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Editorial Policy

Turkish Journal of Water Science and Management publishes the original and innovative articles, in compliance with APA format, within the fields of water management, water quality, water chemistry, water treatment, aquatic ecology, modelling, water resources and climate change, engineering structures and hydraulic, hydrology, water law and policy and floods and droughts.

Aim

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.

Scope

Turkish Journal of Water Science and Management is a reliable, innovative and peer-reviewed scientific journal that is open to all kinds of up-to-date technological and scientific progress suitable for the future education and research needs on water, offering accurate and scientific information to all the readers.

Turkish Journal of Water Science and Management is abstracted and indexed in Dergi Park.

The ideas and ethical problems published in the journal belong to the authors

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Message from the Minister

Veysel EROĞLU, Prof. Dr.

MINISTER OF FORESTRY AND
WATER AFFAIRS
REPUBLIC OF TURKEY

Currently almost half of the world population cannot have access to sufficient and healthy water. Despite the increase of the demand for water every other day, the available water amount decreases due to pollution; and this fact increases the potential of significant conflicts and problems to arise among the countries and societies. On the one hand, the supply of sufficient, high quality and healthy water and on the other hand the efficient management of water are among recent popular research fields.

In the recent years significant research and implementation activities have taken place in Turkey especially with regard to water sciences, hydraulic engineering and water management. At the same time, there are notable developments in the field of water management also under the influence of EU alignment process. On the other hand, various scientific researches are being conducted on issues related to water in more than 200 universities and research institutes in Turkey. As a result of these works, a significant amount of experience and knowledge has accumulated in this field. With the aim of announcing this experience and knowledge along with the results of researches to the scientific and implementation world, it has been decided by the Ministry of Forestry and Water Affairs of the Republic of Turkey to issue a scientific peer-reviewed journal in accordance with international scientific criteria to be published 3 times a year at the first phase, titled as “Turkish Journal of Water Science and Management”. By this way, it is targeted to announce the results of most recent data, knowledge and research to all the relevant parties working in this field.

The aim here is to publish the results of research and implementation works containing the original findings not only in Turkey but also in all the other countries as well. I do hope that this journal will prove to be of success and also of benefit to the scientific world.

Message from the Editor

Cumali KINACI, Prof. Dr.

GENERAL DIRECTOR OF
WATER MANAGEMENT,
MINISTRY OF FORESTRY
AND WATER AFFAIRS

The Turkish Journal of Water Science and Management, targeting to publish the implementation and research results with original outputs in the field of water sciences, hydraulic engineering and water management, has been published for your attention with its first volume. The Turkish Journal of Water Science and Management is being published in accordance with international scientific criteria in certain periods on a continuous basis. The articles which have been peer reviewed by professional and scientifically reputable referees in their own field of expertise, are accepted for the journal.

In this first volume, in total 7 articles, prepared as “invited paper” by Prof. Dr. Zekai Şen who is a well-known figure in the scientific world in the field of hydrology, have been published. In this volume, there are articles on the climate change projections for Turkey and adaptation, water management in dry periods, hydrology, hydraulics, water ecology and water policy. It is expected to have a higher number and diversity of articles in the following volumes.

Articles from almost all fields related to water such as the water chemistry, hydrology, hydraulics, hydro-mechanics, hydraulic engineering, water ecology, fisheries, water quality, water and waste water treatment, flood and drought management, impact of climate change on water resources and adaptation, water legislation and water policy are admitted in the journal.

I do hope that all the scientific world will adopt and support our journal.

TURKISH JOURNAL OF

WATER SCIENCE & MANAGEMENT

Türkiye Su Bilimi ve Yönetimi Dergisi

Rational Method Irrationality with Rectification

Zekâi ŞEN[1]

Abstract

Rational method (RM) is the simplest approach for peak discharge calculation, but it has many simplifying and unrealistic assumptions, which cause biased results in many applications. Among the most important drawbacks are its applicability restriction to small areas, but it is also used without much care even for large, flat and horizontal areas, even though drainage basins might have significant slopes and rough topography. In the RM the rainfall intensity is taken as constant during the storm rainfall duration and over the drainage area coverage. In this paper, first the RM irrationalities are explained and then a modified formulation is proposed by reconsidering geomorphologic and rainfall features. Nonlinear relationships, in the forms of double-logarithmic functions, of peak discharge with drainage area and slope are incorporated in the new formulation. Its application is achieved for a set of drainage sub-basins from the Kingdom of Saudi Arabia.

Keywords: *Drainage area, peak discharge, rainfall intensity, rational method, slopes.*

1. Introduction

Rainfall-runoff relationship plays a key role in any water resources planning, design, operation, and maintenance study. Flood estimations on small drainage basins are required for a number of engineering structures such as dams, levees, culverts and soil conservation purposes. If in a basin designs are of low cost hydraulic structures then the flood estimation models with large amounts of input data are not warranted. Preferably, parsimonious models are considered with simple basic principles for easy use (Linsley, 1982).

Peak discharge calculations are necessary for flood control studies in water engineering domain. Especially, climate change effects trigger floods in different parts of the world in an unprecedented manner, and hence, more refined formulations are necessary for better estimations through simple models that can be used practically by engineers. The most frequently used methods in flood estimations on small catchments are the rational method (RM) and the Soil Conservation Service (SCS) method (SCS, 1971, 1986). Details of these methods can be obtained readily from the relevant literature (Chow et al., 1988; Linsley, 1982). The main parameter for the RM is the runoff coefficient (C) and for the SCS method the curve number (CN). These methods are used for design flood discharge estimation provided that the design rainfall information is given (Şen, 2008).

Pilgrim and Cordery (1993) present the application of the RM as a design procedure. In many applications C value is considered as constant, but in nature, it changes with time and especially in

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the calculation of design discharge average recurrence interval, it plays the single most roles. The variation of C with time must be considered in any formulation for finding refined rainfall-runoff conversion mechanism (Kadioğlu and Şen, 2001). Estimation of the C value is difficult and it is the major source of uncertainty in many water resources projects. The coefficient must account for all the significant factors affecting the peak flow response to average excess rainfall intensity without areal extent and response time restrictions. In any water resources design, the C's are taken from tables based on a set of drainage features (Maidment, 1993). They are chosen in a rather vague manner and largely include subjective judgments rather than actual field data. Additionally, various studies show that C's vary widely from storm to storm particularly depending on different antecedent wetness and environmental conditions (Hjelmfelt, 1991; Ponce and Hawkins, 1996; Kadioglu and Şen, 2001). Generally, the C increases as the average recurrence interval of rainfall increases, thus allowing for non-linearity in runoff response of the drainage basin. Since considerable judgment and experience are required in selecting satisfactory C's for a design, there is a need to check values against observed runoff data.

It is the main purpose of this paper to modify the rational method assumptions so as to obtain a more flexible and useful methodology for peak discharge estimation. In the new method, drainage area is considered as nonlinearly effective on the peak discharge and also the drainage basin slope is taken into consideration in addition to non-linearity in the rainfall intensity. The application of the proposed methodology is given for Wadi Baish in the Kingdom of Saudi Arabia with its 54 sub-basin considerations.

Criticisms

RM is rational on logical bases with simplifying basic assumptions, but it does not seem physically plausible for actual flow cases. Among its assumptions peak flow rate is produced by a constant storm rainfall intensity, which is maintained for a time equal to the period of concentration over the whole drainage basin area. This time is defined theoretically as the time required for the surface runoff from the most remote part of the drainage basin to reach the point of interest. Practically, one cannot measure it in the field, and therefore, it is calculated in an empirical manner (Kirpich, 1944; Şen, 2010). Additionally, there is a set of assumptions that the engineer should be aware of for successful applications and interpretations of the results. Otherwise, the peak discharge estimation by the classical RM may lead to unreliable conclusions. Among such assumptions are the following points for close consideration.

1) Average excess rainfall intensity has the same recurrence interval with the peak discharge,

2) The excess rainfall is uniformly distributed over the drainage area,

3) The excess rainfall intensity is constant during the time of concentration,

4) Peak discharge volume, uniformly distributed over the drainage area, is directly and linearly dependent on the excess rainfall intensity over the same drainage area. The ratio between the two is referred to as the runoff coefficient,

5) The excess rainfall intensity time is identical to time required for the runoff to flow from the hydraulically most distant point in the contributing drainage area to the point of design,

6) It is not possible to satisfy all the assumptions simultaneously in any study and there is a less chance that the rainfall rate used in the design might occur actually. Hence, the safety factor cannot be considered in the design,

7) In general, a difference exists between intense point rainfall areal coverage over some portion or the whole drainage area. In such cases, the classical RM yields excessive peak discharge values, and hence, it is necessary to have an area reduction factor (Omolayo, 1993; Sırdaş and Şen, 2007), which cannot be determined easily in the practical applications,

8) In an irregularly-shaped drainage basin, a part of the area that has a short time of concentration may cause greater peak discharge at the outlet point than the runoff rate calculated for the entire drainage basin. This is because parts of the area with long concentration times are far less susceptible to high-intensity rainfall,

9) A portion of a drainage area with high permeability produces greater amount of runoff than that calculated for the entire area. In order to reduce the effects of the last three points in the calculations, it is better to subdivide the whole drainage area into a set of convenient sub-areas.

Average knowledge is possible only when a phenomenon or process is isolated from surrounding effects through a set of restrictive assumptions that render the problem into the world of certainty by ignoring all uncertain and fuzzy features. For instance, C is a multiplier applied to deterministically (Classical two-valued logic) calculated peak discharge according to RM formulation in hydrology. Thus, by effectively "over-engineering" or "under-engineering" the design by strengthening components or including redundant systems, C accounts for imperfections in hydrologic calculations, flaws in assembly, geomorphologic and geologic degradation, and uncertainty in discharge estimates. In fact, C includes "ignorance component" due to the exclusion of all uncertain information about the hydrologic design. However, fuzzy logic and system help to solve the hydrologic design problem without considering C explicitly (Şen, 2010).

2. Method

Rectification of RM formulation is possible by considering the following logical statements and relationships.

Peak discharge-drainage area relationship

Is it acceptable that peak discharge, Qp, is directly and linearly proportional with the catchment area, A? If this statement is accepted without criticism then the more the area the more the peak discharge is without any limitation. The first part of this statement has logical validity, but the second part “linearity” is not valid in practical applications. This leads to the logical and rational conclusion that such a relation is non-linear, which brings into mind two non-linear alternatives, I and II as in Figure 2.1.

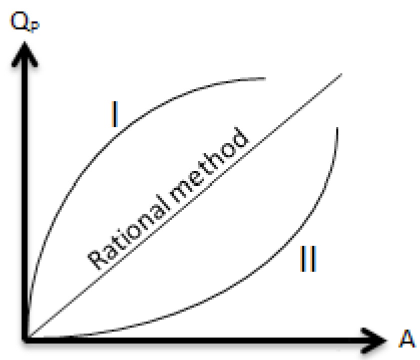

Figure 2.1. Peak discharge drainage area relationship

Rational thinking and many empirical studies indicate that as A increases, excess rainfall initially leads to discharge increment more that linear case (RM) and at large A values the rate of increase starts to decrease. In other words, the slope of peak discharge with respect to area, dQp/dA, is not a constant value but initially more than this constant (linear RM line) and as the area increases the increment in the discharge value decreases. Hence, type-II nonlinearity case is out of order and type-I is plausible. As a result, it is possible to express such a directly proportional expression mathematically as,

$$Q_p \ \alpha_A \ A^n \tag{1}$$

where αA is the proportionality sign and n is a power less than 1, which can be determined empirically from available data set including different catchment areas and their peak discharges.

The relationship between the catchment area and the peak discharge is related to the area directly as in the RM, but the surface roughness (hills and depressions) give rise to a non-linear relationship between these two quantities.

The plot of worldwide data between the peak discharge and drainage basin by Costa (1987) is presented in Figure 2.2 on double logarithmic

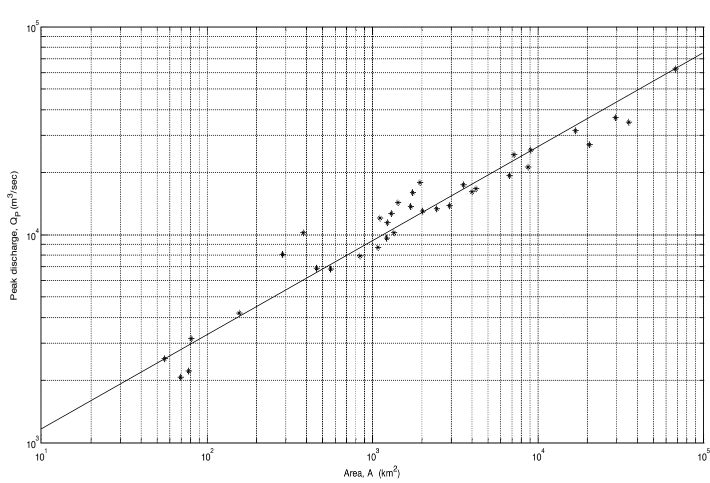

Figure 2.2. Drainage area versus peak discharge

In this figure the straight line on double logarithmic paper yields to a mathematical function as,

$$Q_P = 500A^{0.4} \tag{2}$$

This shows a relationship similar to type I curve in Figure 2.1, which implies that the drainage have more hill effective roughness than depression dominance. On the other hand, such a relationship implies rather prompt response of the drainage basin to rainfall intensity to form the surface runoff.

For instance, Bayazıt and Önöz (2008) in their work to find a relationship between Turkish drainage areas and the peak discharge have led to the following conditional expressions.

QP = 1.81A1.22 $\quad\quad$ $A \leq 300$ $\quad\quad$ (3)

QP = 79A0.5 $\quad\quad$ $300 \leq A \leq 10000$ $\quad\quad$ (4)

In Eq. (1) n = 1 corresponds to flat areas; n ≠ 1 represents rough topography within the drainage basin. If n > 1, then in the drainage basin hilly areas are more dominant over depressions otherwise when n < 1 the depression areas within the drainage basin is more dominant than the hilly areas. A question at this junction, what is meant by hilly (depression) areas? Do we need to consider the heights or the areal extensiveness of these areas? The more extensive the hilly (depression) area the bigger (smaller) is be the n value away from the flat area case of n = 1.

Peak discharge-rainfall intensity relationship

Now, let us ask the same question as for the relationship between the rainfall intensity, I, and the peak discharge, Qp. Logically, the intensity is directly proportional to Qp, but what about its type as for the linearity? Furthermore, if antecedent conditions, such as soil moisture, surface cover features (man-made or natural, i.e., geological) and evapotranspiration are considered, then logical and rational thinking leads to a nonlinear relationship between the discharge ratio, q = Q/Qp and rainfall intensity ratio, i = I/Imax as in Figure 2.3.

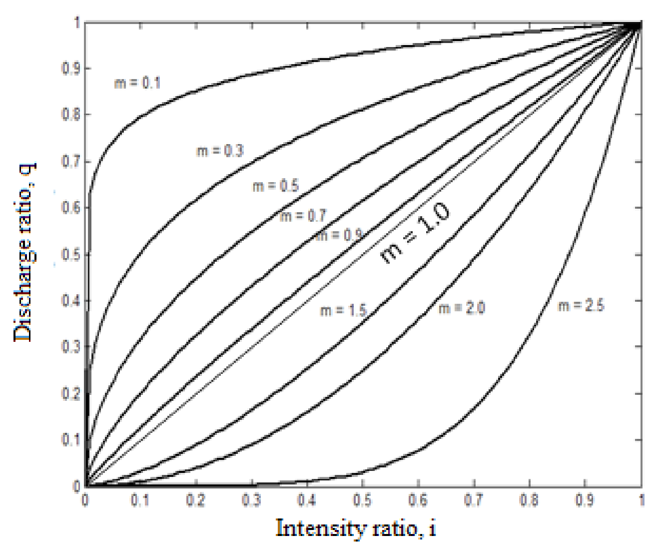

Figure 2.3. Peak discharge excess rainfall ratio relationship

$$Q_P \;\alpha_i\; I^m \tag{5}$$

Herein, m indicates the non-linearity power that depends on the mutual interaction between the rainfall and the drainage basin surface features in addition to the meteorologically prevailing conditions. Logically, low m values correspond to business, residential and asphaltic areas where surface permeability is rather high. High m values imply delay in the surface flow occurrence at small rainfall intensities and after the saturation is reached the runoff takes place at high rates which corresponds to curves below m = 1.0 line in Figure 2.3.

Additional interpretations from Figure 2.3 lead to the following significant points as for the surface flow within a drainage basin.

1) The more (less) permeable the drainage basin surface the bigger (smaller) is the runoff exponent value than m = 1, which corresponds to completely impervious drainage area,

2) For m values more (less) than 1 the surface peak discharge starts rather slowly (rapidly) and then the rate of discharge decreases (increase) with the rainfall intensity.

Peak discharge-drainage slope relationship

Another significance missing factor in the classical RM is the catchment slope. In its present form the RM provides the runoff over a horizontal and flat surface areas, but how could flow take place without slope? Logically, the more the slope the less is the discharge, and therefore, inverse but a non-linear relationship is expected between peak discharge Qp and slope, S.as in Figure 2.4.

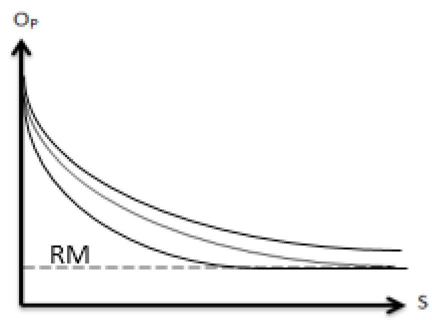

Figure 2.4. Peak discharge slope relationship

This figure indicates that there is an exponential relationship between QP and S, which appears in the mathematical form as,

$$Q_P \;\alpha_S\; e^{-kS} \tag{6}$$

One can write mathematical equation by introducing a proportionality parameter, Cp, leading to,

$$Q_P \;\alpha_G\; A^n I^m e^{-kS} \tag{7}$$

This expression leads to the physical definition of the proportionality parameter as the runoff discharge that corresponds to per drainage basin area (km2), per rainfall intensity (mm) on a flat surface (S = 1).

On the other hand, the same expression can be reduced to the classical rational formula by considering that n = m = 1 and S = 0. In this special case, Cp has then the equivalent value to the runoff coefficient. In the RM physically, C is the ratio of runoff volume to excess rainfall volume over the drainage area, which is dependent on the permeability of the surface material, and accordingly, necessary tables help to identify its numerical value (Maidment, 1993). However, in Eq. (7) Cc has a different definition as reflecting not only the soil permeability but additionally the effects of the non-linearity as explained before.

3. Results

The application of the methodology presented in this paper is applied to Wadi Baish in the Kingdom of Saudi Arabia. It is one of the largest drainage basins in southwestern Saudi Arabia (Figure 3.1) with approximately 5,970 km2 area. Different physiographic variables, in addition to rock, soil and vegetation variables are measured in Wadi Baish drainage area. Several physiographic parameters are measured, reviewed, analyzed and used in appropriate equations to synthesize a unit hydrograph for the Wadi Baish catchment area. Full detail information is available in the report by the Saudi Geological Survey (Al-Zahrani, et al., 2007).

The whole Baish catchment has 54 sub-basins as shown in Figure 3.1, and detailed application of the Soil Conservation Service (SCS) methodology to each sub-basin has provided the basic data including area, slope and discharge values (see Table 3.1).

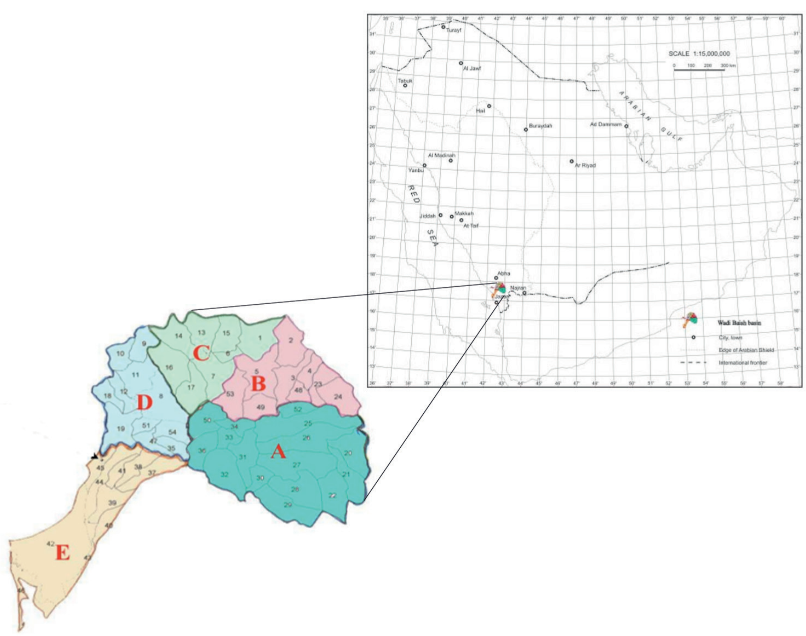

Figure 3.1. Location map of the study area and Wadi Baish sub-basins

Table 3.1.
Geomorphological features of Wadi Baish sub-basins

Sub-basin No.	Area (km^2)	So	Discharge (m^3/sec)	Sub-basin No.	Area (km^2)	So	Discharge (m^3/sec)
1	146.5	0.048	466.066	28	153	0.058	610.9423
2	134	0.058	511.7341	29	146.8	0.045	605.7025
3	100.9	0.064	590.4745	30	51.21	0.068	270.3481
4	51.61	0.098	334.2873	31	112.5	0.051	481.911
5	176.3	0.052	668.0169	32	168.9	0.079	565.8286
6	27.06	0.079	236.0097	33	44.77	0.039	290.6617
7	135.3	0.059	540.8138	34	49.21	0.031	363.7294
8	181.4	0.067	570.6024	35	52.45	0.074	357.2733
9	78.22	0.115	359.756	36	90.7	0.085	447.4473
10	69.96	0.047	339.687	37	108.3	0.051	657.7244
11	118.7	0.041	512.5776	38	74.42	0.032	526.4656
12	58.15	0.044	414.2175	39	93.51	0.007	485.4893
13	113.8	0.079	500.6066	40	53.7	0.041	387.1429
14	126.3	0.071	606.3679	41	41.48	0.018	339.3307
15	104.9	0.074	479.2184	42	535.9	0.002	1239.822
16	146.1	0.065	595.2061	43	49.01	0.021	484.3066
17	123.2	0.046	449.2771	44	112.4	0.023	552.1155
18	57.41	0.039	390.3996	45	60.27	0.016	414.1791
19	144.5	0.033	520.5371	47	53.73	0.029	372.6239
20	128.2	0.042	548.0393	48	43.15	0.095	240.9954
21	99.57	0.026	637.634	49	89.15	0.076	380.698
22	132.1	0.044	526.0269	50	107.7	0.055	434.3845
23	71.45	0.04	358.0542	51	38.3	0.08	269.1822
24	125.3	0.055	495.3614	52	71.45	0.056	371.5351
25	219.6	0.037	903.6417	53	124	0.087	429.8804
26	194.7	0.026	880.6327	54	73.32	0.078	375.4878
27	207.6	0.025	799.1697				

The scatter of peak discharge versus area is presented in Figure 3.2a for ordinary and in Figure 3.2b for double logarithmic scales. One can observe that on the double logarithmic plot the scatter of points lie along a straight-line with slope equal to n = 0.55.

On the other hand, since the straight-line passes through Qp = 500 and A = 100 km2 point, the equation form of Eq. (7) yields the constant as 40. Hence the valid peak discharge-area relationship appears as,

$$Q_p = 40A^{0.55}$$

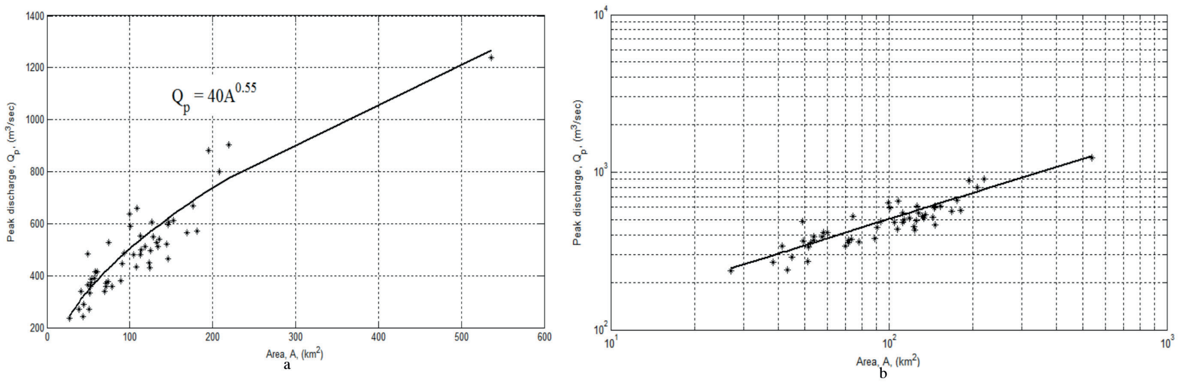

Figure 3.2. Peak discharge – area relationship

The slope relationship with the peak discharge is shown in Figure 3.3, where on the double logarithmic paper the relationship slope is equal to k = 7.63. Since the straight-line goes through the points with coordinates (Qp = 700 m3/sec, S = 0.00) and (QP = 275, S = 0.12), then the proportionality in Eq. (7) in the form of equation leads to a constant value approximately as 700. Hence, the final expression between the peak discharge and drainage slope becomes as,

$$Q_p = 700e^{-7.63SS} \tag{7}$$

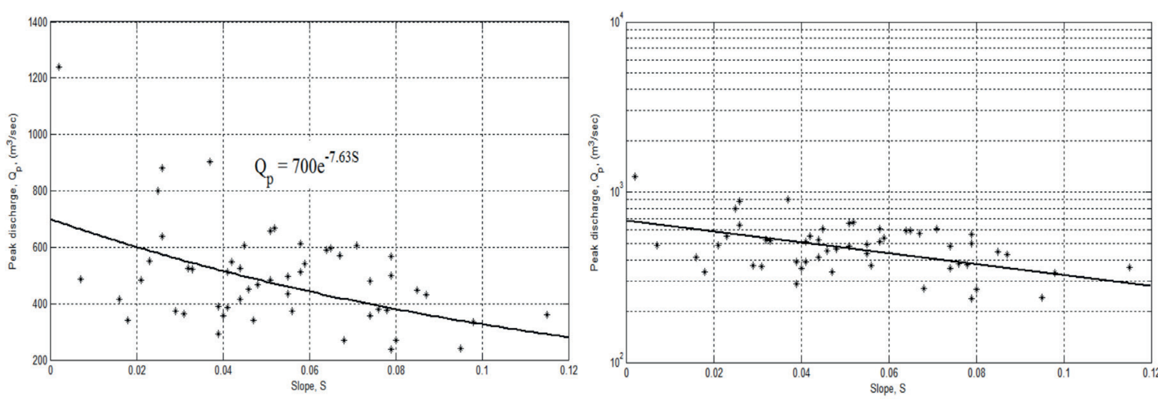

Figure 3.3. Peak discharge – slope relationship

On the other hand, determination of the composite runoff coefficient, Cp, in Eq. (7) is possible by knowing the relationship for any region between the drainage area and the peak discharge, which is given for the study area by Şen and Al-Suba'i (2002) as,

$$Q_P = 43A^{0.52} \tag{8}$$

After all the calculation and determination of the constants, the final formulation for Wadi Baish becomes as follows.

$$Q_P = 55A^{0.55} I^m e^{-7.63S} \tag{9}$$

On the basis of maximum excess rainfall event this expression can be thought of two complementary but separate product components. The first version is for zero slope that indicates the area effect only and the other is unit area case that shows the slope effect. Both of these effects are given separately in Figure 3.4 with 45o straight-line (1:1 line) that shows the model validity. It is obvious that the area effect is more than the slope, but the areal effect by itself cannot make acceptable predictions because all the points (upper triangles in the figure) lie over the straight-line, which implies that such an approach causes overestimation of the discharges. The slope has comparatively very small effect.

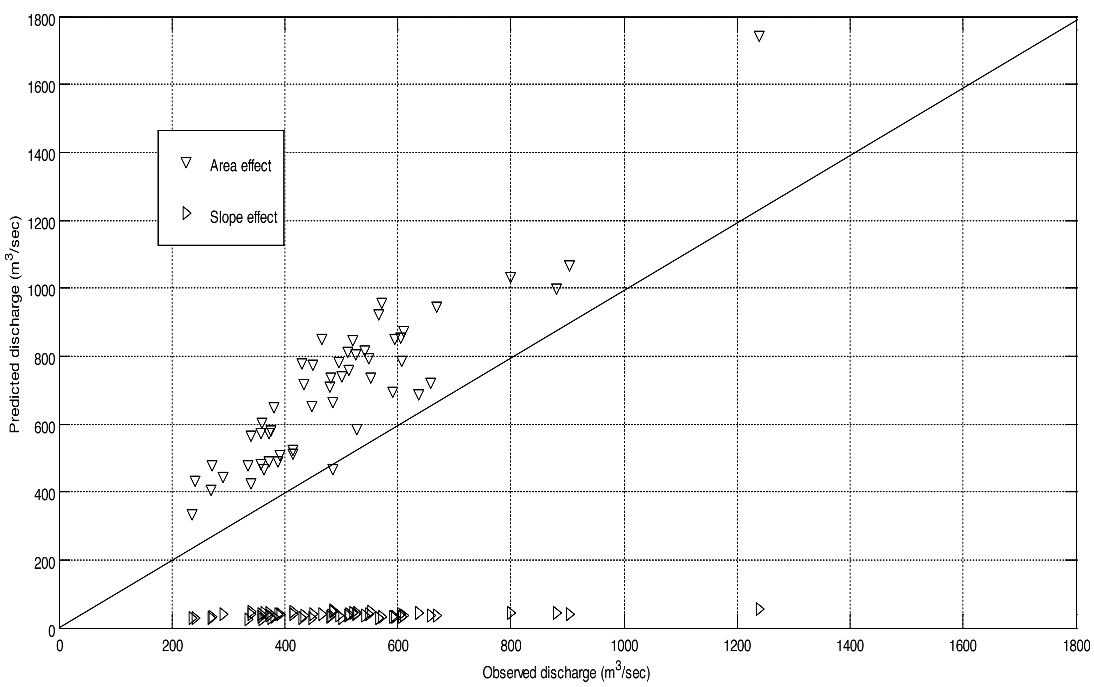

Figure 3.4. Area and slope effect on the discharge prediction

In Figure 3.5, area and slope effects are considered together again for the case of maximum effective rainfall and the scatter of points are now around the 45o straight-line. In the same figure the RM result is shown for C = 0.8 and unit excessive rainfall amount. It is obvious that the RM is far away from the real data and it needs some rectification as presented in this paper.

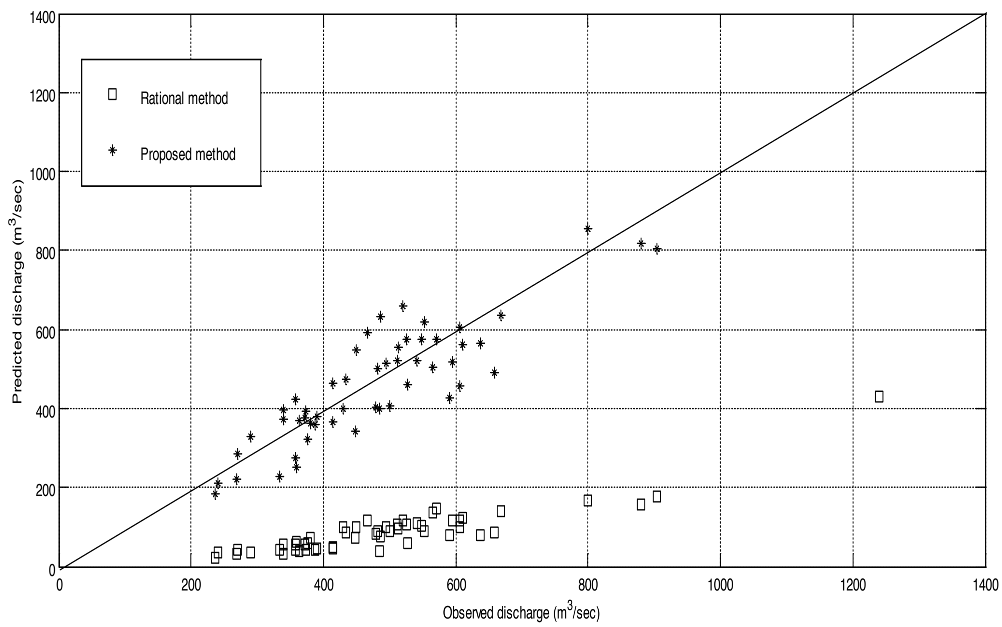

Figure 3.5. Combined effect of area and slope

After the application of the proposed method to given data, prediction errors' histogram and fitted Gaussian probability distribution function (pdf) are presented in Figure 3.6. It is obvious that the error distribution accords with the Gaussian (normal) pdf, which indicates the validity of the proposed model without any bias. The scatter of errors (deviations, residuals) of the proposed methodology scatter diagram from 45o line has almost Gaussian frequency distribution function as in Figure 3.6.

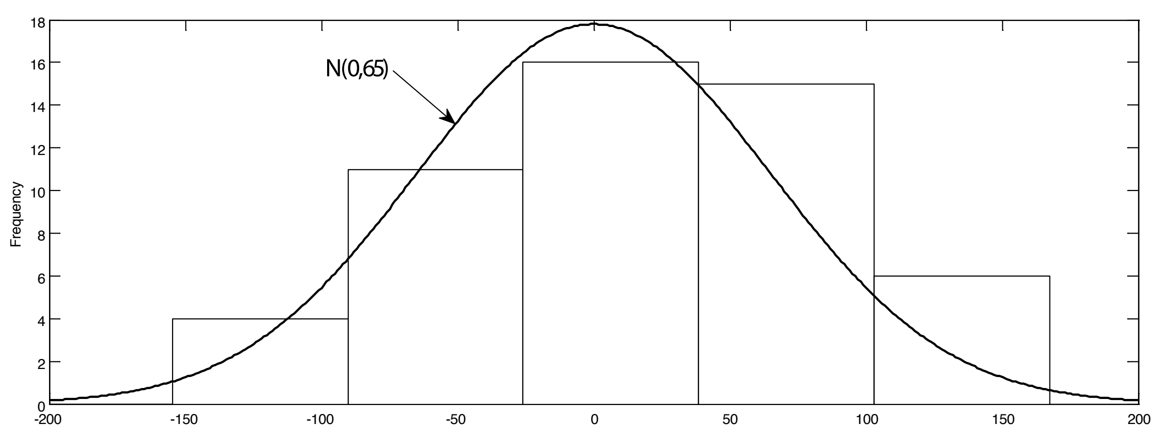

Figure 3.6. Error frequency distribution

4. Discussion and Conclusion

Rational method (RM) formulation is considered as panacea for many practical applications in engineering hydrology such that the very word "rational" in its title leads many researchers not to criticize its structure except that it is restricted for use in small drainage basins only. Logical reasoning of the input variables such as the drainage area and rainfall intensity effect on the discharge impels one to suspect from the directly linear relationship between these parameters in addition to the missing drainage area slope in the formulation. It is well known from many synthetic and empirical studies that the peak discharge is not linearly related to the drainage area, the rainfall intensity and the slope. There is directly non-linear relationship between the peak discharge and the drainage area whereas the relationship between the slope and the peak discharge is inversely non-linear. Additionally, the peak discharge is directly proportional and non-linearly related to rainfall intensity. This paper presents all these logical non-linear relationships for the rectification of the rational formulation, which leads to another and more general peak discharge formulation. The application of this new procedure is checked against the peak discharges from Wadi Baish that lies in the southwestern province of the Kingdom of Saudi Arabia.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Rasyonel Yöntemin Rasyonel Olmayışı ve İyileştirilmesi

Yağış-akış ilişkisi, herhangi bir su kaynağının planlaması, tasarımı, işletmesi ve bakım çalışmasında önemli rol oynamaktadır. Bu ilişkinin tespiti küçük drenaj havzaları üzerine yapılan taşkın tahminleri, barajlar, kuşatmalar, menfezler ve toprak koruma amaçlı yapılar gibi mühendislik yapıları için gereklidir.

Özellikle, iklim değişikliği etkileri benzeri görülmemiş bir şekilde dünyanın farklı yerlerinde taşkınları tetiklemektedir ve dolayısıyla mühendisler tarafından pratik olarak kullanılabilen basit modellerle daha iyi tahminler için daha rafine edilmiş formülasyonlar gereklidir. Küçük akarsularda taşkın tahminlerinde en sık kullanılan yöntemler rasyonel yöntem (RY) ve Toprak Koruma Hizmeti (SCS) yöntemi (SCS, 1971, 1986) 'dir. Bu yöntemler, tasarım yağış miktarı bilgilerinin verilmesi koşuluyla tasarım taşkın tahmini için kullanılır (Şen, 2008).

Birçok uygulamada C değeri sabit olarak kabul edilir, fakat doğada zamanla değişir ve özellikle debi ortalama yineleme aralığı hesaplanırken –önemli bir rol oynar. C değerinin tahmin edilmesi zordur ve birçok su kaynakları projesinde ana belirsizlik kaynağıdır. Oldukça belirsiz bir şekilde seçilirler ve büyük oranda gerçek saha verileri yerine öznel yargılar içerirler. Genel olarak, C, yağışın ortalama yinelenme aralığı arttıkça artmakta ve böylece drenaj havzasının akış geçiş tepkimesinde doğrusal olmayan bir ilişkiye neden olmaktadır..

RY, temel varsayımları mantıksal temelli olarak basitleştirmekle birlikte gerçek akış durumları için fiziksel olarak makul görülmemektedir. Varsayımları arasında pik akış hızı, tüm drenaj havzası alanı boyunca konsantrasyon periyoduna eşit bir süre muhafaza edilen sabit bir yağış yoğunluğu tarafından üretilir. Bu zaman, teorik olarak, drenaj havzasının en uzak kısmından gelen yüzey akışının ilgili noktasına ulaşması için gereken süre olarak tanımlanmaktadır. Sahada ölçülebilmesi mümkün değildir ve bu nedenle ampirik olarak hesaplanmıştır (Kirpich, 1944; Şen, 2010). Buna ek olarak, mühendislerin sonuçların başarılı uygulamaları ve yorumları için bilmeleri gereken bir dizi varsayım vardır.

RY formülasyonunun rektifikasyonu aşağıdaki belirtilen esaslar göz önüne alarak mümkündür.

Pik debi olan Qp, doğrudan ve doğrusal olarak su toplama alanı ile doğru orantılı bir ifadeyi matematiksel olarak aşağıdaki gibi ifade etmek mümkündür:

$$Q_p \; \alpha_A \; A^n \qquad (1)$$

Burada, αA orantılılık işaretidir ve n, 1'den düşük bir değerdir ve bu, farklı toplama alanları ve pik debileri dahil olmak üzere mevcut veri setinden ampirik olarak saptanabilir.

Havza alanı ile pik debisi arasındaki ilişki direkt olarak RY'deki gibi alanla ilgilidir, ancak yüzey pürüzlülüğü bu iki nicelik arasında lineer olmayan bir ilişki doğurmaktadır.

$$Q_p = 500A^{0.4} \qquad (2)$$

Bayazıt ve Önöz (2008), drenaj alanları ile pik yükü arasındaki ilişkiyi bulmak için yaptıkları çalışmalara dayanarak aşağıdaki koşullu ifadeleri öngörmüştür.

QP = 1.81A1.22 $\qquad A \leq 300$ (3)

QP = 79A0.5 $\qquad 300 \leq A \leq 10000$ (4)

Ayrıca toprak nemi, yüzey kaplaması özellikleri ve evapotranspirasyonu gibi öncül koşullar göz önüne alındığında, mantıksal ve rasyonel düşünme, boşalma oranı (q = Q / Qp) arasında doğrusal olmayan bir ilişkiye neden olur ve yağış yoğunluğu oranı, i = I / Imax olarak kabul edilir.

$$Q_P \quad \alpha_i \quad I^m \qquad (5)$$

Burada, m, yağış ile drenaj havzası yüzey özellikleri arasındaki karşılıklı etkileşime bağlı olarak, meteorolojik olarak geçerli koşullara ek olarak doğrusal olmayan ilişkiyi belirtir.

Drenaj havzası yüzeyinin geçirgenliği ne kadar büyükse m = 1'den daha büyük geçirgenlik değerini işaret eder ve bu da tamamen geçirimsiz drenaj alanına karşılık gelir, 1'den daha fazla olan m değerleri için, yüzey pik debisi oldukça yavaş başlar ve daha sonra yağış şiddeti ile debi oranı düşer.

Mantıksal olarak, eğim ne kadar fazla ise debi olur ve dolayısıyla ters, fakat pik debisi Qp ve eğim, S arasında doğrusal olmayan bir ilişki beklenir.

$$Q_P \quad \alpha_S \quad e^{-kS} \qquad (6)$$

Burada, αS başka bir orantı katsayısıdır ve k> 0'dır. Denk. (6), sıfır eğimin, klasik RY'ye uygun olan sabit debiye karşılık geldiğini ima eder.

Yukarıdaki iki değişkenli orantılıkların hepsi çarpım işlemleri ile kombine edilebilir ve son formülasyon küresel bir orantısal katsayısı αG ile aşağıdaki gibi yazılabilir:

$$Q_P \quad \alpha_G \quad A^n I^m e^{-kS}$$

Bir orantı parametresi olan Cp'yi getirerek matematik denklemi yazabilir,

$$Q_P = C_p A^n I^m e^{-kS} \qquad (7)$$

Bu ifade, düz yüzeyde (S = 1) yağış yoğunluğu (mm) başına drenaj havza alanı (km2) için karşılık gelen akış debisi olarak orantı parametresinin fiziksel tanımlanmasına yol açar.

