonra en çok 5, en az 1 ve ortalama 1.57 birim değerlerine sahip olan haritanın kalibrasyonu için kullanılmıştır.

Sonuç olarak Ergene Nehri Havzasında gerçekleşen yüzeysel akışın hacminin taban değer olan 1.437.369.252m^3/yıl ile tavan değer olarak kabul edilebilecek, meteorik suların %40'ına denk gelen 2.535.059.960m^3/yıl arasında olduğu söylenebilir. Mevcut yüzeysel akış hesaplama yöntemleriyle elde edilen sonuçlardan hiçbirisi bu aralıkta yer almamaktadır. Bu değerlendirmelerden sonra Ergene Nehri Havzası açısından edinilen bilgiler, izlenimler ve saha hakkındaki uzman görüşü ışığında kesinliği oldukça yüksek bir değerin zikredilmesi mümkündür. Bu değer Ergene Nehri Havzası ortalama yüzeysel akış miktarının hacimsel ifadesi olarak 2.100.000.000m^3/yıl ±%2 seviyesindedir. Bu değer havzanın genel durumunu ifade etmek için kullanılabilecek güvenilir bir ifade olup, bu çalışmada uygulanan yöntemlerin hiçbirisi söz konusu değere tekabül edecek bir sonuç üretememiştir. Yani Ergene Nehri Havzası için günümüzde yaygın olarak kullanılan yöntemler güvenilir bir sonuç vermekten uzaktır.

Technical Note

Management of Groundwater Quality and Quantity: Gediz River Basin Pilot Study

Yeraltı Suyunun Kalite ve Miktar Bakımından Yönetimi: Gediz Nehir Havzası Örnek Çalışması

Burcu DURU[1] Ahmet Fuat YARGICI[1], Caner TOPÇU[1]
Özgür ÇAKMAK[2], Osman Şerif GÜLTEKİN[2]
Onur Fatih BULUT[3], Filiz B. DİLEK[3], Ülkü YETİŞ[3]

[1]*Fugro Sial Yerbilimleri Müşavirlik ve Mühendislik Ltd. Şti, Farabi Sk. 40/4,*
06690, Çankaya-Ankara
b.duru@fugro.com, a.yargici@fugro.com, c.topcu@fugro.com
[2]*Orman ve Su İşleri Bakanlığı, Su Yönetimi Genel Müdürlüğü,*
06510, Yenimahalle-Ankara
ocakmak@ormansu.gov.tr, ogultekin@ormansu.gov.tr
[3]*Orta Doğu Teknik Üniversitesi, Çevre Mühendisliği Bölümü,*
06800, Çankaya-Ankara
onurfatihbulut@gmail.com, fdilek@metu.edu.tr, uyetis@metu.edu.tr
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Abstract

This study provided methods and methodologies in compliance with the national legislations that will ensure proper management of groundwater in terms of both quality and quantity. The methodologies developed in this manner were implemented in the Gediz River Basin in Turkey. A total of 76 groundwater bodies delineated in the Basin were subjected to characterization, where the anthropogenic pressures on the quality and quantity of groundwater and their possible impacts were determined. Detailed risk analysis done by the available data revealed to the groundwater bodies which were under risk of achieving good status in terms of quality and/or quantity. In order to disclose the current status of all groundwater bodies, in-depth analyses (establishing threshold values, comparison of the measured values to the threshold values/quality standards, water budget calculations, etc.) were performed and supported by the comprehensive field investigations and monitoring. Ultimate results indicated that 33 groundwater bodies out of 76 were in poor status; and hence, all these bodies should be included in the programme of measures. Moreover, all the monitoring points at which the threshold values and/or quality standards are exceeded were also included in the programme of measures. Finally, the required measures to be taken in the Gediz River Basin at different scales (basin, groundwater body and monitoring point); to improve the poor status or to conserve the good status of groundwater, were pointed out considering both its quality and quantity.

Keywords: *groundwater management, quantitative and chemical status assessment, programme of measures, Gediz River Basin.*

Öz

Bu çalışma, hem nitelik hem de nicelik bakımından yeraltı sularının doğru yönetimini sağlayacak yasal düzenlemelere uygun yöntem ve metodolojiler sunmaktadır. Bu kapsamda geliştirilen yöntemler Gediz Nehir Havzası'nda (Türkiye) uygulanmıştır. Gediz Nehir Havzası için belirlenen 76 yeraltı suyu kütlesi, kalite ve miktar bakımından antropojenik baskılar ile bunların olası etkilerinin belirlendiği karakterizasyona tabi tutulmuştur. Mevcut verilerle yürütülen ve konservatif yaklaşımları benimseyen ayrıntılı risk analizi ile miktar ve kalite bakımından iyi bir duruma gelme riski altındaki yeraltı sıuyu kütleleri belirlenmiştir. Tüm yeraltı sularının mevcut durumunu ortaya çıkarmak için kapsamlı saha araştırmaları ve izleme sonuçları ile de desteklenen derinlemesine analizler (eşik değerlerin belirlenmesi, ölçülen değerlerin eşik değer/kalite standartları ile karşılaştırılması, su bütçesi hesaplamaları, vb.) gerçekleştirilmiştir. Nihai sonuçlar, 33 yeraltı suyu kütlesinin genel durumunun zayıf olduğunu ve dolayısıyla bunların tedbirler programına dahil edilmesi gerektiğini göstermiştir. Ayrıca, eşik değerler ve/veya kalite standartlarının aşıldığı tüm izleme noktaları da tedbirler programına dahil edilmiştir. Son olarak bu çalışma kapsamında, Gediz Nehir Havzası için farklı ölçeklerde (havza, yeraltı suyu kütlesi ve izleme noktası) tedbirler önerilmiş; zayıf durumun iyileştirilmesi veya iyi durumdaki yeraltı sularının statüsünün korunması için miktar ve kalite bakımından alınması gerekli tedbirler belirtilmiştir.

Anahtar kelimeler: *yeraltı suyu yönetimi, miktar ve kimyasal durum değerlendirmesi, tedbirler programı, Gediz Nehir Havzası*

Introduction

Freshwater is an indispensable resource for existence of life. Owing to its significance for the survival of societies; laws and regulations related to water rights date back to the world's oldest justice codes; and evolved ever since. Water Framework Directive (WFD, 2000/60/EC) emphasizes the importance of water by stating in its first recital that "*water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*" (European Commission, 2000). Moreover, in today's industrialized societies, it is not only the quantity but the quality of freshwater that has to be considered for its sustainable management. This is the rationale behind WFD set by the Ministerial Seminar held at The Hague in 1991, which recognized "*the need for action to avoid long-term deterioration of freshwater quality and quantity"* and called for *"a programme of actions to be implemented aiming at sustainable management and protection of freshwater resources*".

In 2006, another Directive (2006/118/EC, revised as 2014/80/EU), commonly known as Groundwater Directive (GWD), was published by European Commission (2006, 2014) specifically on the protection of groundwater against pollution and deterioration, focusing on the implementation stages to be completed after groundwater bodies are delineated. Besides, a common strategy for supporting the implementation of WFD (known as Common Implementation Strategy, CIS) was developed aiming to allow a coherent and harmonious implementation of WFD. With this initiative several Guidance Documents and Technical Reports were published. Taking all these Directives and Guidance Documents as reference, Turkish bylaw on protection of groundwater against pollution and deterioration was first issued in 2012 (revised on 2015).

Background Information about Groundwater Management Practices in Turkey

This article focuses on groundwater, which constitutes around 15% of the annual freshwater consumption in Turkey. Although it seems like a minor contribution in total; for rural areas, most of the times, groundwater is the only available freshwater resource to supply domestic and irrigational water demands. Owing to the fact that it is not easily be quantified and characterized like surface water resources, special care and effort should be taken in the management of groundwater resources.