Metodoloji Suudi Arabistan Krallığı'ndaki 54 alt havzaya ayrılmış, 5,970 km2'lik alana sahip olan Wadi Baish'e uygulanmıştır. Wadi Baish drenaj alanında kaya, toprak ve vejetasyon değişkenlerine ek olarak farklı fizyolojik değişkenler ölçülmektedir. Wadi Baish havzası için bir birim hidrografı sentezlemek için çeşitli fizyografik parametreler ölçülmekte, gözden geçirilmekte, analiz edilmekte ve uygun denklemlerde kullanılmaktadır.

Biri çift logaritmik grafiğin noktalarının dağılımı eğrisi n = 0.55'e eşit olan düz bir çizgi boyunca uzanmaktadır. Öte yandan, düz çizgi Qp = 500 ve A = 100 km2 noktasından geçtiği için Denk. (7) sabiti 40 olarak verir. Dolayısıyla geçerli pik debi alanı ilişkisi şöyle gerçekleşir:

$$Q_P = C_p A^n I^m e^{-kS}$$

Çift logaritmik kağıt üzerinde ilişki eğimi k = 7.63'e eşittir. Denk. (7) şeklinde yaklaşık 700 olarak sabit bir değer bulunur. Dolayısıyla, pik debi ve drenaj eğimi arasındaki son ifade şu şekli alır:

$$Q_p = 700e^{-7.63SS}$$

Öte yandan, Eşit akış katsayısının (Cp) (7), çalışma alanı için Şen ve Al-Suba'i (2002) tarafından verilen drenaj alanı ile pik debi arasındaki herhangi bir bölgenin ilişkisini bilmek suretiyle mümkündür,

$$Q_P = 43A^{0.52} \qquad (8)$$

Sabitlerin hesaplanması ve belirlenmesinden sonra, Wadi Baish'in son formülasyonu aşağıdaki gibi olur:

$$Q_P = 55A^{0.55} I^m e^{-7.63S} \qquad (9)$$

Maksimum aşırı yağış olayına dayanarak, bu ifade iki tamamlayıcı fakat ayrı ürün bileşeni olarak düşünülebilir. Alan efektinin eğimden daha fazla olduğu açıktır, ancak tüm alanlar düz çizginin üzerinde kaldığı için bölgedeki alansal etki kendiliğinden kabul edilebilir tahminlerde bulunamaz; bu da böyle bir yaklaşımın aşırı tahmin edilmesine neden olduğu anlamına gelir. Eğim nispeten çok küçük bir etkiye sahiptir.

Maksimum etkili yağış durumunda bölge ve eğim efektleri bir arada düşünülür ve noktaların saçılması 45o düz çizginin etrafındadır. Açıktır ki RY, gerçek verilerden uzaktır ve bu makalede sunulan bazı düzeltmelere ihtiyaç duyar.

Rasyonel yöntem (RY) formülasyonu, mühendislik hidrolojisinde pek çok pratik uygulama için her derde deva olarak kabul edilir; bu nedenle, adında "rasyonel" kelimesi, birçok araştırmacıya, yalnızca küçük drenaj havzalarında kullanım için sınırlandırıldığı için yapısını eleştirmemesine neden olur. Birçok sentetik ve ampirik çalışmadan pik debinin drenaj alanı, yağış yoğunluğu ve eğim ile lineer olarak ilişkili olmadığı çok iyi bilinmektedir. Pik debi ile drenaj alanı arasında doğrusal olmayan bir ilişki bulunurken, eğim ile pik debi arasındaki ilişki tersine doğrusal değildir. Buna ek olarak, pik debi doğrudan doğruya orantılıdır ve yağış şiddetiyle doğrusal olmayan şekilde ilişkilidir. Bu makale rasyonel formülasyonun düzeltilmesi için tüm bu mantıksal lineer olmayan ilişkileri sunmaktadır ve bu da başka ve daha genel bir pik debi formülasyonuna yol açmaktadır.

Climate Change Projections for Turkey: Three Models and Two Scenarios

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Abstract

"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world". The name "representative concentration pathways – RCP's" are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gasses (GHGs) concentrations. In this study, it is intended to reveal the possibilities of future climate change for Turkey and its surrounding region. HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M Global Circulation Models' RCP4.5 and RCP8.5 scenarios outputs were used in the study. Temperature and precipitation projections were produced from these outputs, based on domain with 20 km resolution, covering period between 2016 and 2099 and using regional climate model RegCM4.3.4 and with dynamic downscaling method. According to the models results, it is expected that an increase between 1°C and 6°C in mean temperatures of Turkey. In generally precipitation amount shows a decreasing except winter season. Although there is no regular decreasing or increasing trend throughout projection period, it attracts more attention irregularity of precipitation regime.

Key words: *RCP, HadGEM2-ES, MPI-ESM-MR, GFDL-ESM2M, RegCM.*

1. Introduction

The importance of climate in human life is associated with positive or negative effects of the climate in social and economic life and how it affects (Demir et al., 2013; Demircan et al., 2014 [a],[b],[c]). Many institutions and organizations, both national and international, governmental and non-governmental, have made efforts to determine the possible changes in climate and the impacts of these changes correctly, in order to provide a sustainable life to people.

The most important of these efforts are climate modelling studies. Variables representing environmental conditions may include in the model in more detail in conjunction with the development of technology. From the 1970s climate models began to be used with the proliferation of the use of computers for scientific purposes. In the first climate model studies, climate was modelled according to only the atmosphere and observed parameters in the atmosphere. By the developments in science and technology, land surface, oceans, sea ice, sulphate aerosols,

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carbon cycle, atmospheric chemistry and dynamics of vegetation and other factors have been new parameters that are important inputs to climate models. Both with the development of science and technology and with the guidance of IPCC, climate change studies started to produce more accurate outcomes.

In 2006, a few results from the regional climate model RegCM3 were available for the last 30 years of the 21st century, and this was only under one SRES scenario. Substantial progress has been made since 2006. In recent years, substantial climate simulation studies focusing on Turkey and its surrounding region have been developed. Regional climate change simulation based on the IPCC A2 scenario over the Eastern Mediterranean for the last 30 year of the 21st century were developed by Önol and Semazzi (2009). The climate research group of the Eurasia Institute of Earth Sciences at ITU has carried out a downscaling experiment for Turkey using the outputs of the emission scenario simulations of three different GCMs (TFNC, 2013).

Since 2006, a number of regional climate simulation studies have been carried out on Turkey (its sub regions or with its surrounding region). Regional climate change simulations based on the SRES scenarios have been performed by Krichak et al. (2007), Gao and Giorgi (2008), Turuncoglu et al. (2007), Önol and Semazzi (2009), Zanis et al. (2009), Black et al. (2010), Sen et al. (2011), Demir (2011), Ozdogan (2011), Bozkurt and Sen (2011), Önol (2012), Bozkurt et al. (2012), Önol and Unal (2012), Bozkurt and Sen (2013), Önol et al. (2013). In these studies, they found a temperature increase for the entire region and a decrease in annual precipitation in generally.

State Meteorological Service (SMS) has produced climate projections by downscaling method using global models within the scope of Coupled Model Inter-comparison Project Phase 5 (CMIP5). For the climate projections, new generation concentration scenarios of IPCC AR5 (Representative Concentration Pathways, RCP) were used. As well as, a project titled "The Effect of Climate Change on Water Resources Project - TECCWRP" was started in 2013 by the Ministry of Forestry and Water Affairs, General Directorate of Water Management (GDWM) (SNCT, 2016).

Since 2010, a number of regional climate simulation studies have been carried out for Turkey (its sub regions or with its surrounding region) with new scenarios. Regional climate change simulations based on the RCP scenarios have been performed by Demir et al. (2013), Demircan et al. (2014 [a],[b],[d]), Ozturk et al. (2014), Turp et al. (2014), Unal et al. (2015), Gurkan et al. (2015), Yıldırım et al. (2015), Ozturk et al. (2016), Gurkan et al. (2016), Demiroglu (2016). In these studies, they found a temperature increase for the entire region and decrease of annual precipitation in general.

Climate is the average weather conditions experienced in a particular place over a long period. Climatological normals are averages for consecutive periods of 30 years which are calculated from climatological data (Demircan et al., 2013; Demircan et al., 2014 [a],[b],[c],[d]). Using climate normals are very important tool to provide a standard base for preparing global assessment and climate monitoring studies. The reference period of climate; 1961-1990, 1971-2000 and 1981-2010 as climate normals are used by scientists, national climate services and international institutions in climate monitoring, climate trends, climate change and modelling studies.

2. Method

The study involves projection of climate parameters that are produced by using regional climate model (RegCM4.3.4) with dynamic downscaling method based on RCP4.5 and RCP8.5 scenarios from outputs of 3 Global Circulation Models (HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M).

HadGEM2 is a comprehensive Earth-System Model developed by Hadley Centre of UK Met Office. The standard atmospheric component has 38 levels extending to ~40km height. Horizontal resolution is 1.25° latitude and 1.875° longitude (~112.5 km) (MetOffice, URL). MPI-ESM-MR is a comprehensive Earth-System Model developed by Max Plank Institute (MPI) for Meteorology (MR mixed resolution). It is one of the preferred model in CMIP5 studies. This version resolution is 63 level in horizontal (approximately 1.9° (~210 km) on a Gaussian grid) and 95 level in vertical. GFDL-ESM2M is a comprehensive Earth-System Model developed by National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL). It is one of the preferred model in CMIP5 studies. This version resolution is 2.5° longitude, 2° latitude (~220 km) in horizontal and 24 level in vertical.

Climate models are the primary tools available for investigating the response of the climate system to various forcings, for making climate predictions on seasonal to decadal time scales and for making projections of future climate over the coming century and beyond (IPCC, 2013). Regional Climate Models (RCMs) are limited-area models with representations of climate processes comparable to those in the atmospheric and land surface components of Atmosphere-Ocean General Circulation Models (AOGCMs), though typically run without interactive ocean and sea ice. RCMs are applied over a limited-area domain with boundary conditions either from global reanalyses or global circulation model output. RCMs are often used to dynamically ‘downscale’ global model simulations for some particular geographical region to provide more detailed information (Laprise, 2008; Rummukainen, 2010; IPCC, 2013). By contrast, empirical and statistical downscaling methods constitute a range of techniques to provide similar regional or local detail. Parameterizations are included in all model components to represent processes that cannot be explicitly resolved; they are evaluated both in isolation and in the context of the full model. Atmospheric models must parameterize a wide range of processes, including those associated with atmospheric convection and clouds, cloud-microphysical and aerosol processes and their interaction, boundary layer processes, as well as radiation and the treatment of unresolved gravity waves.

Representative Concentration Pathways – RCP’s

“Experts Meeting” with broad participation was organized by the IPCC in September 2007 for a new approach for climate change scenarios to be used in the IPCC 5th Assessment Report. In this context; a new set of new emission/concentration scenarios were produced. These new emission/concentration scenarios, named Representative Concentration Pathways (RCPs), have specified characteristics. (Table 2.1) (TSMS, 2015).

Table 2.1.

Types of Representative Concentration Pathways (RCP's) (Based on IPCC, 2007)

Name of RCP's	Radiative Forcing	Time	Pathway shape	Concentration (ppm)	Emissions (Kyoto Protocol's greenhouse gases)
RCP 8.5	> 8.5 W/m^2	in 2100	Rising	> ~1370 CO2-eq in 2100	Rising continues until 2100.
RCP 6.0	~6.0 W/m^2	at stabilization after 2100	Stabilization without overshoot	~850 CO2-eq (at stabilization after 2100)	Decline in the last quarter of century
RCP 4.5	~4.5 W/m^2	at stabilization after 2100	Stabilization without overshoot	~650 CO2-eq (at stabilization after 2100)	Decline from the mid-century
RCP3-PD*	~3.0 W/m^2	peak at before 2100 and then decline	Peak and decline	peak at ~490 CO2-eq before 2100 and then decline	Decline in the first quarter of century

Global Models and Data Sets

This study contains the results of the project named "Climate Projections with New Scenarios for Turkey". In this context, three (HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M) Global Circulation Models' data were used based on RCP4.5 and RCP8.5 scenarios. The period 1971-2000 was defined as the reference period and the period 2016-2099 was defined as the future period.

Table 2.2.

Data sets and periods

GCMs Data Set	Reference Observation Data Sets (RODSs)	Reference Period	Projection Period
HadGEM2-ES MPI-ESM-MR GFDL-ESM2M	Climate Research Unit (CRU) University of Delaware (UDEL)	1971-2000	2016-2099

Dynamic Downscaling: RegCM4

RegCM4 which is developed by International Centre for Theoretical Physics in Italy (ICTP) was used in the study (Giorgi et al., 1993 [a],[b]). This model is a limited area atmospheric models that is consisting of the basic equation, hydrostatic, compressible and sigma pressure levels. RegCM4's model physic uses BATS ground surface model (Dickinson et al., 1993), non-local boundary layer diagram (Holtslag et al., 1990), the radiation scheme of the NCAR CCM3 (Kiehl et al., 1996), parameterizations for ocean surface fluxes (Zeng et al., 1998), the explicit moisture scheme of (Hsie et al., 1984), a large-scale cloud and precipitation scheme which accounts for the subgrid-scale variability of clouds (Pal et al., 2000) and various options for cumulus convection (Anthes, 1977; Grell, 1993; Emanuel and Zivkovic-Rothman, 1999).

One-way nesting method was used to downscale from Global Circulation Models to study domain. Resolution of HadGEM2-ES is allowing a direct downscaling to 20 km. On the other hand, resolution of MPI-ESM-MR and GFDL-ESM2M is not allow directly downscaling. Firstly, MPI-ESM-MR and GFDL-ESM2M was downscaled to 50km than they were downscaled to 20 km from 50 km outputs. A domain with 20 km horizontal resolution which has 130x180 grid-scale and 18 pcs sigma level was used for this study. Cumulus convection parameterization of Emanuel on the land and Grell on the sea was used as convective precipitation scheme for projection study.

The Sensitivity and Control Tests

For control tests of GCMs, regional model was run for the period of 1971-2000 and results were compared with RODSs (Table 2.2). Averages of temperature and daily total precipitation that based on seasonal and annual scale were compared with RODs. Results shown in Table 2.3.

Table 2.3.

Seasonal and annual averages of temperature and precipitation within the reference period of 1971-2000 for regional climate model simulation and grided observations

SEASONS	Temperature (°C)					Precipitation (mm/day)				
RCM/ODS	HadGEM	MPI	GFDL	CRU	UDEL	HadGEM	MPI	GFDL	CRU	UDEL
WINTER	0.436	0.525	-0.949	0.561	-0.076	2.159	2.524	1.728	2.126	2.353
SPRING	8.294	8.628	6.996	9.712	9.309	2.622	1.92	2.24	1.973	2.098
SUMMER	20.792	19.603	17.343	20.859	20.7	0.947	0.417	1.769	0.685	0.742
AUTUMN	10.412	11.003	8.404	12.48	11.961	1.83	1.284	1.206	1.332	1.454
AVERAGE	9.987	9.95	7.956	10.906	10.474	1.886	1.532	1.736	1.530	1.664

As seen in Table 2.3, the average temperature results which were obtained with using downscaling from the reference period (1971 to 2000) data of three global models (HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M) were compared with RODSs. HadGEM2-ES's data are seen an overlap with observation data in winter and summer and lower about 1.5°C in spring and autumn from RODSs. MPI-ESM-MR and GFDL-ESM2M's data are seen lower between 1-4°C from RODSs in all season except winter. In winter, MPI-ESM-MR value is overlap with RODSs. According to annual average temperature comparison of Turkey, HadGEM2-ES and MPI-ESM-MR's results are lower about 1°C than CRU and UDEL's observation data sets. There is a difference about 3°C between GFDL-ESM2M's results and RODs (CRU and UDEL).

Daily precipitation results which were obtained with downscaling from the reference period (1971 to 2000) data of three GCMs (HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M) were compared with RODSs. In particularly, downscaled data of HadGEM2-ES in winter and MPI-ESM-MR in autumn are seen overlap with RODs. The results data of MPI-ESM-MR in winter season, HadGEM2-ES in autumn, GFDL-ESM2M and HadGEM2-ES in spring are higher than RODSs. The results data of MPI-ESM-MR in spring and summer and GFDL-ESM2M in winter and autumn are lower than RODs. Considering the overall average, HadGEM2-ES and GFDL-ESM2M'results are higher between 0.2-0.4 mm than RODSs and MPI-ESM-MR's results are overlap with RODSs.

3. Results

In this study, we tried to put forth the possibilities of future climate change for Turkey and its surroundings with the regional climate model RegCM4. RCP4.5 and RCP8.5 scenarios outputs of HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M Global Circulation Models have been used in the study. Projection's domain includes Turkey and its surrounding region with 20 km grid resolution. Using these outputs, temperature and precipitation projections that covering the period 2016-2099 have been produced for Turkey. Future projection period (2016-2099) is divided into three groups 2016-2040, 2041-2070 and 2071-2099 respectively. Seasonal mean values were obtained for these three periods. Differences between reference period (1971-2000) and future periods were calculated for the parameters of temperature and precipitation.

Temperature and Precipitation Projections According to RCP4.5 Scenario

Temperature and precipitation values were obtained from RCP4.5 scenario of HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M Global Circulation Models with using dynamic downscaling method. Then differences of temperature and precipitation were calculated between reference period (1971-2000) and future periods. Anomalies of temperature and precipitation are visualized as seasonally for all periods. In generally all of models show an increasing in temperature and a decrease in precipitation with different anomaly values and spatial patterns from now to until end of the century. (Figure 3.1 and 3.2).

In the first period (2016-2040), temperature anomalies are predicted to increase about 0.5-1.5oC for MPI-ESM-MR and GFDL-ESM2M, and about 1.5-3oC for HadGEM2-ES. HadGEM2-ES's anomaly values are higher than other two models. It would be an increase about 2-3oC in summer temperature, except northeast of Eastern Anatolia Region and east of Black Sea Region (Figure 3.1).

In the second period (2041-2070), according to temperature outputs of HadGEM2-ES it might be an increase about 2-3°C in spring and autumn temperatures and an increase up to 4°C in summer temperature. Generally, in MPI-ESM-MR and GFDL-ESM2M, anomalies are between 1-2°C throughout the country and over the seasons (Figure 3.1).

In the last period (2071-2099), it would be an increase about 2°C in winter temperature and 3°C in spring and autumn temperatures. It would be an increase up to 4°C in summer temperature in the Southeast Anatolia Region and coastal part of the Aegean Region. In MPI-ESM-MR and GFDL-ESM2M, anomalies are between 1-2°C throughout the country and over the seasons in generally and increasing up to 3°C in south and southwest part of Anatolia in summer season (Figure 3.1).

When looking at precipitation projections, according to HadGEM2-ES in the first period (2016-2040), it would be an increase about 10% - 40% in precipitation during the winter months in the coast part of the Aegean, Central Black Sea and East Anatolia Regions. Conversely, other two models show an increase up to 20% in precipitation in interior and north part of country and a decrease in the coast part of the Aegean. Unfortunately it is expected to decrease about 20% in the precipitation in the spring in a large part of the country. HadGEM2-ES and MPI-ESM-MR show similar pattern in spring and summer precipitation. GFDL-ESM2M shows generally an increase in most of the country in spring. In autumn, all models show different precipitation pattern (Figure 3.2).

In the second period (2041-2070), according to HadGEM2-ES and MPI-ESM-MR in generally, it would be a decrease about 20% in winter precipitation in East Anatolia, Southeast Anatolia and central and eastern parts of Mediterranean Region. It would be a decrease about 30% in precipitation except Eastern Black Sea coast according to GFDL-ESM2M in generally. In spring, it would be a decrease in interior part of Anatolia according to all models. According to all models it is expected that would be a decrease around 30% in precipitation in summer season in Eastern Anatolia where summer rainfall is important. It is expected to an increase up to 50% in Marmara Region according to both HadGEM2-ES and MPI-ESM-MR. In autumn, models show a decrease in generally throughout Turkey except coastal part of the Aegean Region (Figure 3.2).

In the last period (2071-2099), it would be an increase about 10% in precipitation especially along coastal line except south part of the Anatolia in winter. It would be a decrease about 20% in spring precipitation except coastal part of the Anatolia according to HadGEM2-ES and MPI-ESM-MR. It would be an increase about up to 40% along to country except south part of the Anatolia according to GFDL-ESM2M. In summer season precipitation it would be a decrease up to 60% except coastal part of the Aegean, Marmara and Black Sea Regions in all models. It would be a decrease in autumn precipitation throughout the country except west part and some small part of interior of country in MPI-ESM-MR and GFDL-ESM2M in generally (Figure 3.2).

Temperature and Precipitation Projections According to RCP8.5 Scenario

Temperature and precipitation values were obtained from RCP8.5 scenario of HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M global circulation model with dynamic downscaling method for project domain. Then differences between reference period (1971-2000) and these periods were calculated for temperature and precipitation. Anomalies of temperature and precipitation are visualized as seasonally for all periods. In generally all of models show an increasing in temperature and a decrease in precipitation with different anomaly values and spatial patterns from now to until the end of the century. (Figure 3.3 and 3.4).

In the first period (2016-2040), it would be an increase about 3°C especially in spring and summer temperatures in HadGEM2-ES and about 0.5-2°C in MPI-ESM-MR and GFDL-ESM2M (Figure 3.3).

In the second period (2041-2070), it would be an increase about 2-3°C in the winter temperature, about 3-4°C in autumn and spring temperatures and about 5°C in summer temperature in HadGEM2-ES. It would be an increase about 1-2°C in the winter temperature, about 1.5-3°C in autumn and spring temperatures and about 5°C in summer temperature in MPI-ESM-MR and GFDL-ESM2M in generally. (Figure 3.3).

According to HadGEM2-ES in the last period (2071-2099), it would be an increase about 3-4°C in west of Trabzon and Mersin line, about 4-5°C in east of Trabzon and Mersin line in winter temperature. With similar pattern in MPI-ESM-MR and GFDL-ESM2M it is expected to an increase about 2-4°C in the winter, 2-5°C in spring temperature. It would be an increase about 6°C in spring and autumn temperatures especially in South East Anatolia Region in HadGEM2-ES. It would be an increase exceeding 6°C throughout the country in HadGEM2-ES and up to 6°C partly in MPI-ESM-MR and GFDL-ESM2M (Figure 3.3).

In the first period (2016-2040), it would be an increase in precipitation during the winter months except west part of the Marmara, east part of the Mediterranean, southeast part of the Central Anatolia and west part of the Southeast Anatolia Regions in HadGEM2-ES. It would be an increase in precipitation in winter in north part of Anatolia in MPI-ESM-MR and GFDL-ESM2M. It would be a decrease in spring precipitation in west of Mersin-Ordu line in HadGEM2-ES and GFDL-ESM2M and in northeast part and Marmara Region in MPI-ESM-MR. It would be an increase about 40% in summer precipitation except west part of the Mediterranean Region in HadGEM2-ES. It would be a decrease in summer precipitation throughout the country in MPI-ESM-MR and GFDL-ESM2M except some local part. It would be a decrease in autumn precipitation throughout the country in HadGEM2-ES and GFDL-ESM2M. (Figure 3.4).

In the second period (2041-2070), it would be an increase in precipitation during the winter months except south part of Anatolia in HadGEM2-ES. It would be an increase in precipitation in winter in north part of Anatolia in MPI-ESM-MR and GFDL-ESM2M. It would be a decrease in spring season except west part of the Aegean, west and east part of the Black Sea and northern part of East Anatolian Regions in HadGEM2-ES and GFDL-ESM2M. It would be a decrease in spring precipitation throughout country in MPI-ESM-MR. It would be a decrease about 50% in summer precipitation throughout the country except west and east part of the Black Sea, coastal part of the Aegean and the Marmara Regions in HadGEM2-ES. It would be a decrease in summer precipitation throughout the country in MPI-ESM-MR and GFDL-ESM2M except some local part. In the autumn precipitation, it would be a decrease throughout the country in generally in HadGEM2-ES and GFDL-ESM2M and except northwest costal and southeast part of Anatolia in MPI-ESM-MR (Figure 3.4).

In the last period (2071-2099), it would be an increase in precipitation during the winter months except south part of Anatolia in HadGEM2-ES and MPI-ESM-MR and eastern part of Black Sea Region in GFDL-ESM2M. It would be a decrease about 20% in spring precipitation except coastal part of the Aegean Region, west and east part of Black Sea Region and northern part of East Anatolia Region in HadGEM2-ES and GFDL-ESM2M and a decrease in throughout the country in MPI-ESM-MR. It would be a decrease in summer precipitation except coastal part of the Aegean, Marmara and Black Sea Regions in HadGEM2-ES. It would be a decrease in summer precipitation throughout the country in MPI-ESM-MR and GFDL-ESM2M in generally. Generally in autumn it would be generally a decrease up to 50% throughout the country in all models (Figure 3.4).

Considering to increasing in temperature and precipitation together in both RCP scenarios: The increase in temperature may cause turn the precipitation type from snow to rain during the winter. Furthermore, it could be caused to early snow melting in spring. The reason of increased precipitation amount would be much more evaporation than normal which caused by increasing temperature in spring and summer season in coastal area. When it is considered with convective characteristic of spring and summer precipitation, it could be caused extreme precipitation events in mentioned regions. And also increasing in temperature could be caused to extreme weather events such as storm, hail and waterspout.

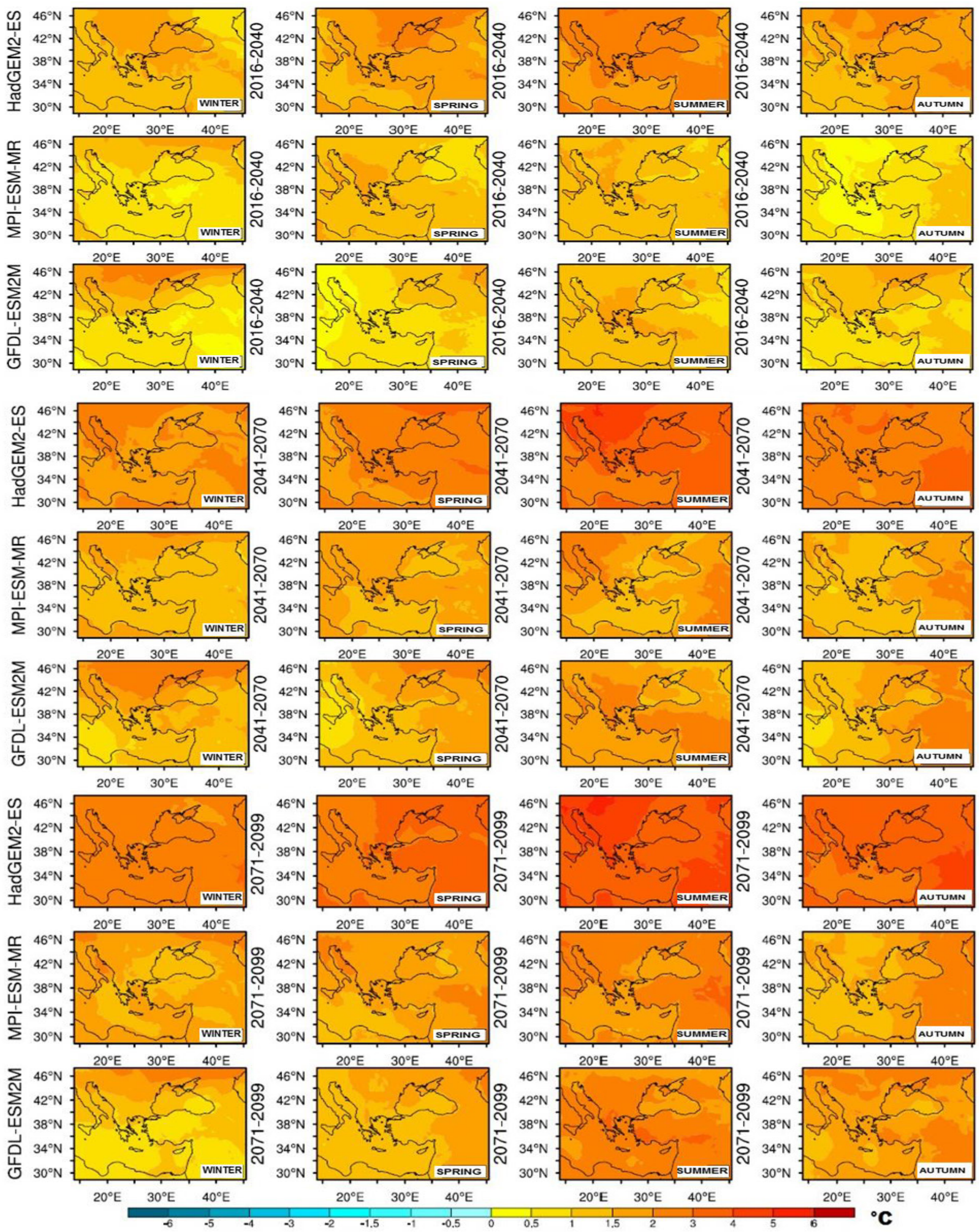

Figure 3.1. Temperature projections according to RCP4.5

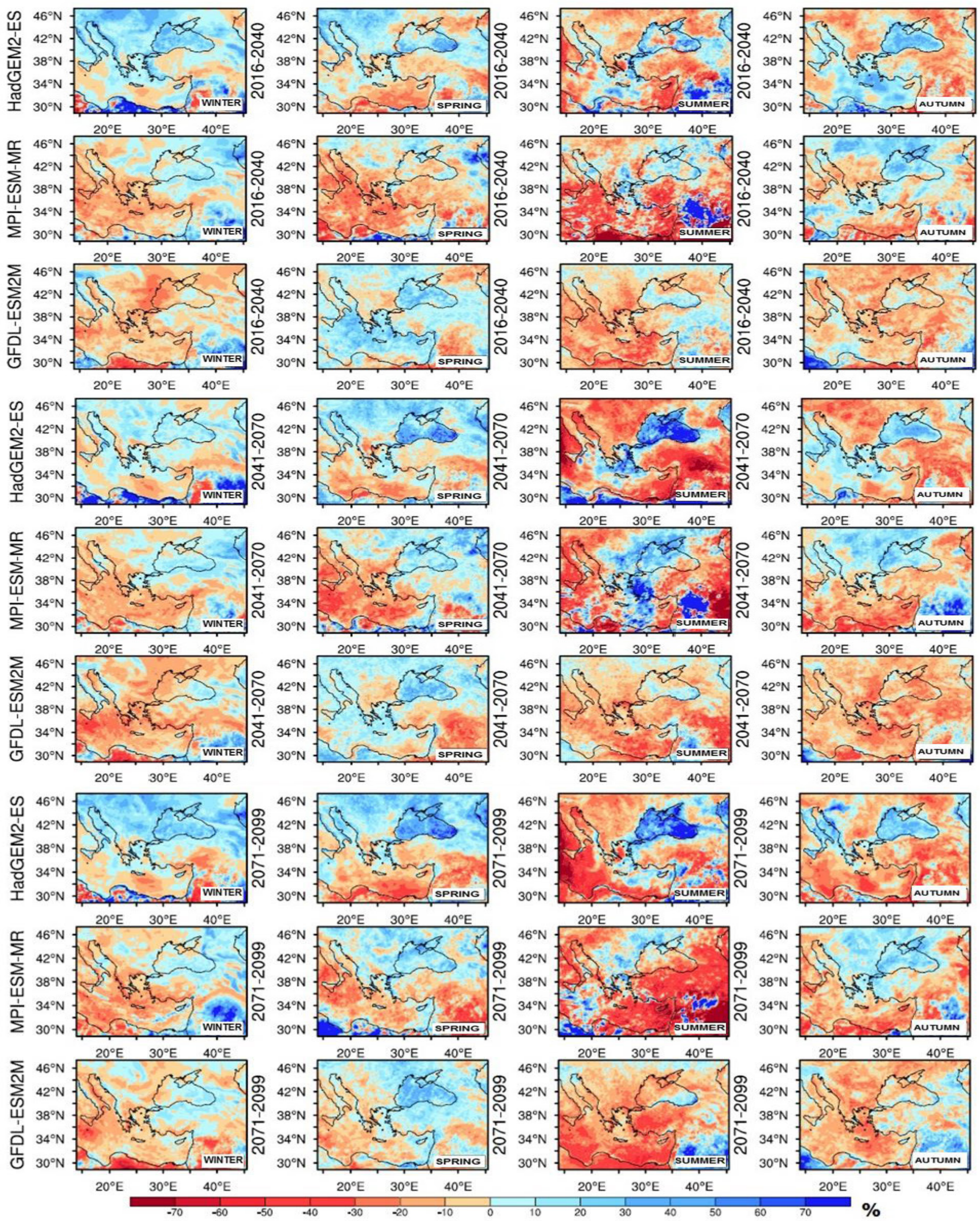

Figure 3.2. Precipitation projections according to RCP4.5

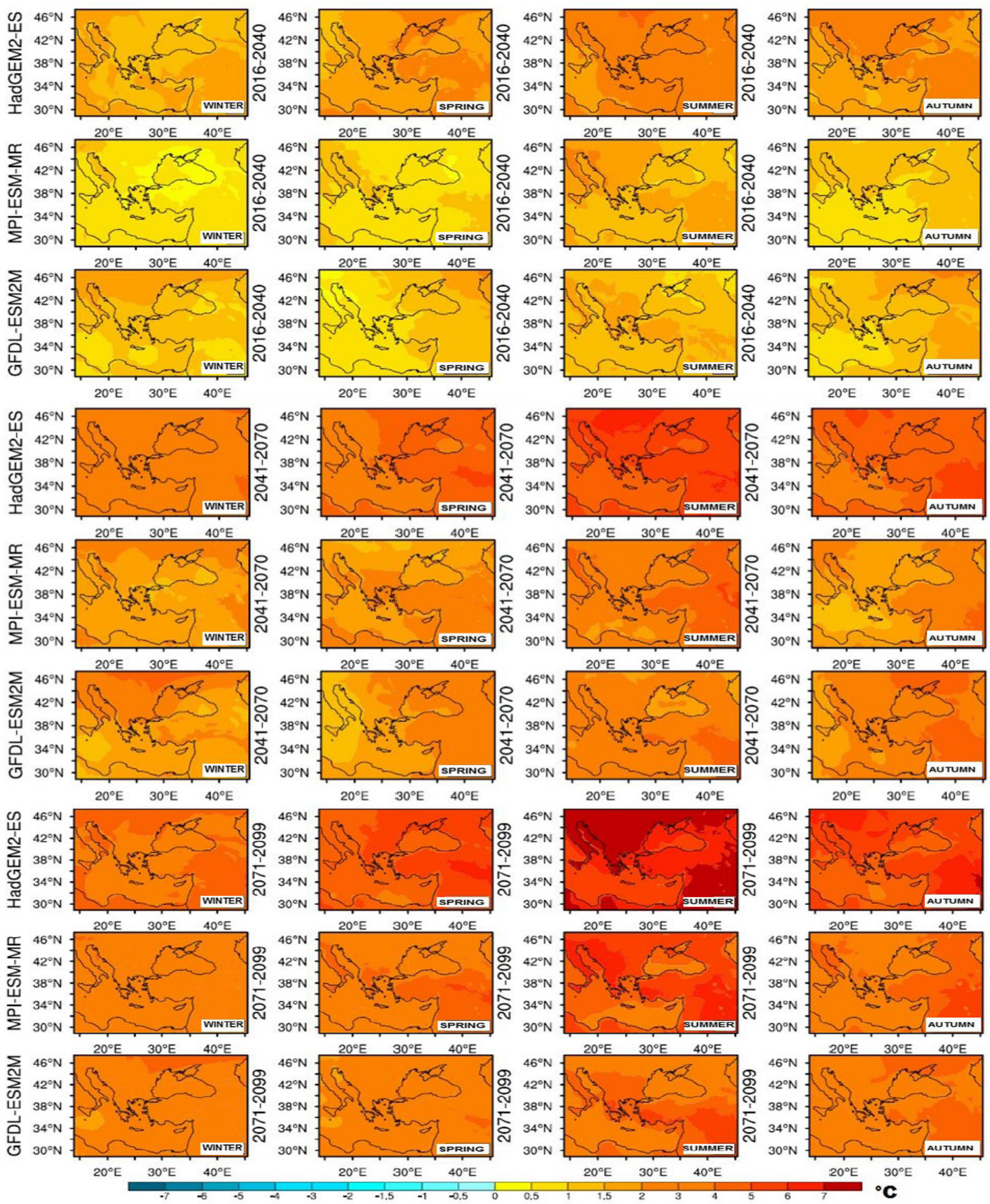

Figure 3.3. Temperature projections according to RCP8.5

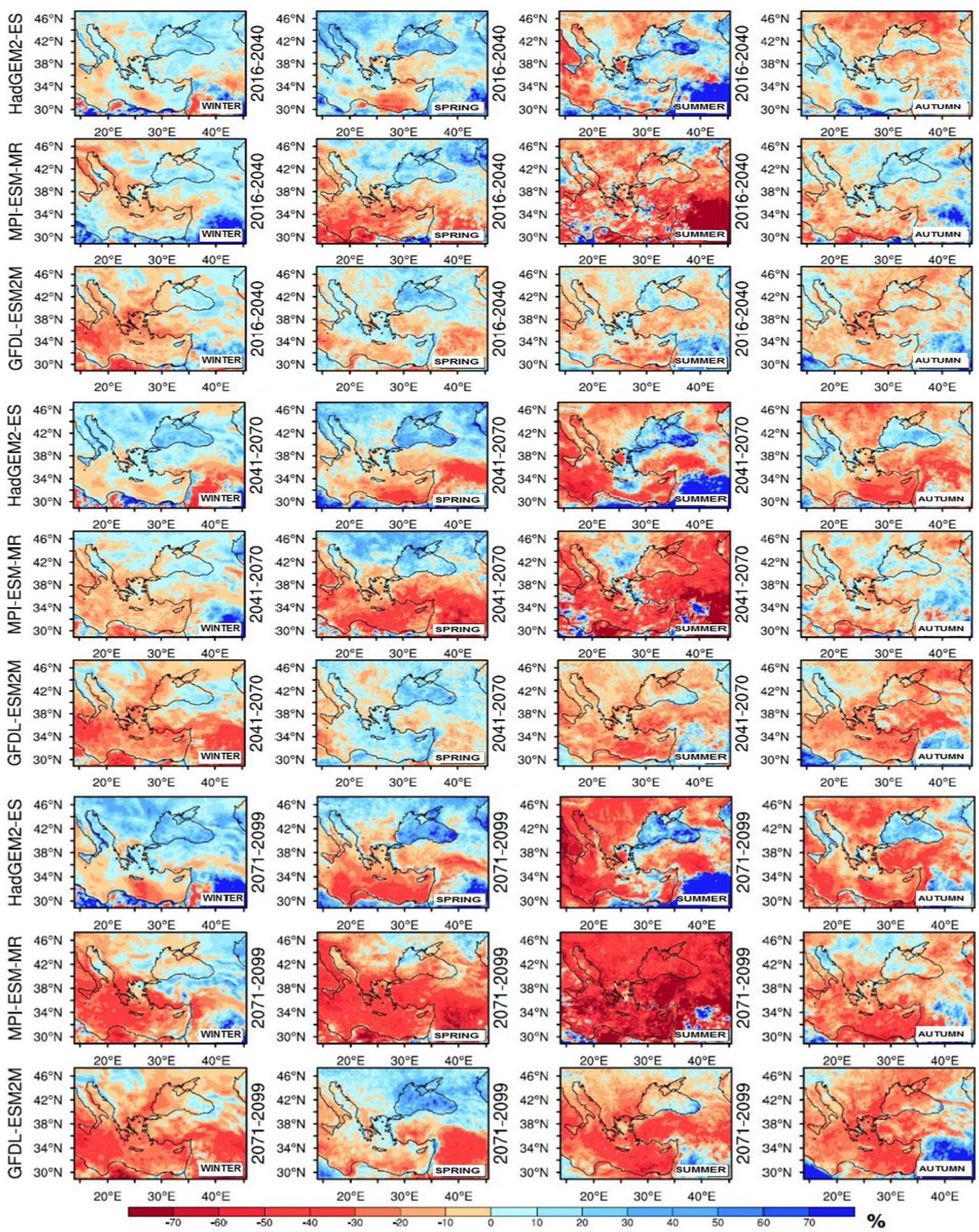

Figure 3.4. Precipitation projections according to RCP8.5

4. Discussion and Conclusion

“Climate Projections with New Scenarios for Turkey” is a project which is made by an official institution with its own resources, personnel, new models and scenarios for the first time in Turkey. In this context, RCP4.5 and RCP8.5 scenarios (2016-2099) of three different models data were downscaled in this project. Project studies are going on with different type climate products. According to obtained results based on through three GCMs (HadGEM2-ES, MPI-ESM-MR and GFDL-ESM2M) and two scenarios (RCP4.5 and RCP8.5), the average annual temperature rising for 2016-2040 in Turkey is expected to vary between 1°C - 2°C. In the period 2041–2070, the increase in the surface temperature is expected to vary between 1.5°C - 4°C. At the last period (2071-2099) the average annual temperature rising is expected to vary between 1.5°C - 5°C. In some scenarios, it is projected that the temperature increase would be reached to 3°C in winter and up to 6°C in summer in the last 30 years of the 21st century (2071–2099). The increase would be higher in winter for the eastern and inner parts of Turkey, while it would be higher in summer for south-eastern Turkey and the coastal regions except Black Sea Region.

Table 4.1.

Summarise table of temperature projections (Temperature anomaly (°C) ranges)

Models	Periods	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
		Winter		Spring		Summer		Autumn	
HadGEM2-ES	2016-2040	1,5 - 2	0 - 1	2 - 3	1 - 2	2 - 3	1,5 - 2	2 - 3	1 - 2
	2041-2070	1,5 - 2	1,5 - 2	2 - 3	2 - 3	2 - 3	3 - 4	2 - 3	2 - 3
	2071-2099	2 - 3	2 - 3	2 - 3	3 - 5	3 - 4	5 - 7	3 - 4	4 - 6
MPI-ESM-MR	2016-2040	0 - 1	0 - 1	0 - 1,5	1 - 1,5	1 - 2	1,5 - 2	0 - 1,5	1 - 1,5
	2041-2070	1,5 - 2	1 - 2	1 - 2	2 - 3	1 - 2	2 - 4	1 - 2	1,5 - 2
	2071-2099	1 - 1,5	2 - 3	1,5 - 2	3 - 5	1,5 - 3	4 - 6	1 - 2	3 - 5
GFDL-ESM2M	2016-2040	0,5 - 1	0,5 - 1	0,5 - 1	0,5 - 1	0,5 - 1,5	1 - 2	0,5 - 1	1 - 1,5
	2041-2070	1 - 1,5	1,5 - 2	1 - 1,5	1,5 - 2	1,5 - 2	2 - 3	1 - 2	2 - 3
	2071-2099	0,5 - 1	1,5 - 2	1 - 1,5	2 - 4	1,5 - 3	3 - 5	1 - 2	3 - 4

Table 4.2.

Summarise table of precipitation projections (Rainfall change (%) ranges)

Models	Periods	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
		Winter		Spring		Summer		Autumn	
HadGEM2-ES	2016-2040	-30, +40	-20, +30	-20, +40	-30, +30	-40, +40	-40, +50	-30, +30	-40, +40
	2041-2070	-20, +30	-30, +30	-30, +30	-40, +40	-60,+60	-60, +60	-40, +40	-40,+40
	2071-2099	-40, +40	-30, +40	-40, +40	-40, +40	-50, +50	-60, +60	-50, +40	-50, +40
MPI-ESM-MR	2016-2040	-30, +30	-30, +30	-40, +30	-40, +40	-50, +50	-60, +50	-40, +30	-40, +40
	2041-2070	-30, +30	-30, +30	-40, +40	-40, +30	-50, +50	-60, +50	-40, +30	-40, +40
	2071-2099	-30, +30	-40, +50	-40, +50	-50, +30	-70, +40	-60, +30	-40, +40	-40, +40
GFDL-ESM2M	2016-2040	-30, +20	-40, +40	-30, +30	-30, +20	-40, +30	-30, +40	-40, +20	-40, +30
	2041-2070	-40, +30	-40, +30	-40, +30	-30, +40	-40, +50	-40, +30	-40, +20	-40, +20
	2071-2099	-30, +30	-40, +40	-30, +30	-40, +40	-40, +40	-50, +30	-40, +30	-40, +40

In context of climate change, serious risks in river basins of Turkey is foreseen to occur due to possible new climate conditions in the future. One of these issues is the trend of decreasing in the amount of rainfall throughout Turkey particularly in the southern and inner parts of Anatolia and especially in Tigris–Euphrates Basin. The second issue is increasing in temperature especially in winter season. The increase in temperature may cause to turn the precipitation type from snow to rain during the winter. Snow is important water source which is supplying water along to year. And also temperature increases could be cause early snow melting in spring. Bozkurt et. al. (2013) and Bozkurt et. al. (2015) also concluded early melting of snow and the temporal shifts in snowmelt runoff in the Euphrates-Tigris Basin. The third issue is increasing in amount of precipitation in west and north coastal part of Anatolia in summer season. This increase could be caused extreme precipitation events in mentioned regions. It is also concluded that in TECCWRP (2016) possibilities of occurring extreme precipitation and floods could be increased in Marmara and Black Sea regions in period of 2015-2100. This extreme precipitation could be cause to flood as seen as in recent years. And also increasing in temperature could be cause to increase the number and severity of extreme weather events such as storm, hail and waterspout. There have been an increasing trend in Turkey's observed temperature and similarly in extreme weather events number since 1997. SCT2015 reported that heavy rain/floods (26%), wind storm (25%), hail (12%), heat wave (11%), and lightning (4%) were recorded as the most observed disaster respectively in 2015. Although rare, 2 dust storm and 4 tornados also occurred in 2015.

Climate change prediction studies provides the main data input to sectors to make plans for adaptation, mitigation and prevention efforts against climate change issue. Under climate change context, high resolution data sets of GCM's is important to prepare a realistic adaptation plan in sectors. Using of these data will contribute to improve the accuracy and success of sectoral planning in adaptation, mitigation and prevention activities.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Türkiye için İklim Değişikliği Projeksiyonları: Üç Model ve İki Senaryo

Senaryo, geleceğin hayali olarak canlandırılması veya alternatif gelecek durumların tasvir edilmesidir. Buna rağmen senaryo, tahmin ile karıştırılmaktadır. Senaryo geleceğin tahmini değil, olması muhtemel alternatif durumların ortaya konmasıdır. Senaryolar, iklim gibi yüksek belirsizliğe sahip karmaşık sistemlerin gelecekteki muhtemel gelişiminin anlaşılması ve değerlendirilmesinde önemli bir rol oynamaktadır. Bunu bize sağlayan ise model çalışmaları ve bu çalışmalar sonucunda elde edilen iklim projeksiyonlarıdır. Bu çalışmada, ülkemizi de içine alan bölgede, bölgesel iklim modeli çalışması ile geleceğe ait iklim değişikliği olasılıkları ortaya konmaya çalışılmıştır. Temsili Konsantrasyon Yolları (RCPs) adı, esas amaçları atmosferik Sera Gazları (GHG) konsantrasyonlarının zaman bağımlı projeksiyonları sağladığını vurgulayan rotalar olmasını temsil etmektedir. Bu çalışmada, Türkiye'yi içine alan bir bölge için gelecekteki iklim değişikliğinin muhtemel sonuçları ortaya konmaya çalışılmıştır. HadGEM2-ES,

MPI-ESM-MR ve GFDL-ESM2M Küresel Dolaşım Modellerinin RCP4.5 ve RCP8.5 senaryolarının sonuçları kullanılmıştır. Bu çıktılardan, Türkiye için sıcaklık ve yağış projeksiyonları; RegCM4.3.4 bölgesel iklim modeli ile dinamik ölçek küçültme yöntemi kullanılarak, 20 km çözünürlükte ve 2016-2099 yıllarını kapsayan bir dönem için üretilmiştir.

İklimin insan hayatındaki önemi, iklimin sosyal ve ekonomik hayatı olumlu ya da olumsuz etkileri ile nasıl etkilediği ile ilgilidir. İnsanların daha iyi koşullar altında, daha sağlıklı bir şekilde yaşamlarını sürdürebilmeleri için, gerek ulusal gerekse uluslararası birçok kurum ve kuruluş, organizasyon, merkezi ve yerel yönetimler ile sivil toplum örgütleri iklimde meydana gelebilecek değişimler ve bu değişimlerin etkilerinin doğru saptanabilmesi için farklı şekillerde çaba sarf etmektedirler.

Bu çabalardan en önemlisi modelleme çalışmalarıdır. Teknolojinin gelişmesi ile birlikte ortam koşullarını ifade eden değişkenler, daha detaylı bir şekilde modellerde yer alabilmektedir. 1970'li yıllardan itibaren bilgisayarların bilimsel amaçlı kullanımlarının yaygınlaşması ile iklim modelleri de kullanılmaya başlamıştır. Çalışılan ilk modellerde sadece atmosfer ve atmosferde gözlenen parametrelere göre çalışmalar yapılmış olup gelişmelere paralel olarak kara yüzeyi, okyanuslar, deniz buzları, sülfat, aerosoller, karbon çevrimi, dinamik bitki örtüsü ve atmosferin kimyası gibi etmenler modellere girdi teşkil eden parametreler olmuştur.

Teknolojinin gelişimi ile daha da küçülen Dünyamızda iklim değişikliği hakkında yapılan çalışmalar, 1990'lı yılardan sonra IPCC (Uluslararası İklim değişikliği Paneli) adı altında oluşturulan birliktelik ve oluşumun yönlendirmeleri ile daha anlamlı bir çaba içine girmiştir. Oluşan bu birlikteliğin çalışma sonuçları belli dönemlerle gerçekleştirilmiştir. IPCC'de yüzlerce bilim adamının katkıda bulunduğu en son 4. Değerlendirme Raporu'nda, önce 40 farklı senaryo gözden geçirilmiş ve bunların içinden 7 senaryo belirlenmiştir. İklim modelleri ayrıntılı bir şekilde ortam şartlarını, beklenen değişimlere göre yeniden kurgulama imkânı vermektedir. Bu bağlamda, 2007'de yayınlanan IPCC'nin 4. Değerlendirme Raporu'ndan bu tarafa, değişen arazi kullanımı/değişimi, sera gazı emisyonları ve konsantrasyonları, aerosol konsantrasyonu bilgileri ile gelişen teknolojik altyapı ve modelleme teknikleri yeni bir değerlendirme raporu hazırlanması ihtiyacını ortaya çıkarmıştır. Bu kapsamda IPCC yeni senaryolar ile 5. Değerlendirme Raporunu hazırlamış ve dünya gündemine sunmuştur.

İklim, geniş zaman dilimlerinde ve daha büyük alanlarda tecrübe edilmiş ortalama hava durumudur. İklim normalleri iklim verilerinden hesaplanan ardışık otuz yılın ortalamasıdır. İklim normallerini kullanmak küresel değerlendirme ve iklim izleme çalışmalarını hazırlamak için standart temel oluşturan çok önemli araçlardır. İklim referans dönemleri; 1961-1990, 1971-2000 ve 1981-2010 iklim normalleri olarak; uluslararası, ulusal ve bölgesel temelli iklim izleme, iklim trendi iklim değişikliği ve iklim modeli çalışmalarında; bilim adamları, ulusal iklim servisleri, uluslararası enstitüler ve organizasyonlar tarafından kullanılmaktadır.

"Türkiye için İklim Değişikliği Projeksiyonları" projesi Türkiye'de ilk kez yeni model ve senaryolar ile bir kamu kurumu tarafından kendi kaynakları ve personeli kullanılarak yapılmıştır. Bu bağlamda, üç farklı küresel modelin RCP4.5 ve RCP8.5 senaryolarının (2016-2099) ölçek küçültme çalışmaları yapılmıştır. Proje çalışmaları farklı iklim ürünleri çalışmaları ile devam etmektedir. Üç Küresel Dolaşım Modeli (GCMs; HadGEM2-ES, MPI-ESM-MR ve GFDL-ESM2M) ve iki senaryodan (RCP4.5 ve RCP8.5) elde edilen sonuçlara göre Türkiye'de yıllık ortalama sıcaklık artışının; 2016-2040 dönemi için 1°C - 2°C arasında; 2041–2070 dönemi için 1.5°C - 4°C arasında ve son dönem olan 2071-2099 dönemi 1.5°C - 5°C arasında olması öngörülmektedir. Bazı senaryolarda 21 yy. son otuz yılında (2071–2100) sıcaklık artışının kış mevsiminde 3°C ve yaz mevsiminde 8°C'ye ulaşması da öngörülmektedir. Yağışlarda; tüm dönemlerde kış mevsimi için ülke genelinde yağış miktarında artışlar, ilkbahar mevsiminde tüm dönemlerde ülkenin sahil ve kuzeydoğu kesimleri haricinde yağış miktarında azalışlar, yaz mevsiminde tüm dönemlerde ülkenin batı sahilleri ve kuzeydoğu bölümleri haricinde yağış miktarında azalışlar ve sonbahar mevsiminde genel olarak yağış miktarında bir azalma öngörülmektedir. Her ne kadar projeksiyon dönemi boyunca (2016-2099) yağış miktarında düzenli bir artış ve azalış eğilimi olmasa da, yağış rejiminin düzensizliği dikkat çekicidir.

İklim değişikliği bağlamında, yeni iklim şartlarında Türkiye nehir havzalarında ciddi risklerin oluşması öngörülmektedir. Bunlardan bir tanesi, özellikle Fırat-Dicle havzası olmak üzere, Anadolu'nun iç kesimleri ve güneyindeki havzalarda yağış miktarındaki azalıştır. İkincisi ise artan sıcaklıkların yağış cinsi değişikliklerine neden olması ve kış mevsimindeki yağan karın yağmura dönüşmesidir. Kar yıl boyunca su sağlayan önemli bir kaynaktır. Ayrıca artan sıcaklıklar karın baharda erken erimesine neden olacaktır. Üçüncü sorun ise, özellikle yaz mevsiminde ve özellikle Anadolu'nun batı ve kuzey sahil kesimlerinde aşırı yağışların oluşma riskidir. Bu aşırı yağışlar son yıllarda olduğu gibi sellere neden olabileceklerdir. Ayrıca artan sıcaklıklar; fırtına, dolu ve hortum gibi aşırı hava olaylarının sayısında ve şiddetinde artışa yol açabilecektir.

İklim değişikliği öngörü çalışmaları bütün sektörlere uyum, önleme ve azaltma çabalarında yani paydaşların gelecek planlarında -ki bunlar iklim ve iklim model çıktıları temelli yapılmalıdır- esas veri ve temel altlığı sağlamaktadır. İklim değişikliği çalışmaları kapsamında farklı iklim modellerinin senaryoları, Türkiye ve çevresi için ölçek küçültme yöntemi ile üretilmelidir. Böylelikle gelecekte muhtemel olması öngörülen iklim değişikliği ihtimallerini daha detaylı görmek mümkün olacaktır. Yüksek çözünürlüklü iklim model projeksiyonları erişilebilir olduğunda ve sektörler bu verileri uyum, önleme ve azaltma planlarında kullandıklarında, çalışmalarının doğruluğu ve başarısı da artacaktır.

Sectoral Impact Analysis Methodology within the Scope of Climate Change Adaptation

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Abstract

The reality that climate change inevitably affects our world at present is taken into consideration and adaptation to climate change studies are becoming more pronounced at international scale. Although there are some studies related to the determination of adaptation measures in our country and in the world, there is still no common methodology for adaptation on a measurable basis. In this study, a new approach developed under the "Effects of Climate Change on Water Resources Project" was used to execute a sectorial vulnerability analysis. Sectorial vulnerability analyses have great importance in terms of determining the most vulnerable sector to climate change and of the related policy.

In this study, the methodology of sectorial vulnerability analysis is explained in water intended for human consumption sector for 2060s and at the scale of Büyük Menderes River Basin. The results showed that the impact level was expected as "medium" for the water intended for human consumption sector.

Key words: *climate change, sectorial impact, vulnerability analysis.*

1. Introduction

Turkey located at the Mediterranean Basin is a vulnerable region regarding adverse effects of climate change. Thus, adaptation to climate change is mandatory to minimize the corresponding negative effects. Climate change is an irreversible phenomenon and hence, adaptation measures should be developed and integrated to the related sectors. Water resources being largely and considerably exposed to negative effects of climate change and many sectors relying on water will indirectly be affected from the probable results. Because of that reason, climate change adaptation planning and execution in water management have a great importance and priority in Turkey (TUBITAK MAM, 2010).

Adaptation to climate change is the overall actions and measures taken by the societies and ecosystems to cope with the varying climatic conditions. In other words, adaptation to climate change is the process of strengthening, developing and executing the strategies to struggle with the effects of climate events (risks), and to manage them (UNFCC Publication, 2007).

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Within the scope of coping with the climate change, Project on ‘The Effects of Climate Change on the Water Resources’ has been executed by the General Directorate of Water Management under the Ministry of Forestry and Water Affairs. It started in December 2013 and lasted almost 3 years. The Project aimed to make projections regarding the expected conditions of the surface and groundwater resources of the all river basins in the country until 2100 by means of climate change projections, to determine surface and groundwater potential specific for the each river basin, and to estimate water budget changes in the basins that will suffer from the effects of climate change. Moreover, sectorial impact analysis for 4 essential sectors namely water intended for human consumption, agriculture, industry, and ecosystem have been executed in 3 pilot river basins in terms of the effects of climate change on water resources, and corresponding measures have been proposed as adaptation activities (SYGM 20016).

Climate change projections have been obtained with a resolution of 10 km with RegCM regional model by using the data sets of HadGEM2-ES, MPI-ESM-MR and CNRM-CM5 earth system models, and the findings were used to run the hydrologic and hydraulic models in all the 25 river basins of Turkey. It is seen that while temperatures exert a constant tendency to increase, precipitation anomalies were sometimes positive, but sometimes negative in the studies. In the projections executed for all basins of Turkey, a decrease was generally observed as expected. After obtaining the results, water potentials were determined for 25 river basins by running the hydrologic and hydraulic models with 3 models and 2 scenarios resulting in totally 6 conditions (SYGM 2016).

A vulnerability analysis methodology has been developed for the 4 main sectors (water intended for human consumption, agriculture, industry and ecosystem) in the 3 pilot river basins (Büyük Menderes, Meriç-Ergene and Ceyhan River Basins) to perform sectorial impact levels based on the outcomes of the project. The methodology in question has been specifically developed for the country in line with the general flow diagram of the impact analysis mentioned in the 4th and 5th Reports of the Intergovernmental Panel on Climate Change (IPCC AR4 and AR5). Similarly, the terminologies used in these reports are also kept on.

Sectorial Impact Analysis

Impact should be determined with respect to climate change adaptation. It is the indication of the impact level of a system from climate and adverse effects of climate change including extreme climatic conditions and that to what extent it has been affected and not been able to overcome.

Definitions used in the developed methodology

Intergovernmental Panel on Climate Change defines the climate change effect as a function of 3 main elements (IPCC AR5);

- The types and the magnitude of exposure to climate change,
- Vulnerability of the systems at any level,
- Resilience and adaptation capacity of the system.

These elements can be better explained below.

Impact (E) is the observation level of a system exposed to climate change and not be able to overcome its adverse effects, and it also includes the climate variability and the extreme weather conditions. Impact is a function of a system's exposure to climate change and its characteristics, magnitude and speed, vulnerability and adaptation capacity.

Exposure (M) indicates the changes in the examined elements of the system based on the climate variability or changing speed in average climatic conditions, including extreme weather events.

Sensitivity (D) is positive or negative impact level of a system caused by climate variability or change. This impact may be direct (such as mean temperature, a change in a crop yield caused by temperature changes) or indirect (such as damages caused by floods due to sea level rise on the coasts).

Adaptation Capacity (UK) means the ability of a system to climate change, variability and possible extreme and average damage levels, that of having the opportunities or resilience. The overall methodology of the sectorial impact analysis is indicated in Figure 1.1.

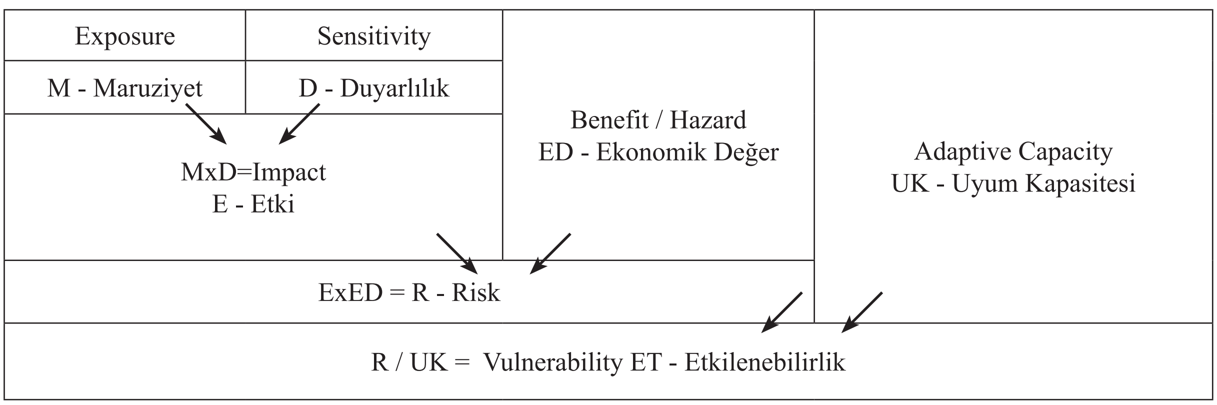

Figure 1.1. Sectorial Impact Methodology

The terms used in the methodology are explained below.

• Exposure (M): It is the only variable in the system and is calculated according to the model results, which are obtained from "the Climate Change Impacts on Water Resources Project executed by the Ministry of Forestry and Water Affairs", indicating the 50% possibility in every 10-year-period. That value is calculated for RCP 4.5 and RCP 8.5 scenarios, respectively.

• Sensitivity (D): It is calculated for every sector (water intended for human consumption, agriculture, tourism and ecosystem) in a way to indicate the current situation. The data of year 2014 is used.

• Impact (E): Exposure (M) x Sensitivity (D)

• Economic Value (ED): It is calculated for every sector (water intended for human consumption, agriculture, tourism and ecosystem) in a way to indicate the current situation. The data of year 2014 is used.

• Risk (R): Impact (E) x Economic Value (ED)

• Adaptation Capacity (UK): It is calculated for every sector (water intended for human consumption, agriculture, tourism and ecosystem) in a way to indicate the current situation. The data of year 2014 is used.

• Vulnerability (ET): Risk (R) / Adaptation Capacity (UK)

After calculation the elements above mentioned based on expert judgements, indices were determined from 1 to 4 in order to simplify the vulnerability projections, which are defined under the "Method".

2. Method

The methodology used for analysing vulnerability at each sectorial basis comprise calculation of the corresponding sensitivity, economic value and adaptation capacity indexes. This calculation is explained below for the example of water intended for human consumption sector in the Büyük Menderes River Basin.

A 5th sector is included to the analysis in each pilot river basins with the contemplation of evaluating one more sensitive sector based on the expert judgements and interviews between the stakeholders, and this last sector varied according to the basins. In Büyük Menderes Basin, the 5th sector is tourism. An assessment systematic has been constituted in order to quantify the impact level of 5 sectors (water intended for human consumption, agriculture, tourism and ecosystem) to be analysed. This systematic gives result in a way to evaluate the impact level of every sector in 4 categories as shown in Table 2.1.

Table 2.1.
Sectorial Impact Degree

Impact Level	Impact Score
Low	1
Medium	2
High	3
Very High	4

Sensitivity, impact, economic value, risks and adaptation capacity values are calculated according to the current situation of the river basins. All studies are carried out on the basis of indexes formed by taking into account the related sectors. This study was executed for all 5 sectors. However, in this paper only the water intended for human consumption will be referred as an example to show the outlines of the methodology developed. The sectorial based impact levels of the basin at the end of the studies are given in Table 2.2.

As it is shown in the Figure 1.1, the numeralisation started with the exposure and sensitivity levels according to the expert judgement. Those two values were multiplied to reach the value of Impact. Then, impact were multiplied with Benefit/Hazard value to have the risk level. After dividing the risk level by Adaptive Capacity, which was also determined by the expert judgement, Vulnerability was found. Those numbers were classified to get impact scores shown in Table 2.2 to ease the evaluation impact analysis.

Table 2.2.

Sectorial Impact Levels of the River Basins

Vulnerability Range	Impact Score	Impact Level
1 - 3	1	Low
3 - 5	2	Medium
6 - 9	3	High
9<	4	Very High

3. Results

An Example: Water Intended for Human Consumption Sector

Four different indices are determined for the sensitivity parameter of the water intended for human consumption sector specific to Büyük Menderes River Basin by taking into consideration the River Basin Protection Action Plans (SYGM, 2016; TUBİTAK MAM, 2004 and 2010). The indexes and impact ratios are given in Table 3.1.

Table 3.1.

Sensitivity Indices for water intended for Human Consumption Sector

Index	Index Definitions	Impact Ratio
Index I	Sensitivity of Humans to Climate Change	60%
Index II	Population Density	20%
Index III	Climate Index (t25)	10%
Index IV	Climate Index (CDD)	10%

• Index I - Sensitivity of Humans to Climate Change: It is foreseen that the quantity of water intended for human consumption would be differentiated depending on climate change, but the sensitivity of humans or other living species in this aspect would be very high. Therefore, it is suggested that the humans have the same high sensitivity regardless of any classification.

• Index II – Population Density: Population density is calculated for every river basin in Turkey, grading being made for each of the river basins based on population density.

• Index III – Climate Index (t25): The climate index value indicating the number of the summer days above 25°C is calculated by averaging 3 models for every river basin and then graded.

• Index IV – Climate Index (CDD): The climate index value indicating the number of consecutive dry days is calculated by averaging 3 models for every river basin and then graded.

The weighted index value for the sensitivity parameter for the water intended for human consumption sector is given in Table 3.2.

Table 3.2.

Weighted Index Value for Sensitivity of the Sector "Water Intended for Human Consumption"

Index	Index Definitions	Index Value	Impact Ratio	Weighted Index Value
I	Sensitivity of Humans to Climate Change	4	60%	2.40
II	Population Density	2	20%	0.40
III	Climate Index (t25)	2	10%	0.2
IV	Climate Index (CDD)	2	10%	0.2
			Overall Sensitivity	3.20

Economic value (ED)

Two different indices for economic value parameter are determined for water intended for human consumption sector as are given in Table 3.3.

Table 3.3.

Economic Value Indices for the Sector "Water Intended for Human Consumption"

Index	Index Definitions	Impact Ratio
I	Equivalent population	70%
II	Ratio of water loss due to leakage and/or technical failure	30%

• Index I – Equivalent Population: It indicates permanent population together with animals like cows and cattle, sheep and goats. Equivalent population values of year 2014 are used.

• Index II – Ratio of Water Loss due to leakage and/or technical failure: It indicates an average seepage loss value that is a ratio known for the cities in the river basin. The corresponding value for the basin is determined in line with the ratio of the cities in the basin.

The weighted index value for the economic value parameter for water intended for human consumption sector is given in Table 3.4.

Table 3.4.

Weighted Index Value for the Economic Value of the Sector "Water Intended for Human Consumption"

Index	Index Definitions	Index Value	Impact Ratio	Weighted Index Value
I	Equivalent Population	2	70%	1.40
II	Ratio of water loss due to leakage and/or technical failure	2	30%	0.60
III	Overall Economic Value	2.00	10%	0.2
IV	Climate Index (CDD)	2	10%	0.2
			Overall Sensitivity	3.20

Adaptation capacity (UK)

Two different indices for adaptation capacity parameter are determined for water intended for human consumption sector as given in Table 3.5.

Table 3.5.
Adaptation Capacity Indices for water intended for Human Consumption Sector

Index	Index Definitions	Impact Ratio
I	Technical Feasibility	50%
II	Socio-Economic Development	25%
III	Financial Development	25%

• Index I – Technical Feasibility: It refers to the availability of applicable methodologies to reduce the seepage loss ratio.

• Index II – Socio-Economic Development: It is calculated by multiplying development indices of the cities with the related population ratios in the basins.

• Index III – Financial Development: It is calculated by multiplying financial development indices of the cities with the related population ratios in the basins.

Table 3.6.
Weighted Index Value for Adaptation Capacity for Sector "Water Intended for Human Consumption"

Index	Index Definitions	Index Value	Impact Ratio	Weighted Index Value
I	Technical Feasibility	3	50%	1.5
II	Socio-Economic Development	2	25%	0.5
III	Financial Development	3	25%	0.75
			Overall Sensitivity	2.75

4. Discussion and Conclusion

Discussion

The results of the sectorial impact application of the above –mentioned methodology is given in Table 4.1. The values of sensitivity, impact, economic value, risk and the adaptation capacity parameters are calculated according to the current situation of the river basins.

The impact changes are further calculated as a function of exposure parameter through the 10-year-intervals where the exposure parameter is the only variable in the developed methodology for the 10-year-period during the projection time.

When the exposure level for this example is considered as a value of 2 for the 2060s, the resulting impact levels indicated in the Table 4.1 as an example regarding the sectors can be obtained.

Table 4.1.
Impact levels obtained on sectorial basis for the 2060s in case the exposure level is foreseen as 2

	Exposure (M)	Sensitivity (D)	Impact (E)	Economic Value (ED)	Risk (R)	Adaptation Capacity (UK)	Impact (ET)
Water intended for human consumption	2	3.20	6.40	2.00	12.80	2.75	5
Agriculture	2	2.17	4.34	2.13	9.25	3.25	3
Industry	2	2.75	5.50	2.5	13.75	2.85	5
Ecosystem	2	2.20	4.40	1.5	6.60	2.4	3
Tourism	2	3.23	6.47	2.2	14.23	2.45	6

Impact levels of the basin are given in Table 4.2. Accordingly, the impact level for water intended for human consumption sector may be inferred as of medium intensity for the years of 2060s, and as high intensity for the tourism sector.

Table 4.2.
Impact Level of the Basin on Sectorial Basis

Impact Interval	Impact Score	Impact Level
1 - 3	1	Low
3 - 5	2	Medium
6 - 9	3	High
9<	4	Very High

Conclusion

Adaptation to climate change is the overall actions and measures taken by the societies and ecosystems to cope with the varying climatic conditions. In other words, adaptation to climate change is the process of strengthening, developing and executing the strategies to struggle with the effects of climate events (risks), and to manage them.

Adaptation activities have quite a systematic structure. Initially, it is required to carry out the impact determination studies related to water resources, agriculture and food security, public health, natural ecosystems and biodiversity, coastal zones, etc. “Impact assessment” should be executed related to water shortage, drought, desertification, rise in disasters, decline in crop yield, food security, deterioration in public health, deterioration in terrestrial and marine ecosystems, negative effects on energy, tourism and fisheries. These experiences depend on the mentioned impacts and related to threats on coastal zones caused by sea level rise. “Adaptation action plans” including adaptation actions and measures for those being prepared and integrated to sectorial development plans (SYGM, 2016).

Analysis methodology have been developed for the 4 main sectors (water intended for human consumption, agriculture, industry and ecosystem) in the 3 pilot river basins (Büyük Menderes, Meriç-Ergene and Ceyhan River Basins) to execute sectorial impact analysis with the results of “the Effects of Climate Change on Water Resources Project” (SYGM, 2016).

In this study, sectorial impact assessment is examined for the water intended for human consumption sector by scrutinizing the Büyük Menderes River Basin as an example within the scope of calculating the values of sensitivity, impact, economic value, risks and adaptation capacity for impact assessment. Exposure level has been determined based on 2060s according to the water potential results within the scope of "the Effects of Climate Change on Water Resources Project", the impact level is determined as "medium" for the water intended for human consumption sector. The study has also been repeated for the other sectors as well. According to the results presented in Table 4.1, tourism is the most vulnerable sector (High Impact), whereas the agriculture and the ecosystem sectors are found as the least vulnerable (Medium Impact) sectors due to climate change in the 2060s. This study is expected to form a basis for the future projects which aim to determine the most probable sectors to be affected from the results of climate change in Turkey.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

İklim Değişikliğine Adaptasyon Kapsamında Sektörel Etki Analizi Metodolojisi

İklim değişikliğine uyum, toplumların ve ekosistemlerin değişen iklim şartları ile baş edebilmelerine yardımcı olmak için gerçekleştirilen eylemler ve alınan önlemlerdir. Bir diğer deyişle iklim değişikliğine uyum; iklim olaylarının (risklerinin) etkileriyle mücadele etmek, fayda sağlamak ve etkileri yönetebilmek için stratejilerin güçlendirilmesi, geliştirilmesi ve uygulanması sürecidir.

Uyum çalışması oldukça sistematik bir yapıya sahiptir ve iklim değişikliğine uyum konusunda öncelikle etkilenebilirliğin tespiti gereklidir. Etkilenebilirlik, bir sistemin maruz kaldığı iklim değişikliğinin ve değişkenliğinin özelliği, boyutu ve hızının, duyarlılığının ve uyum sağlama kapasitesinin bir fonksiyonudur.

Hükümetler arası İklim Değişikliği Paneli (IPCC); iklim değişikliğinden etkilenebilirliği 3 ana unsurun bir fonksiyonu olarak tanımlar. Bunlar;

- İklim değişikliğinin etkilerine maruz kalma türleri ve boyutu,
- Sistemlerin, belirli düzeyde maruz kalmaya duyarlılığı,
- Sistemin başa çıkma veya uyum sağlama kapasitesidir.

Öncelikle iklim değişikliğinden olumsuz etkilenebilecek su kaynakları, tarım ve gıda güvenliği, halk sağlığı, doğal ekosistemler ve biyoçeşitlilik, kıyı bölgeleri vb. sektörlere ilişkin “etkilerinin belirlenmesi” çalışmalarının yapılması gereklidir. Bu etkilere bağlı olarak yaşanacak su sıkıntısı, kuraklık, çölleşme, afetlerdeki artış, tarımsal üretimde düşüş, gıda güvenliği, halk sağlığında bozulma, kara ve deniz ekosistemlerindeki bozulma, enerji, turizm ve balıkçılığın olumsuz etkilenmesi, deniz seviyesindeki yükselmeye bağlı kıyı bölgelerinde yaşanacak tehditlere ilişkin “etkilenebilirlik değerlendirilmesi” yapılarak, bunlar karşısında gerçekleştirilecek uyum eylem ve önlemlerini içeren “uyum eylem planlarının” hazırlanması ve bu planların mutlaka ulusal, sektörel gelişme planlarına “entegre edilmesi” gerekmektedir.

Bu hedefler ile gerçekleştirilen “İklim Değişikliğinin Su Kaynaklarına Etkisi Projesi” sonucu elde edilen sonuçlar ile sektörel etki analizlerinin gerçekleştirilebilmesi için pilot havzalarda (Büyük Menderes, Meriç-Ergene ve Ceyhan Havzaları) 5 ana sektör için (içme kullanma suyu, tarım, sanayi, ekosistem ve turizm) analiz metodolojisi geliştirilmiştir. Böylelikle, havzanın her sektörden etkilenme şiddetini 4 sınıfta değerlendirebilecek şekilde 1: Az etki; 2: Orta etki; 3: Yüksek etki; 4: Çok yüksek etki derecesi ile bir sınıflandırma yapılmıştır.

Bu çalışmada, örnek teşkil etmesi amacıyla Büyük Menderes Havzası incelenerek, duyarlılık, etki, ekonomik değer, risk ve uyum kapasitesi değerleri çerçevesinde yine örnek olarak içme ve kullanma suyu sektöründe sektörel etkilenebilirlik analizi metodolojisi irdelenmiştir. Su potansiyeli sonuçlarına göre tespit edilen maruziyet seviyesi 2060’lı yıllar baz alınarak belirlenmiş olup, bu kapsamda içme ve kullanma suyu sektörü etkilenme şiddeti “Orta Şiddet”te olarak tespit edilmiştir. Çalışma, diğer sektörler için de taslak olarak tamamlanmıştır. Sonuçlara göre 2060’lı yıllarda iklim değişikliğinden en çok etkilenmesi beklenen sektörün Turizm (Yüksek Şiddet), en az etkilenmesi beklenen sektörün ise Tarım ve Ekosistem (Orta Şiddet) olduğu belirlenmiştir.

Essential Tools to Establish a Comprehensive Drought Management Plan - Konya Basin Case Study

Mustafa Berk DUYGU[1], Bilal KİRMENCİOĞLU[1], Maruf ARAS[1]

Abstract

Drought is a vital phenomenon in semi-arid regions; particularly in closed basins where water resources are scarce to meet demands. Konya Basin of Turkey is a closed basin which is susceptible to droughts at the ultimate level. In order to estimate drought risks and establish necessary measures against drought events, a Drought Management Plans is prepared for this basin. This study is aimed to share experiences achieved during the preparation of this plan and discuss essential tools to establish a comprehensive drought management plan. Preparation of a drought management plan includes, determination of prospective drought risks, climate change analyses, assessment of water budget, vulnerability assessment and essential measures to be taken at pre-drought, during drought and post drought stages.

Key words: *drought, drought analyses, climate change, water scarcity, mitigation*

1. Introduction

Droughts occur as a result of natural (climatological) processes and it can affect specific areas for specific time intervals. Although, drought is a natural disaster, such as floods and earthquakes, it has a much longer onset and effecting period. The duration of a significant drought event can be expressed in terms of years. Drought emerges slowly but the consequences it causes can be serious and costly. In order to mitigate the impacts of droughts, drought vulnerability of the affected region must be very well assessed.

Turkey has been quite often exposed to the effects of this natural disaster. Although, spatio-temporal analyses are not sufficient for earlier droughts, it has been known that the serious droughts occurred in 1804, 1876 and 1928 caused loss of agricultural products and livestock as well as the migration of desperate farmers. It is estimated that the drought event occurred in 1876 caused loss of 200.000 lives by causing famines and diseases. In the republic era, in 1928, 1973, 1989, 1990, 1993, 1998-2001, 2008 and 2013, serious droughts were also observed (Yağcı, 2007).

Especially for the Mediterranean countries, adverse effects of the global climate change are observed and drought is becoming a serious problem. Mediterranean countries such as Turkey are expected to observe temperature increases and precipitation deficiencies in near future which may increase severity and frequency of drought events (IPCC, 2014).

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Having limited amount of water resources and vast agricultural land as well as being a closed basin make Konya Basin where the most vulnerable area of Turkey against droughts. A drought Management Plan for this basin has been prepared to mitigate the negative impacts of possible droughts and keep water scarcity at the minimum level by determining measures to be taken before, during and after the drought periods (SYGM, 2015).

Drought risk assessment, climate change analyses, determination of water budget, sectorial vulnerability assessment are vital to prepare a comprehensive drought management plan. All these steps are the essential tools to determine the necessary measures at all stages of droughts and to prepare a drought management plan.

The purpose of this study is to discuss the essential of a drought management plan by addressing the experiences obtained from the preparation process of Konya Basin Drought Management Plan.

Drought and Drought Management

"Drought" means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems. (UNCCD, 1994).

An efficient drought mitigation can only be possible with an effective drought management which can be operated efficiently by a drought management plan. Drought management plans must include actions to be taken at pre-drought, during drought and post drought phases as well as the responsible actors who are responsible from taking these actions.

Drought management plans are the important elements of integrated water management of any water basin. In order to determine measures at all phases of a drought, meteorological, hydrological and agricultural drought characteristics, vulnerability of ground and surface waters against droughts, drought effects on different parties and water users, possible effects of global climate change on future droughts have to be considered while determining the measures in the drought management plan.

Konya Basin

Konya Basin is a closed basin, which is surrounded by Sakarya and Kızılırmak River Basins in the north, Kızılırmak and Seyhan River Basins in the east, Eastern Mediterranean Basin in the south and Antalya and Akarçay River Basins in the west. The basin is the third biggest basin among 25 basins in Turkey, and has a surface area of 50.073 km². Most of the basin is covered with large plains having an altitude ranging between 900-1050 meters that constitutes the Central Anatolian Plateau. Since the basin is surrounded by high mountains, the basin does not have any other inputs than precipitation. The precipitation amount is more in the south and southwest of the basin in comparison with its north and east. The annual average precipitation height of the basin is 384 mm. approximately 15% of the annual average precipitation creates surface runoff and constitutes the surface water resources of the basin.

Konya Basin is one of the 25 river basins of Turkey. Konya Basin covers some of the areas of Aksaray, Ankara, Antalya, Isparta, Karaman, Konya, Mersin, Nevşehir and Niğde provinces (Figure 1.1.).

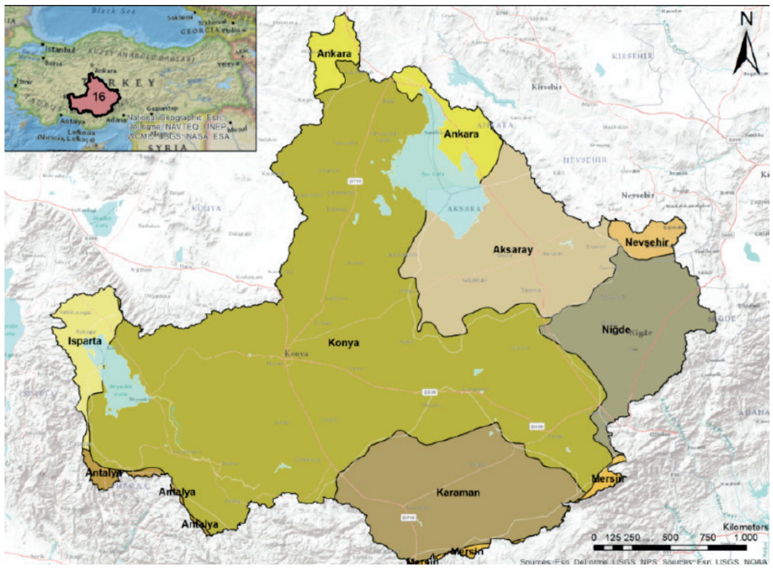

Figure 1.1. Konya Basin

2. Method

Climate Modelling

In order to estimate local effects of global climate change, downscaling approaches were developed which downscales the global estimates of climate into local scale (Wilby et al., 2002; Tripathi et al., 2006; Okkan & Inan, 2014). There are two main downscaling methods in the literature namely dynamic and statistical downscaling (Wilby et al, 2002).

In this study, both of these methods were utilized together. For dynamic downscaling method, for both Konya Basin and Turkey, the most appropriate global circulation models were determined. The outputs of the climate model were statistically downscaled to meteorological observation stations. The differences between the outputs of dynamic and statistical downscaling were eliminated using appropriate methods (such as bias correction) and for further studies, the outputs of dynamic downscaling method was utilized.

The global models –MPI-ESM-MR, HadGEM2-ES and GFDL-ESM2M– used in the project are the general circulation models developed by Max Planck Meteorology Institute (Germany), Met-Office Hadley Centre (England) and NOAA Geophysical Fluid Dynamics Laboratory (USA), respectively. Those global models have been previously evaluated by centers developing Regional Climate Models, particularly by Abdus Salam International

Theoretical Physics Center (ICTP), and are used within the scope of this project since they produce the accurate model results for the Mediterranean region.