Turkish bylaw on the protection of groundwater against pollution and deterioration was first issued in 2012 (Official Gazette 28257, 07.04.2012) and revised in 2015 (Official Gazette 29363, 22.05.2015), taking the WFD and the GWD as reference. This bylaw obliges the determination of groundwater bodies, as the management units of groundwater resources, which will be the basis of the succeeding implementation stages, from characterization to status assessment. On the other hand, determination of the status of groundwater in terms of quality and quantity; and development of a programme of measures (PoM), is a vital part of River Basin Management Plans (RBMP). Having such significance, General Directorate of Water Management – established under the Ministry of Forestry and Water Affairs (MoFWA) carried out a pilot project for developing and implementation of methodologies for determination and assessment of groundwater quantity and quality, in line with the above-mentioned bylaw (MoFWA, 2017). Within the content of this project ("*Developing and Implementation of Methodologies/Methods for Determination and Assessment of Groundwater Quantity and Quality: Gediz Basin Pilot Study*"), which forms the basis of this paper, all provisions of WFD on groundwater were realized; methodologies were developed for each implementation stage; and tested on a pilot river basin (Gediz River Basin shown in Figure 1).

The GRB is listed among the nine river basins having priority according to the "Action Plan on Groundwater Management" put in force in 2013 (MoFWA, 2013). The GRB is named after its major river (Gediz River) having an approximate length of 400 km, draining a basin of about 17,500 km² and discharging to the Aegean Sea, along the western coast of Turkey. Basin hosts the very fertile agricultural lands, animal husbandry activities, organized industrial sites, high potential geothermal fields, variety of mineral deposits; in addition to the densely populated settlements. All these factors impose a complex and interacting set of natural and anthropogenic pressures on both quality and quantity of water resources in the basin.

Purpose, Scope and Impact of the Study

As mentioned above, this study sets up the very first steps in Turkey on the implementation of the provisions of the WFD, GWD and the Turkish bylaw on the protection of groundwater against pollution and deterioration. In this sense, its scope was setting up structured methodologies, which are applicable for Turkey, for each implementation step of the bylaw minimizing the differences in the execution on country scale and allowing flexibility for minor modifications to adapt into different river basins in Turkey. Moreover, it should be noted that this study aimed to build on the results achieved with the already completed and/or ongoing projects in various scales and scopes, which are executed by the MoFWA. The significance of this study derives from the fact that it constituted the first step in order to close the gap in the implementation of the groundwater management policy in terms of both quality and quantity. Its impacts will be more apparent in time, as the similar scoping studies will start to build on the methodologies developed with this one; and once PoM proposed with this study is started to be executed.

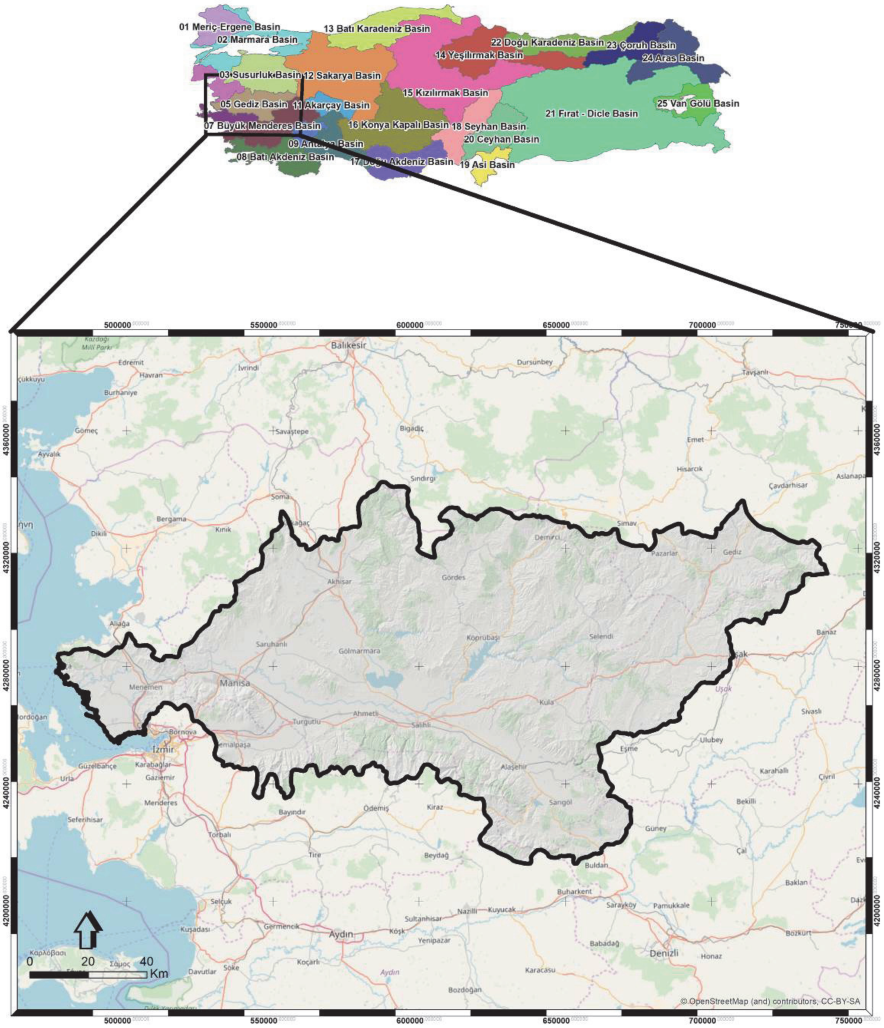

Figure 1. Location map of Gediz River Basin

Method

Implementation Steps and Methodologies

As implied by the legislation, the ultimate scope is to preserve the status of groundwater that is classified to be of good status; and to protect and improve the status of the groundwater against pollution and deterioration. To reach this goal a methodological and stepwise approach was introduced and a PoM was also set up based on the results and findings throughout the study.

Delineation of Groundwater Bodies

Within the scope of the Turkish bylaw on the protection of groundwater against pollution and deterioration, “groundwater body” is defined as the significant amount of groundwater in aquifer(s), and it is introduced as the basis for the other implementation steps. Therefore, in every consequent implementation step from characterization to risk analysis, determination of threshold values, assessment of status and establishing of the PoM; groundwater bodies to be determined at this stage shall be used.

Upon the examination of various guidance documents and applications; it was observed that different methodologies were applied and different criteria were taken into consideration in delineation of groundwater bodies, due to the local characteristics that can be quite different in each country/basin. While some of these criteria (hydraulic properties, hydro/geological boundaries, etc.) were taken into account in almost all applications; use of other criteria (ecosystems, water use, pressures, risk potential, differences in status etc.) seem to depend on local characteristics. Moreover, very specific criteria (temperature, vertical flow, topography, administrative units/boundaries, etc.) were also considered to address unique and rare characteristics of the area. Hence, it is not possible to apply these not often seen distinguishing criteria in all applications.

The methodology for delineation of the groundwater bodies in the GRB was developed with thorough investigations and revised in line with the opinions and remarks of the decision making and implementing institutions. The resulting methodology was set up by combining the geological and hydrogeological criteria used in most applications together with the criteria having great importance for Turkey (such as drinking water use and protection requirements for ecosystems and agricultural pressures). The 7-tier methodology is composed of the following stages:

- **Tier-1:** Division of the basin according to the boundaries of the geological units
- **Tier-2:** Grouping units according to their water bearing potential (as *aquifers* and *non-aquifers*)
- **Tier-3:** Identification of ecosystems (potentially) associated with groundwater
- **Tier-4:** Classification of aquifers according to their hydrogeological properties (as *higher-yield aquifers of significant groundwater potential* and *lower-yield aquifers of limited groundwater potential*)
- **Tier-5:** Assessment of wells/springs used for drinking water above a certain yield (determined to be 10 l/s, for the GRB)

- **Tier-6:** Implementation of scoring system (considering *hydraulic conductivity* and *specific capacity* of the units, which are indicative of productivity of the aquifers; and *population density* and *land use* that can be used as a preliminary indication of pressures on groundwater). In that sense, this stage is a kind of control mechanism to check if there is a critical location which could not be determined in previous stages; and if so include them in process.
- **Tier-7:** Sub-division/aggregation of groundwater bodies (groundwater bodies of small outcrops located at close proximity and of similar characteristics were combined; while larger ones were divided into smaller ones, if there are locally different types of pressures

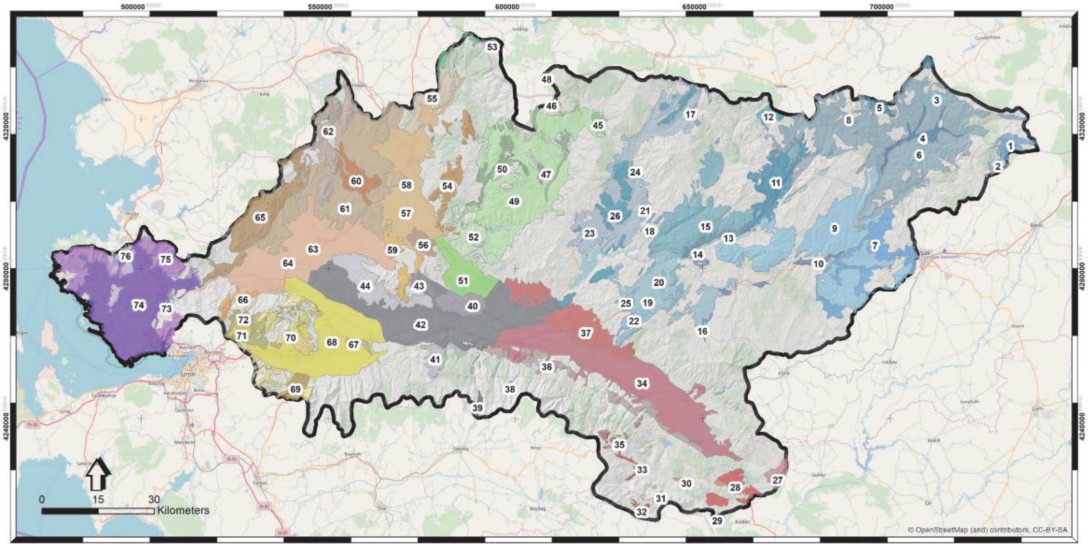

Figure 2. Groundwater bodies delineated in the Gediz River Basin.

Finally, following the guidance of the 7-tier methodology, 76 groundwater bodies, total area of which corresponds to 54% of the basin, were identified (Figure 2).

Initial characterization.

Following delineation of groundwater bodies, it is necessary to carry out characterization studies. As stated in WFD, initial characterization to be implemented for all identified groundwater bodies, should be based on existing information and be supported with the conceptual models, where appropriate.

According to WFD, following information must be specified for each groundwater body: location and boundaries of groundwater bodies; pressures on groundwater bodies; general characteristics of the formations located in drainage area recharging groundwater bodies; and groundwater bodies on which surface water or terrestrial ecosystems directly depend. On the other hand, determination of the pressures on quantity and quality of groundwater and possible impacts of these pressures require very detailed studies. Therefore, within the scope of current implementation step (initial characterization), pressures on the quantity and quality of groundwater and probable impacts were discussed briefly; while the detailed work carried out regarding these stages were elaborated in next steps of implementation ("Determination of Pressures and Impacts" and "Risk Assessment"). The general aspects were elaborated in order to clarify characteristics of both groundwater bodies and the basin more clearly and have been enriched by including additional parameters. As a result, all parameters selected for the initial characterization of groundwater bodies are listed below in Table 1. By using these criteria; characterization tables were generated for each groundwater body together with a generalized section and a map showing geographical location of the body in the basin.

Table 1

Contents of Initial Characterization Tables

Main Context	Required information/data
General Information	1. Groundwater body number and code
	2. Central point coordinate
	3. Area
	4. Surrounding groundwater bodies
Geology	5. Geological unit
	6. Lithological structure
Hydrogeology	7. Groundwater level
	8. Annual groundwater level fluctuation
	9. Aquifer type
	10. Aquifer thickness
	11. Hydraulic conductivity
	12. Surface water bodies and wetlands within groundwater body boundaries
Hydrogeochemistry	13.Physicochemical parameters
Pressures	14.Type of pressure
	15.Land use
	16.Possible hazardous substances
	17.Purpose of abstractions
	18.Artificial recharge

Determination of pressures and impacts.

For each groundwater body, pressures on quantity and quality of groundwater, and their possible impacts, were examined in detail. All related works were carried out in compliance with the legislation.

Determination of Pressures and Impacts on Groundwater Quantity

The main pressure resulting from human activities on the quantity of groundwater is groundwater abstractions in the basin. Its possible impacts can be determined directly by the evaluation of the long-term groundwater level changes. The impacts can also be determined indirectly by the ratio of quantity of abstraction to recharge. Within the scope of this study, due to the absence of historical groundwater monitoring data representing each groundwater body; indirect method, based on the comparison of quantities of groundwater recharge and abstraction, was used. Amount of recharge was calculated by “hydrological model” approach. The amount of groundwater abstractions were calculated on basis of studies presented in the GRB Hydrogeological Investigation Report (MoFWA, 2015). In this approach, the amount of abstraction and recharge, together with their proportion as a percentage, were calculated in Geographical Information System environment. Consequently, the classification of pressure (such as high, medium, low, and no pressure) was determined according to the ratio for each groundwater body.

On the other hand, impacts of these pressures could be determined directly by assessing of the long-term groundwater level changes, which were not available for all groundwater bodies. For this reason, classification of pressure at this stage was done based on all quantitative assessments throughout the consecutive implementation steps.

Determination of Pressures and Impacts on Groundwater Quality

In the basin, the main pressures on quality of groundwater were determined as agriculture, livestock, solid waste storage, urban and industrial activities, as well as mining and geothermal activities. Each groundwater body was classified in four classes (high, medium, low, no pressure) in terms of each pressure element, by calculating pressure class intervals obtained from the statistical analysis. Information on criteria by which each pressure element is classified is summarized below.

- ***Pressures from agricultural activities*** were related to the size of agricultural areas within the boundaries of groundwater bodies, using CORINE (EEA, 2012) data.
- ***Pressures from livestock activities*** were expressed in terms of total pollutant loads within the boundaries of each groundwater body. For this purpose, pollutant load constants determined in Basin Protection Action Plan (BPAP) for the GRB (MoFWA, 2013) and number of livestock were used.
- ***Pressures from solid waste disposal activities*** were evaluated by relating these pressures to the capacities of waste disposal areas located within the boundaries of each groundwater body.
- ***Pressures from domestic activities*** were represented by wastewater discharge. The amount of wastewater discharge was determined using population dependent wastewater generation coefficients given in BPAP per capita and the census information for all settlements within boundaries groundwater bodies.
- ***Pressures from industrial activities*** can vary widely depending on type of active industry, produced product and quantity of the waste generated. For this reason, it is not possible to clearly identify, grade and compare pressures arising from industrial activities. It shall be a safe approach to represent pressures of industrial activities with quality of the resulting receiving environment (surface waters); all of which were classified either as contaminated or very contaminated water within the scope of "Application of Total Maximum Daily Load Approach Project in the GRB (TMDLAP)" (MoFWA, 2017). Therefore, with a conservative approach, groundwater bodies where industrial activities are present were classified to be under high pressure.
- ***Pressures from geothermal activities*** were expressed by the number of geothermal wells per groundwater body; as they may put a pressure on the quality of groundwater due to the problems with their installation and due to improper re-injection of the abstracted hot water.
- ***Pressures from mining activities*** were related to the presence of mining operations, which may be associated with uncontrolled discharges and wastes; as the main purpose of this implementation step is to examine pressures of anthropogenic activities rather than natural enrichment of certain elements.