Drought Analyses

Drought has been characterized for its meteorological, hydrological, agricultural, geographic and economic aspects and analyzed under different definitions. This characterization and definitions include the evaluation of many different drought variables and parameters as well as the possible adverse impacts of droughts. Extreme events occurred as a result of deficiency or excessiveness of variables such as precipitation, temperature, moisture, evaporation, transpiration and wind speed are taken into account in drought analyses (Türkeş, 1990).

Meteorological drought means the decrease in rainfall compared to long term averages for a certain duration. In order to determine meteorological droughts, different statistical methods and threshold values are used for different areas. For example, for a certain location, if the total of 21 days precipitation is below 1/3 of normal levels or there is no rainfall for 15 days, the situation can be evaluated as meteorological drought. (Türkeş, 1990).

Hydrological drought is deficit of water in hydrological respect where decreases in surface and ground waters are taken as the basis of drought. Hydrological drought and its severity can be measured by water level measurements of water environments (such as rivers, lakes, reservoirs, groundwater, etc.). Because of the linear time dependent relation between precipitation deficiency and water deficit in lakes and reservoirs, hydrological drought is not one of first indicators of drought. Even after the end of meteorological droughts, hydrological drought may affect the region for a long period with certain lag times, depending on the physiographical conditions and soil characteristics of the region. (Türkeş, 1990)

Agricultural drought means the inadequacy of soil water in the root zone which hinders plant growth. Especially at the growth period where the plant is highly vulnerable to water deficiency, if the soil moisture is not adequate, agricultural drought occurs (Wilhite & Glantz, 1985). Agricultural drought may occur just after meteorological droughts at rainfed agricultural areas, it may also occur as a result of hydrological drought at irrigated areas.

As drought severity, duration and vulnerability of communities increase, and if a drought risk management plan is either not available or not working properly, socio-economical drought may occur as a result of the consequences of meteorological, hydrological and agricultural droughts. (Wilhite & Glantz, 1985)

In order to determine and classify the complicated process of droughts by means of their severity, duration and geographical distribution, several climatological, meteorological or hydrological drought indices appears in literature. Drought indices can identify the drought occurrence, evolution and severity in a very explicit manner. Each one of them has its own characteristics and in general similar indices produce similar results. Eight of the most common drought indices were utilized in this study (Table 2.1).

Table 2.1.
Drought indices used in drought analyses and their field of study

Index	Meteorological Drought	Agricultural Drought	Hydrological Drought	Climatological Drought	Agro-hydrological Drought	Climate Change Scenarios	Historical Analysis	Risk Analysis	Monitoring, Prediction
Percentage of Normal Precipitation (PNI)	*	*							
Standardized Precipitation Index (SPI)	*		*						*
Palmer Drought Severity Index (PDSI)	*	*					*	*	
Palmer Hydrologic Drought Index (PDHI)			*						*
Palmer Moisture Anomaly Index (ZNDX)					*				
Aydeniz Index				*					
Erinç Drought Index (Im)		*		*		*			*
Aridity Index (AI)	*	*		*		*			*

Modelling Water Budget

Drought related changes in precipitation and temperatures hydrologically triggers the changes in streamflow. Therefore, significant changes in water potential is an expected result of droughts. Changing of water potential during droughts effect many water users and sectors including municipal water, agriculture and energy. Reservoirs which were planned and constructed in accordance with observed streamflow situations may not be operated efficiently under the conditions influenced by the climate change. Therefore, it is vital to estimate drought related changes and explain the uncertainty in the water budget. Otherwise, characteristics and dimensions of additional measures (such as new storages, interbasin water transfers, etc.) taken against the thread may not be appropriate enough. These inappropriateness, as a result, may cause waste of both natural and financial resources.

In this project, a regional analysis is performed by using three different global climate model outputs and dynamical and statistical downscale methods. The impacts of the changes in the hydro-meteorological parameters on streamflow are analyzed using parametric rainfall-runoff models. The water budget of the basin is determined by using internationally recognized parametric water budget models (HEC-HMS and Thronthwaite Monthly Water Balance Model). The models are operated with hydro-meteorological data created in monthly time-scale with annual periods for the years between 2015 and 2020 and with 5-year periods for the years between 2020 and 2050 and thusly future streamflow values are estimated.

The results obtained at this stage and the current situation surface and subsurface water resources are used in projecting water potential for future and calculating the water budget.

3. Results

Potential Effects of Climate Change on Konya Basin

In order to assess the potential effects of global climate change on Konya Basin, climate modelling and projection has been made. The projections up to 2050 were considered for three different global circulation models and two different scenarios. The results suggest that the total precipitation has a decreasing trend between 6 to 15 percent and the average temperature has an increasing trend between 1 to 2.5 °C.

Changes in average surface temperature

The estimated surface temperature changes until 2050 in accordance with GFDL-ES-M2M global circulation model and RCP 4.5 scenario are shown with respect to months in Figure 3.1. The results suggest that, especially for summer session, temperatures will increase around 1.5 to 2 °C.

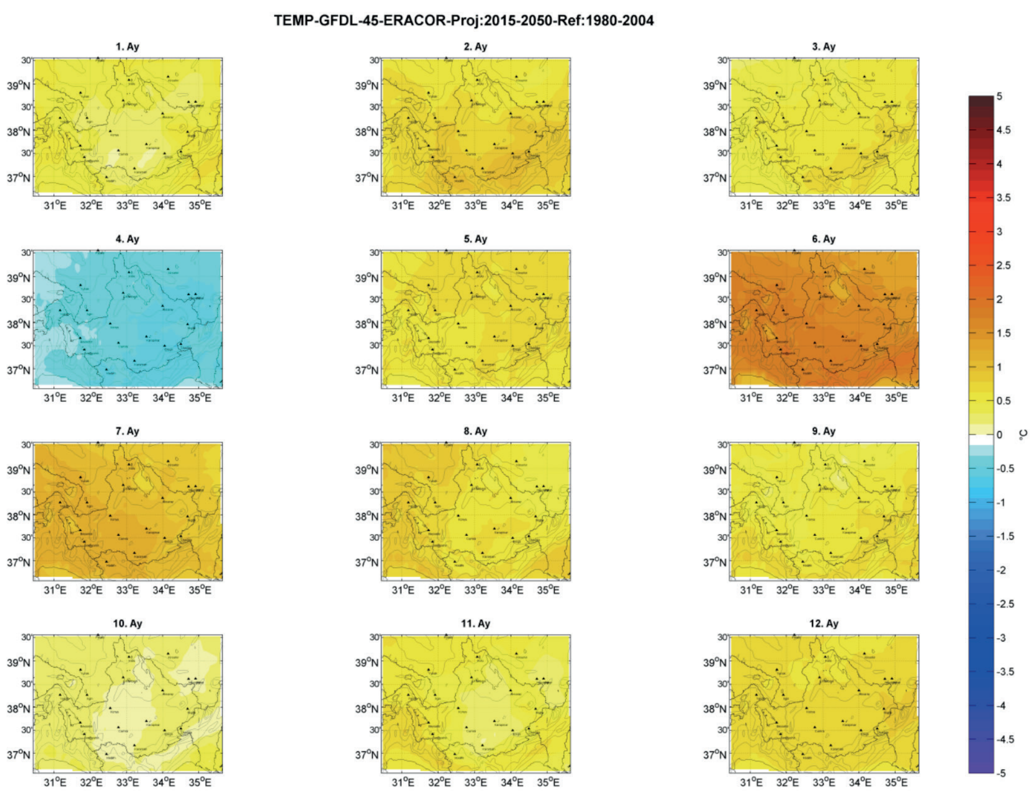

Figure 3.1. Expected changes in average surface temperature in Konya Basin in accordance with GFDL-ESM2M global circulation model and RCP 4.5 scenario.

Changes in precipitation

Expected changes in the precipitation in accordance with three global circulation models and two different scenarios are shown in Figure 3.2.

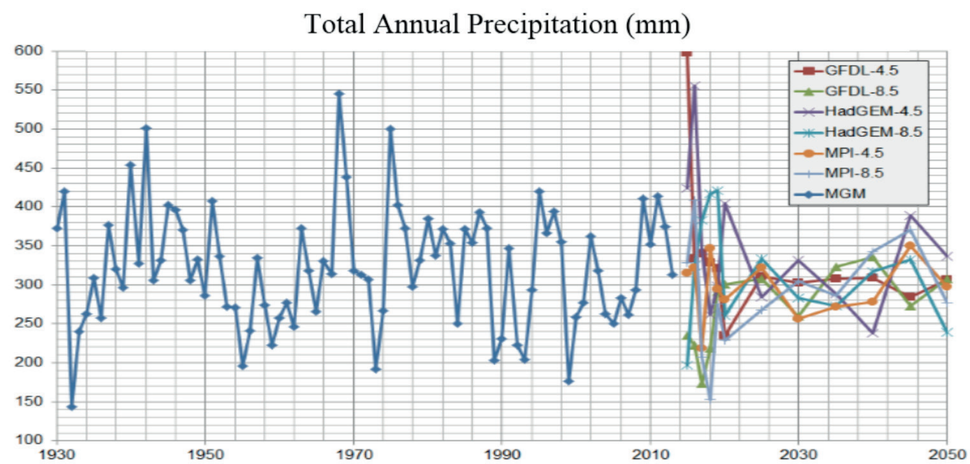

Figure 3.2. Expected changes in the precipitation in Konya Basin

The estimated winter precipitation changes until 2050 in accordance with HAD-GEM global circulation model and RCP 4.5 scenario are shown with respect to months in Figure 3.3. The main actor of the water budget of the Konya Basin is the winter precipitation which seems to have a decreasing trend according to the future projections.

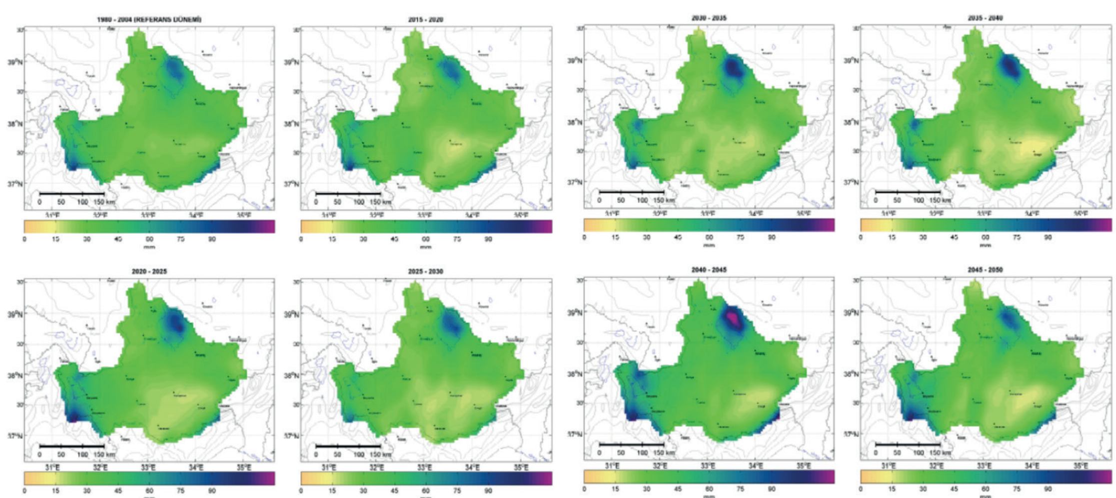

Figure 3.3. Expected winter precipitation changes in Konya Basin in accordance with GFDL-ESM2M global circulation model and RCP 4.5 scenario.

Drought Analyses of Konya Basin

Past drought events of Konya Basin were determined as it was mentioned in Section 2.2 by using 19 meteorological observation stations' long term data by using several drought indices. The results of all indices were used to determine common drought periods of the basin. The results indicate that 1972-1974, 1984-1985, 2000-2001, 2004-2005, 2004-2008 and 2013 are the common drought periods of Konya Basin. Spatial distribution of drought periods whic were determined using PDSI are shown in Figure 3.4.

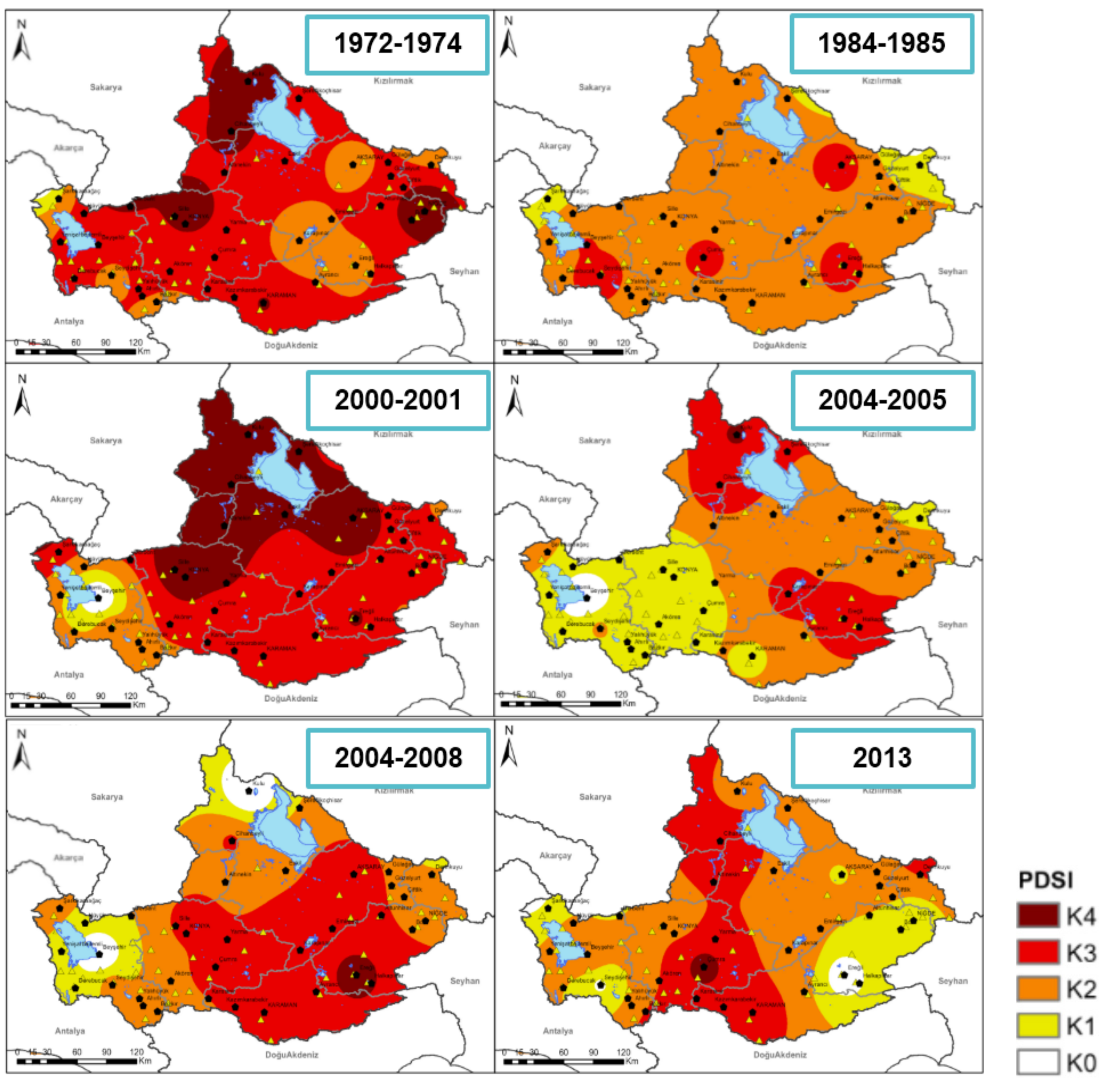

Figure 3.4. Common drought periods of Konya Basin (PDSI)

The results obtained from climate modelling study (Section 2.1) were used in calculating drought indices (Section 2.2) and potential future droughts were estimated. The results suggest that probability of occurrence of extreme droughts may increase around 12% to 46% until the year 2050.

Determination of Changes in the Water Budget of Konya Basin

Groundwater and surface water potentials of the basin were calculated using annual precipitation data recorded at 1974-2013 period. The utilizable water potential of Konya Basin is assessed as 4.679 hm³/year. 57.2% (2.676 hm³/year) of the potential is surface water resources and 42.8% (2.003 hm³/year) of the potential is groundwater resources. The water balance diagram of the basin is shown in Figure 3.5.

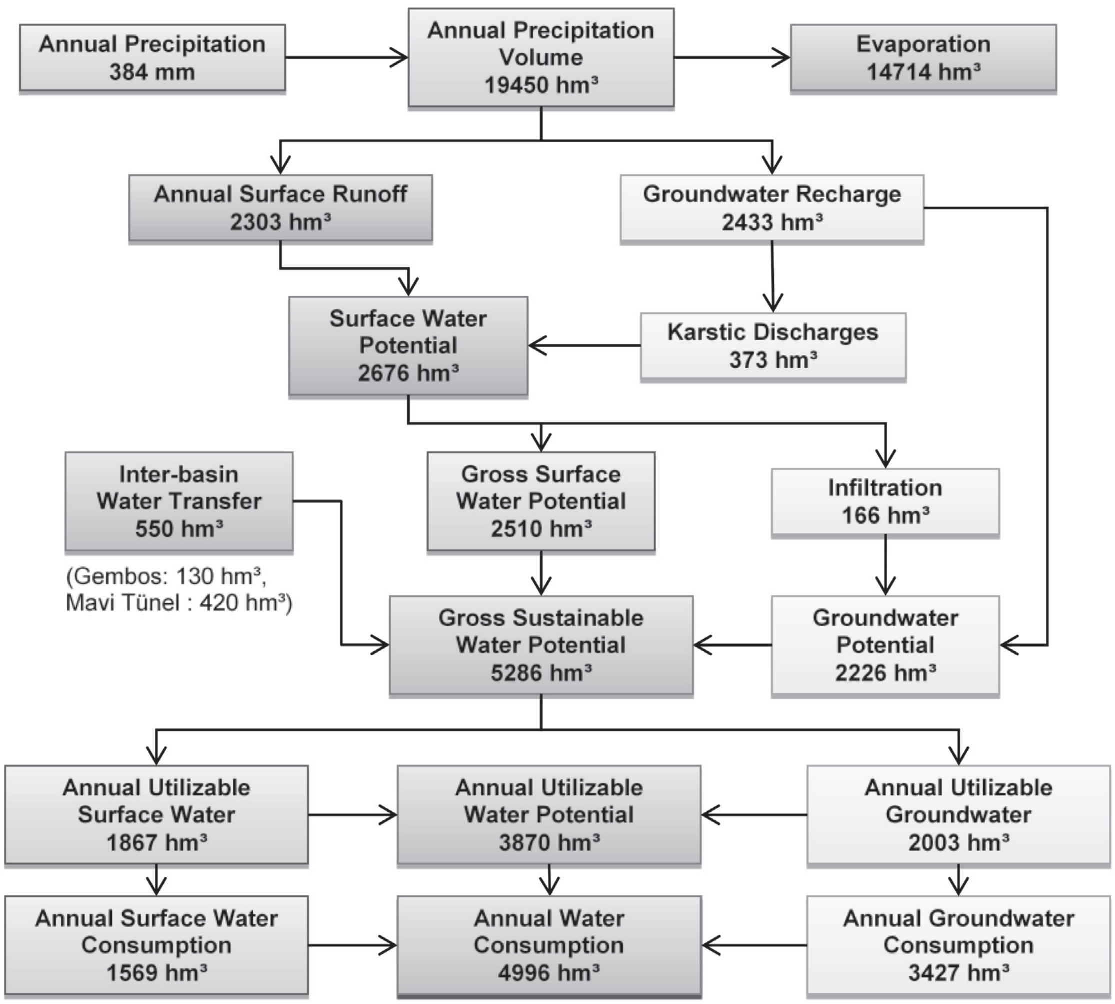

Figure 3.5. Konya Basin water balance diagram

Before starting the hydrological studies, climatologic outputs of HadGEM2-ES model (Section 2.1) with RCP 4.5 and RCP 8.5 scenarios were corrected with the ground data of the meteorological observation network and Era-Interim data. Potential changes in the water potential of Konya Basin as a result of the expected changes, obtained as the output of the climate model HadGEM2-ES (Section 2.1), are presented in Figure 3.6 and Figure 3.7. The figures are depicted as box-and-whisker plots to summarize large number of qualitative data. In those figures, the upper and lower lines show the maximum and minimum values, respectively, the lower box shows the median and the first quarter, and the upper box shows the median and third quarter, while the black points show the mean and the black dashed line shows the interannual variations of mean values. Significant decreasing trends were observed for both surface water (Figure 3.6) and groundwater potentials (Figure 3.7) for the years 2035 and 2040.

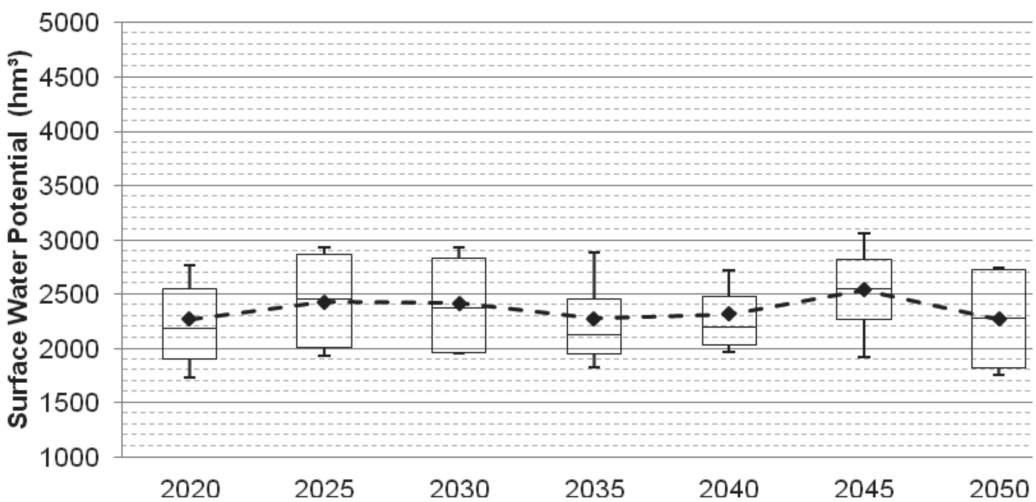

Figure 3.6. Expected changes in surface water potential of Konya Basin (2020-2050)

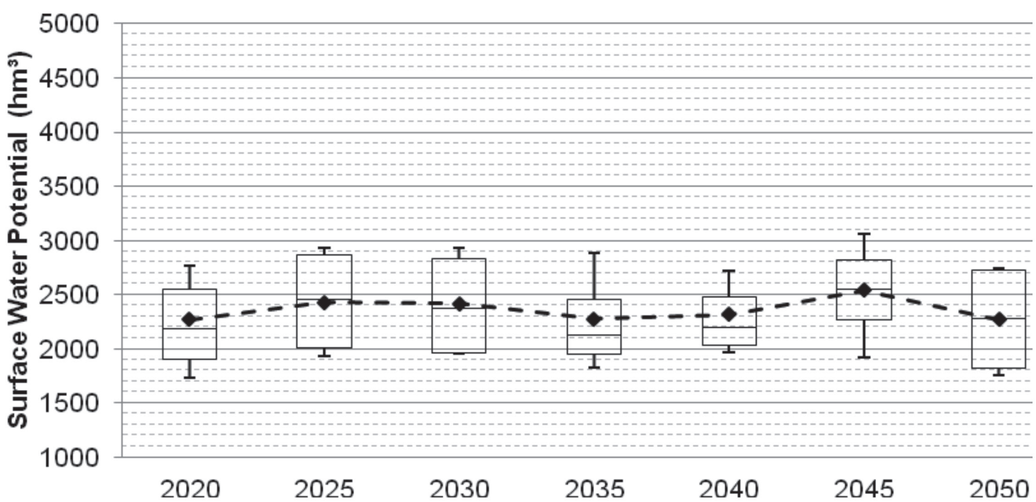

Figure 3.7. Expected changes in groundwater potential of Konya Basin (2020-2050)

Drought Vulnerability Analyses

Vulnerability (sensitivity, susceptibility) assessment is an innovative analysis method, which has been developed to create a bridge for the determination of measures using the results of the impact assessment by focusing the attention of the decision makers on the reasons creating the vulnerability instead of the analysis of negative impacts that may occur as the result of a triggering event such as drought (natural disaster).

The basic components of vulnerability assessment are: the thread created by drought on the inspected region, the sensitivity of the region to drought, potential impacts based on experiences, and the adaptation capacity of the region to the drought conditions.

For four main sectors in Konya Basin (Agriculture, municipal water, industry and ecosystem) sectoral vulnerability assessments were conducted.

Required water is supplied from surface or groundwater resources. Almost all of the surface water resources and substantial amount of the groundwater resources are consumed in agriculture and the remaining is used to meet potable and industrial water demand. It is determined that 4.749 hm^3 water is used for irrigation, 180 hm^3 water is used as potable water and 67 hm^3 water is used as industrial water, corresponding to a total of 4.996 hm^3 water use in the basin. In accordance with this data, 95% of the water provided to the consumers in the basin is used in irrigation. The amount of water used as potable water and industrial water are 4% and 1%, respectively.

It is estimated that 4.356 hm^3 water will be used for irrigation, 400 hm^3 water will be used as potable water and 142 hm^3 water will be used as industrial water, corresponding to a total of 4.898 hm^3 in the basin in 2050. In accordance with this estimation, it is predicted that 89% of the water provided to the consumer in the future will be used for irrigation, 8% for potable water and 3% for industrial water.

The main reasons of the decrease in groundwater table in the last two decades are inability to supply agricultural demand from surface water resources and agricultural practices have not been performed compatible with the water budget of the basin.

Precipitation is not sufficient to recharge groundwater resources and the decrease in groundwater table. Water restrictions would be obvious in the future considering further impacts of climate change in the region, unless an effective basin management plan implemented for the basin.

Water budget deficiencies and decreases in groundwater table are forecasted for the 2015-2050 period considering trends in population growth, changes in water demand of water-consuming sectors and changes in water potential (surface- and ground-water) according to global climate models.

The vulnerability of the irrigated-agriculture lands, which is a sub-sector of agricultural sector, is assessed in the light of expected deficiencies in the water budget and decreases in groundwater table. Mean annual decrease of water table is 0.99m in Konya Basin (Table 3.1)

Table 3.1.
Decreases in ground water levels in sub-basins of Konya Basin

Sub-Basin	Sub Basin No	Well No	Name of the Well	# of years measured	Decrease	
					Total (m)	Average (m/year)
Beyşehir (16/1)	16/1-a	52770	Doğanbey	3	5.20	1.73
	16/1-b	49340	Taşağıl	3	1.79	0.60
Konya-Çumra-Karaman (16/2)	16/2-a	8185	Hatip	34	39.00	1.15
	16/2-c	181	Fethiye	19	16.50	0.87
	16/2-c	52267	Arıkören	19	22.00	1.58
	16/2-c	9431	A.Hüyüğü	28	14.10	0.50
	16/2-d	52268	Eğilmez	31	37.40	1.21
	16/2-d	52258	Gülfet Yayla	39	31.60	0.81
Karaman-Ayrancı-Akçaşehir (16/3)	16/3-a	30642	Erentepe	15	13.00	0.87
	16/3-a	28719	Güneysınır	15	23.30	1.55
	16/3-b	20122	Sudurağı	16	39.00	2.44
	16/3-c	30270	Höyükburun	12	17.00	1.42
	16/3-c	13314	Akçaşehir	29	31.00	1.07
Ereğli-Bor (16/4)	16/4-b	52259	Yeniköy	13	14.00	1.08
	16/4-b	9749/A	Y. Zengen	13	2.00	0.15
Sultanhanı (16/5) Altınekin	16/5-b	52266	Eşmekaya	16	17.20	1.07
	16/6	221	Tutup	40	22.20	0.56
	16/6	46392	Meydan	13	17.55	1.35
Cihanbeyli-Yeniceoba-Kulu (16/7)	16/7-a	53704	Sığırcık	8	4.55	0.57
	16/7-a	53706	K. Kartal	8	2.00	0.25
	16/7-c	53707	Kulu	5	5.00	1.00
Average				18	16.79	0.99

The potable water sector constitutes less than 5% of the total water need of Konya Basin, however it is vital for human life. The potable - use water sector is used for meeting the needs of public and households, commercial, public institutions, schools, hospitals, charity institutions and some small - medium scaled industrial facilities.

95% of the water use in the basin is currently being used by the agriculture sector. It is calculated that this value will decrease and become 85% in the future. Since the water resources are limited, the vulnerability of potable and use water sector to drought conditions is directly proportional with the water need of the agriculture sector.

Konya Basin Drought Management Plan

In order to mitigate and/ or eliminate the negative impacts of drought and water scarcity on the production resources and socio-economic life, to ensure the sharing of water among sectors under drought conditions, and to ensure the rational and sustainable use of limited water resources, the economic, sustainable and technically applicable measures that will be applied in Konya Basin and the contribution provided by each measure to the target of mitigating the impacts of drought and water scarcity are determined, assessed and put in a rank of priority.

Care is paid to ensure that the measures proposed within the scope of this report are compliant with "Strategy and Action Plan for Combating Agricultural Drought (2013-2017)" document prepared under the coordination of Ministry of Food, Agriculture and Livestock (MFAL). Furthermore, the policies, strategies and actions indicated in the "Tenth Development Plan (2014-2018)" and "Regional Development National Strategy (2014-2023)" prepared under the coordination of Ministry of Development, the "KOP Action Plan (2014-2018)" prepared by Konya Plain Regional Development Administration; the "Strategic Plan of Ministry of Food, Agriculture and Livestock (2013-2017)"; the targets for 2023 determined by the Ministry of Forestry and Water Affairs, "2013-2017 Strategic Plan" and "DSİ Strategic Plan (2015-2019)" are taken into consideration.

While determining the measures, matters such as the impact of climate change on the moderate, severe and extreme drought risks of the basin, the probable droughts in the future, the future water budget, the way in which all water-using sectors will be impacted (municipal, agriculture, industry and ecosystem) are taken into consideration in addition to the planned irrigation investments and agricultural policies. Furthermore, national and international references (action plans, strategy documents, academic publications, projects) are examined and new methods that can be applied in Konya Basin are included in the scope.

In Konya Basin Drought Management Plan, the agencies responsible for the application of the measures and partner agencies, which can be cooperated during the application of the measures are identified with detailed information about the determined measures. The measures are grouped under eight main goals of drought mitigation:

1. Improve Water Availability Monitoring and Drought Impact Assessment

2. Increase Public Awareness and Education

3. Enhance Mechanisms to Provide Water Supplies to Sub-basins That Are Under Risk of Water Shortage During Droughts

4. Coordinate and Provide Technical Assistance for Planning Efforts for Development of Water and Soil Resources by Local Administrations, General and Regional Directorates of Ministries

5. Reduce Water Demand, Encourage Water Use Efficiency and Conservation of Water Resources and Water Quality

6. Reduce Drought Impacts on Konya Basin's Economy, People and Ecosystem
7. Develop Interagency Stakeholder Coordination
8. Evaluate Potential Impacts from Climate Change

4. Discussion and Conclusion

Konya Basin is the driest hence the most vulnerable area of Turkey against droughts. The water potential of the basin fails to meet the water consumption, so water transfer projects like "Mavi Tunnel" have already been carried out. Such projects are also aimed at reducing the pressure on groundwater. In this basin, tremendous amount of agricultural activities are being conducted and 95% of the water provided to the consumers in the basin is used in agricultural irrigation. In this study, annual utilizable water potential was calculated as 3870 hm^3 where the annual consumption is 4996 hm^3. Thus, groundwater table of the basin is decreasing around one meter per year.

In drought periods, due to lack of sufficient water resources, Konya Basin is expected to experience further difficulties and faster decreasing of the groundwater table. In order to mitigate the risk of potential droughts, a Drought Management Plan for this basin was prepared.

In this study, necessary measures are identified for pre-drought, post-drought and during drought stages to provide an efficient drought mitigation at Konya Basin considering prospective drought risks. Implementation of these measures which were defined by considering water budget of the basin and drought vulnerability will increase drought resistance and decrease drought related losses.

A series of scientific studies were conducted in order to define the measures which includes evaluation of drought characteristics and water potential of Konya Basin. Climate studies were conducted to estimate future climatological conditions of the basin which may occur as a result of global climate change. Climate studies were conducted using different global circulation models and different scenarios. Drought analyses were made by using both the current conditions and the estimated future conditions of the climate. Sectorial vulnerability assessment was made by evaluating water budget of the basin by using current and the potential future water demand of different type of water users and sectors.

All of these works are essential to estimate the damage of future droughts on different parties which is also essential to establish a proper drought management mechanism and define proper measures against prospective drought risks. Measures are defined by considering the capacities of the related institutions and for each measure responsible institutions were clearly indicated.

However, all of the measures defined in this study are based on current data and some projections which may not include potential unanticipated changes. In order to include unanticipated changes in climatology and socio-economy in the basin, drought management plans have to be revised on certain periods especially after drought events.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Kapsamlı Bir Kuraklık Yönetim Planı Oluşturulması İçin Gerekli Araçlar - Konya Havzası Çalışması

Kuraklık doğal (iklimsel) süreçler sonucu oluşarak belirli zaman aralıkları için belirli bölgeleri etkisi altına alabilir. Taşkın ve deprem gibi doğal bir afet olan kuraklık bu afetlerden farklı olarak çok uzun bir oluşma ve etkileme süresine sahiptir. Belirgin bir kuraklık olayının etki süresi yıllarla ifade edilebilir. Kuraklığın gelişmesi uzun yıllar alsa da doğurduğu sonuçlar ciddi ve maliyetli olmaktadır. Kuraklığın etkisini gösterdiği dönemde ve sonrasında oluşturacağı etkilerin azaltılabilmesi için etki ettiği bölgenin kuraklık hassasiyetinin en iyi şekilde tanımlanması gerekmektedir.

Birleşmiş Milletler Çölleşme ile Mücadele Sözleşmesinde belirtilen tanıma göre kuraklık, yağışların kaydedilen normal düzeylerin önemli ölçüde altına düşmesi sonucu arazi ve kaynak üretim sistemlerini olumsuz olarak etkileyen ve ciddi hidrolojik dengesizliklere yol açan doğal olaydır (UNCCD,1994). Kuraklık, su kaynaklarının kısıtlı olduğu kurak ve yarı kurak alanlarda ve özellikle kapalı havzalarda çok önemli bir sorun haline gelmiştir.

Ülkemizin 25 havzasından biri olan Konya Havzası kapalı bir havza özelliği taşımakta ve Türkiye'nin kuraklık riskinin en yoğun olarak yaşandığı alanlarının başında gelmektedir. Konya Havzasının üretim kaynakları, sosyo-ekonomisi ve ekosistemi uzun süreli kuraklık koşullarına karşı hassas olup kuraklık etkileri, kuraklığın nerede meydana geldiğine bağlı olarak değişiklik göstermektedir. Havzada kuraklık koşullarının erken tespiti ve etkili müdahalesi azami derecede gerekli ve önemlidir.Muhtemel kuraklık risklerinin olumsuz etkilerinin azaltılması ve kuraklık problemlerinin çözümüne yönelik olarak Konya Havzası için kuraklık yönetim planı hazırlanmıştır. Kuraklık Yönetim Planının maksadı, havza sınırları içerisinde yaşanabilecek farklı şiddetlerdeki kuraklık koşullarında kısa veya uzun vadeli olumsuz etkileri azaltmak için etkili ve sistematik bir çerçeve oluşturmaktadır.

Bu çalışmada söz konusu yönetim planının hazırlanması sürecinde elde edilen tecrübelerin paylaşılması ve kapsamlı bir kuraklık yönetim planı oluşturulması için gerekli araçların tartışılması amaçlanmıştır. Kuraklık yönetim planlarının hazırlanması, kuraklık risklerinin tespiti, iklim değişikliği analizleri, su bütçesinin ve su bütçesinde meydana gelebilecek değişimlerin tespiti, sektörel etkilenebilirlik analizi ile kuraklık öncesi, sonrası ve esnasında alınacak önlemlerin yer aldığı kuraklık yönetim planının hazırlanması aşamalarından oluşmaktadır.

İlk olarak küresel iklim değişikliğinin gelecekte Konya Havzasında oluşturması muhtemel etkilerinin tespiti için iklim modellemesi çalışmaları gerçekleştirilmiştir. Gelecek dönemde havza genelinde yağışların azalacağı ve sıcaklıkların artacağı öngörülmektedir. Bu değişimlerin havzada gelecek dönemde yaşanması muhtemel kuraklıkların karakteristiklerini ne şekilde değiştireceğinin tespit edilmesi için de kuraklık risk analizleri gerçekleştirilmiştir. Kuraklık risklerinin tespiti için, uluslararası literatürde kabul görmüş farklı kuraklık indisleri kullanılmıştır. Karmaşık bir süreç olan kuraklığı belirlemek ve nitelendirmek için, çok sayıda klimatolojik, meteorolojik ya da hidrolojik indikatör ve indis kullanılmaktadır. Kuraklık indisleri, kurak koşulların ortaya çıkışını ve gelişimini çok açık bir biçimde tanımlayabilmektedir. Bu sayede

havzada geçmiş dönemde yaşanmış kuraklıklar ölçüm istasyonlarından temin edilen tarihsel veriler, gelecek dönemde yaşanması muhtemel kuraklıklar da iklim modellerinin sonuçları dikkate alınarak tespit edilmiştir. Gelecek dönemde yaşanacak kuraklıkların daha şiddetli ve daha uzun süreli olacağı, özellikle 2035-2040 yılları arasında havzada ciddi kuraklıklar yaşanabileceği model sonuçlarında görülmektedir.

Kuraklık nedeniyle yağış ve sıcaklık değişimlerinden en çok etkilenecek hidrolojik süreçlerin başında akarsu akımları gelmektedir. Bu nedenle kuraklığın havzaların su potansiyellerinde önemli değişimlere neden olması beklenen bir sonuçtur. Havza su potansiyellerinin değişmesi ise özellikle bu havzalarda yer alan içme suyu, sulama ve enerji amaçlı baraj haznelerinin arz sürekliliklerinde önemli sıkıntılar ortaya çıkaracaktır. Geçmiş yıllarda, farklı akım koşulları altındaki gözlemlere dayalı olarak planlanan ve inşa edilen bu barajlar, iklim değişikliği nedeniyle değişen yeni akım koşullarında, planlandıkları esaslar dâhilinde işletilemeyecek, planlanan arz değerlerine ulaşamayacaklardır. Bu nedenle, kuraklığın neden olacağı değişimlerin önceden kestirilip, su potansiyellerindeki belirsizliğin açıklanması büyük önem taşımaktadır. Bu çalışmada üç farklı küresel iklim modeli çıktıları kullanılarak dinamik ve istatistik ölçek indirgeme yöntemleri kullanılarak bölgesel analiz gerçekleştirilmiş; elde edilen hidrometeorolojik parametrelerdeki değişimlerin akımlar üzerindeki etkileri ise yağış-akış modelleriyle irdelenmiştir. Su bütçesi modelleri (HEC-HMS, Thronthwaite Monthly Water Balance Model) son 40 yıllık yağış, sıcaklık ve akış verileriyle kalibre edilerek model parametreleri belirlenmiştir. Kalibre edilen model, 2015-2020 yılları arası dönem için yıllık, 2020-2050 yılları arası dönem için 5 yıllık periyotlarla aylık ve mevsimlik zaman ölçeğinde yaratılan yağış ve sıcaklık verileriyle çalıştırılarak gelecekteki akımlar hesaplanmıştır. Yapılan çalışmalar sonucunda ortaya çıkan veriler ışığında havzada yüzeysuyu ve yeraltısuyu kaynaklarının mevcut durumu ve projekte edilen dönemler için su bütçesi hesaplanmıştır. Havza'nın toplam yeraltı ve yerüstü su potansiyeli 1974-2013 periyodunda düşen yıllık ortalama toplam yağış değeri dikkate alınarak hesaplanmıştır. Bu çalışmada, yıllık kullanılabilir su potansiyeli 3870 hm^3, yıllık kullanım ise 4996 hm^3 olarak hesaplanmıştır. Bu durum havza yeraltı suyunun her yıl ortalama 1m aşağı çekilmesine yol açmaktadır.

Konya Havzasında tüketiciye sunulan suyun %95'i tarımsal amaçlı olarak kullanılmaktadır. Toplam tarımsal su ihtiyacının %68'i (3.227 hm^3) yeraltısuyu kaynaklarından, %32'si (1.521 hm^3) yüzeysel su kaynaklarından karşılanmakta; 635.221 ha alan yeraltısuyu ve 295.285 ha alan yüzeysel su kaynakları ile sulanmaktadır. Su kaynaklarının kısıtlı olması sebebiyle içme ve kullanma suyu ve sanayi sektörlerinin kuraklık koşullarından etkilenebilirliği tarım sektörünün su ihtiyacı ve tarımsal sulamaya ayrılacak su miktarı ile doğru orantılı olacaktır.Belirtilen tüm bilimsel gerçekler ışığında, Konya Havzasında muhtemel kuraklık riskleriyle karşılaşıldığında yaşanacak olan olumsuz etkilerin azaltılması ve kuraklık problemlerinin çözümüne yönelik olarak kuraklık öncesinde, esnasında ve sonrasında alınacak tedbirler belirlenmiştir. Tedbirlerin uygulanmasından sorumlu kurum/kuruluş ile tedbirlerin uygulanması sırasında işbirliği yapılabilecek yardımcı kurum/kuruluşlar ile tedbirlerin havzanın kuraklık hassasiyeti göz önüne alınarak belirlenen öncelik durumu kuraklık yönetim planında belirtilmiştir.