After pressure classes were obtained for each activity; pressure class of the highest order was defined as the general quality pressure class of the groundwater body. On the other hand, in most cases, it is not possible to determine the individual impacts of all these anthropogenic pressures. As mentioned in Guidance Document

No. 3 (Analysis of Pressures and Impacts), due to the fact that many of the impacts are not easily measurable, quality information of groundwater is often used as an indicator of, or surrogate for, impact (EC, 2003).

Within the scope of this study, impacts of anthropogenic pressures on quality of groundwater were determined using the results of the previous chemical analysis. The results of these analyses were compared to the limit values determined by the Regulation on Waters for Human Consumption in all groundwater bodies from which drinking water is supplied; and compared to the limit values determined by the Draft Regulation on Quality of Irrigation Waters and Reuse of Wastewater (MoFWA) for the groundwater bodies used only for irrigation. Impact assessment was performed on the parameters, for which limit values are set in both regulations. As a result of the detailed analyses, the level of impact on each groundwater body was classified under three classes as “impact”, “potential impact”, and “no impact” (Figure 3).

Risk assessment.

Risk Assessment Methodology of groundwater bodies is shown in flow chart below (Figure 3). As seen from this flow chart, the first step of the risk assessment is “Determination of Pressures and Impacts”. According to the methodology specified in Figure 3, after pressures derived from the human activities and their impacts on quantity and quality of groundwater are revealed, determination of groundwater bodies at risk was carried out in 4 stages. These four steps and applied methodologies are presented below in detail.

Determination of groundwater bodies at risk in terms of quantity (Step 1): The main pressures on quantity of groundwater are abstractions and artificial recharges. In the present case, there is no artificial recharge in the GRB. In order to determine the risk quantitative risk status of groundwater bodies, groundwater level changes must be revealed by long-term monitoring activities. However, as previously mentioned, information on long-term changes in groundwater levels is not adequate. In such cases, Guidance Documents suggest that classification systems can be used at preliminary assessments. Therefore, in this study, pressure classes set up based on the ratio of abstraction to the recharge; were converted to risk classes. This is a fairly conservative approach as no adequate data for groundwater levels is available. As a result, of the 76 groundwater bodies, 12 were defined to be at risk, 8 were defined to be at potential risk and 56 of them were defined to be at no risk.

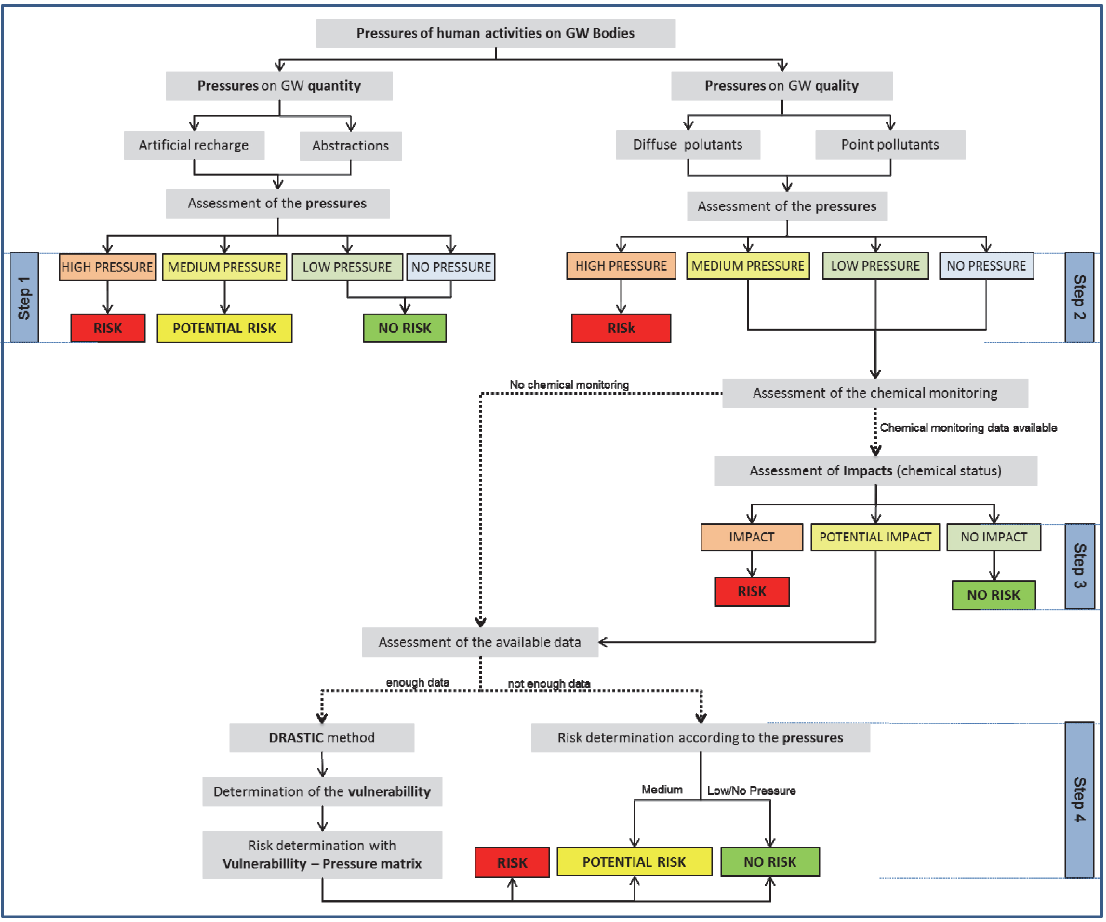

Figure 3. The flow chart of the Risk Assessment Methodology

Risk assessment in accordance with pressures (Step 2): As described above, each groundwater body was assigned an overall quality pressure class (high/medium/low/no pressure) considering each pressure element. At this step, all the groundwater bodies previously determined to be under high pressure, were directly determined to be at risk, without any further analysis.

Risk assessment in accordance with impacts (Step 3): In the GRB, for 55 groundwater bodies, there are previous chemical analyses results revealing their quality. For those groundwater bodies where previous chemical monitoring data is available, a Classification Approach was applied, and impact classes were associated to the risk classes. At this step of the methodology; the groundwater bodies determined as impacted and no impact, were identified to be at risk and no risk, respectively.

Risk assessment with sensitivity - pressure analysis (Step 4): Risk status of the groundwater bodies, for which there are no previous chemical analyses that can be used as a direct indicator of impacts; together with those, which were identified as potentially affected in Step 3; was determined by the indirect methods based on the correlation of pressures of pollutants and the vulnerability of aquifers to pollution. As noted in Guidance Documents; indirect methods have been used while assessing risk of groundwater contamination during initial implementation of WFD. At this step DRASTIC method was applied to determine the vulnerability of groundwater bodies to pollution in case sufficient data and information are available. Pollution vulnerability determined by DRASTIC method was then associated with pressures of pollutants on the groundwater body in order to assign to the risk status of groundwater bodies, indirectly. In the cases where data and information were insufficient or limited for the application of DRASTIC method; then, risk classification was based on the pressures regardless of the vulnerability; which was a highly conservative approach. This approach, referred to as "weight of evidence", is defined in Guidance Document No. 26 (Guidance on Risk Assessment and the use of Conceptual Models for Groundwater) as the use of whatever data are available to make an assessment of the most likely outcome or the 'direction of travel' in the assessment (EC, 2010). Hence, low pressure class was classified as "no risk"; while medium pressure class was associated with "potential risk".

As a result of risk assessment process for the quality aspects, 34 of 76 groundwater bodies in the GRB were determined to be at risk, 7 at potential risk, and 35 at no risk.

Further characterization.