Mevcut durumda havzaya ait olan veriler ve bu veriler üzerinden gerçekleştirilen projeksiyonlar kuraklık yönetim planında yer almaktadır. Havza koşullarında meydana gelebilecek beklenmedik değişimlerin (sektörel değişimler, ciddi kuraklık olayları vb.) hesaba katılabilmesi için kuraklık yönetim planının belirli periyotlarla, güncellenmesi gereklidir.

Low Streamflow Trends in the United States

Gökçe CEYLAN[1], Upmanu LALL[2]

Abstract

This research considered low streamflow features which are an important indicator of droughts and suggests significant information for water-resources decision making. Consecutive low flow conditions in a river can create chronic water scarcity. Water scarcity is one of the main drivers of a social and economic conflicts. This research has observed not only locations where suitable adaptive management measures are needed but also locations where low flow regime changes due to natural / climate effects or anthropogenic impacts. Trends in low flows in the United States were evaluated using Mann-Kendall and the Sen-Slope trend tests. 5% significance level is used and an evidence of mostly upward trends in low flows in the United States was found. Trends in referenced (not exposed to anthropogenic impacts) and non-referenced stations (exposed to anthropogenic impacts) were also investigated separately, and then compared. Results illustrate that the percentage of significant low flow trends in non-referenced stations are higher than referenced stations. Furthermore, wavelet, PCA and clustering analysis were also performed. Wavelet analysis was used to determine the amplitude and timing of such low streamflow discontinuities for specific wavebands. Clustering analysis helped to determine a grouping low streamflow patterns with similar annual flow behaviors.

Key words: *low streamflow, trend analysis, streamflow*

1. Introduction

Hydrological Drought

National Oceanic and Atmospheric Administration (NOAA) defines drought as a deficiency in precipitation over an extended period resulting in a water shortage causing adverse impacts on vegetation, animals, and people. Drought is a temporary anomaly from normal climate conditions and may vary significantly by region. Water demand and water management can increase the impact of drought on a particular region. According to NOAA, there are three main types of drought which are meteorological, agricultural and hydrological.

Hydrological Drought is an extended precipitation shortage period that adversely impacts water supplies such as streamflow, reservoir, lake and groundwater. It results significant social impacts. Droughts are one of the costliest weather events in terms of economics and loss of human life (NOAA, 2008).

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Low Flow Hydrology

Low flow is the minimum flow in a river during the dry season. Low flow is seasonal phenomenon and an indicator of hydrologic droughts. Hydrological drought can be defined as water reduction in reservoirs, lake storage, groundwater levels and streamflow discharge (Smakhtin, 2000).

The ability to predict the occurrence of low flows is critical to the management and operation of reservoirs that often serve multiple, conflicting purposes including water storage and flood control. Trends in low flows could be seen as potential evidence of climate change and the impact of this evidence lead to shifts in the availability of water across the U.S. (Douglas, Vogel, Kroll, 2000). Adaptation to these shifts would be environmentally and economically very costly. Thus, statistical investigation of low flow trends is crucial for proper future adaptations.

Natural and Anthropogenic impacts on low flows

There are natural and anthropogenic factors which affect low flows. Streamflow is a part of natural system and sensitive to recharge of the system. Precipitation is the major component which plays an important role of recharge (Smakhtin, 2000). Other natural factors which have impacts on the low flow behavior are infiltration characteristics of soils, hydraulic characteristics of aquifers, frequency, rate and the amount of recharge, evapotranspiration rates of basin, vegetation types, topography and climate (Smakhtin, 2000).

Human activities have direct impact on low flow. Examples of these activities are remove/add water from/to streamflow for agricultural, industrial and municipal purposes. Additionally, irrigation return flows, direct effluent flows to river, inter-basin transfers, and dam construction are also other examples of human activities (Smakhtin, 2000).

Importance of Low Flows

Low flow is important for water-supply planning, reservoir storage design and planning, irrigation, recreation, and ecological conservation (Smakhtin, 2000). Predicting low flows would be very beneficial to the management and operation of reservoirs. Water managers and decision makers have concerned about possible impacts of the climate variability and human induced climate change on the hydrology of the United States. Furthermore, low flow is an important driver for environmental flow to maintain aquatic and riparian ecosystems. Reduction or augmentation in low flow would change water temperature and concentration levels of solutes. These changes would affect habitat conditions for fish and other biota (Clausen et al., 2004).

Pagano and Garen (2004) states that variations and changes of the climate shift the balance between snow and rainfall and result in changes in streamflow seasonality and create a possibility of an intensified extreme hydrologic events. Therefore, management of natural resources in a climate-induced changing environment could be very challenging. Detecting trends in annual low flows and the magnitude of extreme events could be helpful to managers.

Determination of Low Flows

Low flow estimation is made with frequency analysis of flow events from streamflow time series. Smakhtin (2000) claims that widely used low flow characteristics are the magnitudes of annual low flows, variability of flows and the rate of streamflow depletion in the absence of rain, duration of continuous low-flow events, and relative contribution of low flows to the total streamflow hydrograph.

2. Method

Data

Analyses were performed on USGS - Gages II (Geospatial Attributes of Gages for Evaluating Streamflow) data which contains geospatial data and classifications. Gages II provides stream flow values recorded on a daily basis at 9,322 gaging stations across the continental United States. The Gages II contains daily streamflow records collected between 1880 and 2015 (not necessarily continuous or complete).

Gages II is an update to the original Gages and has two distinctive purposes. First purpose is that it provides long flow record data set and the second one is to provide a determination of watersheds which are least disturbed by human influences and other watersheds. Gages which are located at least-disturbed watersheds are called as referenced gages and others are called as non-referenced gages. Providing referenced and non-referenced gages information is very important to achieve the goal of this study. It would help to understand whether low flow regime changes due to natural / climate effects or human activities / anthropogenic impacts (James A. Falcone, 2011). The Gages II based on 12 major eco-regions across the United States. Total number of gaging stations are 9,322 and 2,057 are classified as referenced and 7,265 as non-referenced.

Figure 2.1. Distribution of GAGES II stations in the United States, including Alaska, Hawaii, and Puerto Rico

Data Analysis

Data Analysis was performed on Gages II stations with at least 80-year streamflow data and no more than 10 percent missing values. There are 727 Gages II stations which belong to minimum 80-year of streamflow data with 10 percent missing values. 87 of them are referenced stations and 640 of them are non-referenced stations.

Low flow computation

U.S. Geological Survey explains that a hydrologically based design flow is defined with the lowest flow event from each year of record. Selecting and identifying an extreme low flow value can be done statistically. In this study, the lowest 7-day average flow and the lowest 30-day average low flow in a year were used as characteristics of low flows in streams. 7-day low flow represents annual series of the minimum values of mean discharge over any 7 consecutive days. 30-day low flow represents annual series of the minimum values of mean discharge over any 30 consecutive days. Identification of 7-day and 30-day low flow is very common for water resources design and planning purposes (United States Environmental Protection Agency, EPA).

USGS defines hydrologic regions based on the perimeter of drainage areas which was constituted by the terrain and characteristics of the nature. Defining hydrological regions creates a baseline drainage boundary framework. Regional analysis was performed at hydrologic regions which are determined by USGS, but final results will be given for the whole country in the following sections. Also, not all of the regions meet defined station criteria which is 80-year streamflow data with 10 percent missing value. Thus, analysis does not cover on all of these determined sixteen regions.

Hypothesis test

Mann-Kendall trend test was used to perform trend analysis in hydrologic data. Mann-Kendall hypothesis test is a non-parametric test and it determines monotonic change. Normality assumption is not required for this test. However, there must be no serial correlation for the resulting p-values to be correct (USGS, Statistical Methods in Water Resources). It is a rank based method for detecting the presence of trends in time series. Main purpose of the test is to determine whether the median changes over time.

In order to perform the test, streamflow values and time data were used, and then p value and Kendall's were calculated. Trends with p values lower than 0.05 were considered as statistically significant. If p value is smaller than 0.05, there is a monotonic trend. The null hypothesis “no trend” was rejected when p is significantly different than zero (larger than 0.05).

Wavelet analysis

Wavelet transforms are used to evaluate surface water resources for water management problems. Signal of a wavelet transform provides time and frequency information (Cannas et al.2005). In this study, wavelet analysis will help to identify annual variability of low flows in the United States. All low flow series were standardized, so the global wavelet is comparable. Also, the inter-annual and spatial variability in low streamflow time series based on region can be done with wavelet power spectra assessment.

Clustering analysis

Basic concept of the cluster analysis is to divide data into relevant groups. This study identifies a groping procedure for low flow patterns that have similar annual low flow behaviors across the country. Low flow variability information is the integrated response of the river basin area, topography, soil type, vegetation and climate. Therefore, grouping gaging stations will provide information about external impacts. Hierarchical clustering was performed on annual low flow data. It is a method of cluster analysis which builds a hierarchy of clusters (Wikipedia/ Cluster analysis). Each connected components in dendogram forms a cluster.

Principal component analysis

Principle component analysis (PCA) is a tool for analyzing data and identifies patterns in data. Patterns are helpful to understand data groups, unusual records, and dependencies. PCA provides similarities and differences of data set (Smith, 2002). PCA is a statistical procedure which interests in clarifying covariance structure of variables.

It is a method to underline data variation and determine strong patterns in a data set in order to explore and visualize data easily. It identifies the principal directions in which the data varies (Imperial College London, DOC493: Intelligent Data Analysis and Probabilistic Inference Lecture 15).

3. Results

Mann-Kendall Trend Test Results

The results of the MK test for across the United States are given in this section. Mann-Kendall trend test was performed on both referenced and non-referenced stations. Average p values and Sen-Slopes were calculated from historical data at GAGES II referenced and non-referenced stations for the whole country. Only stations that have minimum 80-year data with maximum 10 percent missing values were used during the analysis. According to results, 7 and 30-days minimum stream flow data show mostly upwards significant trends in the country.

Comparison of referenced and non-referenced stations illustrate 58 percent of the 7-day low flow non-referenced stations show significant trends, while 29 percent of the referenced stations show significant trends. When the same comparison was made for the 30-day low flow test results, it was found that 31 percent of the referenced stations have significant trends while 59 percent of non-referenced stations show statistically significant trends.

Figure 3.1 visualizes MK trend test results for all stations with 7 day low flow and Figure 3.2 represents MK trend test results for all stations with 30 day low flow. Blue color represents referenced stations while red ones show non-referenced stations. Filled triangle means related station has a significant trend and unfilled triangles are belong to the stations with non-significant trends. Additionally, direction of a triangle gives information about tendency of the trend (upwards or downwards).

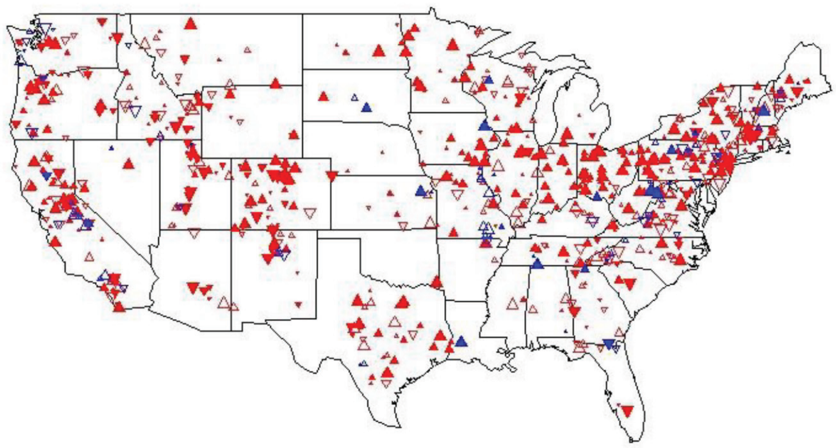


Figure 3.1. 7-day low flow MK Test Results for all stations

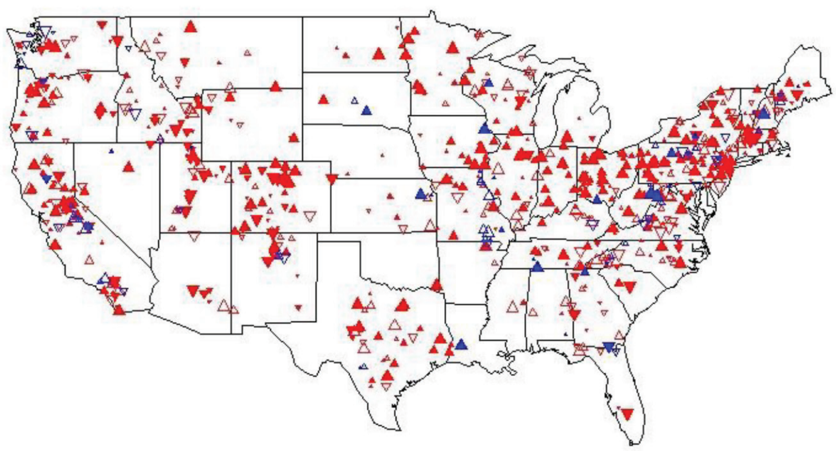


Figure 3.2. 30-day low flow MK Test Results for all stations

As it can be seen from the figures above, MK Trend test results are very close to each other and there is a slight difference between them.

Clustering Analysis Results

Cluster analysis was used to divide 7-day annual minimum data set into relevant groups. Therefore, low flow patterns with similar annual low flow behaviors across the country were identified. Clustering results would also lead us to low flow variability information which is the response of the river basin area, topography, soil type, vegetation and climate. 7-day and 30-day annual minimum flows were used to perform clustering analysis. Five main clustering groups based on similar low flow behaviors were detected in all stations for 7-day annual low flows.

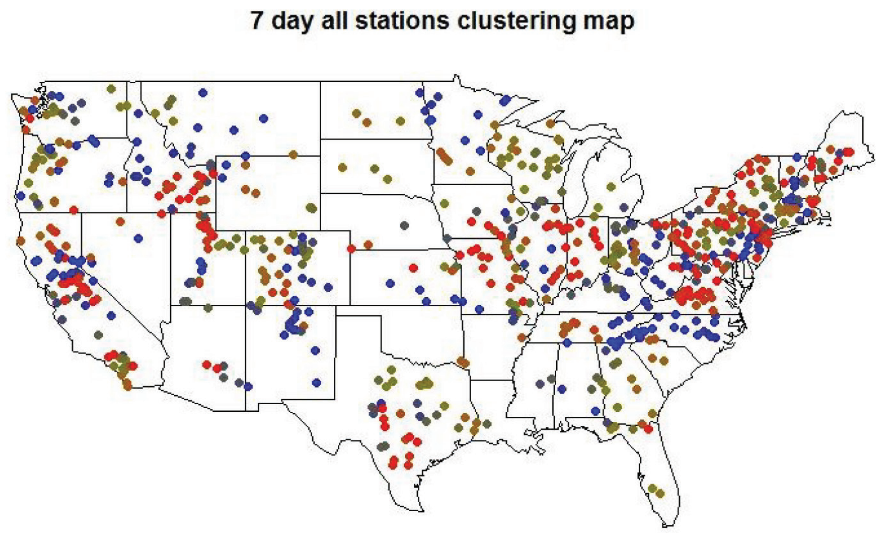


Figure 3.3. 7-day low flow Clustering map for all stations

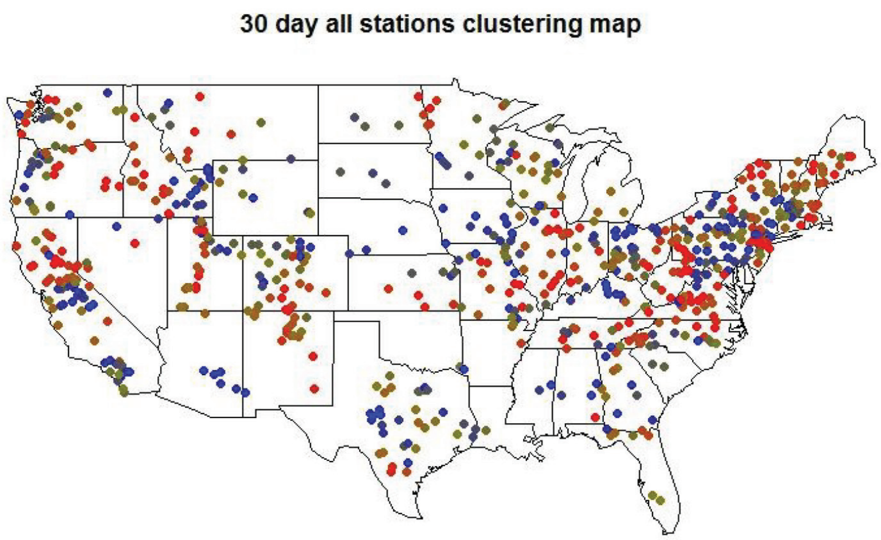


Figure 3.4. 30-day low flow Clustering map for all stations

Wavelet Analysis and Principle Component Analysis Results

Wavelet analysis is used to identify and describe variability in annual low streamflow and to gain insights into the dynamical link between the streamflow and both the climate variability and the anthropogenic effects in the country. Principal component Analysis (PCA) was used to construct regional time series to identify links with probable teleconnection pattern time series (Lins, 1985). Low streamflow variation at 727 locations across the United States during the period 1955–2010 were defined by using principal components.

Time series of mean 7-day and 30-day annual streamflow illustrate very different trend behavior for each principal component. The main reason behind these large differences comes from the contribution percentage of components to variance. The highest and the most significant contribution percentage belong to the first component for both 7-day and 30-day flows. Therefore, time series of PC-1 explains the variability accurately.

It is possible to explain the variance in the correlation matrix with the first component regarding to the obtained information from Figure 3.5. and Figure 3.9. . The optimum number of components can be defined as one in this case, because, first component accounts for the maximum possible variance. There is an upward trend in low flows based on the information gathered from the first component (PC-1). This results also supports the obtained results from Mann-Kendall Test.

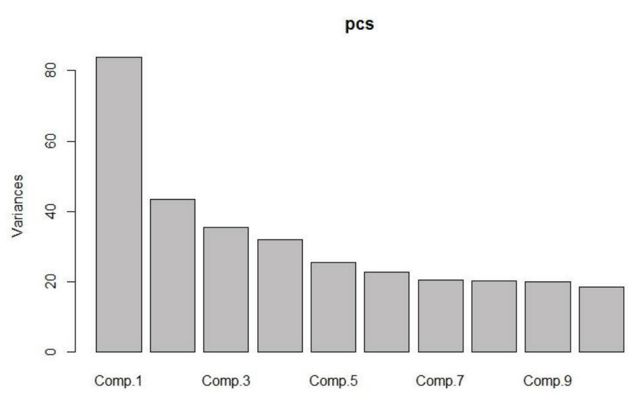


Figure 3.5 Principle Components, 7-day low flow for all stations

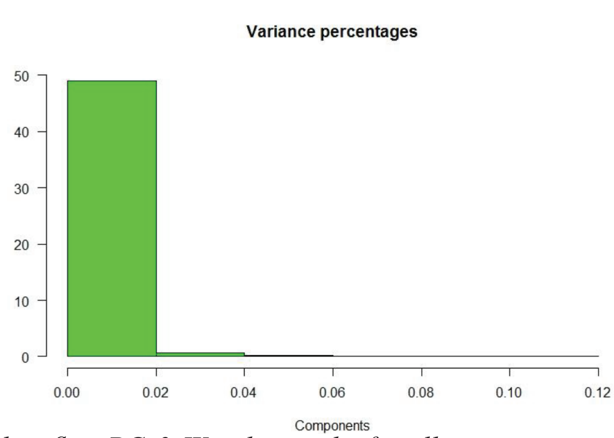
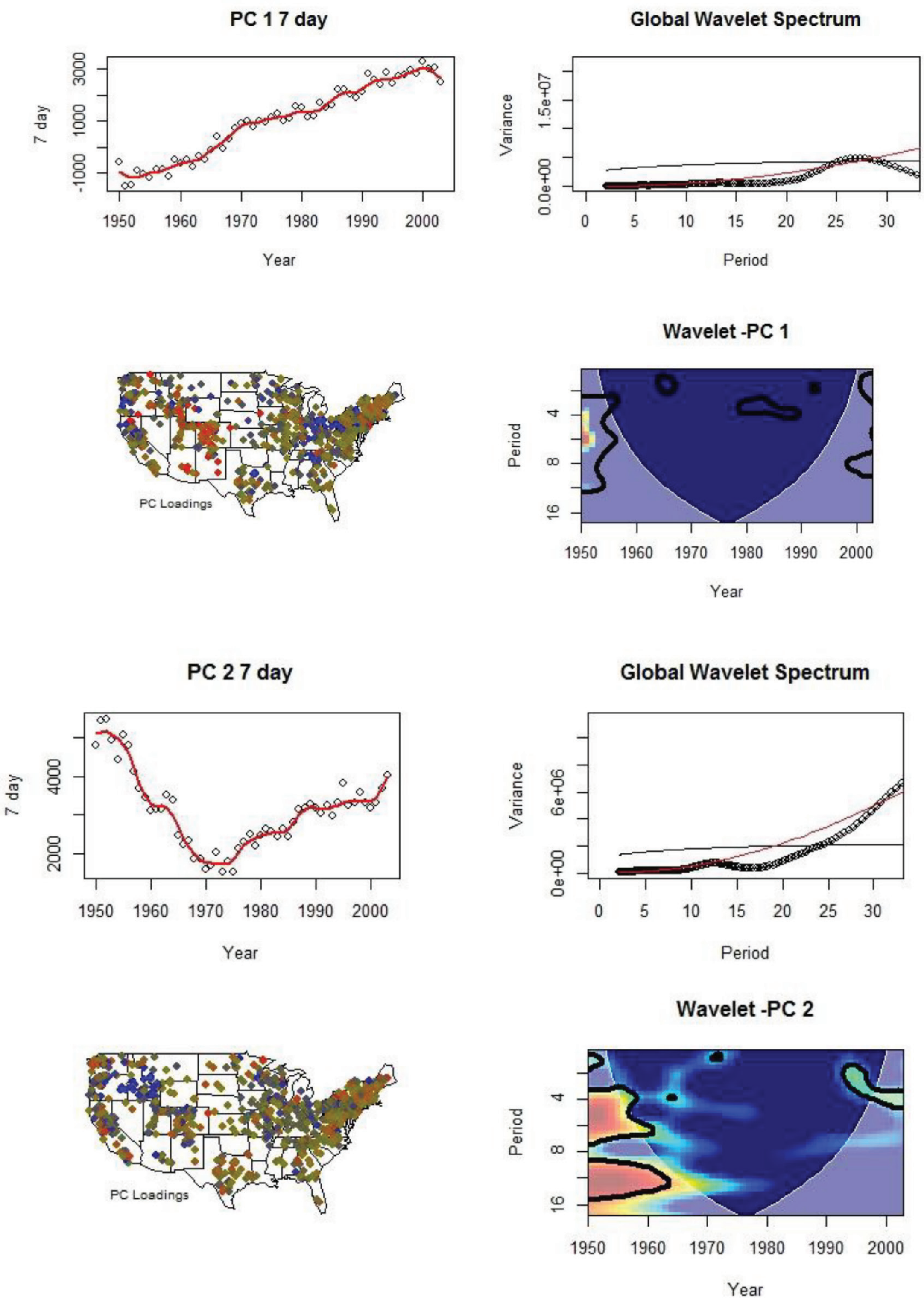


Figure 3.7 7-day low flow PC & Wavelet results for all stations


PC 1 7 day
7 day
Year
Global Wavelet Spectrum
Variance
Period
PC Loadings
Wavelet -PC 1
Period
Year
PC 2 7 day
7 day
Year
Global Wavelet Spectrum
Variance
Period
PC Loadings
Wavelet -PC 2
Period
Year

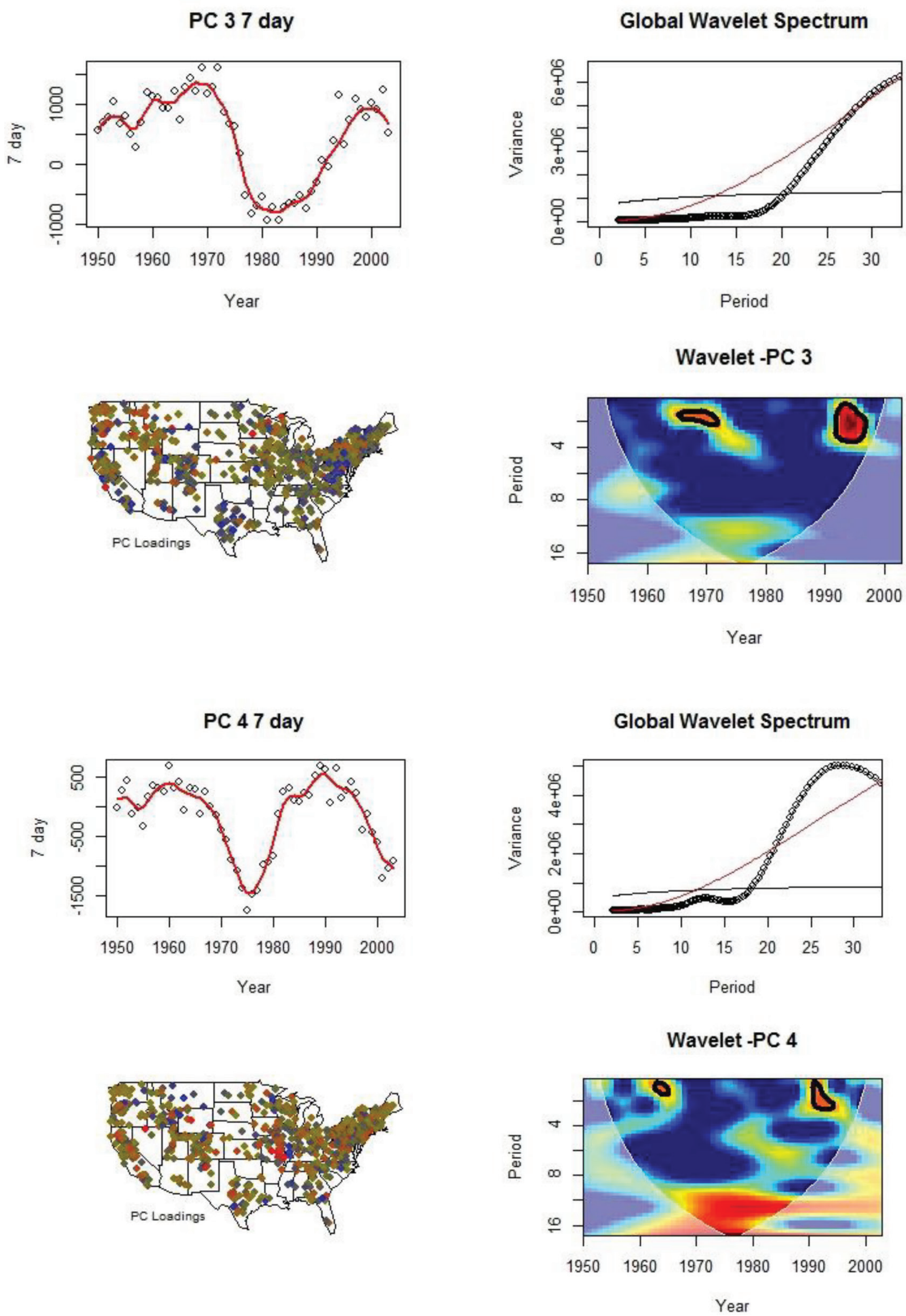
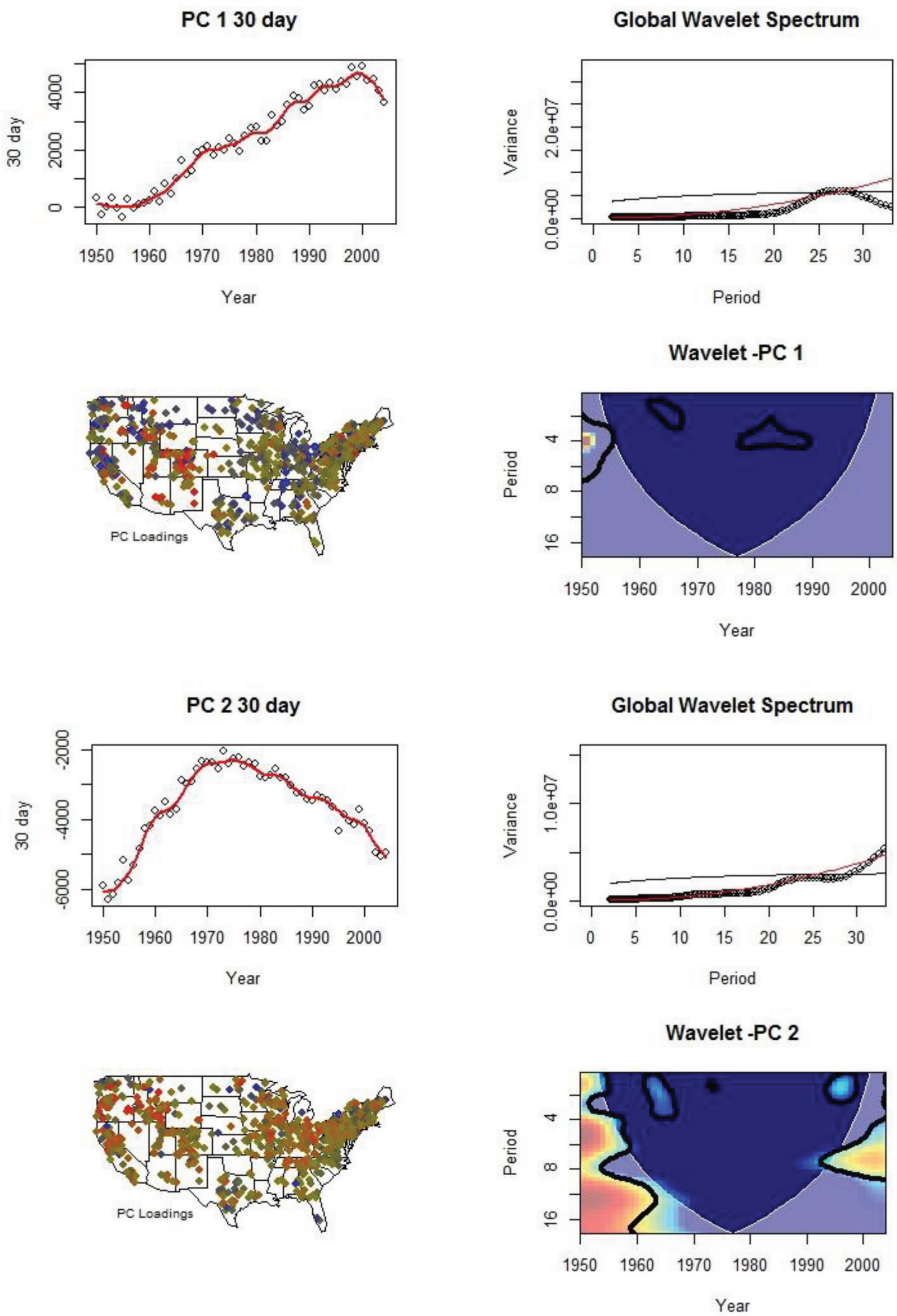


Figure 3.7 7-day low flow PC & Wavelet results for all stations


PC 1 30 day
30 day
0
2000
4000
1950 1960 1970 1980 1990 2000
Year
Global Wavelet Spectrum
Variance
0.0e+00
2.0e+07
0 5 10 15 20 25 30
Period
PC Loadings
Wavelet -PC 1
Period
4
8
16
1950 1960 1970 1980 1990 2000
Year
PC 2 30 day
30 day
-6000
-4000
-2000
1950 1960 1970 1980 1990 2000
Year
Global Wavelet Spectrum
Variance
0.0e+00
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8
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1950 1960 1970 1980 1990 2000
Year

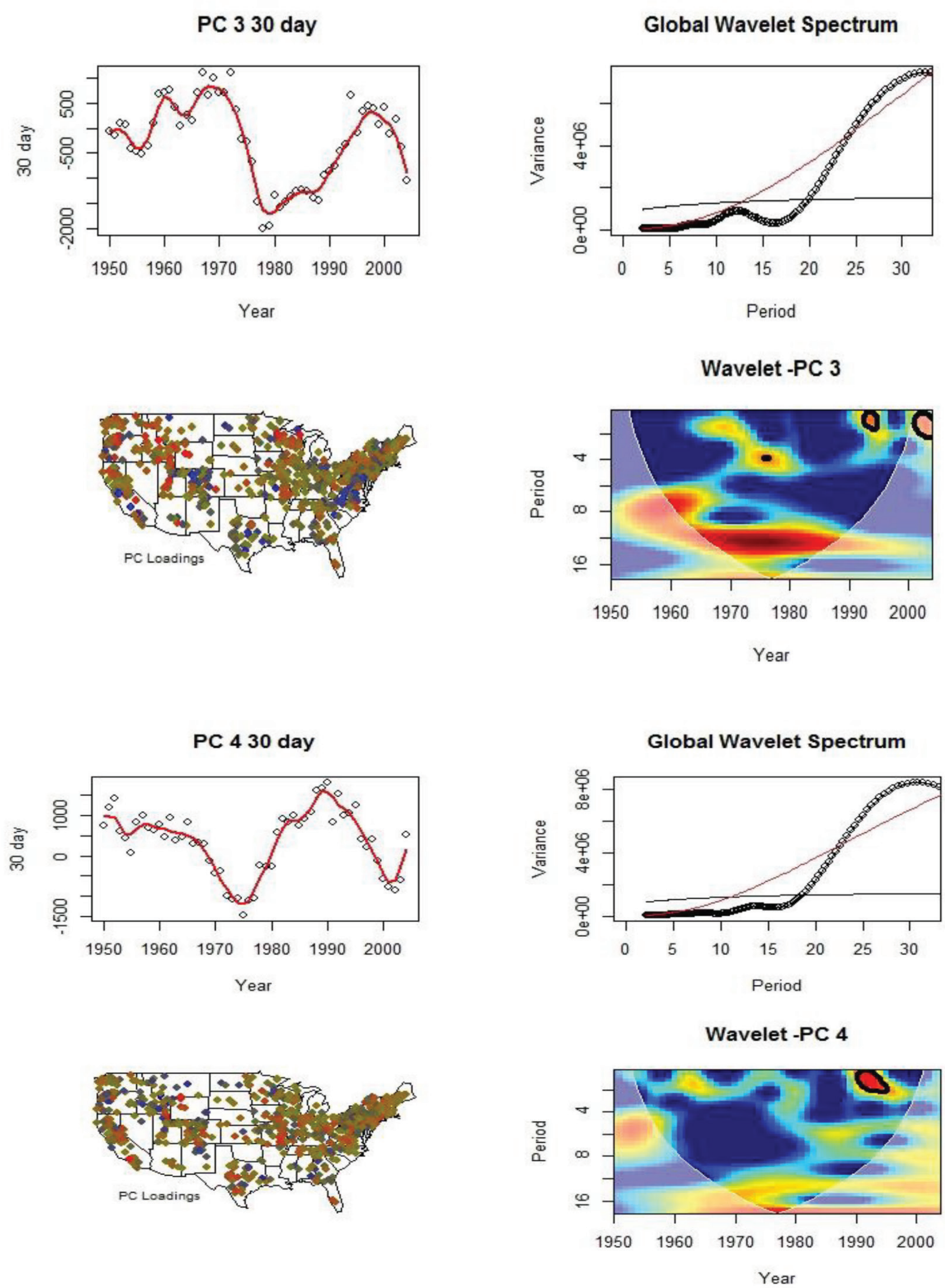

Figure 3.7 7-day low flow PC & Wavelet results for all stations

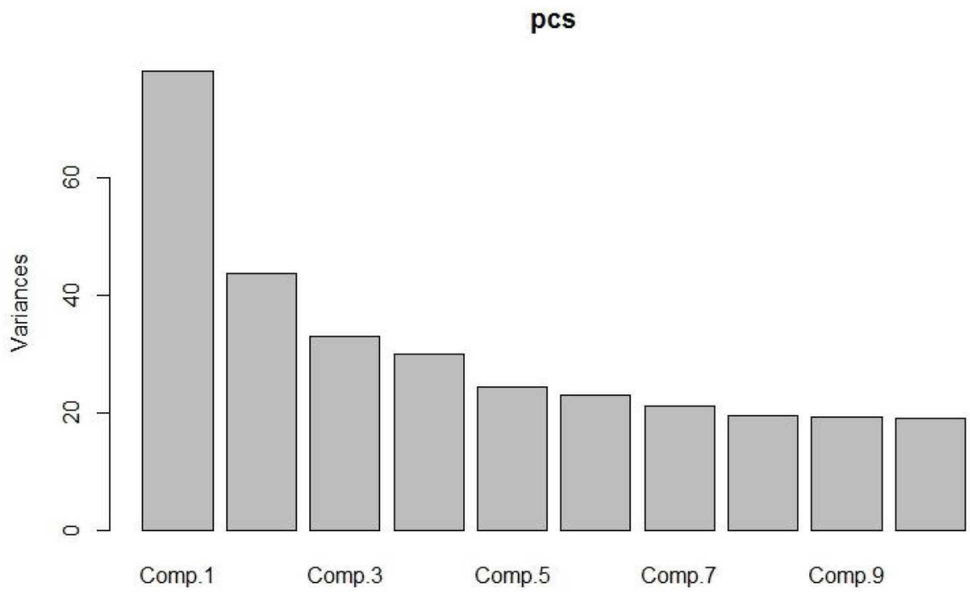

Figure 3.7 7-day low flow PC & Wavelet results for all stations

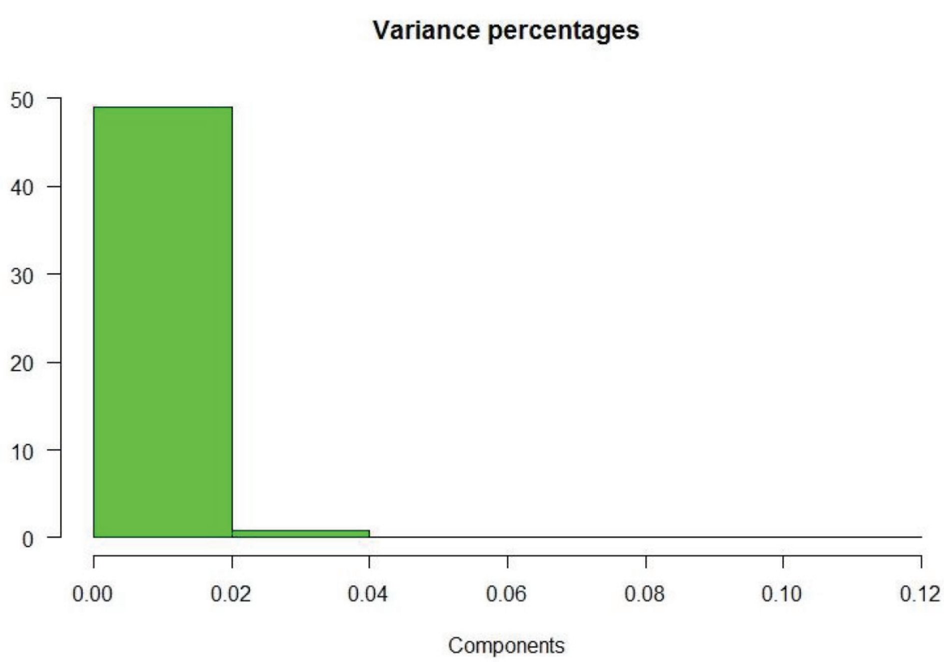

Figure 3.10. Percentage of variance explained, 30-day low flow for all stations

4. Discussion and Conclusion

Trends in low flows were evaluated in the United States by using Mann-Kendall Trend Test and the Sen Slope. Trends were considered statistically significant if the significance was less than 0.05. Statistically significant upward trends in low flows were found in most regions in the United States. Sample size of the referenced stations is pretty low compared to the non-referenced stations. Only number of non-referenced stations is appropriate for a reasonable trend assessment. Therefore, it has been decided to compare these referenced and non-referenced stations with the percentage of their significant trends. 29 percent of referenced stations have significant trends while 58 percent of non-referenced stations have significant trend results based on 7-day low flow data. 26 percent of referenced and 41 percent of non-referenced stations show upward trends in 7-day low flows. There has been found a slight increase in percentage of significant trends when it comes to 30-day low flow. 31 percent of referenced stations have significant trends while 59 percent of non-referenced stations have significant trend results based on 30-day low flow data. 25 percent of referenced stations and 45 percent of non-referenced stations have upward trends in 30-day low flows.

Table 4.1.

Percentages of statistically significant stations

	Referenced Station %	Non-referenced Station %
7 day low flow	29	58
30 day low flow	31	59

Furthermore, cluster analysis was performed to group low streamflow patterns across the United States to detect similar annual flow behaviors. There have been found 5 main groups in 7-day annual low flows and 6 main groups in 30-day annual low flows. Analysis also performed only referenced and non-referenced stations to make a comparison. Referenced stations have more homogeneous distribution of grouping low streamflow patterns.

Lastly, principle component analysis was applied to annually low streamflow observations in order to characterize variability. The highest and the most significant contribution percentage belong to the first component (PC-1) for both 7-day and 30-day flows. Therefore, it is possible to say time series of PC-1 explains the annual low flow variability accurately. There is an upward trend in 7-day and 30-day low flows based on the information gathered from the PC-1. This results also supports the obtained results from Mann-Kendall Trend Test and Sen-Slope.

Wavelet spectral shape is determined by the distribution of event time-scales. However, more work is needed to establish the use of wavelets for much accurate and reasonable low streamflow analysis, obtained results suggest that low flows may be classified into distinct categories.

It is also reasonable to identify the correspondence between low flow and climatic changes. Changes in hydrological drought indicators and climate is linked to the behavior of low flows. This research only shows that human disturbed stations have higher significant trends than the least disturbed stations. This provides an evidence that water resources / low streamflow is impacted by environmental change and climate variability. Thus, it is possible to say observed trends in low streamflow is affected by human activities. However, there are also climate teleconnection patterns as natural variability and they have possible impacts on low flows. Therefore, naturally occurring teleconnection patterns should also be considered before making a final decision.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Amerika Birleşik Devletleri'ndeki Minimum Akım Trendleri

Dünya Meteoroloji Örgütü'nün tanımına göre minimum akım; kurak mevsimdeki süre boyunca nehirdeki suyun akışıdır. İzin verilebilen deşarj limitlerini belirlemek için istatistiksel hesaplamalarda 7 günlük ve 30 günlük en düşük akım değerleri kullanılmaktadır.

Kuraklık kavramının belirleyici faktörlerinden olan minimum akım, ayrıca su kaynaklarının yönetimi için de oldukça önemli bir unsurdur. Ülkedeki su kaynaklarının sahip olduğu minimum akım davranışı ve eğilimleri, gelecek için karar oluşturma ve etkin planlama gibi stratejik öneme sahip süreçlerde kullanılabilecek bilgilerdir. Minimum akımın uzun vadeli olarak birbirini takip etmesi sonucunda kronik su kıtlığı oluşabilir. Su kıtlığı; bölgedeki kullanılabilecek su kaynaklarının talep edilen miktarı karşılayamamasından dolayı ortaya çıkan bir sorundur. Bahsedilen su kıtlığı sorunu ise ülkedeki sosyal ve ekonomik yapıyı önemli ölçüde etkileyen etkenlerden birisidir. Talep edilen su miktarının karşılanamaması, ülke ekonomisine katkıda bulunan tarımsal ve endüstriyel üretimi olumsuz etkileyeceği gibi temel insan ihtiyaçları arasında olan evsel su kullanımının karşılanmasının da zorlaştırmaktadır.

Bu çalışma; iklim değişikliği ve antropojenik etkilere maruz kalan tüm bölgeler ile sürdürülebilir yönetim adaptasyonu uygulanabilecek diğer bölgeleri kapsamaktadır. Ülkedeki minimum akım trendleri Birleşik Devletler Jeoloji Kurumu (United States Geological Survey – USGS) nun akım gözlem istasyon verileri kullanılarak hesaplanmıştır. Akım gözlem istasyonları; insan aktivitelerine maruz kalmış (antropojenik) ve bu aktivitelerden etkilenmemiş olarak iki ayrı kategoriye ayrılıp incelenmiş ve trend karşılaştırma analizi yapılmıştır. Karşılaştırma analizi sonuçları sayesinde ülke genelindeki minimum akım eğilimlerinin, antropojenik aktivitelerden etkilenip etkilenmediğini ve doğal bir döngüye dahil olup olmadığı incelenmiştir.

Gerçekleştirilen minimum akım trend analizleri parametrik olmayan Mann-Kendall ve Sen-Slope trend testleri kullanılarak değerlendirilmiştir. Birleşik Devletler Jeoloji Kurumunun, toplamda 727 adet akım gözlem istasyonunun verileri %95 önem düzeyi kullanılarak analiz edilmiştir. Bahsi geçen 727 adet akım gözlem istasyonunun her biri 80 yıllık günlük minimum akım verisine sahip olup istasyonların günlük verileri; 7 günlük ve 30 günlük minimum akım verilerine dönüştürüldükten sonra Mann-Kendall ve Sen-Slope Trend testleri uygulanmıştır. Parametrik olmayan bu istatistiksel testlere göre Birleşik Devletler genelinde minimum akım için artan yönde bir trend tespit edilmiştir.

Antropojenik etkilere maruz kalan akım gözlem istasyonları ile bu etkilere maruz kalmamış olan akım gözlem istasyonları trend karşılaştırma analizi sonucunda; antropojenik etkilere maruz kalmış olan istasyonlardaki istatistiksel olarak önem arz eden akım trend yüzdelerinin, etkiye maruz kalmamış olan akım gözlem istasyonlarına oranla daha yüksek olduğu bulunmuştur.

Bahsedilen trend analizlerinin dışında, Dalgacık Dönüşümü (Wavelet Analysis), Temel Bileşen Analizi (Principle Component Analysis – PCA) ve Kümeleme Analizi (Clustering Analysis) de 80 yıllık günlük minimum akım verisine sahip olan 727 adet akım gözlem istasyonuna uygulanmıştır. Uygulanan bu analizler ile minimum akım büyüklüğü ve süreksizlikler tespit edilmiştir. Ayrıca, Birleşik Devletler genelinde benzer minimum akım trendleri ve özellikleri gösteren istasyonlar gruplandırılmıştır. Bu sayede ülke genelinde, benzer yıllık minimum akım yapısına sahip olan akım gözlem istasyonlarının bulunduğu bölgeler coğrafi olarak tespit edilmiştir. Tüm akım gözlem istasyonları ise kümeleme analizi sonuçlarına göre kendi içerisinde 7-günlük minimum akım için 5 ana gruba; 30 günlük minimum akım için ise 6 ana gruba ayrılmaktadır. Analizler aynı zamanda antropojenik etkiye maruz kalan ve maruz kalmamış olan gözlem istasyonları için de uygulanıp karşılaştırma yapılmıştır. Antropojenik etkiye maruz kalmayan doğal ortamdaki akım gözlem istasyonları gruplandırmada, antropojenik etkiye maruz kalan istasyonlara göre çok daha homojen bir dağılım göstermektedir.

Temel bileşen analizi (PCA) sonuçları Mann-Kendall ve Sen-Slope Trend testi sonuçlarını desteklemekte olup, birinci bileşenin (PC-1) zaman serileri yıllık minimum akım verilerinin değişkenliğini karakterize etmektedir. Dalgacık Dönüşümü (Wavelet) Analizi ise zaman serilerindeki minimum akım olayı dağılımını tespit ederek dalgacık spektral şeklini ortaya çıkarmaktadır.

Son olarak; minimum akım ile iklim değişikliği bileşenleri arasındaki uygunluk analizi yapılarak minimum akım davranışının iklim değişikliği ve diğer kuraklık indikatörleri ile bağlantısını dikkate alıp daha detaylı bir çalışma yapılabilir. Çalışmanın sonucunda tespit edilen insan etkilerine maruz kalan istasyonlardaki eğilim yüzdesinin etkilere maruz kalmayanlara oranla daha yüksek olması, su kaynaklarının insan etkileri sonucu oluşan çevresel değişiklerden ve iklim değişikliğinden etkilendiğini göstermektedir.

First Biological Monitoring in the Akarçay Basin According to the Water Framework Directive: Phytoplankton and Phytobenthos

Nilsun DEMİR[1], Tolga ÇETİN[2], Caner GÖK[2], Müge ŞANAL[1]

Abstract

In this study, it was aimed to investigate of phytoplankton and phytobenthos in 19 rivers and Lake Eber for the assessment of ecological quality in the Akarçay basin. A total of 63 phytoplankton species were identified. Phytoplankton was evaluated according to sensitive species and pollution indicators in rivers. Lake Eber was determined as eutrophic and sensitive area according to phytoplankton functional groups and Q Index. The presence of phytobenthic macroalgae was detected only some sampling points in rivers. Therefore diatoms were used as phytobenthos quality element. A total of 64 diatom species were identified and diatom indices were calculated. Concerning the phytobenthos assessment, IDP index ranged between 2 and 4, and ecological status changed between medium and very bad.

Key words: *Water Framework Directive, ecological quality, phytoplankton, phytobenthos, diatom*

1. Introduction

The foundation of the legislation on water quality was laid by the Water Framework Directive (WFD) 2000/60/EC (Anonymous, 2000) and related directives in the European Union. Adopting the understanding that stand-alone assessment of physical and chemical analyses which are traditionally carried out for the determination of water quality does not suffice, WFD puts the biological monitoring activities at the core of the determination of water quality. WFD offers various steps in order to execute the biological monitoring in a systematic way. Establishing a typology system which starts with the delineation of water bodies that are the smallest manageable units of water bodies in a river basin which classifies the water bodies according to abiotic criteria sets the basis for those steps (Anonymous 2003a; b). Definition of undisturbed or least impaired reference sites which need to be identified for each type of water body is a new concept in the biological monitoring activities, and it constitutes the most important step of the biological monitoring system according to the Directive (Anonymous 2003b). Water bodies and their types were identified for Turkey (Anonymous 2014a) and the activities for determination of reference sites and country-specific indices are still ongoing. A twinning project was executed for the transposition of the WFD in the field of protection and management of water resources, and "By-law on Monitoring Surface and Ground Waters" has been drafted for protecting and monitoring waters.

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Phytoplankton and phytobenthos are listed among the biological quality elements that should be monitored in water bodies according to the WFD. In order to evaluate the phytoplankton according to the WFD, indices based on biomass, abundance and composition were developed (Anonymous 2014b; Mischke et al. 2011; Padisak et al. 2006; Philips et al. 2011). There were some researches concerning the use of phytoplankton in monitoring in Turkey (Çelekli and Öztürk 2014; Çelik and Ongun 2008; Demir et al. 2014).

Adaptation of phytobenthos to the methodologies of European countries was a more challenging process compared to the phytoplankton. As a matter of fact, phytobenthos contains all phototrophic organisms from microscopic unicellular organisms to macrophytes taller than 2 meters (Anonymous 2010) and phytobenthos includes non-macrophytic components of benthic flora accordingly. Due to the lack of practical methods to use phytobenthic macroalgae in the assessment of water quality and due to the fact that phytobenthic macroalgae are used for the assessment only in three countries (Czech Republic, Austria and Germany) (Anonymous 2015), diatoms have started to be used considering that they represent an important component of phytobenthos quality element. Many studies were executed on diatom indices for the water quality assessment (Anonymous 2014c; Dell'Uomo 2004; Gomez and Licursi 2001, Kelly 1998). Certain studies were carried out for the determination of water quality by using diatom indices in Turkey (Kalyoncu et al. 2009; Solak 2011). But this is the first study for ecological assessment of Akarçay basin according to WFD aims.

Regarding the diatom studies which were carried out in Akarçay Basin, 107 epipelic diatoms were identified as a result of the sampling on a monthly basis from four points from March to December in 2008 in Akarçay River (Kıvrak and Uygun 2012). Water quality was assessed according to epipelic diatoms and aquatic macrophytes which were sampled in the Akarçay River (Kargıoğlu et al. 2012). The correlation between diatom indices and environmental variables were also examined (Kıvrak et al. 2012). The algal flora of Lake Akşehir was identified by Elmacı and Obalı (1998). But this lake could not be sampled because of shallowness.

Monitoring activities were started in five basins within the scope of the harmonization process of the WFD in Turkey. In this study, it is aimed to monitor the Akarçay Basin on a basin scale and to obtain findings of phytoplankton and phytobenthos to estimate the ecological quality.

2. Method

Akarçay Basin is a closed basin located between Central Anatolia, Aegean and Mediterranean regions (30º 02' – 31º 51' E and 38º 04' – 39º 09' N). The length of the basin is approximately 130 km and width is 20 km. The main source of Akarçay River is constituted by the confluence of Acıçay and Aksu streams. Akarçay can be used as drinking water in upstream but the water quality declines in downstream mainly because of agricultural and other anthropogenic activities. The river discharges into Lake Eber after 80 km of the source and causes eutrophication of the lake (Anonymous 2013a; Kıvrak and Uygun 2012; Kıvrak et al. 2012).

The precipitation area of Akarçay Basin is 7605 km^2 and the mean annual precipitation changes between 400 and 500 mm. The climate of the basin is continental type with a temperature of 20-25^{o}C in summer and 0-3^{o}C in winter (Anonymous 2013b; Kargıoğlu et al. 2012).

The biological monitoring of Akarçay Basin was carried out in 20 water bodies (19 rivers and Lake Eber) in April 2013. Sampling points were identified by the Directorate General for Water Management of the Ministry of Forestry and Water Affairs (Figure 1). The locations of the sampling stations are given in Table 1. Lake Akşehir was very shallow and covered by macrophytes. Thus phytoplankton could not be sampled. Also, two streams feeding the lake were found to be dry and not sampled.

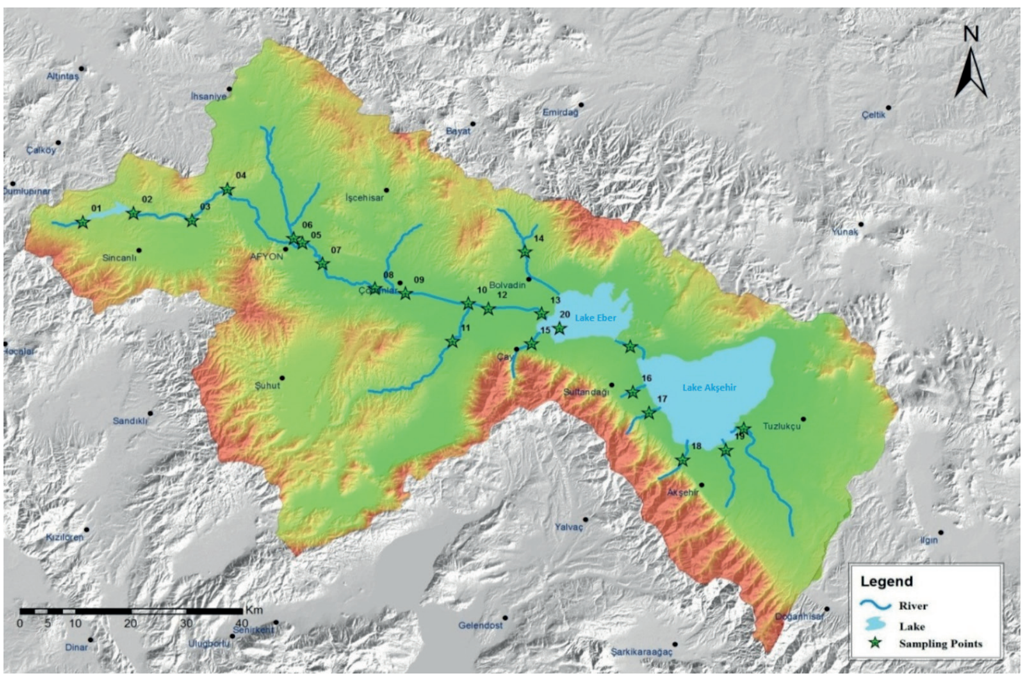

Figure 1. Map of sampling points in Akarçay Basin

Phytoplankton samples were taken from active flows in rivers and from euphotic zone (pelagial) by Ruttner sampler in Lake Eber. A plankton net (55 µm mesh size) was used for qualitative analysis. Samples were preserved by Lugol solution. Phytoplankton were identified by a trinocular microscope (Leica DM750) and counted in 5 or 10 ml Hydrobios chambers by inverted microscope (Leica DMIL) with a camera (Anonymous 2006). The key books (John et al. 2002, Komarek and Anagnostidis 1999, 2005; Komarek and Fott 1983; Krammer and Lange-Bertalot 1985, 1986, 1988, 1991a, b; Lind and Brook 1980; Popovski and Pfiester 1990; Prescott 1973) were used for the identification. Cell dimensions of phytoplankton species were measured with a Leica DMIL microscope, digital camera and Leica Application Suite. Phytoplankton biovolume was calculated and biomass was estimated corresponding geometrical forms on the basis of wet weight (Hillebrand et al. 1999; Rott 1981). The Q Assemblage index was estimated from the biomass of phytoplankton functional groups in Lake Eber (Padisak et al. 2006) and ranged from 0 to 5 on a scale according to the WFD requirements. Values of the index between 0 and 1 are classified as bad, between 1 and 2 as tolerable, 2 and 3 as medium, 3 and 4 as good, and 4 and 5 as of excellent ecological quality.

Table 1.
Sampling points, codes, coordinates, water body types and locations in Akarçay Basin

Point	Code	Coordinate	Typology	Water Body Name & Location
01	SMAKR01	38°47'46.14"N 30°07'33.48"E	A2R2E1Y2D1J2	Eğrek Stream Afyon Sinanpaşa - Karacaören Village
02	SMAKRY01	38°48'45.05"N 30°13'32.70"E	A2R2E1Y2D1J1	Akarçay Afyon Sinanpaşa - Akdeğirmen Village
03	SMAKRY02	38°48'05.10"N 30°20'45.60"E	A2R2E1Y2D1J1	Akarçay Afyon Sinanpaşa - Balmahmut Village
04	OMAKR03	38°51'32.96"N 30°24'47.97"E	A2R2E1Y2D1J1	Akarçay Afyon - Bayramgazi Village
05	OMAKR04	38°46'11.60"N 30°34'28.40"E	A2R2E1Y2D2J1	Akarçay Afyon - Akçın Village
06	SMAKR1102	38°46'51.00"N 30°33'27.70"E	A2R2E1Y2D1J2	Çayırbaşı Stream Afyon - Organized Industrial Zone
07	SMAKRY03	38°44'08.40"N 30°37'09.30"E	A2R2E1Y2D2J1	Akarçay Afyon - Airport
08	SMAKRY04	38°41'06.82"N 30°46'12.33"E	A2R2E1Y2D2J1	Akarçay Afyon - City Center
09	OMAKR0405B	38°40'51.74"N 30°47'45.09"E	A2R2E1Y2D2J2	Akarçay Afyon - Çobanlar
10	OMAKR09	38°40'09.60"N 30°55'32.00"E	A2R2E1Y2D2J2	Akarçay Afyon Bolvadin - Kadıköy
11	PAZARAĞAÇ	38°36'02.30"N 30°53'37.64"E	A2R2E1Y2D2J1	Kali Stream Afyon Çay - Maltepe Village
12	OMAKR10	38°39'41.46"N 30°58'06.38"E	A2R2E1Y2D2J2	Akarçay Afyon Bolvadin - Kadıköy
13	OMAKR0405A	38°39'47.26"N 31°04'00.17"E	A2R2E1Y2D2J2	Akarçay Afyon Bolvadin - Lake Eber Input
14	OMAKR25A	38°46'26.00"N 31°02'17.40"E	A1R2E1Y1D1J2	Kirazlı Stream Afyon Bolvadin - Dişli Village
15	OMAKR27B	38°36'19.60"N 31°04'09.90"E	A2R3E2Y2D1J1	Çay Stream Afyon Bolvadin - Yeşilyurt Village
16	SMAKR17	38°30'12.80"N 31°17'47.30"E	*	Afyon Sultandağı - Dereçine Village
17	SMAKR19	38°28'32.80"N 31°19'43.90"E	*	Konya Akşehir - Gölçayır Village
18	SMAKR21	38°24'29.80"N 31°22'51.40"E	A1R3E2Y2D1J1	Nazilli Stream Konya Akşehir - Atakent Village
19	OMAKR22	38°26'19.90"N 31°28'23.50"E	A2R2E1Y2D1J2	Adıyan Stream Konya Akşehir - Karabulut Village
20	SMAKL03	38°36'56.10"N 31°07'34.30"E	R2D1A2J1	Lake Eber Afyon Bolvadin

**Typology of the water body could not be determined since the Strahler order is lower than 3.*

In the stream bed and cross sections, macroalgae was observed visually and abundance of macroalgae was estimated on a scale between 1 and 5 (Anonymous 2010). Samples were preserved by Lugol solution and dominant macroalgae were identified using John et al. (2002). Diatoms were scraped with a brush from submerged substrates primarily from removable cobbles or small boulders (epilithic). When there was no removable stone present in the stream bed, samples were collected from submerged common reeds (Phragmites australis (Cavanilles) Trinius et Steudel). P. australis is an ideal macrophyte for the sampling of diatoms (epiphytic) (King et al. 2006). Submerged parts of reeds were cut and placed in 300 ml container with some water and shaken vigorously. Plants were removed from the container and samples were preserved (Anonymous 2004). If the bottom structure was not rocky which was composed of sand, silt, particulate organic matter or clay, sediment samples were taken by a pipe (epipelic) and preserved (Anonymous 2002).

Epiphytic diatoms were sampled from the reed belt in the middle of Lake Eber. Hydrogen peroxide was used for the cleaning of diatom frustules in lab and slides were prepared by Naphrax (Anonymous 2004). Diatoms were identified with trinocular Leica microscope-camera using relevant taxonomic literature (Cox 1996, Krammer and Lange-Bertalot 1985, 1986, 1988, 1991a, b, Lange-Bertalot 2013). Diatom indices such as SLA, DES, IDG, SHE, TDI, CEE, IPS, IDAP and IDP were calculated by using OMNIDIA 5.3 (Lecointe et al., 1993). Results were evaluated according to IDP (Gomez and Licursi 2001). IDP is classified between 0 and 0.5 as excellent, 0.5 and 1.5 as good, 1.5 and 2.0 as medium, 2.0 and 3.0 as bad and more than 3.0 as very bad ecological quality according to WFD requirements.

3. Results

A total of 63 phytoplankton species were identified from sampling points of Akarçay Basin, which belongs to Bacillariophyta (25), Chlorophyta (23), Ochrophyta (2), Cryptophyta (2), Cyanobacteria (8) and Euglenozoa (3) (Table 2). In rivers, phytoplankton biomass was quite low and mostly it was consisted of periphytic species which belong to Bacillariophyta division. Phytoplankton Q index could be applied only to Lake Eber among the sampling points in Akarçay Basin. Because true phytoplankton community did not occur in rivers in Akarçay Basin.

In Lake Eber, it was concluded that J group which was one of the dominant functional groups in small and lakes rich in nutrients accounts for 36% of total phytoplankton biomass, and J group was followed by C with 25% which is dominant in eutrophic and small-medium sized lakes. Also F (%9.5), X1 (%7.8) and S1 (%5.8) groups were found. In the Akarçay Basin, Lake Eber was the only water body where phytoplankton index was used. Q index was predicted as 2.57 (medium ecologic status) based on phytoplankton functional groups. Although the species belong to Cyanobacteria were not proportionally high in the sampling period, the presence of some species pointed out that there might be sudden algal blooms in summer and autumn in the lake. For this reason, medium ecologic status was pre-assessment and monitoring studies should be continued.

Phytobenthic macroalgae, *Hydrurus foetidus* (Villars) Travisan from Chrysophyceae was identified in the sampling points 16 and 18. *Oscillatoria limosa* (C. Agardh) Gomont from Cyanobacteria and Spirogyra sp. from Chlorophyta were found in the sampling point 5 pointed out organic pollution. Due to the fact that phytobenthic algae were rarely distributed between %1-5, the assessment of indices were carried out by using diatoms. Diatom species identified in the Akarçay Basin are shown in the Table 3.

Table 2.

Total abundance, biomass and biomass based composition (%) of phytoplankton species in Akarçay Basin

	Species	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
	Achnanthidium minutissimum (Kützing) Czarnecki	3.8	24.1	0.3	1,0	-	-	-	3.5	-	-	-	-	-	-	-	-	-	-	-	-
	Asterionella formosa Hassall	14.4	-	6.1	5.5	-	-	4.8	28.1	7.9	2.2	-	2.4	-	-	-	-	-	-	-	-
	Aulacoseira granulata (Ehrenberg) Simonsen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6
	Brebissonia lanceolata (C.Agardh)Mahoney& Reimer	-	-	-	-	-	-	-	-	-	-	2.1	-	-	-	-	-	-	-	-	-
	Caloneis amphisbaena (Bory) Cleve	-	-	-	-	21.5	-	14.0	-	-	11.0	2.1	7.0	5.9	-	-	-	-	-	-	-
	Cyclotella meneghiniana Kützing	-	-	0.2	0.5	-	1.0	0.6	0.2	7.2	-	-	0.8	0.4	-	-	-	-	-	-	24.7
	Diatoma vulgaris Bory	-	-	-	4.7	8.6	-	1.6	6.5	-	-	-	6.4	-	-	-	-	-	-	-	-
	Encyonema minutum (Hilse) D.G.Mann	1.2	14.8	-	1.0	-	-	-	-	-	-	-	-	-	1.3	-	-	-	-	-	-
	Fragilaria construens (Ehrenberg) Grunow	23.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gomphonema olivaceum (Hornemann) Brébisson	7.1	-	-	2.1	-	11.0	3.3	19.1	2.2	-	5.6	-	-	13.4	-	-	-	-	-	-
	Melosira varians C.Agardh	2.3	18.9	-	2.3	2.9	-	2.1	2.9	-	1.8	0.9	-	0.9	-	-	-	-	-	-	-
	Navicula cryptocephala Kützing	-	-	-	0.7	0.9	13.8	2.7	0.7	12.5	2.8	1.1	4.9	2.0	1.1	-	-	-	-	-	-
BA	*Navicula gregaria* Donkin	-	-	-	-	6.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Navicula lanceolata Ehrenberg	-	-	-	-	-	19.7	-	-	-	-	-	14.9	-	-	-	-	-	-	-	-
	Navicula tripunctata (O.F.Müller) Bory	2.0	25.4	1.5	12.7	6.5	-	44.1	-	8.7	2.5	25.0	-	11.2	-	-	-	-	-	-	-
	Nitzschia acicularis (Kützing) W.Smith	37.0	5.6	0.4	0.5	6.0	0.9	2.5	3.7	6.4	4.4	-	0.9	0.7	0.8	-	-	-	-	-	1.3
	Nitzschia dissipata (Kützing) Rabenhorst	-	-	0.2	0.3	2.4	-	-	1.3	-	-	-	-	-	0.4	-	-	-	-	-	-
	Nitzschia palea (Kützing) W.Smith	-	-	12.2	0.7	17.0	2.2	1.4	2.4	12.5	14.5	-	8.2	5.6	24.5	-	-	-	-	-	-
	Nitzschia sigmoidea (Nitzsch) W.Smith	-	-	32.0	37.5	-	21.8	-	-	-	26.7	59.8	-	-	-	-	-	-	-	-	-
	Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	-	-	-	-	-	-	-	-	-	-	0.2	-	0.2	-	-	-	-	-	-	-
	Sellaphora pupula (Kützing) Mereschkovksy	-	-	-	0.3	-	-	-	-	1.0	1.4	-	-	-	-	-	-	-	-	-	-
	Surirella brebissonii Krammer & Lange-Bertalot	-	-	-	-	-	-	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-
	Tryblionella hungarica (Grunow) Frenguelli	-	-	0.7	1.5	-	2.7	4.7	6.5	-	1.7	-	-	0.4	4.6	-	-	-	-	-	-
	Ulnaria acus (Kützing)Aboal	1.3	-	-	-	-	-	-	-	-	2.5	-	-	-	15.9	-	-	-	-	-	-
	Ulnaria ulna (Nitzsch) Compére	-	-	25.8	25.5	24.9	11.1	15.4	21.6	35.8	25.0	-	51.7	37.3	9.5	-	-	-	-	-	-
	Actinastrum hantzschii Lagerheim	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2
	Acutodesmus acuminatus (Lagerheim) P.M.Tsarenko	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.2
	Chlamydomonas sp.	-	-	-	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-	-	-
	Crucigenia tetrapedia (Kirchner) Kuntze	-	-	-	-	-	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Desmodesmus opoliensis (P.G.Richter) E.Hegewald	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6
	Dictyosphaerium ehrenbergianum Nägeli	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.1
	Gregiochloris lacustris (Chodat) Marvan, Komarek & Comas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2
	Monoraphidium arcuatum (Korshikov) Hindák	-	-	0.1	0.1	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	-
	Monoraphidium contortum (Thuret) Kom.-Legn.	-	-	-	0.2	1.5	3.6	1.7	2.7	3.9	2.1	-	2.2	-	-	-	-	-	-	-	4.6
	Monoraphidium irregulare (G.M.Smith) Kom.-Legn.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3
	Monoraphidium komarkovae Nygaard	2.4	-	-	-	-	0.7	-	-	-	0.2	-	0.2	-	-	-	-	-	-	-	1.0
CH	*Monoraphidium minutum* (Nägeli) Komárková-Legn.	-	-	-	-	-	-	-	-	0.3	0.1	-	-	-	-	-	-	-	-	-	0.7
	Monoraphidium tortile (West & G.S.West) Kom.-Legn	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oocystis lacustris Chodat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
	Pediastrum dublex Meyen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**
	Pseudopediastrum boryanum (Turpin) E.Hegewald	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7
	Pseudodidymocystis planctonica (Korshikov) E.Hegewald & Deason	-	-	-	-	-	-	-	-	-	-	-	-	-	13.8	-	-	-	-	-	-
	Scenedesmus quadricauda (Turpin) Brébisson	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7
	Schroederia setigera (Schröder) Lemmermann	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9
	Sphaerocystis schroeteri Chodat	-	-	-	-	-	11.2	-	-	-	-	-	-	-	9.8	-	-	-	-	-	-
	Tetraedron caudatum (Corda) Hansgirg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**
	Tetraedron minimum (A.Braun) Hansgirg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**
	Tetrastrum staurogeniiaforme (Schröder) Lemm.	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7	-	-	-	-	-	4.5

	Species	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
OC	*Dinobryon divergens* O.E.Imhof	5.4	11.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mallomonas heterospina J.W.G.Lund	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
CR	*Cryptomonas ovata* Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0
	Plagioselmis nannoplanctica (H.Skuja) G.Novarino, I.A.N.Lucas & S.Morrall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**
CY	*Anabaenopsis elenkinii* V.V.Miller	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0
	Aphanocapsa incerta (Lemmermann) G.Cronberg & Komárek	-	-	**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1
	Komvoporon sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
	Merismopedia glauca (Ehrenberg) Kützing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.3
	Oscillatoria sp.	-	-	-	-	-	-	-	-	-	-	-	-	10.3	-	-	-	-	-	-	-
	Planktothrix agardhii (Gomont) Anagnostidis & Komárek	-	-	-	0.2	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
	Pseudanabaena limnetica (Lemmermann) Komárek	-	-	5.7	0.5	0.5	0.4	-	-	-	0.2	-	-	-	-	-	-	-	-	-	4.9
	Spirulina corakiana Playfair	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**
EU	*Euglena viridis* (O.F.Müller) Ehrenberg	-	-	13.8	2.2	-	-	1.3	-	-	-	3.2	-	24.2	3.2	-	-	-	-	-	-
	Lepocinclis acus (O.F.Müller) Marin & Melkonian	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-	-
	Phacus caudatus Hübner	-	-	1.1	-	-	-	-	-	1.6	-	-	-	-	-	-	-	-	-	-	-
	Total abundance (individual/ml)	1216	195	1030	444	2737	6668	818	1246	1246	5385	1165	3904	1864	501	***	***	***	***	***	56884
	Total biomass (mg wet weight/l)	0.37	0.07	0.67	0.43	0.77	2.12	0.48	0.42	0.31	2.52	2.17	1.99	1.69	0.15	***	***	***	***	***	6.11

BA; Bacillariophyta, CH; Chlorophyta, OC; Ochrophyta CR; Cryptophyta, CY; Cyanobacteria, EU; Euglenozoa

*** Rarely found. *** Biomass couldn't be calculated since the phytoplankton was rarely found.*

Table 3.

The composition of phytobenthic diatom species (%) in sampling points of Akarçay Basin

Species	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Achnanthidium exiguum (Grunow) Czarnecki	-	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Achnanthidium minutissimum (Kützing) Czarnecki	55.10	2.39	2.50	2.79	1.53	58.16	3.33	2.32	31.28	0.20	16.01	0.25	0.50	5.85	11.97	69.81	78.47	76.54	15.65	1.37
Amphora ovalis (Kützing) Kützing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.24	0.55
Amphora pediculus (Kützing) Grunow ex A.Schmidt	2.35	-	2.27	3.26	1.53	-	0.67	0.19	0.47	0.59	1.72	-	1.25	0.73	0.70	0.24	0.50	0.99	1.47	10.11
Brebissonia lanceolata (C.Agardh) Mahoney & Reimer	-	0.48	0.68	0.23	-	-	0.22	-	6.64	-	-	-	-	0.24	-	0.48	0.25	-	0.24	-
Caloneis amphisbaena (Bory) Cleve	-	-	-	-	-	0.95	0.22	0.19	-	0.20	-	0.50	3.75	-	-	-	-	-	0.24	-
Caloneis silicula (Ehrenberg) Cleve	-	-	-	-	0.25	-	-	-	0.47	-	-	-	-	-	-	-	-	-	-	-
Cocconeis pediculus Ehrenberg	0.20	0.48	1.36	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.24	-
Cocconeis placentula Ehrenberg	0.59	0.48	3.41	0.23	-	-	0.67	0.39	1.66	0.40	1.48	-	-	-	-	-	-	1.23	1.22	8.74
Craticula accomoda (Hustedt) D.G.Mann	-	-	0.23	-	-	0.24	-	-	-	-	3.45	-	-	-	24.65	-	-	-	-	0.55
Craticula ambigua (Ehrenberg) D.G.Mann	-	-	-	-	1.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Craticula cuspidata (Kützing) D.G.Mann	-	-	0.68	-	0.51	-	2.66	-	-	-	-	-	-	0.24	-	-	-	-	0.49	-
Cymatopleura elliptica (Brébisson) W.Smith	0.39	-	3.18	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.73	-
Cymatopleura solea (Brébisson) W.Smith	0.59	-	0.45	0.23	-	-	0.22	-	1.42	-	0.99	0.25	-	-	-	-	-	-	-	-
Cymbella excisa Kützing	4.71	2.63	1.82	0.70	0.51	-	1.33	-	1.18	-	-	-	-	-	-	-	-	-	0.98	-
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	-	-	-	-	-	-	-	-	0.47	-	-	-	-	-	0.23	-	-	-	-	-
Cymbella neocistula Krammer	-	4.77	-	-	-	-	-	-	-	-	-	-	-	0.98	4.46	-	0.25	0.74	0.73	7.10
Diatoma mesodon (Ehrenberg) Kützing	-	-	-	-	-	-	-	-	-	-	-	-	-	1.22	1.41	-	-	0.49	0.49	-
Diatoma tenuis C.Agardh	-	0.48	0.45	0.47	2.80	0.71	4.43	7.53	0.47	1.78	-	1.75	6.00	8.54	-	-	-	-	-	-
Diatoma vulgaris Bory	-	-	2.50	-	-	0.47	-	-	-	-	6.40	-	-	1.22	2.58	0.48	-	0.25	8.31	-
Diploneis separanda Lange-Bertalot	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-
Encyonema minutum (Hilse) D.G.Mann	1.18	0.48	1.59	-	0.51	2.36	-	-	-	-	-	-	3.00	1.95	7.28	0.97	1.24	0.49	5.62	3.55
Epithemia sorex Kützing	-	-	-	-	-	-	-	-	-	-	1.72	0.75	-	-	-	-	-	-	-	-
Fallacia pygmaea (Kützing) Stickle & D.G.Mann	-	-	-	-	1.27	-	-	1.16	0.71	1.19	1.48	-	2.75	0.49	-	0.24	-	-	-	5.46
Fragilaria capucina Desmaziéres	2.35	-	3.18	-	-	-	-	0.19	-	-	-	-	-	-	-	-	-	0.25	3.67	-

Fragilaria construens (Ehrenberg) Grunow	1.96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fragilaria vaucheriae (Kützing) J.B.Petersen	-	-	0.45	-	-	-	-	0.19	-	-	1.97	0.25	-	0.73	-	-	-	0.25	2.44	-
Gomphonema olivaceum (Hornemann) Brébisson	2.16	1.91	1.36	0.47	1.02	0.47	0.89	1.35	0.47	0.59	-	1.00	0.50	0.73	2.35	0.24	0.74	-	1.47	-
Gomphonema parvulum (Kützing) Kützing	4.51	1.43	-	1.63	9.16	3.55	1.77	7.72	0.47	5.53	-	4.74	15.00	6.83	4.93	0.48	1.49	1.48	3.67	-
Gyrosigma acuminatum (Kützing) Rabenhorst	0.20	0.48	0.23	-	-	-	-	-	0.24	-	-	-	-	0.24	-	-	-	-	0.49	-
Halamphora veneta (Kützing) Levkov	-	-	-	0.47	0.25	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hannaea arcus (Ehrenberg) R.M.Patrick	-	-	-	-	-	1.89	-	-	-	-	-	-	-	0.49	9.15	23.43	5.45	1.98	9.54	-
Hantzschia amphioxys (Ehrenberg) Grunow	-	-	-	-	-	-	-	-	-	-	-	-	0.50	0.73	0.23	-	-	-	-	-
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	-	-	-	-	0.51	-	-	-	-	-	-	-	0.50	-	-	-	-	-	-	-
Mayamaea atomus (Kützing) Lange-Bertalot	-	-	-	2.79	2.80	-	-	-	1.42	-	-	-	0.50	6.83	5.16	-	-	2.72	0.73	2.73
Melosira varians C.Agardh	-	-	0.91	-	2.29	-	-	-	0.47	-	-	0.75	-	-	-	-	-	-	0.73	-
Meridion circulare (Greville) C.Agardh	-	-	2.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.49	6.85	-
Navicula cryptocephala Kützing	0.78	0.72	-	-	32.32	7.57	-	-	7.35	3.56	1.72	10.47	5.75	-	5.40	1.21	1.98	0.25	1.47	2.73
Navicula lanceolata Ehrenberg	-	0.24	0.45	-	15.52	5.91	0.44	-	-	24.70	0.99	3.99	5.25	0.24	0.47	-	-	0.49	0.49	1.09
Navicula radiosa Kützing	-	-	-	-	-	-	-	-	-	-	-	-	-	0.24	-	-	-	-	-	6.83
Navicula rhynchocephala Kützing	-	-	-	-	-	-	-	0.58	-	-	-	-	-	-	0.23	-	-	-	0.73	-
Navicula tripunctata (O.F.Müller) Bory	0.98	44.63	5.23	2.79	1.78	0.71	14.63	2.90	0.71	0.40	17.98	-	0.25	1.22	5.16	0,48	1.24	3.95	3.91	3.28
Navicula trivialis Lange-Bertalot	-	1.19	1.14	0.70	1.02	0.95	-	0.19	-	-	-	-	-	-	-	-	-	-	-	-
Navicula veneta Kützing	1.18	0.48	0.68	-	-	-	-	-	-	-	-	-	-	-	-	0,48	0.50	1.48	0.73	-
Nitzschia acicularis (Kützing) W.Smith	0.39	-	-	-	-	0.47	3.33	2.32	-	0.59	1.23	-	0.25	-	-	-	-	-	-	8.74
Nitzschia amphibia Grunow	-	-	-	-	2.54	0.24	-	-	0.47	0.20	-	1.25	-	2.20	-	-	-	-	-	14.21
Nitzschia dissipata (Kützing) Rabenhorst	8.63	30.55	17.95		3.82	1.18	18.18	14.29	17.54	3.95	-	2.74	8.75	32.68	8.22	0,72	3.47	2.47	10.51	-
Nitzschia linearis W.Smith	2.16	-	2.95	0.70	0.25	0.24	-	0.19	0.71	-	-	0.25	0.25	0.24	-	-	-	0.25	4.65	-
Nitzschia palea (Kützing) W.Smith	-	0.48	5.45	4.42	8.40	4.02	11.31	15.06	8.29	37.15	28.82	10.22	11.00	0.24	-	-	3.71	-	-	6.83
Nitzschia sigmoidea (Nitzsch) W.Smith	0.20	3.58	7.27	1.16	0.51	-	0.22	0.19	1.90	-	-	0,50	-	-	-	-	-	-	0.73	-
Pinnularia brebissonii (Kützing) Rabenhorst	-	0.24	0.68	-	-	-	-	0.19	-	-	-	-	-	0.24	-	-	-	-	0.24	-
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	0.98	-	0.68	2.79	-	-	-	0.19	-	0.40	1.97	-	2.00	8.78	3.52	0,48	0.50	1.73	1.22	-
Reimeria sinuata (W.Gregory) Kociolek & Stoermer	-	-	-	-	-	-	-	-	0.71	-	0.74	-	-	-	0.47	0,24	0.25	1.23	0.73	-
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	-	-	0.45	-	-	-	-	0,19	0.24	-	-	-	-	-	-	-	-	-	0.49	-
Rhopalodia gibba (Ehrenberg) O.Müller	0.20	0.48	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-
Sellaphora pupula (Kützing) Mereschkovksy	1.18	-	2.95	0.23	0.25	0.24	0.67	1.16	0.47	-	1.48	4.24	7.50	0.98	-	-	-	-	0.24	0.82
Surirella angusta Kützing	-	-	0.45	-	-	-	-	0.19	0.71	-	-	0.25	-	0.24	-	-	-	-	0.98	-
Surirella brebissonii Krammer & Lange-Bertalot	3.92	0.48	6.59	0.70	1.53	1.65	-	2.32	1.66	10.47	2.46	4.49	2.25	0.73	0.47	-	-	-	2.44	-
Surirella ovalis Brébisson	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-	-
Surirella minuta Brébisson ex Kützing	0.20	-	-	-	-	0.47	-	-	-	-	1.23	-	-	-	0.23	-	-	-	-	0.27
Tryblionella hungarica (Grunow) Frenguelli	0.39	-	5.68	1.16	4.33	5.67	14.41	10.62	5.45	5.53	6.16	35.91	17.00	1.95	-	-	-	-	1.22	3.28
Ulnaria acus (Kützing) Aboal	-	-	-	-	-	-	-	-	0.24	0.99	-	-	-	-	-	-	-	-	0.24	11.75
Ulnaria capitata (Ehrenberg) Compére	-	-	0.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ulnaria ulna (Nitzsch) Compére	2.55	0.95	11.14	3.49	1.02	1.65	20.40	28.19	5.45	1.19	-	15.21	5.25	11.95	0.70	-	-	0.25	2.69	-

Results were assessed by selecting indices among the ones in the OMNIDIA programme which include diatom species identified in the Akarçay Basin (Table 4).

Table 4.