In line with WFD requirements, "Further Characterization" studies have to be executed for groundwater bodies identified as "at risk". Moreover, the groundwater bodies determined to be potentially at risk; were also included in this implementation step. As a result, "Further Characterization" studies were carried out for a total of 44 groundwater bodies according to the risk classes considering both quantity and quality. In this stage, studies carried out in "Initial Characterization" were elaborated with the additional data/information. Moreover, during "Further Characterization" studies, new data/information was compiled to overcome deficiencies. In cases, where there is no information available based on the performed office and field studies, this missing information was completed by methods such as literature survey, stimulating groundwater bodies, etc. At this implementation step, two main groups (Classification and Land Use) were added to the existing five main context presented in the initial characterization table (Table 1). The complementary items added to the initial characterization table (Table 1) are:

- Hydrogeology: porosity; neighbouring groundwater bodies in the lateral plane; neighbouring groundwater bodies in the vertical plane
- Pressures: quantity of abstractions; recharge
- Hydrogeochemistry: chemical class; parameters that cause the groundwater body to be defined as impacted
- Land use: large surface water storage structures
- Classification: pressures; impacts; risks

Finally, further characterization table included a total of 29 parameters under 8 main contexts with the inclusion of the context "Other", which includes the following information:

- Site location maps showing geographical location of each groundwater body in the basin;
- Properties and spatial distribution of soil hydrotypes within the boundaries of the bodies;
- Generalized stratigraphic sections for the groundwater bodies, representative well logs and geological cross sections;
- Piper Diagrams used to demonstrate chemical class of groundwater;
- Inventory tables that summarize the pressures on each groundwater body;
- Maps showing land use of each groundwater body according to CORINE (2012) data and
- Maps showing distribution of total nitrogen and phosphorus loads calculated for micro-basins for surface water bodies as an indicator of the pressures from human activities;
- Maps showing distribution of quantity and quality monitoring points within the groundwater body.

Groundwater monitoring.

The aim of this implementation was to establish a groundwater monitoring programme so that data/information on the quantity and quality of groundwater can be obtained. Considering the duration and the scope of the study conducted in the GRB, it was taken three rounds for monitoring of groundwater. One of the important factors in the design of the monitoring network was the location of pressure elements with respect to the locations of current wells and springs. In addition, groundwater flow directions were also taken into consideration in order to infer the possible impacts. Similarly, to reveal pressures on quantity, the areas where abstractions are concentrated were taken into account. Consequently, a preliminary field study was conducted to determine the current conditions of the monitoring points; and to replace the selected monitoring points with appropriate alternatives, if required.

Quality Monitoring Programme: 107 groundwater samples were collected from wells/springs; and besides 3 samples were also collected from surface waters. In process of determining the parameters to be analysed, outputs of the Determination of the Pollutants having Potential to Seep into Groundwater Project (DPPSGP), MoFWA (2015), were utilized. Within the scope of that project, possible contaminants that may emerge from industrial activities; together with the widely used pesticides were determined for the GRB, which were all included into the monitoring programme. In addition to this list, results of surface water chemical analyses carried out in TMDLAP were evaluated and seven parameters having potential to seep into groundwater were also added to the list. As a result, 151 parameters were analysed in each sample.

Quantity Monitoring Programme: Groundwater level measurements were performed at the selected 145 points to be able to assess groundwater quantity for three periods.

Distribution of the monitoring points within the GRB is presented in Figure 4. The results obtained from this monitoring programme guided the consecutive implementation steps (determination of thresholds, assessment of status, setting up of the PoM, etc.). It should be noted that the quality and quantity of groundwater at the scale of groundwater bodies in the basin was firstly done by this study. Therefore, the continuation of this monitoring programme is of utmost importance in terms of ensuring the persistence of all implementation stages.

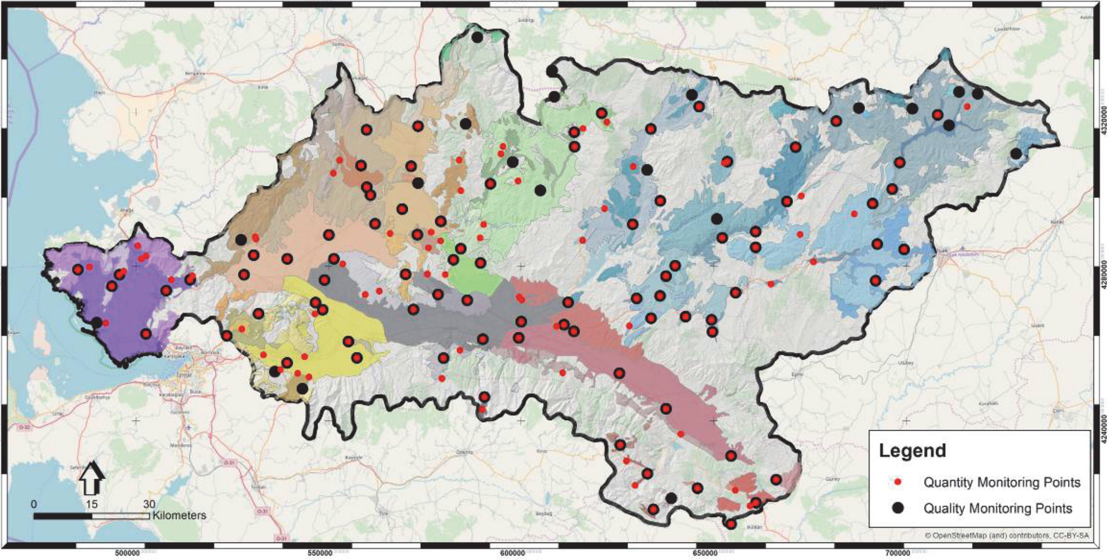

Figure 4. Monitoring network for the Gediz River Basin

Determination of threshold values.

One of the main objectives in management of water resources, as emphasized both in national and European Union (EU) legislation, is to ensure that water bodies are in good qualitative status. For the assessment of chemical status of groundwater bodies; measured and observed chemical properties of groundwater are compared with specific criteria; which are the groundwater quality standards and the threshold values.

- ***Groundwater quality standards*** for nitrates and pesticides were established at community scale with WFD in EU; and were set by the bylaw in our country.
- On the other hand, for all the other parameters, ***threshold values*** have to be determined specifically, on the required scale considering the availability and extend of the monitoring data. Therefore, determination of the threshold values is a very critical step in qualitative status assessment.

According to the legislation, for the groundwater bodies defined to be at risk; it is necessary to set threshold values for each parameter causing that groundwater body to be classified as at risk; namely constituting risk on the quality of groundwater. Throughout the studies for determination of the threshold values, 151 parameters analysed within the scope of this project at 110 sampling points for the three periods were taken as the basis. Accordingly, threshold values for those parameters having enough data and deemed to pose risk according the results of the analysis were determined.

When directives, regulations and applications based on them are examined, it is seen that process of determining threshold values basically is based on the principle of comparing criterion value of relevant parameter with its natural background levels. Thus, one of the two most important issues in establishing the threshold values stands for the natural background levels (NBGLs), the other is the selection of appropriate reference values (REF). Upon determination of these two values separately for each parameter; threshold value of relevant parameter is determined based on the method in which NBGL and REF values are compared. It should be noted that this method provides an approximate range of values, within which threshold values can be set; rather than imposing a single precise value, thus providing flexibility to the decision makers. In this manner, administrative decisions are included in a process of setting up of the threshold values. Within the scope of this project, methodologies implemented by EU countries and suggested by BRIDGE (Background cRiteria for the IDentification of Groundwater thrEsholds) project (EU FP6, 2006), were adopted in the process of determining thresholds and natural background levels.

As a result of the analysis and evaluations made in accordance with the methodology for the establishment of the threshold values, among the 151 parameters analysed, threshold values for 37 parameters and two groups of parameters (trihalomethanes and sum of trichloroethylene and tetrachloroethylene) were specified. Moreover, it should be noted that nitrate and pesticides already have quality standards determined by regulations.

Assessment of the status.