Values of diatom indices in the sampling points of Akarçay Basin

Nokta	SLA/4	DES/5	IDG/5	SHE/7	TDI/100	CEE/10	IPS/5	IDAP/5	IDP/4
1	1.62	3.99	3.05	4.77	47.20	7.50	3.28	2.75	2.40
2	1.28	4.89	4.03	4.96	81.90	7.60	2.59	3.85	2.11
3	1.74	4.11	3.19	4.84	73.20	5.90	2.47	2.95	2.31
4	1.44	4.65	3.01	4.67	94.40	7.10	1.35	3.06	2.52
5	1.48	3.10	2.91	3.86	86.40	4.50	2.30	2.60	2.93
6	1.71	3.17	2.88	4.29	43.50	7.40	3.69	2.66	2.87
7	1.84	3.71	2.96	4.54	76.30	5.20	2.17	2.92	2.57
8	1.97	2.85	2.66	4.31	74.60	4.20	1.93	2.63	2.68
9	1.73	3.66	2.87	4.48	63.50	6.70	2.48	2.94	2.77
10	1.52	2.11	2.73	3.13	91.10	3.90	1.85	2.76	3.21
11	1.92	3.06	2.63	3.29	72.50	4.90	2.47	3.06	2.78
12	2.24	2.41	2.65	4.17	77.90	4.10	2.30	2.37	2.74
13	2.03	2.89	2.67	3.90	83.90	4.30	2.16	2.39	2.84
14	1.53	4.07	2.99	4.65	80.30	6.30	2.04	2.81	2.31
15	0.74	4.12	3.87	4.40	40.50	7.90	3.78	3.32	2.44
16	0.50	4.04	4.25	4.39	20.50	8.90	4.82	3.11	2.18
17	0.79	4.17	4.30	4.69	33.10	8.70	4.43	3.17	2.48
18	1.33	4.45	3.42	4.13	35.70	8.50	4.36	3.10	2.09
19	1.21	4.31	3.65	4.84	55.40	7.50	3.46	3.15	1.84
20	1.97	3.22	2.89	4.71	82.10	4.90	2.61	2.95	2.54

According to calculated index scores, the water quality of Akarçay Basin varied from medium to very bad status. It was estimated that the water quality in 18 points was bad, the quality was medium in sampling point 19 and it was very bad in sampling point 10 according to the IDP index. Index results were colored and schematized in a way to represent the water quality in 5 classes according to the WFD (Figure 2).

4. Discussion and Conclusion

Phytoplankton were identified and their biomass were estimated in rivers in Akarçay Basin but indices were not been used. The most critical reason of not using indices for rivers in this study was that phytoplankton indices were developed for lakes. Furthermore phytoplankton did not occur in fast-flowing and relatively small rivers. Low phytoplankton biomass in river water bodies in Akarçay Basin also possibly resulted from the bad water quality. Phytoplankton as a biological quality element should be monitored in all categories of water bodies (rivers, lakes, transitional and coastal waters) according to the WFD (Anonymous 2000). However given the studies conducted by the EU Member States, it is known that only six member states (Belgium, Romania, Hungary, Slovakia, Germany and Lithuania) monitor phytoplankton in rivers (Anonymous 2015). The organisms in the water column change their places by drifting constantly towards downstream and therefore phytoplankton communities do not occur. On the other hand true phytoplankton communities could develop in slow-moving, large, lowland rivers. It was not always possible to set reliable reference conditions in these types of rivers due to the high level of natural variability. Therefore, it was not relevant to use phytoplankton as a quality element in rivers in the Akarçay Basin.

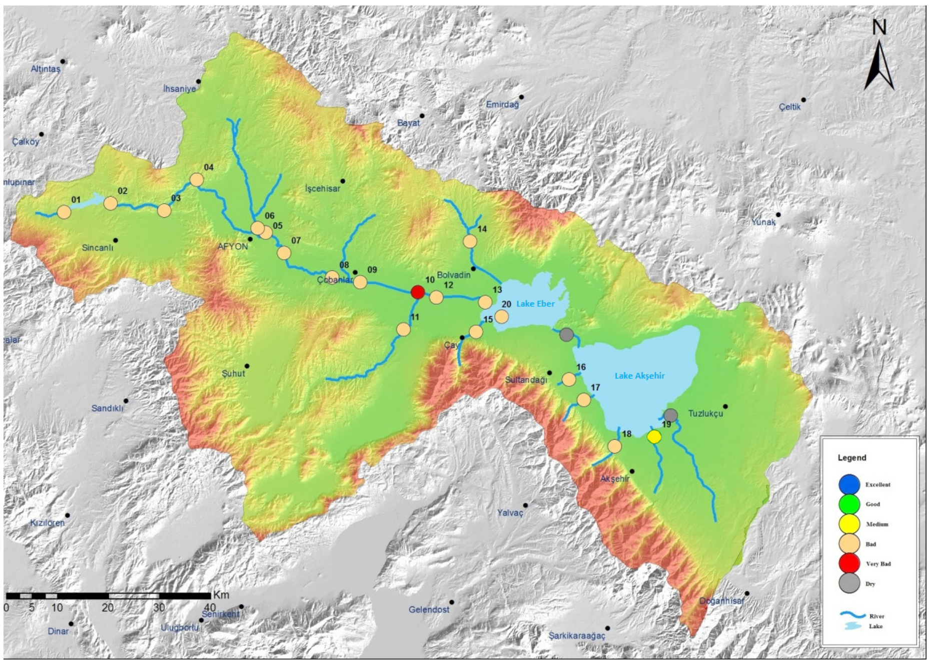

Figure 2. Ecological quality of Akarçay Basin based on phytobenthos

However it might be recommended to follow up sensitive species and/or increases in some phytoplankton species which were resistant to polisabrobic conditions such as Euglena in rivers. For instance, the fact that the biomass of the species called *Euglena viridis* was turned out to be as high as 24% in total phytoplankton biomass pointed out organic pollution in the sampling point 13. The fact that the amount of suspended solid was high in rivers in the Akarçay Basin makes the counting of phytoplankton difficult. Sensitive species of phytoplankton in Turkish basins need to be defined for water quality assessments. Lake Eber was sampled as a source of stagnant surface water in Akarçay Basin. While the ecological quality was concluded as moderate according to the results of the Q index in the Lake Eber, it was identified that species/functional groups were commonly found in eutrophic waters according to Reynolds et al. (2002). The presence of functional groups reflected the conditions which were rich in nutrients and which were turbid and deficient of light conditions. Biomass of phytoplankton was estimated as 6 mg wet weight/l. This value pointed out that the ecological quality of the lake was bad according to Sondergaard et al. (2005). Phytoplankton was sampled in April and this period was not critical in terms of phytoplankton and water quality. Therefore it is recommended to carry out monitoring activities at least in 2 periods -one in spring and the other in autumn- in Lake Akşehir and Lake Eber, and to monitor especially Cyanobacteria blooms in certain periods in which the water temperature rises. Concerning the phytobenthos in Lake Eber, *Nitzschia amphibia* can be found in various conditions from waters poor in electrolyte to waters rich in electrolyte. *Ulnaria acus* occurs in mesotrophic and eutrophic waters. *Amphora pediculus* is tolerant to α-β mesosaprobic conditions (Cox 1996). Epiphytic diatom composition pointed out high organic pollution and degredation in Lake Eber. It is estimated to be α-mesosaprobic in terms of saprobity. Results of Q index indicated that Lake Eber had a moderate status, overall ecological quality turned out to be bad (poor) in the final assessment when the status was bad according to the phytobenthos. The lake could be designated as a sensitive area when eutrophication, organic pollution indicators, phytoplankton biomass and diatom indices were taken into account all together.

The water quality was estimated as moderate status according to the IDP index only in the sampling point 19 in Akarçay Basin. The water quality in the sampling point 10 was estimated as very bad status. Therefore swift action is needed. Apart from those points, the water quality was relatively better in the sampling points 16, 17 and 18. The sensitive macroalgae (*Hydrurus foetidus* (Villars) Travisan) was identified in the sampling points 16 and 18. It has been reported that this species is found mostly in very clean water bodies or water bodies containing nutrients at a mild level (Rott et al. 2006). *H. foetidus* was first identified by Çevik et al. (2007) in the Şiryan River in Turkey. This species was observed in mountainous rivers in general terms and it was resistant to strong flows. Concerning the phytobenthos, *Hannaea arcus* -one of the diatom species- was found abundantly in the same points. It is specified that this diatom species is found mostly in very clean creeks and rivers (Lange-Bertalot 2013). The co-existence of macroalgae and diatoms stated above supports the finding that the water quality was relatively good in those points. Monitoring results of the phytobenthos indicated that the Akarçay Basin was under considerable pollution pressure. Burgan et al. (2013) reported that there was numerous pollution sources in the basin, there were no treatment plants or they did not operate in the settlements except for the city of Afyon, there were no industrial waste water treatment plants, and there were indications of fertilizers and pesticides used in the agricultural lands. Relevant ecological quality element for rivers in the Akarçay basin is diatoms. The diatom indices used in the Akarçay Basin was reflected results that were prone to pollution. Therefore diatoms should be used as phytobenthic ecological quality element in the monitoring activities to be executed in upcoming periods.

Other biological quality elements had also been studied within the scope of this study in the Akarçay Basin (Anonymous 2013c) and final ecological status had been determined based on the indicator showing the worst status. Reference values were not used in the ecological quality values in this first study which had been carried out on a basin scale and based on the biological monitoring according to the requirements of the WFD. Sampling points from which reference values can be obtained in the basin should be investigated.

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Akarçay Havzası'nda Su Çerçeve Direktifine Göre İlk Biyolojik İzleme: Fitoplankton ve Fitobentoz

Türkiye'de, Avrupa Birliği (AB) üyelik süreci münasebetiyle Çevre Faslı kapsamında AB mevzuatında yer alan direktiflerin uyumlaştırılması için birçok proje yürütülmektedir. Su kalitesi konusunda yürütülen çalışmaların temelini Su Çerçeve Direktifi (SÇD) (2000/60/AT) ve kardeş direktifler oluşturmaktadır. SÇD'nin uyumlaştırılması çalışmalarında ise izleme faaliyetlerinin önemi oldukça büyüktür. SÇD ile birlikte su kütlelerinin sadece fiziksel ve kimyasal açıdan izlenmesi yerini biyolojik kalite unsurları (fitoplankton, fitobentoz, makroomurgasız, makrofit, balık, makroalg ve angiosperm) temeline dayanan ekolojik bazlı değerlendirmeye bırakmıştır.

Türkiye'de ilk defa Su Çerçeve Direktifi kapsamında havza bazlı izleme çalışmalarına T.C. Orman ve Su İşleri Bakanlığı Su Yönetimi Genel Müdürlüğü tarafından 5 havzada (Akarçay, Meriç-Ergene, Susurluk, Gediz ve Sakarya) başlanmıştır. Bu çalışmalar kapsamında su kütlelerinde SÇD'ye göre biyolojik, hidromorfolojik, fizikokimyasal ve kimyasal parametrelerin izlenmesi ve uygun metotların geliştirilmesi hedeflenmiştir. Akarçay Havzası; İç Anadolu, Ege ve Akdeniz bölgelerinin kesiştiği noktada yer alan ve sularını denize ulaştıramaması nedeniyle kapalı bir havzadır. Bu nedenle kıyı ve geçiş suyu kütleleri bulunmadığı için Akarçay Havzasında sadece nehir ve göl suyu kütlelerinde izleme çalışmaları yürütülmüştür. Havzanın en büyük gölü olan Akşehir Gölü'nden, gölün sığlaşması, makrofitlerle kaplanması ve botla pelajial bölgeye ulaşılamaması nedeniyle örnek alınamamıştır. SÇD'ye göre nehir ve göllerde fitoplankton, fitobentoz, makrofit, balık ve makroomurgasızlar izlenmektedir. Bu çalışma Akarçay Havzasında SÇD hedeflerine uygun olarak gerçekleştirilmiş ilk çalışmadır, 2013 yılı Nisan Ayında yürütülerek 19 nehir ile 1 göl (Eber Gölü) su kütlesinde fitoplankton ve fitobentoza yönelik sonuçların elde edilmesi amaçlanmıştır.

Akarçay Havzası'nda kantitatif fitoplankton örnekleri, akarsuda aktif su akışının olduğu yerlerden, Eber Gölü'nde ise öfotik bölgeden (pelajial) Ruttner aleti ile alınmıştır. Kalitatif analizler amacıyla 55 µm göz açıklığında plankton kepçesi ile plankton çekimleri yapılmıştır. Laboratuar çalışmasında öncelikle plankton kepçesi ile alınan su örnekleri mikroskop yardımıyla incelenmiş ve baskın türler teşhis edilmiştir. İkinci aşamada direkt olarak alınan su örnekleri, fitoplankton yoğunluğuna göre plankton sayım çemberlerine konmuş, Lugol solüsyonu damlatılarak bir gece bekledikten sonra fitoplankton kameralı inverted mikroskop altında fotoğraflanmış, teşhis edilmiş, sayılmış ve fitoplankton bolluğu hesaplanmıştır. Fitoplankton biyokütlesi analizinde, fitoplankton türleri teşhis edildikten sonra hücrelerin boyutları ölçülmüş, hücre hacimleri hesaplanmıştır. Örnekte bulunan hücre sayısı hücre hacmiyle çarpılarak türün örnekteki toplam hacmi belirlenmiş ve biyokütle yaş ağırlık bazında tahmin edilmiştir. Eber Gölü'nde fitoplankton fonksiyonel gruplarına göre Q indeksi hesaplanmıştır. Q indeksi 0 ile 5 arasında değişmektedir ve Su Çerçeve Direktifi'ndeki değerlendirme sistemine göre 0-1 kötü, 1-2 tolere edilebilir, 2-3 orta, 3-4 iyi ve 4-5 çok iyi ekolojik kalite sınıfını temsil etmektedir.

Fitobentoz örneklerinin toplanması amacıyla akarsu kesitinde kıyı ve dip yapısı incelenerek su içerisinde ve su yüzeyinde uygun substratlarda makroalg varlığı araştırılmıştır. Makroalgler öncelikle makroskobik, daha sonra mikroskop yardımıyla incelenmiş ve teşhis edilmişlerdir. Diyatomeler, akarsularda öncelikle küçük kaya/taşlar gibi sert substratlar üzerinden (epilitik diyatome) fırçalanarak toplanmıştır. Örnekleme yapılan su kütlesinde taş bulunmadığında diyatome örnekleri yaygın olarak bulunan kamışlar üzerinden alınmıştır. Seçilen istasyonlarda dip yapısı kayalık değilse ve yumuşak taban yapısına sahipse sediment içinde bulunan diyatomeler (epipelik) ince bir boru yardımıyla alınmıştır. Eber Gölü'nde gölün orta kesiminde bulunan kamışlık alandan epifitik diyatome örnekleri alınmıştır. Laboratuvarda diyatome früstüllerinin incelenmesi amacıyla soğuk hidrojen peroksit metodu kullanılmıştır ve Naphrax kullanılarak daimi preparatlar hazırlanmıştır. Diyatomeler mikroskop ve kamera yardımı ile fotoğraflanarak taksonomik literatüre göre teşhis edilmişlerdir. Diyatome indekslerinden SLA, DES, IDG, SHE, TDI, CEE, IPS, IDAP ve IDP, OMNIDIA programı kullanılarak hesaplanmıştır. Sonuçlar IDP indeksine göre değerlendirilmiştir. Su Çerçeve Direktifi'ndeki değerlendirme sistemine göre IDP indeksi 0-0,5 arasında çok iyi, 0,5-1,5 iyi, 1,5-2,0 orta, 2,0-3,0 kötü ve 3,0< çok kötü ekolojik durumu temsil etmektedir.

Akarçay Havzasında Bacillariophyta (25), Chlorophyta (23), Ochrophyta (2), Cryptophyta (2), Cyanobacteria (8) ve Euglenozoa'dan (3) olmak üzere toplamda 63 fitoplankton türü teşhis edilmiş ve biyokütle hesaplamaları gerçekleştirilmiştir. Akarsularda fitoplankton biyokütlesi oldukça düşük çıkmış ve indeks hesaplanamamıştır. Havzada örnek alınan noktalarda gerçek akarsu planktonunun gelişmediği gözlenmiştir ve bu nedenle Akarçay Havzası akarsularında fitoplanktonun bir kalite unsuru olarak izlenmesi uygun değildir. Fitoplankton, Avrupa'da sadece geniş nehirlerde izlenmektedir. Bu yüzden akarsularda fitoplankton sadece hassas ve kirlenme göstergesi olan türler üzerinden değerlendirilmiştir. Eber Gölü'nde ise fitoplankton fitoplanktonun değerlendirilmesi için fonksiyonel gruplardan ve aynı zamanda fitoplankton biyokütlesinden faydalanılmıştır. Fonksiyonel gruplar, Q indeksi ve biyokütle değerlendirmeleri sonucunda Eber Gölü ötrofik bir özellik göstermiş ve hassas alan olarak belirlenmiştir.

Fitobentoz açısından bakıldığında, akarsularda fitobentik makroalg varlığı sadece birkaç noktada tespit edilebildiği için ekolojik kalitenin karşılaştırılabilmesi açısından fitobentozun en önemli bileşeni olan diyatomeler kullanılmıştır. Toplamda 64 diyatome türü teşhis edilerek, diyatome indeksleri kullanılmıştır. Akarsular, 2 ve 4 arasında değişen IDP indeksi değerlerine göre antropojenik ve organik kirlenme açısından orta-çok kötü arasında ekolojik durum sergilemiştir. İleride yapılacak izleme çalışmalarında nehirler için fitobentoz izlemelerinde diyatomeler kullanılmalıdır.

Su Çerçeve Direktifi gereklilikleri doğrultusunda havza bazında ve aynı zamanda biyolojik izleme temelli gerçekleştirilen bu ilk çalışmada, hesaplanan indeks değerlerinde referans değerler kullanılamamıştır. Akarçay Havzası'nda ya da aynı su kütlesi tiplerine sahip olmak şartıyla diğer havzalarda referans alabilecek noktaların araştırılması gerekmektedir.

Assessment of Flood Control Capabilities for Alternative Reservoir Storage Allocations

Mustafa DEMİREL[1], Ralph A. WURBS[2]

Abstract

Multiple-purpose reservoir system operations are based on the conflicting objections of maximizing storage contents to assure high water supply reliability and maximizing empty storage space to mitigate flood risk. Reallocation of storage capacity between conservation and flood control purposes provides a strategy for optimizing limited available storage capacity in response to growing demands and changing objectives. A modeling and analysis methodology is presented in the article for assessing alternative reservoir storage allocations. Flood control capabilities are evaluated in terms of the probabilities of overtopping the storage capacities of the reservoirs in the system. Water supply capabilities are quantified in terms of reliability metrics. Flood control analysis capabilities are implemented in a modeling system originally created for detailed assessments of water supply capabilities. The methodology is applied to a system of eight multiple-purpose reservoirs in the Dallas and Fort Worth metropolitan area in the Trinity River Basin of Texas in the United States. The generalized modeling system and analysis methods are applicable to reservoir systems located anywhere including systems that may be very complex.

Key words: *storage reallocation, reservoir system modeling, flood frequency analysis, water supply reliability*

1. Introduction

Dams and appurtenant structures are required to control highly fluctuating river flows to reduce downstream flooding and develop reliable water supplies. Conservation purposes include agricultural, municipal, and industrial water supply, hydroelectric energy generation, recreation, and maintenance of environmental flows. Flood control and conservation purposes may be served by the same reservoir by designating separate operating pools defined by a top of conservation pool elevation that is the bottom of the flood control pool. Reservoir operations are based on maintaining conservation pools as full as feasible while supplying water demands and maintaining flood control pools as empty as feasible to mitigate flood risk. Storage reallocations are implemented by raising or lowering the designated top of conservation pool either permanently or as a function of season or other changing conditions.

Population and economic growth results in intensifying demands on limited stream flow and reservoir storage capacity. Construction of new reservoir projects is severely constrained

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by economic, financial, environmental, and institutional considerations. Reallocation of storage capacity and related modifications in the operations of existing reservoirs are growing in importance as a water management strategy.

The generalized Water Rights Analysis Package (WRAP) river/reservoir modeling system contributes significantly to water management in Texas and has also been applied in several other countries. WRAP has been extensively applied in Texas in regional and statewide planning studies and administration of a water right permit system that focus on water supply and other conservation storage purposes without consideration of flood control. Capabilities for modeling reservoir flood control operations were recently added to the modeling system.

A strategy for combining flood frequency analysis methods with WRAP capabilities for simulating reservoir operations is presented in this paper. The risks of exceeding flood control storage capacities and reliabilities of supplying water demands are assessed for alternative storage allocation plans. The modeling and analysis methodology is applied in a storage reallocation study for a system of eight multiple-purpose reservoirs operated by the U.S. Army Corps of Engineers (USACE) to control floods and supply water for the Dallas and Fort Worth metropolitan area.

Storage levels in the eight reservoirs depend upon the effects of numerous water users and other reservoirs on inflows to the eight reservoirs as well as multiple-purpose, multiple-reservoir operations of the eight-reservoir system. Flood storage frequency analyses are performed in the study reported here by applying the log-Pearson type III probability distribution to annual series of maximum reservoir storage contents in each year. Storage frequency analyses of peak annual storage volumes are performed for both historical observed storage levels and storage levels derived from the simulation model. The analysis of simulated storage levels overcome issues of non-stationarity and record length that are inherent in analysis of observed storage. Comparisons of observed and simulated storage provide insight on the validity of the simulation results. A key metric resulting from these analyses is the probability that the flood control storage capacity in each reservoir will be exceeded. Conventional WRAP reliability indices are employed to assess water supply capabilities provided by alternative storage allocations.

2. Reservoir System Operations

Many reservoirs are operated either for only flood control or for only conservation purposes. For reservoirs with both flood control and conservation storage, operations are based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing future flood waters to reduce downstream damages.

Reservoirs contain one or more of the following four vertical zones called pools: inactive, conservation, flood control, and surcharge (Wurbs, 1996, 2016). Operations are based on maintaining reservoir contents as close to the top of the conservation pool as feasible while supplying needs of water users. Water use demands are supplied by releases or withdrawals from conservation storage. Flood control operations are activated whenever high inflows result in storage levels rising above the top of the conservation pool.

Most flood control reservoirs in the United States with operating decisions implemented by opening and closing of outlet gates are operated by the U.S. Army Corps of Engineers (USACE). Most of the numerous smaller flood retarding structures owned by non-federal entities are designed for releases to be controlled by the discharge capacity of ungated outlet structures.

USACE flood control operations are based on two sets of procedures referred to as regular and emergency operations (USACE, 1987; Wurbs 2016). Regular operations are employed whenever the storage level is within the flood control pool. Releases are based on emptying flood control pools as expeditiously as feasible without contributing to flows at downstream gaging stations exceeding maximum non-damaging flow levels. Multiple reservoirs share the same downstream gaging stations and channel capacity limits. In some cases, the USACE varies the maximum allowable non-damaging flow levels depending on storage contents of the flood control pools.

Emergency procedures are activated only during extreme flood events when the flood control storage capacity is exceeded, with the storage level encroaching into the surcharge pool. Emergency operations are based on assuring that the safety of the dam is never threatened. Releases and uncontrolled spills from the surcharge pool, above the top of flood control pool, will typically contribute to flows at downstream locations exceeding non-damaging levels.

The USACE owns and operates over 500 reservoirs throughout the United States constructed pursuant to the Flood Control Act of 1936 and subsequent legislation (Wurbs, 2016). The USACE is also responsible for flood control operations in multiple purpose reservoir projects constructed by the U.S. Bureau of Reclamation. The USACE owns and operates 28 reservoirs in Texas that provide water supply and recreation and in some cases hydropower in addition to flood control and two other flood control reservoirs that contain no water supply storage. The eight USACE reservoirs in the Trinity River Basin discussed in this paper are operated for both flood control and water supply following conventional USACE procedures.

Inclusion of water supply storage in USACE reservoirs is authorized by the Water Supply Act of 1958. All construction, maintenance, and operation costs allocated to water supply are the responsibility of nonfederal sponsors. The federal government funds all costs of federal reservoirs allocated to flood control. Reallocation of storage capacity between flood control and conservation pools has occurred at 44 USACE reservoirs following rules outlined in the Water Supply Act of 1958 (Carter, 2010). Recognizing a growing interest in additional storage reallocations, the USACE published proposed rules in the Federal Register in December 2016 clarifying and simplifying cost sharing and other institutional aspects of storage reallocations (USACE 2016). McMahon and Farmer (2004, 2009) and Carter (2010) outline institutional and technical issues involved in implementing reallocations of reservoir storage capacity.

3. Modeling And Analysis Of Reservoir System Operations

Wurbs (1996) and Labadie (2004) review the massive literature on applying systems analyses techniques to optimization of reservoir operations. Wurbs (2011) provides a comparative review of generalized reservoir/river system simulation models including the WRAP modeling system employed in the study reported in this paper. The numerous early reservoir systems analysis studies published in the literature focus on various aspects of conservation storage operations and to a lesser extent on flood control operations, but interactions between flood control and conservation purposes was addressed very little. However, more recent publications, such as those cited below, deal with flood control in multiple-purpose reservoirs and storage reallocations.

Dittman et al. (2009) developed operating schedules for reservoirs in Germany that combine flood control and ecosystem protection. Liu et al. (2010) developed operating rules for the Three Gorges Reservoir in China that provide seasonal flood control safety while optimizing water supply and hydroelectric energy objectives. Fu and Wang (2014) present a procedure applied to allocate flood reserve capacity of reservoirs in Yangtze River Basin. Song et al. (2015) balanced flood control and irrigation operations for three reservoirs in Korea. Ma et al. (2015) developed computational algorithms for balancing dam safety, downstream flood protection, irrigation, and hydropower generation in large reservoir projects. Wan et al. (2016) developed a probability based hedging rule refilling procedure for managing flood risk while meeting water supply needs for a reservoir in China. Chou and Wu (2013) investigate a pre-release strategy for improve flood control capabilities by partially emptying the conservation pool in anticipation of forecasted floods. Meng et al. (2016) varied the normal storage elevation during the flood season considering interactions between flood protection, hydropower, and water supply.

Chou and Wu (2015) developed a framework of reservoir release rules for managing flood risk based on dividing flood events into three stages. Che and Mays (2015) also investigate a modeling system that supports real-time reservoir operations before, during, and after an extreme flood event. Chen et al. (2014) explore the many sources of uncertainties in real-time reservoir flood control operations.

The U.S. Water Resources Council (1981) evaluated alternative probability distribution functions available for performing flood frequency analyses and adopted the log-Pearson type III for use by federal agencies in the United States. The log-Pearson III based procedure is explained by Wurbs and James (2002) and implemented in the WRAP and USACE software (Hydrologic Engineering Center, 2010) employed in the study presented here.

4. Modeling System Adopted For This Study

The modeling strategy employed in assessing changes in flood control and water supply capabilities associated with alternative plans for reallocating storage capacity between the flood control and conservation pools of the system of eight reservoirs in the upper Trinity River Basin operated by the USACE employs WRAP/WAM and USACE HEC computer programs (Demirel, 2015). Detailed flood control operating rules were incorporated in the Trinity WAM in conjunction with the research. HEC-DSSVue, HEC-SSP, and another WRAP post-simulation program were used to analyze WRAP simulation results.

Water Rights Analysis Package (WRAP) and Texas Water Availability Modeling (WAM) System

The Water Rights Analysis Package (WRAP) is a generalized modeling system for simulating water resources development, management, allocation, and use in river basins located anywhere in the world. WRAP is designed for assessing reliabilities in meeting water supply, hydroelectric power, and environmental flow needs and also includes optional capabilities for tracking salinity (Wurbs, 2006, 2015, 2015). WRAP was recently expanded to include simulation of reservoir operations for flood control (Wurbs and Hoffpauir, 2015).

The Texas Commission on Environmental Quality (TCEQ) in collaboration with the Texas Water Development Board (TWDB), university research entities, consulting engineering firms, and the water management community has developed and routinely applies a Water Availability Modeling (WAM) System consisting of WRAP and WRAP input datasets for the 23 river basins of Texas (Wurbs, 2005, 2015). The WAM system supports a regional and statewide planning process, administration of water allocation systems, and other water resources management functions. Activities of numerous water management entities operating 3,450 reservoirs and other facilities in accordance with a USA-Mexico treaty, five interstate compacts, two water right permit systems with 6,200 active permits, and other institutional arrangements are simulated. The generalized WRAP reservoir/river system modeling system combined with an input dataset from the WAM System for a particular river basin is called a water availability model (WAM). An expanded version of the daily Trinity River Basin WAM was employed in the study presented in this paper.

WRAP and the Texas WAM System employ a monthly step time. However, recent versions of WRAP also include capabilities for daily simulations (Wurbs and Hoffpauir, 2015). The daily version of the modeling system has been motivated largely by the need for expanded capabilities for modeling environmental flow requirements and issues (Wurbs and Hoffpauir, 2013; Pauls and Wurbs, 2016). The WRAP daily modeling system includes the following additional features used only with a daily computational time step: (1) disaggregation of monthly naturalized flows to daily, (2) flow routing and forecasting, (3) disaggregation of diversion, hydropower, and instream flow targets, (4) simulation of high flow pulse environmental flow requirements, (5) simulation of reservoir flood control operations, and (6) additional frequency analysis capabilities.

Multiple-reservoir system flood control operations based on procedures employed at USACE reservoirs are modeled in the new expanded version of the WRAP simulation model. Regular and emergency flood control operations are modeled as follows. Only conservation operations are in effect unless the storage level exceeds the specified conservation pool capacity. If the storage level is above the top of conservation pool and below the top of flood control pool, the flood waters are released as quickly as possible subject to the constraints of (1) not exceeding the discharge capacity of the outlet structures and (2) allowing no releases that contribute to river flows exceeding specified channel capacities at downstream gauged control points. If flood inflows exceed the flood control storage capacity at the designated top of flood control elevation, the flows are passed through a reservoirs as spills over an emergency spillway. Multiple-reservoir system operations are based on user-specified rules for balancing the volume of water stored in the flood control pools of each of the multiple reservoirs.

5. Modeling And Analysis Of The Usace Reservoir System In The Upper Trinity River Basin

The Fort Worth District Office of the USACE constructed and now operates a system of eight large multiple-purpose reservoirs located in the upper Trinity River Basin. The USACE is solely responsible for flood control operations. The water supply storage capacities are controlled by non-federal project sponsors that include the Trinity River Authority, Tarrant Regional Water Authority, North Texas Municipal Water District, Dallas Water Utilities, City of Fort Worth, and several smaller cities. This complex multiple-purpose, multiple-reservoir system provides a case study to support development and demonstration of the modeling strategy presented in this paper.

The objective of the simulation modeling study is to develop meaningful information to support assessments of the impacts on both flood control and water supply capabilities of alternative reallocations of storage capacities. The water supply reliability metrics incorporated in the WRAP/WAM modeling system are adopted. Flood risk is analyzed as the probability of exceeding flood control storage capacity. The fundamental concept of flood control operations is to make no releases that contribute to damages unless the flood control storage capacity is expected to be exceeded. If the flood control capacity is exceeded, spills causing downstream damages are necessary to protect the safety of the dam.

Trinity River Basin

The Trinity River Basin extends 400 miles from north of the Dallas-Fort Worth metropolitan area to Galveston Bay, east of the city of Houston, as shown in Figure 1. The watershed area is approximately 47,000 square kilometers. Mean annual rainfall ranges from 1,350 mm near Galveston Bay to 74 mm in the northwestern extreme of the upper basin.

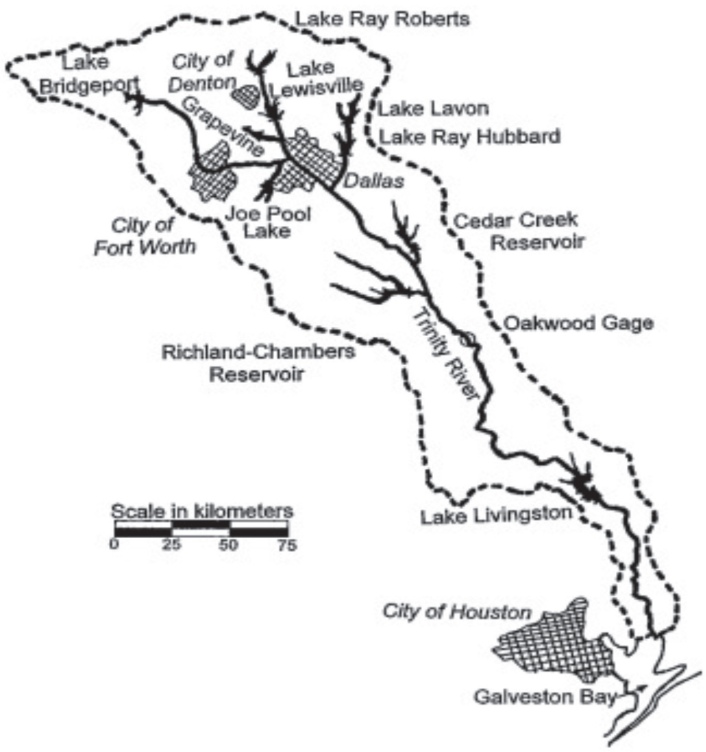

Figure 5.1. Trinity River Basin

The population of the state of Texas increased from 20,850,000 people in 2000 to 25,390,000 in 2010 and is projected to increase to 29,510,000 by 2020 and 46,355,000 by 2060 (Texas Water Development Board, 2017). With a combined 2010 population of 6,372,000 people, the many cities of the Dallas-Fort Worth metroplex in the upper Trinity River Basin account for 25.3 percent of the population of Texas. This is one of the fastest growing large metropolitan areas in the United States. The City of Houston in the San Jacinto River Basin has a pipeline from Lake Livingston on the lower Trinity River to supplement its other water supply sources in meeting intensifying water demands.

The TCEQ WAM System WRAP input dataset for the Trinity River Basin, called the Trinity WAM, models about 600 water rights permits that include storage capacity in 697 reservoirs and water supply diversions of 6.57 billion m3/year, with about 58% municipal, 35% industrial, and 7% agricultural irrigation use. Recreation is popular at the eight USACE reservoirs and most of the nonfederal reservoirs. The eight USACE reservoirs listed in Table 5.1 contain 31.9 percent of the total conservation storage capacity of the 697 reservoirs and all of the flood control storage capacity. Lakes Livingston, Richland-Chambers, Cedar Creek, and Ray Hubbard, which are the four largest non-federal reservoirs in the basin, contain 53.4 percent of the total conservation capacity of the 697 reservoirs and zero flood control storage capacity. Several of the nonfederal water supply sponsors for the USACE reservoirs also own other reservoirs. Water supply reliabilities for water right holders associated with the eight USACE reservoirs and stream flows throughout the river system are affected by all of the reservoirs, water right diversions, and return flows in the WAM. Drawdowns of conservation pools in the multiple-purpose reservoirs increase flood control storage capabilities.

Table 5.1.

USACE reservoirs

USACE	Storage Capacity (acre-feet)		Storage Capacity (1,000 m^3)	
Reservoir	Conservation	Flood Control	Conservation	Flood Control
Benbrook	88,250	76,550	108,900	94,460
Joe Pool	176,900	127,100	218,300	156,840
Ray Roberts	799,600	265,000	986,710	327,010
Lewisville	618,400	340,777	763,110	420,520
Grapevine	162,500	244,400	200,530	301,590
Lavon	456,500	291,700	563,320	359,960
Navarro Mills	63,300	148,900	78,110	183,740
Bardwell	54,900	85,100	67,750	105,010
Total	2,332,100	1,579,527	2,986,710	1,949,140

6. Results

Flood Frequency Analysis for Trinity River Basin Reservoirs

In this article, risk of the exceedance probability of the flood control pool capacity of the Trinity River Basin dams were analyzed based on observed annual maximum reservoir storage. The annual exceedance probability (P) is probability that a specified storage magnitude will be equaled or exceeded in any year. The return period or the recurrence interval (T) is the mean interval, in years, between occurrence of flood events equaling or exceeding a specified storage magnitude. The relationship of between annual exceedance probability (P) and recurrence interval (T) in years is

$$T=1/(P) \text{ or } P=1/T \quad (1)$$

After obtaining the report of analyses, interpolation was done in order to find the exact risk of exceedance probability based on reservoirs` flood control storage capacity. After obtaining the percent chance of exceedance values, Equation 1 was used to calculate recurrence time for exceeding flood control pool capacity in years. Wurbs (1996) noted that for federal reservoirs, flood control storage capacities typically were designed for at least 50-year recurrence interval; in addition to that, most projects` flood control pools were sized for 100-year recurrence interval. As an example, Benbrook Reservoir's plots and tables are as follows.

Benbrook reservoir FFA based on observed annual storage

A frequency analysis for peak annual storage contents of Benbrook Reservoir was performed in HEC-SSP alternatively applying the log-normal and log-Pearson type III probability distributions. The total storage capacity of Benbrook Reservoir below the top of flood control pool is 164,800 acre-feet, which can be to the storage-frequency relationships presented in Table 6.1, Table 6.2, Figure 6.1 and Figure 6.2.

Table 6.1.

Benbrook Reservoir FFA log-normal probability distribution

Computed Curve (ac-ft)	Expected Probability (ac-ft)	Percent Chance Exceedance	Confidence 0.05 (ac-ft)	Limits 0.95 (ac-ft)
226,597	235,244	0.2	262,153	202,948
209,852	215,901	0.5	239,725	189,637
196,970	201,409	1	222,717	179,275
183,797	186,908	2	205,567	168,552
165,670	167,426	5	182,422	153,544
151,070	152,077	10	164,231	141,181
135,103	135,571	20	144,920	127,266
109,106	109,106	50	115,334	103,215
88,112	87,808	80	93,538	82,144
78,799	78,277	90	84,319	72,485
71,855	71,101	95	77,530	65,257
60,437	59,105	99	66,402	53,450

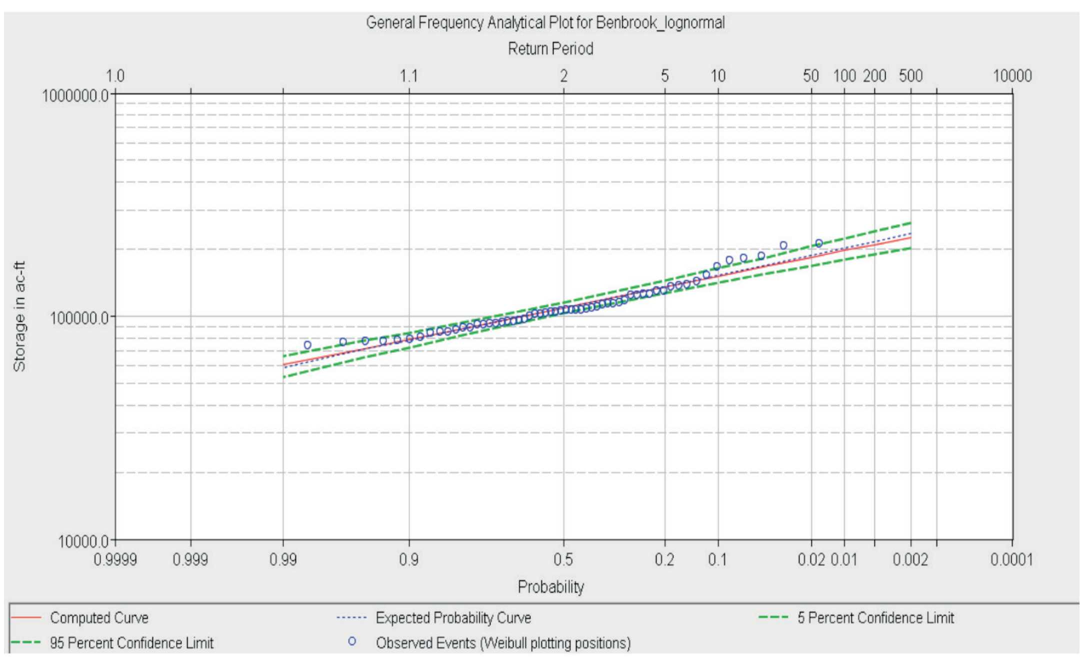

Figure 6.1. Benbrook Reservoir FFA log-normal probability distribution

Table 6.2.