One of the fundamental objectives for the management of water resources is to reach the good status in quantity and quality for all water bodies, as emphasized both in the legislation of Turkey and the EU. Criteria to be used in determination of the status of groundwater bodies are determined in such directives and legislations. However, even though general definitions are outlined; no precise information is available regarding the method to be implemented or the methodologies to be followed for the assessment of the status of groundwater. For this purpose, some classification tests are introduced with CIS Guidance Documents. These classification tests would be implemented as per the status of information about existing data and system. To determine the status of groundwater bodies in the GRB, all the information and data gathered in the previous stages were considered and suitable tests were performed. Assessments were carried out in the three phases as summarized below:

Quantitative Status Assessment: Considering the existing data/information for the GRB; Water Budget Test was implemented to assess the quantitative status. Basic parameters considered in this test are groundwater recharges and abstractions; which were already calculated in the previous steps. For the Water Budget Test, ratio of abstraction to recharge in each groundwater body was used. Considering safe yield of the aquifers, groundwater bodies for which the ratio is over %75 were defined as in the poor status; while groundwater bodies in which this ratio is equal to or less than %75 were classified as in the good status.

Qualitative Status Assessment: Assessment of the qualitative status is basically based on a comparison of the threshold values (TV) and the quality standards (QS) to the measured concentrations. However, exceedance at one or more points within the boundaries of the groundwater body is not sufficient to classify it as in the poor status; but further analysis and additional assessments (classification tests) are required. Hence, a methodology based on comparison of TV and QS with the measured concentrations; and enriched with the tests to be conducted with the available data/information and point based investigation of pollutant sources was set up as follows:

- ***Comparison of Measured Concentrations with TV and QS***: Groundwater bodies, where TV and QS are not exceeded, were classified to be at good status.
- ***Implementation of Relevant Tests***: In cases of exceedance, classification tests should be executed. In this study, considering the available data/information and those required for the tests; General Quality Assessment Test was implemented. It involves the comparison of the TV and QS to the spatial average for the relevant parameter calculated for all monitoring points within the boundaries of a groundwater body. If the spatial average does not exceed TV and QS; the groundwater body is classified to be at good status.
- ***Distinguishing between Anthropogenic and Natural Sources of Pollution***: In cases where spatial average exceeds TV and QS; its reasons should be investigated. For this purpose, a detailed field survey was conducted to distinguish between anthropogenic and natural sources behind the exceedance. If it is associated with human activities, the groundwater body is classified to be at poor status. On the contrary, if it is derived from natural reasons, the groundwater body is classified to be at good status.

Integrated Status Assessment of Groundwater Bodies in terms of Quantity and Quality: At this stage, ultimate status of the groundwater was determined as per the relatively worse one of the qualitative and quantitative status.

Results

A number of strategies should be developed in order to reach good status for all water bodies and to prevent the groundwater from pollution as well as to keep them under control. Firstly, the groundwater bodies and monitoring points, where the measures should be taken, need to be determined. As a result of the comprehensive works and analysis, it was determined that overall status of 33 groundwater bodies in the basin, has to be improved. Hence, they were included in the PoM. Monitoring points located in groundwater bodies having good status, while the TV and QS were exceeded were also included in the PoM. Figure 5 presents the map showing the overall status of groundwater bodies and the monitoring points included in the PoM.

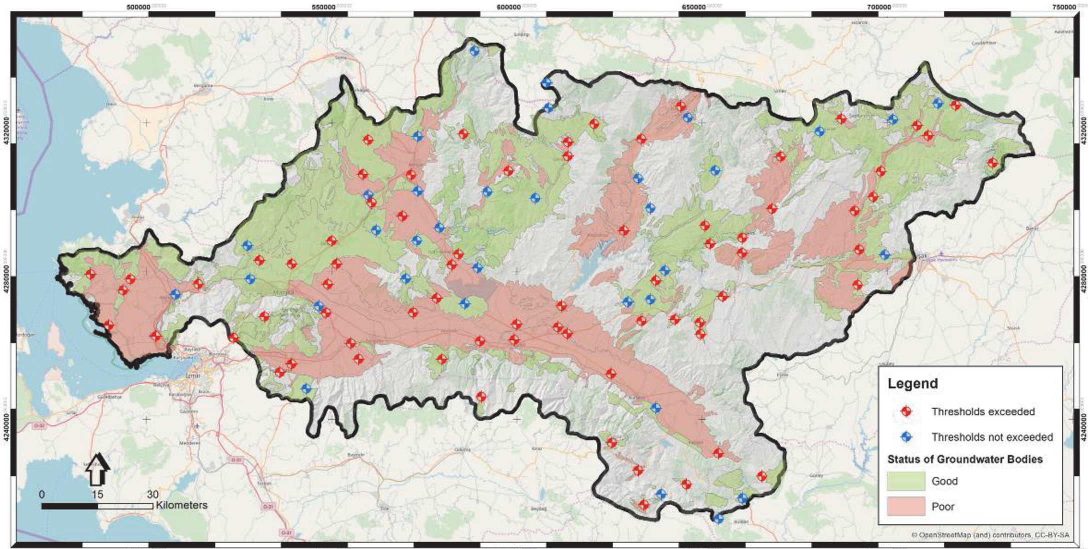

Figure 5. Overall status of groundwater bodies and monitoring points included in PoM.

After determination of the groundwater bodies and monitoring points to be counted in the PoM, detailed studies were conducted both in the office and at the field. As previously mentioned, an extensive field investigation was performed and every anthropogenic pressure element was investigated and associated to the high concentration of the measured parameters, if possible. On the basis of the monitoring points, at the 35 groundwater sampling locations (among 106); reasons of exceedance were associated with the anthropogenic pressures. It is notable that among these 35 points, where threshold values or quality standards were exceeded due to the human activities; 30 of them were associated to agriculture, followed by animal husbandry (6), domestic discharges (4), solid waste disposal (2), geothermal activities (2) and mining activities (1). All of these were included in the PoM and measures were provided at several scales.

In the end, a PoM was set up in the compliance with the regulations including basic measures, specific measures and measures that should also be taken with the purpose of protections of coastal aquifers and groundwater bodies supplying drinking water. It should be noted that while some measures (like prohibition of direct discharges, monitoring and auditing) are valid for all groundwater bodies, some measures might pertain to a specific groundwater body (prevention of salt water intrusion along coastal aquifers) or even to a specific monitoring location (closing the geothermal wells executing improper re-injection). Moreover, some aspects recommended in the PoM (such as commissioning waste water treatment plants, conversion to regular waste storage, etc.) were also debated, prioritized and scheduled in BPAP (dated back to 2013). However, it was observed that implementation of the proposed actions in BPAP, is currently far behind the proposed schedule, in many aspects.

Discussion and Conclusion

In this study, the framework determined with national regulation on protection of groundwater against pollution and degradation was taken as basis. In that sense, this is the first study, in which the requirements of the national regulation were implemented in line with the guidance of the EU directives. Considering the fact that this was the first study executed in our country; the outcomes of project were aimed to be a guide for the projects following it. Therefore, while methodologies were being set up for each implementation step, it was aimed that the proposed methods would be applicable with already existing and/or obtainable data/information. In such studies to be conducted either in the Gediz River Basin or in the other basins from then on, continuity and improvement of the proposed methods and methodologies would be possible by filling out the gaps in the data/information outlined with the outcomes of this study.

Continuation of the monitoring studies that were started in the basin with this study would be very crucial. However, it should be emphasized that monitoring studies conducted within the scope of this study included only existing wells and springs. Although, the most representative points were selected; it should be noted that the distance of existing wells to the pollution sources would complicate the determination of a possible pollution due to the dilution and attenuation processes along the transport pathway. Hence, a supplementary monitoring network was designed proposing new wells closer to the possible pollution sources; which is one of the most significant outcomes of this study for the future implementations.

Moreover, this being a part of the proposed PoM; BPAP, which was observed to fall behind the schedule foreseen, should be kept on track. Concurrently, implementation of the measures proposed as the outputs of this study should be ensured. Close and regular follow-up of the execution of the PoM is strongly recommended, to observe the effects of the decisions made and detect the trends in the status of groundwater bodies, which supposed to improve, if all the measures are taken on time.

Acknowledgement

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Yeraltı Suyunun Kalite ve Miktar Bakımından Yönetimi: Gediz Nehir Havzası Örnek Çalışması

Bu çalışma, ülkemizin en önemli doğal kaynaklarından biri olan yeraltı sularının miktar ve kalite özelliklerinin belirlenmesi süreçlerini kapsamaktadır. Ayrıca AB mevzuatlarını uyumlaştırma çalışmaları sonucunda yayımlanan "Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmelik"inde yer alan tüm uygulama adımlarının Türkiye'de uygulanabilmesi için yöntem ve metodolojilerin geliştirilmesi ve bunların Gediz Nehir Havzası örneğinde uygulanması hedeflenmiştir.

Söz konusu yönetmeliğin ilk uygulama adımı olan "***Yeraltı Suyu Kütlelerinin Belirlenmesi***" aşaması, yeraltı suyu yönetimine ilişkin uygulamalarda, kendisinden sonra gelecek çalışmaların temelini oluşturması bakımından büyük önem arz etmektedir. Bu konu ile ilgili daha önceki çalışmalar incelendiğinde farklı metodolojilerin uygulandığı ve farklı kriterlerin dikkate alındığı görülmüştür. Bu çalışmada; pek çok örnek uygulamada kullanılan jeoloji ve hidrojeoloji kriterlerine ek olarak Türkiye için önem arz eden diğer kriterlerin de dahil edilmesiyle 7 aşamalı bir metodoloji oluşturulmuş ve Gediz Nehir Havzası için, 76 adet yeraltı suyu kütlesi belirlenmiştir.

Belirlenen tüm kütleler için "***Başlangıç Karakterizasyonu***" uygulama adımının gerçekleştirilmesi gerekmektedir. Bu adım temel uygulama adımlarından olan "Baskı ve Etkilerin Belirlenmesi" ve "Risk Değerlendirmesi" aşamalarını da kapsamaktadır. Ancak, her birine ilişkin mevzuatın ayrıntıları ile ortaya koyulabilmesi ve metodolojilerin ayrı ayrı incelenebilmesi amacıyla, her bir süreç ayrı başlıklar altında değerlendirilmiştir. Bu aşamada, tüm yeraltı suyu kütlelerini başlangıç düzeyinde karakterize edebilmek amacıyla seçilen parametreler yanı sıra; genelleştirilmiş kesitlerin ve yer bulduru haritalarının da yer aldığı karakterizasyon tabloları oluşturulmuştur.

"***Baskı ve Etkilerin Belirlenmesi***" çalışmalarında, insani faaliyetlerin oluşturduğu baskılar; ve baskıların muhtemel etkilerinin belirlenmesi için gerçekleştirilen tüm çalışmalar miktar ve kalite olarak iki ana başlık altında incelenmiştir. Havzada ***yeraltı suyunun miktarı üzerindeki baskılar***, çekimlerden kaynaklandığından tüm kütleler için Çekim-Beslenim Analizi yapılarak miktar üzerindeki baskılar belirlenmiştir. Buna ek olarak uzun dönem yeraltı suyu seviyelerinin ölçüldüğü lokasyonlarda da Yağış-Rasat Analizleri gerçekleştirilmiştir. Havzada ***yeraltı suyunun kalitesi üzerindeki baskılar*** noktasal (kentsel, endüstriyel, madencilik ve jeotermal) ve yayılı kirleticiler (tarım, hayvancılık ve katı atık depolama) olarak iki temel grupta incelenmiş ve her bir yeraltı suyu kütlesi için tüm bu baskılar derecelendirilmiştir. İnsani faaliyetlerden kaynaklanan bu baskıların, yeraltı sularının kalitesi üzerinde oluşturduğu etkiler ise; mevcut kimyasal analiz sonuçları kullanılarak belirlenmiştir.

"***Risk Değerlendirmesi***" uygulama adımının temelini bir önceki uygulama adımında belirlenen baskı ve etki sınıfları oluşturmaktadır. Risk altındaki yeraltı suyu kütlelerinin belirlenmesi için söz konusu iki uygulamanın birbirleri ile ilişkilerini de içeren 4 aşamalı bir metodoloji oluşturulmuştur. Buna göre; hem miktar hem de kalite bakımından risk altındaki yeraltı suyu kütleleri belirlenmiştir.

İlgili mevzuat gereği, "risk altında" olarak tanımlanan yeraltı suyu kütleleri için "***Ayrıntılı Karakterizasyon***" çalışmalarının tamamlanması gerekmektedir. Bu doğrultuda, başlangıç karakterizasyonunda gerçekleştirilen çalışmalar risk altındaki yeraltı suyu kütleleri için ayrıntılandırılmış ve karakterizasyon adımı tamamlanmıştır. Sonuçlar kütle bazında hazırlanan tablolar, haritalar, grafikler şeklinde sunulmuştur.

"***Yeraltı Sularının İzlenmesi***" uygulama adımı kapsamında, iki yağışlı, biri kurak olmak üzere üç dönem izleme çalışmaları yapılmıştır. İzleme noktaları mevcut kuyu ve kaynakların konumları dikkate alınarak, miktar ve kalite durumunu en iyi şekilde temsil edebilecek noktalardan seçilmiştir. Bu program kapsamında, 110 numunede 151 parametrenin analiziyle yeraltı sularının kalitesi ve 145 noktada yapılan yeraltı suyu seviye ölçümleriyle de yeraltı sularının miktarı izlenmiştir.

Yeraltı suyu kütlelerinin iyi durumda olup olmadıkları kimyasal açıdan değerlendirilirken; ölçülen ve gözlemlenen kimyasal özellikler belirli kriterler ile karşılaştırılır. Bu kriterler yeraltı suyu kalite standartları ve eşik değerlerdir. Bu nedenle, "***Eşik Değerlerin Belirlenmesi***" uygulaması; takip eden aşamalarda kullanılacak temel kriterleri oluşturmaları bakımından; sürecin en önemli adımlarından birini teşkil etmektedir. AB'de ve Türkiye'de nitratlar ve pestisitler için kalite standartları belirlenmiştir. İlgili mevzuat gereği, su kütlesinin risk altında olarak sınıflandırılmasına sebep olan her parametre için eşik değerlerin belirlenmesi süreci, kriter değer ile doğal arka plan seviyelerinin karşılaştırılmasına dayanmaktadır. Bu çalışma kapsamında, Yeraltı Suyu Eşik Değerlerinin Belirlenmesi için Arka plan Kriterleri (BRIDGE: Background Criteria for the Identification of Groundwater Thresholds) projesi incelenmiş ve bu projenin çıktıları olan metodolojiler takip edilmiştir. Sonuç olarak, yönetmelikteki kalite standardı bulunan parametrelere ek olarak, havzada yeraltı sularının kalitesi üzerinde risk teşkil ettiği belirlenen 37 parametre ve iki parametre grubu (trihalometanlar ile trikloretilen ve tetrakloretilenin toplamı) için de eşik değerler belirlenmiştir.

Yeraltı suyu kütlelerinin iyi duruma ulaştırılması amacıyla takip edilecek olan metodolojinin büyük bir bölümü Türkiye'de yürürlükte olan Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmelik ile belirlenmiştir. Buna ek olarak, sınıflandırma testleri ise; mevcut verilerin ve sistem ile ilgili bilgilerin durumuna göre yapılabilmektedir. Miktar ve kalite bakımından ayrı ayrı "***Durum Değerlendirmesi***" yapılmış ve bu iki değerlendirmenin sonucu birlikte ele alınmıştır. Her bir yeraltı suyu kütlesi, görece daha zayıf olana göre belirlenen tek bir durum ile ifade edilmiştir. Gediz Nehir Havzası için belirlenen 76 kütleden 33'ü zayıf durumda; diğer 43 tanesi ise iyi durumda olarak sınıflandırılmıştır.