Benbrook Reservoir FFA log-Pearson type III probability distribution

Computed Curve (ac-ft)	Expected Probability (ac-ft)	Percent Chance Exceedance	Confidence 0.05 (ac-ft)	Limits 0.95 (ac-ft)
290,532	311,578	0.2	350,631	252,474
253,354	266,527	0.5	298,667	223,901
227,566	236,324	1	263,461	203,713
203,545	209,127	2	231,371	184,578
174,101	176,798	5	193,116	160,565
153,195	154,613	10	166,850	142,998
132,979	133,563	20	142,406	125,376
105,485	105,485	50	111,442	99,682
87,792	87,579	80	93,217	81,813
81,174	80,845	90	86,654	74,955
76,728	76,277	95	82,289	70,329
70,347	69,703	99	76,060	63,689

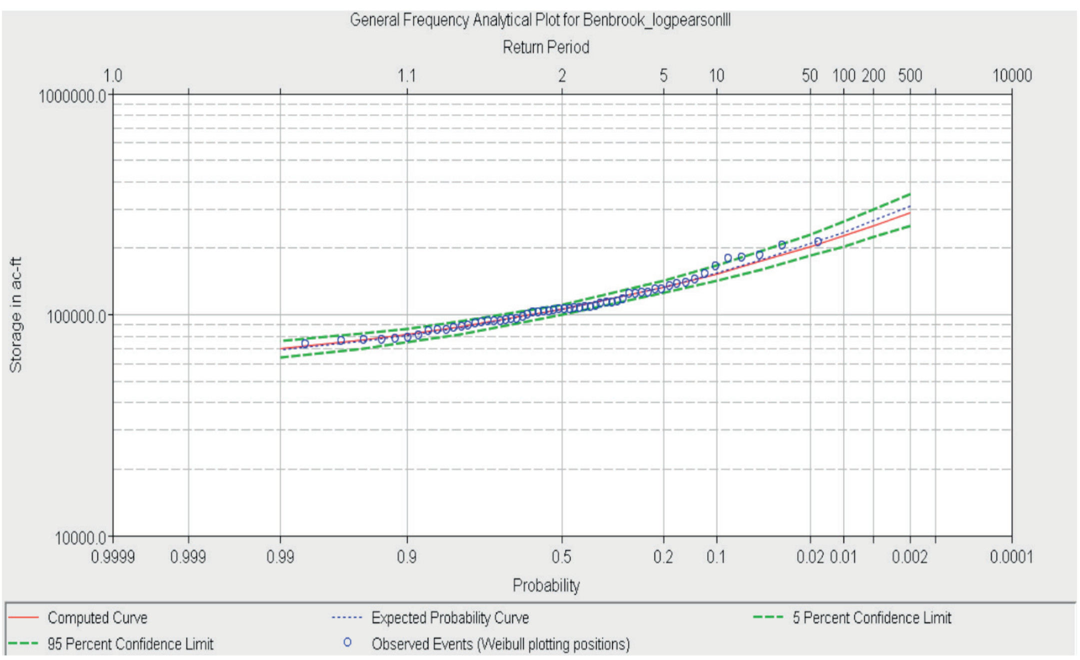

Figure 6.2. Benbrook Reservoir FFA log-Pearson type III probability distribution

Discussion of the Frequency Analysis Results

Total storage volumes associated with specified annual exceedance probabilities are presented in the preceding Tables 2-3 and Figures 2-3 for Benbrook Reservoir. HEC-SSP was applied alternatively using the log-normal and log-Pearson type III probability distribution for comparison. The frequency analyses are based on the maximum actual observed storage volume for each year since the reservoir initially filled after construction.

Although the reservoirs are in the same river basin and operated by the same agency, results of the frequency analyses of observed annual maximum storage are significantly different between the reservoirs. These differences might be the cause of different reservoir operation strategies. As shown in the Table 4, return periods vary between 10 to 1,000 years and 11 to 416 years based on log-normal and log-Pearson type III distributions, respectively. According to Wurbs, federal dams are typically designed for at least a 50-year recurrence interval (Wurbs, 1996). Unfortunately, as these results show us, in reality, return period is as low as 10 years for log-normal and 11 years for log-Pearson type III probability distributions for Lewisville Dam. On the other hand, some of them have over 100-year return periods.

The log-normal and log-Pearson type III yield similar results for six of the results. However, the two alternative probability distributions result in very different probability estimates for Joe Pool and Navarro Mills Reservoirs. The return periods shown in Table 4 for Joe Pool and Navarro Mills Reservoirs are 1,000 years and 98 years based on the log-normal distribution and are 140 years and 416 years based the log-Pearson type III distribution, respectively. Log-Pearson type III probability distribution fits the data better than the log-normal probability distribution. Samples are generally between confidence intervals in the log-Pearson type III probability distribution. Different periods-of-analysis (sample sizes) might cause large differences between the log-normal and log-Pearson type III distributions. The analyses for Benbrook, Joe Pool, Ray Roberts, Lewisville, Grapevine, Lavon, Navarro Mills, and Bardwell Reservoirs have periods-of-analyses of 58, 26, 26, 25, 58, 38, 50, 49 years.

Table 6.3.

Recurrence interval of exceeding top of flood control pools

No	Reservoirs	Top of Flood Control (ac-ft)	Percent Chance Exceedance (log-normal)	Return Period (log-normal) (year)	Percent Chance Exceedance (log-Pearson Type III)	Return Period (log-Pearson Type III) (year)
1	Benbrook	164,800	5.30	18.87	7.22	13.85
2	Joe Pool	304,000	0.10	1000.00	0.71	140.85
3	Ray Roberts	1,064,600	6.89	14.51	6.75	14.81
4	Lewisville	959,177	9.60	10.42	8.89	11.25
5	Grapevine	406,900	3.63	27.55	4.57	21.88
6	Lavon	748,200	8.79	11.38	7.08	14.12
7	Navarro Mills	212,200	1.02	98.04	0.24	416.67
8	Bardwell	140,000	0.43	232.56	0.39	256.41

The WRAP Simulations and Storage Reallocations for Trinity River Basin Reservoirs

The TCEQ WAM system involves variation of datasets for alternative scenarios. Full authorized water use (run 3) and current water use (run 8) are two scenarios that were simulated for water usage. Full authorized scenario (run 3) are performed based on all water right permit holders which withdraw full amount of water that they authorized in their permit and there is not return flow. On the other hand, current water use (run 8) are performed based on water right permit holders which withdraw less amount of water than authorized.

WRAP alternative simulation runs

This article involved six alternative simulation runs in order to enhance understanding impacts on permanent storage reallocation on water supply and flood frequency analysis and confirm its validity. Daily time step simulations` hydrologic period-of-analysis were 1940 through 2012. Alternative simulation runs, as shown in Table 5, include six daily time step. Some of reservoirs were simulated as component (multiple-owner) reservoirs while rest of them were simulated as single owner reservoirs. Also, simulations included current water use and full authorized water use scenarios. Three of six daily time step runs were performed for storage reallocation. Permanent reallocations simulations involved three alternative scenarios which were allocating reservoir storage from flood control pool to conservation pool with amount of 10%, 20%, and 50% for eight reservoirs in the Trinity River Basin. Alternative simulation runs are defined as follows.

Table 6.4.

Alternative simulation runs

Simulation Label	Time Step	Water Use Scenario	Flood Control Operation	Component Reservoir	Reallocation
D1	Daily	Authorized	Yes	No	No
D2	Daily	Authorized	Yes	Yes	No
D3	Daily	No Withdrawn	Yes	No	No
D4	Daily	Authorized	Yes	No	Yes (10%)
D5	Daily	Authorized	Yes	No	Yes (20%)
D6	Daily	Authorized	Yes	No	Yes (50%)

Simulation results

The six alternative simulation runs were evaluated by comparing simulation results and observed data in order to enhance understanding the impact of alternative permanent storage reallocations on water reliabilities and flood frequency analyses for the system of eight reservoirs in the Trinity River Basin. Simulation D1 is main run which was in daily time step, modeled as full authorized water use, set up as existing storage allocation, has flood control operation and designed as single-owner reservoirs. Simulation D2 is identical with D1 except reservoirs were modeled as multiple-owner. D3 is identical with D1 except water rights were entered as zero in order to see flood frequency changes when conservation pool is full. Three of six daily time step simulations, D4, D5, and D6 were only for alternative permanent storage reallocation for eight reservoirs.

Simulation D1 versus observed annual maximum reservoirs storage

The simulation D1 represents existing reservoir storage as shown Figure 4, full authorized water use, daily time step, single-owner, and has flood control operation. The simulation D1 was considered as base simulation and compared with other alternative simulation runs. In order to check it`s validity, D1 storage capacity, flood return periods were compared with observed values. In addition to that, water reliability summary table was developed to compare with other simulations result in order to show differences.

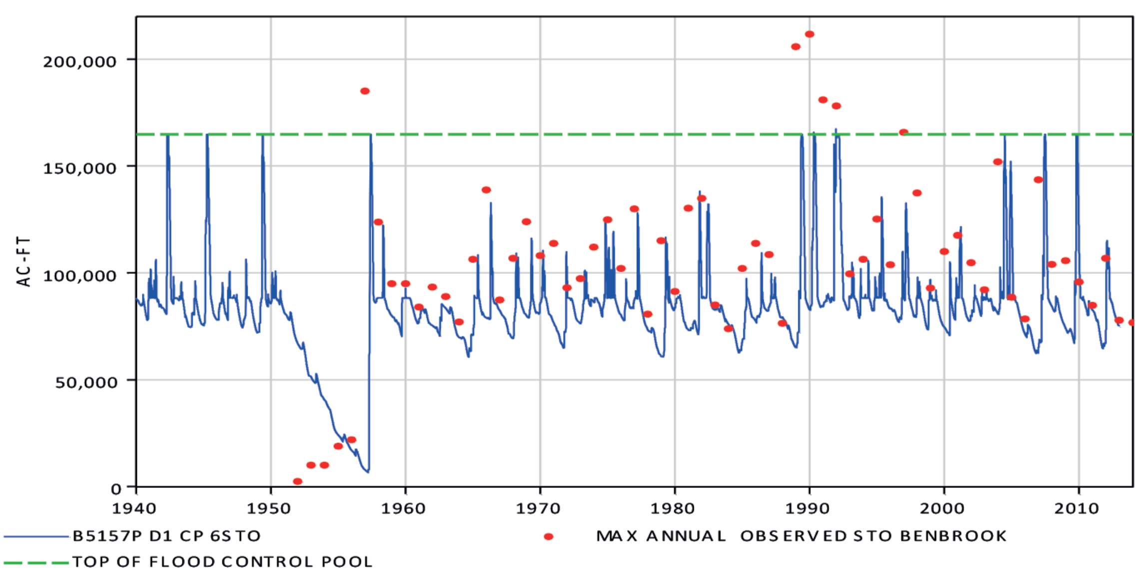

Figure 6.3. Benbrook Reservoir simulation D1 versus max annual observed storage

Comparison of flood frequency analyses

Flood frequency analyses and return periods were performed with HEC-SSP and WRAP for observed data and simulation D1 respectively for the eight reservoirs. WRAP post simulation has capabilities to perform flood frequency analysis based on only for reservoir storage and summation of reservoir storage and excess flow. Excess flow represents maximum daily flow volume for each year whenever flows exceed the top of controlled flood control pool.

Flood frequency analyses were performed by employing both log-normal and log-Pearson type III probability distributions for simulation D1 and observed reservoir storage. Table 6.5 were created by using log-normal distribution and compared with observed data and only reservoir storage, and summation of reservoir and excess flow. Likewise, Table 6.6 were created by using log-Pearson type III distribution and compared with observed data, only reservoir storage, and summation of reservoirs and excess flows.

Return period of observed storage for both log-normal and log-Pearson type III distribution were close to each other except Joe Pool and Navarro Mills. Return period of D1 simulation storage for both log-normal and log-Pearson type III distribution were far away from each other for only reservoir and summation of reservoir storage and excess flow. Log-normal distribution`s results for simulation D1 were closer to observed reservoir storage return period than log-Pearson type III distribution. However, specifically, Ray Roberts, Lewisville, and Grapevine Reservoirs' simulation D1 storage levels were lower than observed storage level. Although, for these reservoirs, simulation D1 storage levels were low, return period for flood event was very frequent for log-normal distribution. Log-normal probability distribution did not reflect storage level`s value for flood frequency analysis. Because of that, log-Pearson type III distribution exceedance probability of controlled flood control pool fit better than log-normal probability distribution.

Joe Pool and Ray Roberts Reservoirs were completed after 1980 and their periods-of-analysis are shorter than for the other reservoirs. Fewer years of record means a smaller sample size for the statistical analyses. Also, for Lewisville and Lavon Reservoirs, storage reallocations were made in 1989 and 1976 respectively. Because of reallocation, flood frequency analyses were performed by maximum storage level after reallocation was done, so sample size was low for these reservoirs. However, in the all simulation, hydrologic period was from 1940 to 2012. This difference affected return period. In addition to that as mentioned before, D1 was performed for full authorized water use scenario.

Table 6.5.

Comparison of observed storage and simulation D1 exceedance probability of top of controlled flood control pool log-normal distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	5.30	18.87	10.73	9.32	17.38	5.75
2	Joe Pool	304000	0.10	1000.00	9.32	10.73	9.32	10.73
3	Ray Roberts	1064600	6.89	14.51	7.84	12.76	7.84	12.76
4	Lewisville	959177	9.60	10.42	8.04	12.44	8.04	12.44
5	Grapevine	406900	3.63	27.55	11.46	8.73	11.55	8.66
6	Lavon	748200	8.79	11.38	11.28	8.87	12.09	8.27
7	Navarro	212200	1.02	98.04	3.38	29.59	3.44	29.07
8	Bardwell	140000	0.43	232.56	1.90	52.63	1.90	52.63

Table 6.6.

Comparison of observed storage and simulation D1 exceedance probability of top of controlled flood control pool log-normal distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	0.10	1000.00	16.68	6.00
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	3.52	28.41
5	Grapevine	406900	4.57	21.88	0.23	434.78	0.40	250.00
6	Lavon	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	212200	0.24	416.67	1.26	79.37	1.43	69.93
8	Bardwell	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D1

The water supply reliability table was developed for control points located at dams for simulation D1 as shown in Table 6.7. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. On the other hand, Joe Pool, Ray Roberts, Lewisville, Grapevine Reservoirs have water shortage. Joe Pool water reliability was almost 100%. However, Ray Roberts Reservoir had very low water reliability in terms of period and volume. One of the research objectives is how reallocation affects water reliability.

Table 6.7.

Water supply reliability for D1

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	~~~~~~~~~ PERCENTAGE OF DAYS ~~~~~~~~~~~ WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	+++++++++ PERCENTAGE OF MONTHS +++++++++ 100%	95%	90%	75%	50%	25%	1%
B5157P	125768.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	400242.1	170.20	98.95	99.96	99.0	100.0	100.0	100.0	100.0	100.0	100.0	98.9	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634935.06	20.38	20.59	20.4	20.5	20.5	20.8	21.2	21.6	22.8	11.3	11.4	11.9	14.5	18.7	26.1	42.8
B2456A	921060.9	534674.75	53.56	41.95	53.6	53.6	53.7	54.1	55.1	57.0	74.5	45.0	45.9	46.8	48.9	54.8	61.6	81.6
B2362A	171537.5	72116.69	58.34	57.96	58.3	58.4	58.4	58.8	59.5	61.5	70.1	51.0	51.8	52.3	53.9	59.0	65.4	81.2
B2410A	128754.7	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	176698.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	151885.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	2875550.0	1241896.75		56.81														

Simulations D1 versus D2

The simulation D2 represents existing reservoir storage, full authorized water use, daily time step, has flood control operation, and was developed as component reservoir system. Component (multiple-owner) reservoir system means, for same reservoir, different agencies have water right contracts. To protect their water rights from other contractor, reservoirs were split up as components. Thus, contractor cannot withdraw much water that they were authorized. Because of that, conservation and flood control pools were divided based on contract proportion for Benbrook, Ray Roberts, Lewisville, Grapevine, and Lavon Reservoirs. However, flood control operation for component reservoirs did not work out. Component reservoir system for some years, even if water level in reservoir was lower than top of controlled flood control pool (FCGATE), in AFF file, there was excess flow. That was not supposed to be occurred. Excess flow was supposed to be only occurred when water level exceeded the top of controlled flood control pool. The reason for excess flow for component reservoir might be that one of the components in the same reservoir might overtop to top of flood control pool while others had low water level. Even if one of components was exceed flood control pool, it would cause excess flow.

Originally, Trinity WAM was designed as component reservoir for water allocation. However, the research focused on flood control operation, because of that, reservoirs were converted to single owner reservoir and base simulation (D1) was single owner reservoir. Simulation D1 and D2 were compared for water storages and water reliabilities to check how single-owner simulation make changes as shown Figure 6.4.

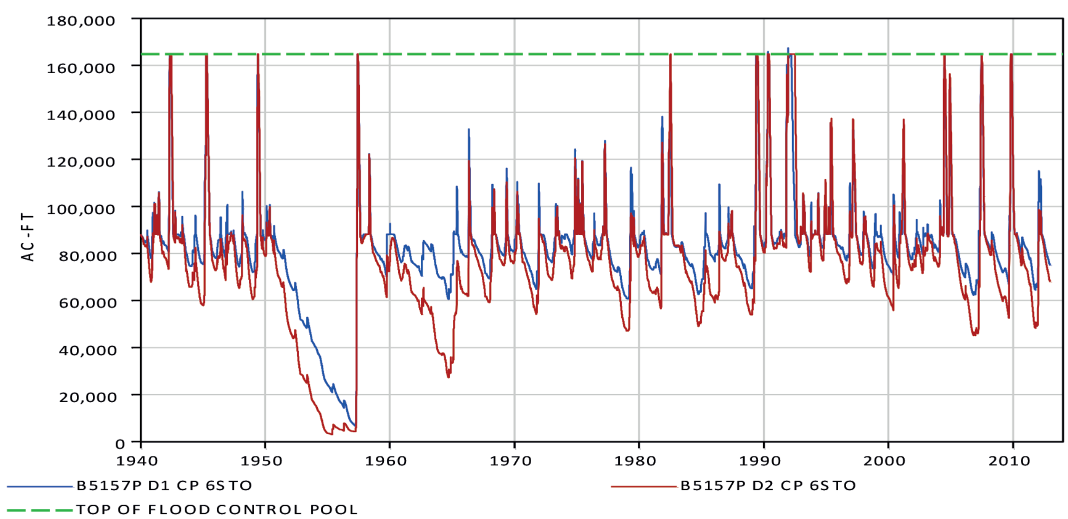

Figure 6.4. Benbrook Reservoir simulations D1 versus D2

Simulations D1 versus D3

The simulation D3 represents existing reservoir storage as shown Figure 6.5, no water withdrawn from the eight reservoirs, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D3 was executed in order to show how conservation pool affected flood frequency analysis. After a severe drought conservation, pool becomes empty and after drought season ends, at first conservation pool becomes full then starts to fill flood control pool. In other words, at the beginning of flood event, conservation pool behaves as flood control pool and stores water. In order to see how conservation pool affect flood control operation, simulation D3 was developed by changing water rights values as zero thus conservation pool remain full for the eight reservoirs.

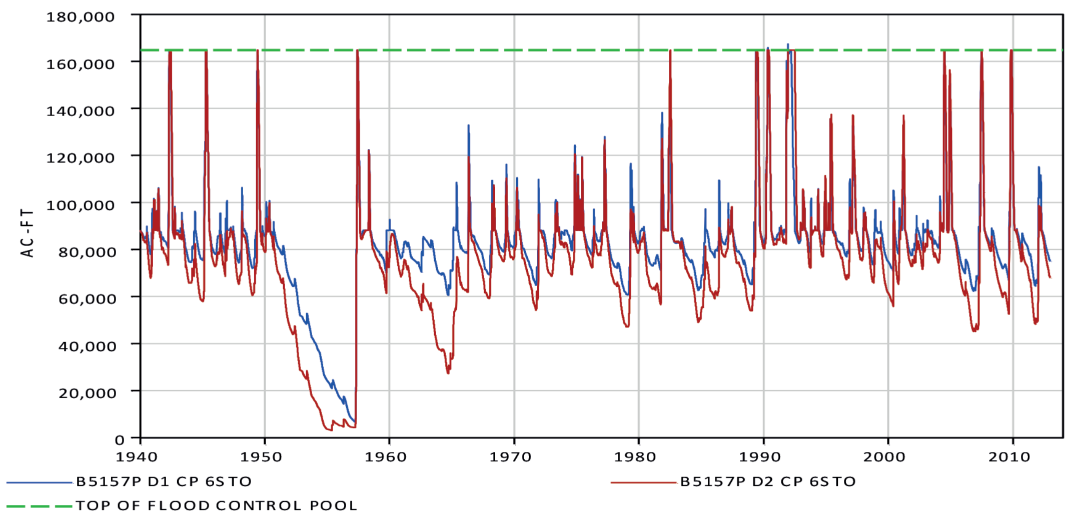

Figure 6.5. Benbrook Reservoir simulations D1, D3 versus max annual observed storage
3.2.3.1. Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D3 was performed for log-normal and log-Pearson type III distribution, compared with simulation D1 and observed flood frequency analysis. For both distributions, simulation D3 return period values were expected lower than simulation D1 because there was not withdrawn for simulation D3 and water levels were higher than simulation D1.

Return period and statistical tables were developed for log-normal distribution as shown in Tables 7. However, return period values for simulation D3 was higher than simulation D1 except for Ray Roberts and Lewisville Reservoirs. The result for log-normal distribution was not expected since D3 simulation return period should have been lower than D1. Log-normal distribution did not work well.

Return period and statistical tables were developed for log-Pearson type III distribution as shown in Table 6.8 and Table 6.9. Return period for simulation D3 values were lower than Simulation D1 and observed flood frequency analysis as expected. Simulation D1 flood return periods were significantly higher than simulation D3. For this study, log-Pearson Type III distribution fit better. Because of that, rest of the simulation was evaluated only with log-Pearson type III distribution.

These results show that conservation pools have great impact on flood control operation and flood frequency analysis. Especially after a severe drought like 1950-1957 drought, there was a flood event. The simulation D3 showed that in 1957 controlled flood control pools were overtopped for most of reservoirs. Consequently, conservation pools reduce flood events when they have water storage place.

Table 6.8.

Comparison of observed storage, D1 and D3 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto.)		Sim D1 (Res. Sto.+Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	16.53	6.05
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	12.28	8.14
4	Lewisville	959177	8.89	11.25	3.52	28.41	9.87	10.13
5	Grapevine	406900	4.57	21.88	0.40	250.00	5.66	17.67
6	Lavon	748200	7.08	14.12	0.10	1000.00	9.62	10.40
7	Navarro	212200	0.24	416.67	1.43	69.93	3.13	31.95
8	Bardwell	140000	0.39	256.41	0.10	1000.00	1.14	87.72

Simulations D1, D4 versus observed annual maximum reservoirs storage

The simulation D4 represents 10% flood control reservoir storage converted to conservation pool capacity as shown Figure 6.6, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D4 was executed in order to show how 10% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

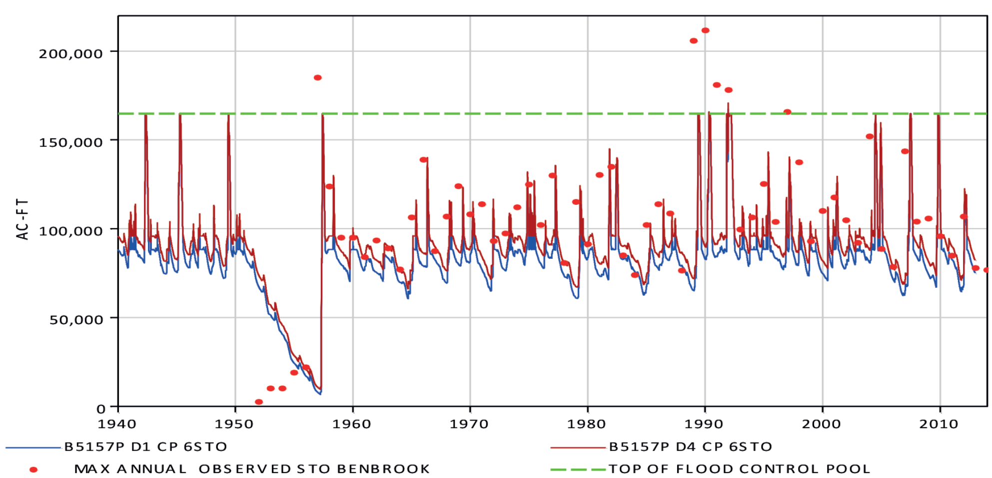

Figure 6.6. Benbrook Reservoir simulations D1, D4 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D4 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and observed flood frequency analysis. The simulation D4 return period values were expected lower than simulation D1 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D4 and water levels were higher than simulation D1.

Return period table was developed for log-Pearson type III distribution as shown in Table 10 Return period for simulation D4 for values were lower than simulation D1 as expected.

Table 6.9.

Comparison of observed storage, D1 and D4 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Control Point	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D4 (Res. Sto. +Excess Flow)	
				Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	B5157P	164800	7.22	13.85	16.68	6.00	19.68	5.08
2	Joe Pool	B3404A	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	B2335A	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	B2456A	959177	8.89	11.25	3.52	28.41	3.75	26.67
5	Grapevine	B2362A	406900	4.57	21.88	0.40	250.00	1.79	55.87
6	Lavon	B2410A	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	B4992A	212200	0.24	416.67	1.43	69.93	2.50	40.00
8	Bardwell	B5021A	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D4

Water supply reliability table was developed for control points that located at dams for simulation D4 as shown in Table 6.10. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target is 100% met in terms of simulation duration and diversion amount. There were little increase of water reliabilities for Joe Pool, Ray Roberts, Lewisville, and Grapevine Reservoirs in simulation D4 than simulation D1. Joe Pool water reliability was almost 100%. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume.

Table 6.10.

Water supply reliability for D4

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
B5157P	132812.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	422737.6	110.80	99.22	99.97	99.2	100.0	100.0	100.0	100.0	100.0	100.0	99.2	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634899.62	20.39	20.60	20.4	20.5	20.6	20.8	21.2	21.6	22.8	11.3	11.5	12.1	14.4	18.6	26.3	42.8
B2456A	918848.8	530853.25	53.84	42.23	53.8	53.9	54.0	54.4	55.4	57.3	74.6	45.1	46.0	46.8	49.0	54.9	62.2	82.0
B2362A	171130.4	69271.57	59.86	59.52	59.9	59.9	60.0	60.3	61.0	62.9	71.3	52.7	53.4	53.8	55.4	60.5	66.7	82.0
B2410A	128420.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	192768.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	158580.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	2924901.2	1235135.38		57.77														

Simulations D1, D5 versus observed annual maximum reservoirs storage

The simulation D5 represents 20% flood control reservoir storage allocated to conservation pool capacity, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D5 was executed in order to show how 20% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

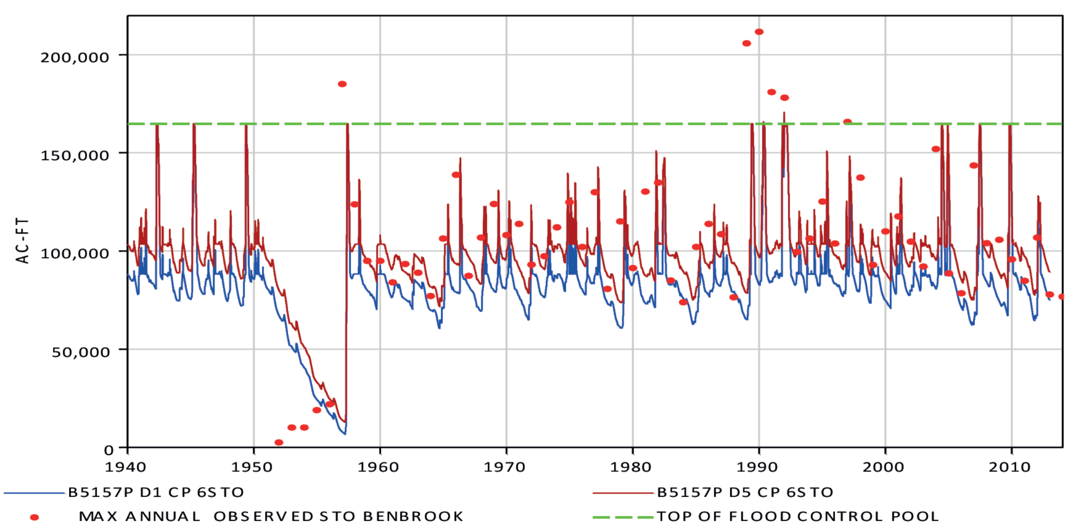

Figure 6.7. Benbrook Reservoir simulations D1, D5 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D5 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and observed flood frequency analysis. The simulation D5 return period values were expected lower than simulation D1 and D4 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D5 and water levels were higher than simulations D1 and D4.

Return period and statistical tables were developed for log-Pearson type III distribution as shown in Table 6.11. Return period for simulation D5 for values were lower than simulation D1 as expected.

Table 6.11.

Comparison of observed storage, D1 and D4 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D5 (Res. Sto. +Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	24.26	4.12
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	4.03	24.81
5	Grapevine	406900	4.57	21.88	0.40	250.00	2.13	46.95
6	Lavon	748200	7.08	14.12	0.10	1000.00	0.10	1000.00
7	Navarro	212200	0.24	416.67	1.43	69.93	3.73	26.81
8	Bardwell	140000	0.39	256.41	0.10	1000.00	0.10	1000.00

Water supply reliability for D5

Water supply reliability table was developed for control point that located at dams for simulation D5 as shown in Table 6.12. Benbrook, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. There were little increase of water reliability for Joe Pool, Ray Roberts, Lewisville, and Grapevine Reservoirs in simulation D5 than simulation D1. Joe Pool water reliability was almost 100%. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume.

Table 6.12.

Water supply reliability for D5

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
B5157P	139237.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	467670.6	54.27	99.61	99.99	99.6	100.0	100.0	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634597.25	20.44	20.64	20.4	20.5	20.6	20.8	21.2	21.7	22.8	11.3	11.6	12.0	14.5	18.7	26.4	42.8
B2456A	916337.8	526631.56	54.16	42.53	54.2	54.2	54.3	54.7	55.7	57.7	74.8	45.1	46.2	47.1	49.4	55.5	62.2	81.7
B2362A	170838.0	67141.30	61.00	60.70	61.0	61.1	61.1	61.4	62.2	64.1	72.2	53.8	54.5	55.3	56.6	62.1	67.5	82.4
B2410A	128827.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	212999.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	166852.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	3002364.2	1228424.25		59.08														

Simulations D1, D6 versus observed annual maximum reservoirs storage

The simulation D6 represents 50% flood control reservoir storage allocated to conservation pool capacity, full authorized water use, daily time step, has flood control operation, and was developed as single-owner reservoir system. Simulation D5 was executed in order to show how 50% storage reallocation from flood control pool to conservation pool affects flood frequency analysis and water reliability.

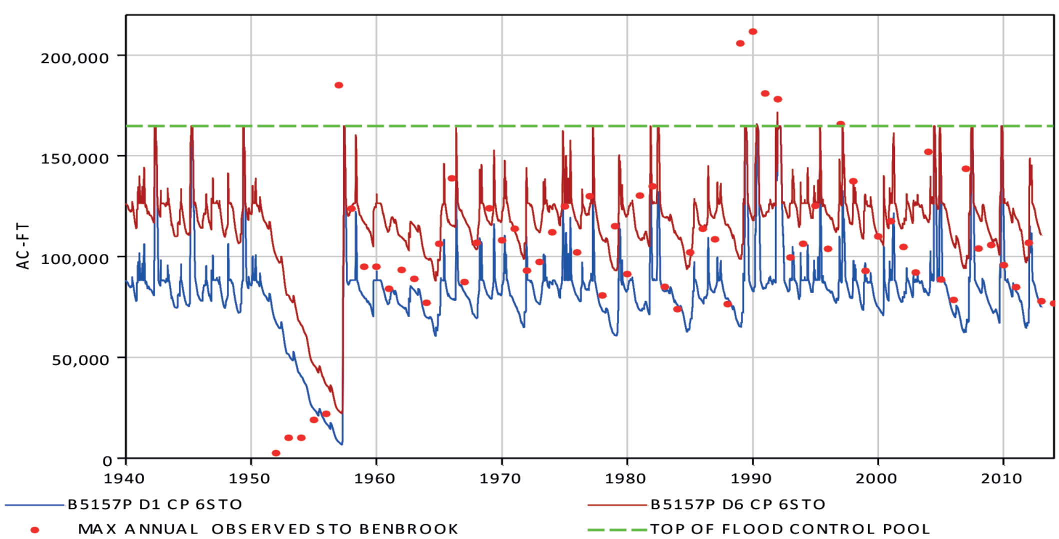

Figure 6.8. Benbrook Reservoir simulations D1, D6 versus max annual observed storage

Comparison of flood frequency analyses

Exceedance probability of top of controlled flood control for simulation D6 was performed for log-Pearson type III distribution for summation of reservoir storage and excess flow, then compared with simulation D1 and was observed flood frequency analysis. The simulation D6 return period values were expected lower than simulations D1, D4 and D5 return period because conservation storage capacity increased and flood control storage capacity decreased in simulation D6 and water levels were higher than simulations D1, D4 and D5.

Table 6.13.

Comparison of observed storage, D1 and D6 exceedance probability of top of flood control pool log-Pearson type III distribution

No	Reservoir	Top of Flood Control (ac-ft)	Observed		Sim D1 (Res. Sto. +Excess Flow)		Sim D5 (Res. Sto. +Excess Flow)	
			Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)	Percent Chance Exceedance	Return Period (year)
1	Benbrook	164800	7.22	13.85	16.68	6.00	38.63	2.59
2	Joe Pool	304000	0.71	140.85	0.10	1000.00	0.10	1000.00
3	Ray Roberts	1064600	6.75	14.81	0.01	10000.00	0.01	10000.00
4	Lewisville	959177	8.89	11.25	3.52	28.41	5.19	19.27
5	Grapevine	406900	4.57	21.88	0.40	250.00	4.38	22.83
6	Lavon	748200	7.08	14.12	0.10	1000.00	24.50	4.08
7	Navarro	212200	0.24	416.67	1.43	69.93	15.88	6.30
8	Bardwell	140000	0.39	256.41	0.10	1000.00	7.86	12.72

Water Supply Reliability for D6

Water supply reliability table was developed for control points that located at dams for simulation D6 as shown in Table 6.14. Benbrook, Joe Pool, Lavon, Navarro Mills, and Bardwell Reservoirs water diversion target 100% met in terms of simulation duration and diversion amount. There were little increase of water reliability for Ray Roberts, Lewisville, and Grapevine Reservoirs from in simulation D6 than simulation D1. However, like simulation D1, Ray Roberts Reservoir had very low water reliability in terms of period and volume. Storage reallocations increased water reliability but it was not much. However, return period of flood event increased especially simulation D6 was much than water reliability increase.

Table 6.14.

Water supply reliability for D6

Daily Data from January 1940 through December 2012

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT						
					100%	95%	90%	75%	50%	25%	1%	100%	95%	90%	75%	50%	25%	1%
B5157P	160831.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B3404A	601974.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B2335A	799601.8	634122.00	20.52	20.70	20.5	20.6	20.7	20.9	21.3	21.8	22.9	11.3	11.6	12.1	14.6	19.3	26.3	42.7
B2456A	910953.8	517188.50	54.97	43.23	55.0	55.1	55.1	55.5	56.5	58.4	75.2	46.1	47.3	48.1	50.5	56.2	63.1	82.2
B2362A	170052.3	61839.68	64.17	63.63	64.2	64.2	64.2	64.5	65.2	66.9	74.2	57.8	58.2	59.0	60.4	65.4	70.1	83.7
B2410A	129264.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B4992A	271708.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B5021A	185777.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	3230163.8	1213150.12		62.44														

7. Discussion And Conclusion

The probability of storage exceeding the top of flood control pool provides a concise metric for quantifying flood control capabilities. The recurrence interval computed as the reciprocal of this exceedance probability also provides a convenient storage capacity metric. Recurrence intervals associated with filling flood control pools are tabulated in Table 7.1. The recurrence interval estimates in Table 16 are based on the frequency analyses of observed storage.

Table 7.1.

Comparison of recurrence intervals for overtopping flood control pools based on applying the log-Pearson type III (LP) and log-normal (LN) distributions to observed storage, simulated storage, and simulated storage plus excess flow

Reservoir	Storage (ac-ft) at Top of		Observed		Simulation		Excess Flow	
	Conservation	Fld Control	LP	LN	LP	LN	LP	LN
Benbrook	88,250	164,800	13.9	18.9	1,000	9.32	6.00	5.75
Joe Pool	176,900	304,000	141	1,000	1,000	10.7	1,000	10.7
Ray Roberts	799,600	1,064,600	14.8	14.5	10000	12.8	10000	12.7
Lewisville	618,400	959,177	11.3	10.4	28.4	12.4	28.4	12.4
Grapevine	162,500	406,900	21.9	27.6	435	8.73	250	8.66
Lavon	456,500	748,200	14.1	11.4	1,000	8.87	1,000	8.27
Navarro	63,300	212,200	417	98.0	79.4	29.6	69.9	29.1
Bardwell	54,900	140,000	256	233	1,000	52.6	1,000	52.6

The recurrence intervals shown in Table 7.1 vary greatly between reservoirs, vary greatly between observed and simulated storage, and vary significantly between the log-Pearson III (LP) and log-normal (LN) distributions. The recurrence interval estimates are unrealistically high is some cases and too low in other cases.

In addition to the base daily simulation (D1) included in Table 7.1, eight other simulations are presented to explore the effects of various factors on storage levels. Various issues affecting storage contents are addressed. Key issues are highlighted as follows.

Analyses based on observed flows are appealing but reflect significant shortcomings. The sample size of the annual frequency analyses is limited by the number of years in the period-of-record of observed storage. Impoundment of flows in Benbrook, Joe Pool, Ray Roberts, Lewisville, Grapevine, Lavon, Navarro Mills, and Bardwell Reservoirs began in 1952, 1985, 1987, 1952 (1989), 1952, 1952, 1953 (1975), 1963, and 1965. Several years were required to initially fill the conservation pools. Storage reallocations raising the top of conservation pools of Lewisville and Lavon Reservoirs occurred in November 1989 and December 1975, respectively. The years required to initially fill the conservation pools and the years before the storage reallocations at Lewisville and Lavon were not included in the frequency analyses. The simulation model has a consistent 73-year 1940-2012 period-of-analysis. The simulation model also applies a constant specified water management scenario and reservoir operating rules throughout the 1940-2012 hydrologic period-of-analysis.

Storage draw-downs in conservation pools provide additional storage of flood waters reducing the storage contents of flood control pools. For example, the 1950-1957 most severe drought on record ended with a major flood in April-May 1957, with much of the flood waters captured in conservation pools. The WAM dataset adopted for this research incorporates the authorized use scenario which is based on the premise that all water users use the full amounts authorized in their water right permits. Simulations presented in the preceding pages show the significant increases in storage contents of flood control pools that result from adopting the current water use scenario or no water use in the simulations.

Simulation results are presented preceding pages for alternative hypothetical storage relocation plans consisting of converting 10%, 20%, and 50% of the flood control pool storage capacity in each of the eight reservoirs to water supply by raising the designated top of conservation pool. Simulations D4, D5, and D6 were described in the preceding pages are identical to simulation D1 except for the reallocation of storage capacity. The volume reliability for the aggregated totals of all water supply diversions from the eight reservoirs for the alternative storage allocations are tabulated in Table 7.2 along with the recurrence intervals for overtopping the flood control pools.

Table 7.2.

The recurrence intervals shown in Table 7.1 vary greatly between reservoirs, vary greatly between observed and simulated storage, and vary significantly between the log-Pearson III (LP) and log-normal (LN) distributions. The recurrence interval estimates are unrealistically high is some cases and

	D1	D4	D5	D6
Reliability	0%	10%	20%	50%
	56.81%	57.77%	59.08	62.44%
Recurrence Interval (years) for Overtopping FC Pool				
Benbrook	6.00	5.08	4.12	2.59
Joe Pool	1,000	1,000	1,000	1,000
Ray Roberts	10,000	10,000	10,000	10,000
Lewisville	28.4	26.7	24.8	19.3
Grapevine	250	55.9	48.0	22.8
Lavon	1,000	1,000	1,000	4.08
Navarro	69.9	40.0	26.8	6.30
Bardwell	1,000	1,000	1,000	12.7

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Extended Turkish Abstract (Genişletilmiş Türkçe Özet)

Alternatif Reservuar Hacim Değişimlerinin Taşkın Kontrolu Açısından Değerlendirilmesi

Barajların işletilmesi ve rezervuar hacimlerinde yapılan değişimler, belediye, endüstriyel kullanım, hidroelektrik enerji üretimi, rekreasyon, baraj gölünde taşımacılık, balık ve suda yaşayan canlılar için su sürekliliğinin sağlanması ve ayrıca insanların hayatını ve mülklerini taşkından korumak için su yönetim uzmanları açısından Teksas'da ve dünyanın heryerinde önemli bir görevdir. Bu makalede, alternatif rezervuar hacim değişimlerinin sonuçlarını değerlendirmek için, WAM (Texas Water Availibility Modeling) sisteminden alınan Trinity Nehir Havzası verileri ve WRAP (Water Right Analysis Package) programı kullanıldı. Çok amaçlı rezervuarlarda taşkın kontrol ve su temini hacimlerinin değişimleri sonucunda taşkın tekerrür periyodu ve su temini güvenirliliği değerlendirildi. Trinity Nehri Havzasında USACE'ye (United States Army Corps of Engineers) ait olan sekiz adet çok amaçlı rezervuar örnek olarak incelendi.

Taşkın kontrolü için WRAP/WAM rezervuar sistemi işletim similasyonu test edildi ve geliştirildi. Modellenen rezervuar işletim stratejisi similasyonları ve gözlenen maksimum yıllık hacim seviyesi verileriyle sıklık analizi yapıldı. Sıklık analizi, taşkın kontrol hacminin geçme olasılığı hesaplamasında kullanıldı. HEC-SSP (The Hydrologic Engineering Center-Statistical Software Package) programı gözlenmiş verilerin sıklık analizini yapmak için log-normal ve log-Pearson type III dağılımları ile kullanıldı. Çok amaçlı reservuar sistemi simulasyonunda ve hacim sıklık analizi sırasında ortaya çıkan problemler araştırıldı.

Sekiz rezervuar için yeniden hacim tahsisi, su temini hacminin maksimum su seviyesini yükselterek taşkın kontrolü hacminden su temini hacmine yer verilerek yapılabilir. Bu çalışmada, similasyon sonucunda yapılan değişikliğin taşkın kontrolündeki etkileri, taşkın kontrol hacminin tamamen dolma olasılığı açısından değerlendirildi. Su güvenirliliği değişikliği etkileri, su temini açısından değerlendirildi.

Trinity Nehri Havzası Rezervuarları için WRAP programı ile alternatif altı simülasyon yapıldı. Altı simülasyondan üç tanesi taşkın kontrol hacminden su temini hacmine tahsis edilerek yapıldı. Rezervuar su seviyeleri, taşkın sıklık analizi ve su temini güvenirliliği gözlenmiş ve similasyon sonuçlarıyla karşılaştırıldı ve değerlendirildi.

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