Sonuç olarak; yeraltı sularının kirlenmesini önlemek ve kirliliği kontrol altında tutmak için bir takım stratejiler geliştirilmesi gerekmektedir. Ayrıca, kütlelerin durumları ve izleme programı neticesinde elde edilen sonuçlar dikkate alınarak, bir tedbirler programı hazırlanmalıdır. İlgili yönetmelikteki "***Tedbirler Programı***" kapsamında, temel tedbirler, özel tedbirler ve ilave tedbirlerin yanı sıra kıyı akiferlerinin ve içme suyu amaçlı olarak kullanılan yeraltı suyu kütlelerinin korunması için gereken tedbirler yer almalıdır. Gediz Nehir Havzası için zayıf durumda olduğu belirlenen yeraltı suyu kütleleri tedbirler programına dahil edilmiştir. Bunlara ek olarak; iyi durumda olan ancak, herhangi bir noktasında eşik değer ve/veya kalite standartlarının aşıldığı izleme noktaları da tedbirler programına alınmış ve bu lokasyonlar için ofis ve sahada detaylı çalışmalar gerçekleştirilmiştir. Bir sonraki aşamada ise havzadaki tüm baskı unsurları için havzanın mevcut durumu dikkate alınarak ayrı ayrı tedbirler sunulmuş; bunlara ek olarak içme suyu amaçlı kullanımlara; koruma alanlarına ve kıyı akiferlerine yönelik tedbirlerin de eklenmesi ile tedbirler programı zenginleştirilmiştir.

Türkiye’de yürürlükte olan Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmeliğin gerekliliklerinin baştan sona uygulandığı ilk çalışma bu proje olmuştur. Bu nedenle proje süresince gerçekleştirilen çalışmaların yeni çalışmalar için de yol gösterici olması hedeflenmiştir. Bu proje kapsamında başlatılan izleme çalışmalarının sürdürülmesi en önemli kazanımlardan biri olacaktır.

Case Study

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

Türkiye için En Uygun Nehir Hidromorfolojisini Değerlendirme Metotlarının Belirlenmesi

Serhat Fatih KILINÇ[1], Paul KAY[2]

[1] *Ministry of Forestry and Water Affairs, General Directorate of Water Management,*
06510, Yenimahalle-Ankara Turkey
serhatfatih@ormansu.gov.tr
[2]*School of Geography, University of Leeds, Leeds, UK, LS2 9JT*
p.kay@leeds.ac.uk

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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

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

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

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

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:

$$C.R. = \frac{C.I.}{R.I.}, \tag{4}$$

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

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).

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

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

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

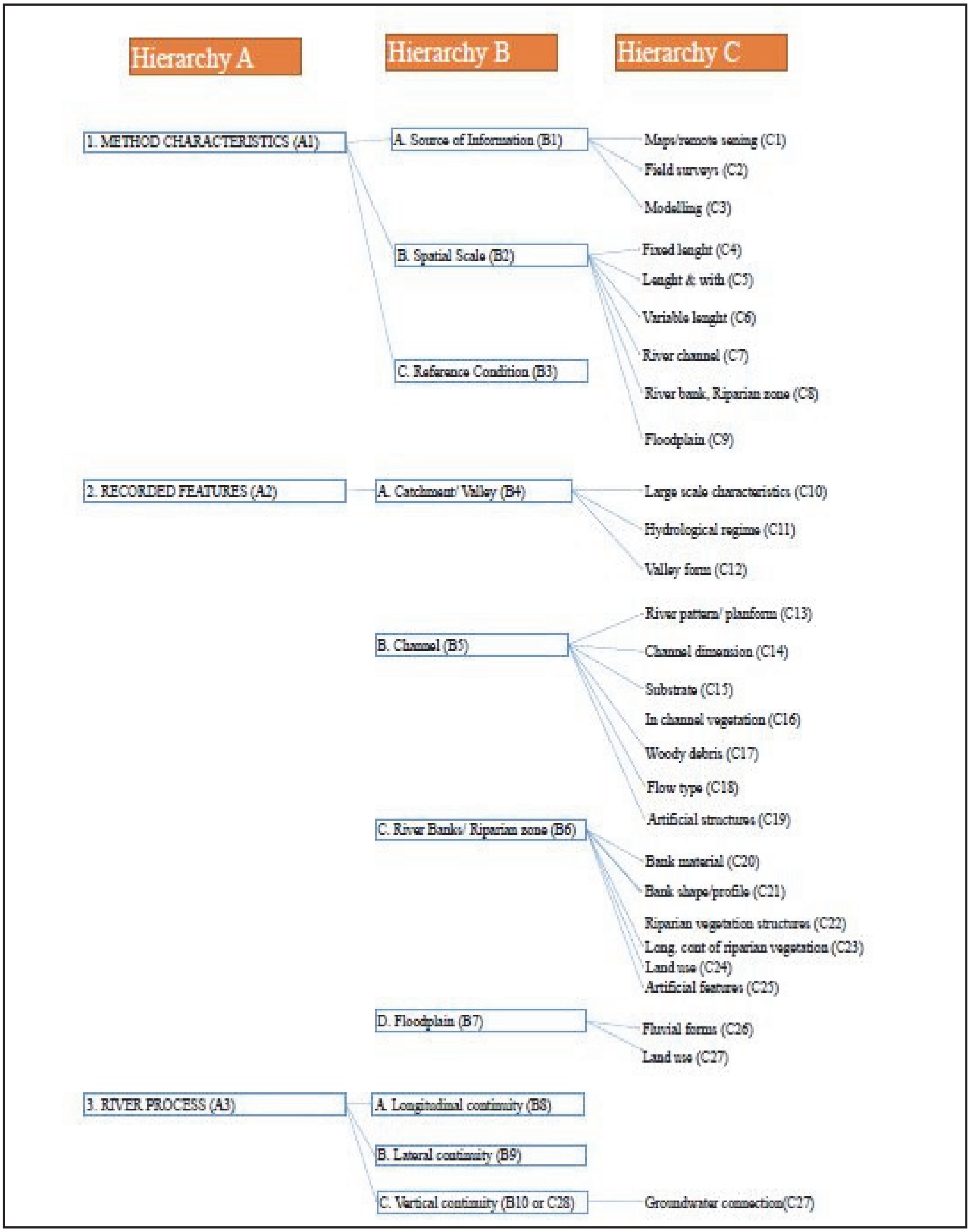


Figure 1. Hierarchical structure for AHP and a list of hydromorphological assessment features.

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. SPA TIA L SCA LE	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$_{10-12}$

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**

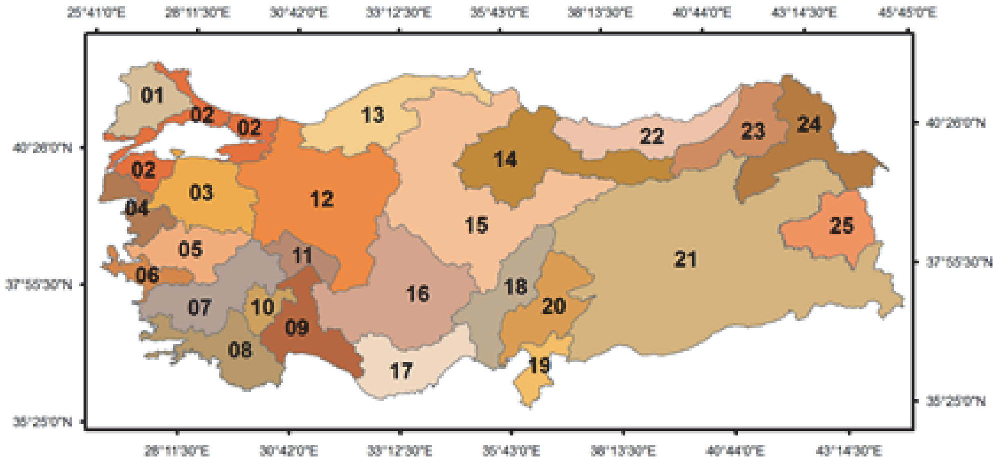
Note.CR=0.00, *C26*=fluvial flows*,* *C27*=fand use.

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**
Dams	1159	121	144
	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.

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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.

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Beştepe District Alparslan Türkeş Street No: 71 Yenimahalle/ANKARA
+90 (312) 207 50 00 • Fax: +90 (312) 207 51 87