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Trend analysis of maximum flows under climate change evaluation and its impact on spillway safety

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Abstract The design, construction and operating of spillways, as an important part of dams, are very important, because of the parameter of flood discharge capacity under climate change effects. In addition to observe the trends, risks of spillways must be evaluated by risk analysis using same observed maximum flow data.

By using maximum flow parameters, it is reported existence the trends and safety level of spillways for selected dams. That results show us, the process of observation of updated maximum flow data and its effect on risk level for dam safety. At the same time, it is evaluated the risk level of some previous studies under updated data.

***Index Terms*—Flood, Risk analysis, Spillway, Trend analysis.**

I. INTRODUCTION

Dams keep huge amount of water in their reservoirs so dams are under the risk at whole their economic life. These risks can be classified as structural deficiencies, earthquakes, flood and other environmental risks (Cheng, 1993; Vischer and Hager, 1998; Cooper and Chapman, 1993). When the dam failures catastrophic impacts are evaluated, it is clear, providing that dam safety under the influence of such risks is very important.

ICOLD (International Commission on Large Dams) has investigated important dam failures and these studies has been given in the literature comprehensively. According to this, two major causes of dam failures are foundation problems and insufficient spillway capacity (Kite, 1976; Uzel, 1991; Yenigun and Erkek, 2002). In addition, spillway insufficiencies have been indicated a cause which triggers the foundation problems by ICOLD. Main design parameter of spillways is maximum discharge of flood and estimation of this is generally difficult due to stochastic properties of maximum discharge of flood which is highly affected by different causes like climate change.

The fact of climate change getting more and more popular recently because of its possible impacts on engineering systems. Especially, investigation of the effects of climate change on water structures is very important for the aspects of design and operation of such water structures. In context of studies performed on this situation, Kang et. al. (2007) have made some sensitivity analysis of the flood safety of Yongdam Dam using different climate change model and the have obtained that single flood events got more critical in the long time of period. Zhang et. al. (2008) have performed analysis based on historical records for Yangtze Delta using power spectrum analysis and continuous wavelet transform methods for detecting the changing characteristics of flood change and they have obtained that climate change might increase the frequency of extreme weather events in the Yangtze Delta. Bouwer et. al. (2010) have indicated that increasing trend of possible flood damages caused of climate and socioeconomic change by means of annual expected flood damages. Yenigun and Ecer (2013) have carried out trend analysis of maximum flow values using overlay mapping technique in the Euphrates basin and they have clearly seen that effects of climate change and usability of overlay mapping technique. Chernet et. al. (2014) have investigated that possible climate change effects on future safety of the Aurland hydropower dams during future floods using different future climate scenarios and they have found that there was a change in the magnitude of the floods. All of these studies indicates, the fact of the climate change should be taken into account in order to consider risk and uncertainty in the water structures.

Uncertainty and risk in water structures and many different risk analysis methods are developed by different researchers. These methods can be listed briefly as return period, safety factor and safety margin, Monte Carlo simulations, integration and Second Order Moment Methods. (Turkman, 1990; Yen and Tung, 1993; Yenigün, 2001). There are some advantages and disadvantages of each method. Goodarzi et al. (2013) have chronologically listed the development of the risk analysis methods mentioned before.

In this study, it is primarily aimed to obtain the existence of climate change effects on maximum flow trends and determine its possible impact on spillway's risk values. Thus, it will be possible to evaluate the existing dams risk conditions under the impact of maximum flow parameters. In order to achieve this, different dams selected in the Turkey to represent different geographical locations and trend and risk analyses are

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performed on these dams. Previous studies that performed with former data are updated with recent data sets due to increase the success of study.

II. MATERIAL AND METHOD

A. Study Area

Study area is Turkey which take place in the intersection of the Asia and Europa continents and lies between 26-45° east longitudes and 36-42° north latitudes (Kayabalı and Akın, 2003). Turkey is located in Mediterranean macroclimate region. However, some geographical factors cause variation on climate conditions (İkiel, 2005). Hydrological characteristics of country show important spatial and temporal variations (Kahya and Demirel, 2007). In addition, it can be said that Turkey is placed in semi-arid climate zone. Handled dams in context of this study are represented in Figure 1.

Figure 1. Study area: selected dams

Properties of selected dams are given in the Table 1. These dams are Çatalan, Manavgat, Oymapınar and Demirdöven dams.

B. Data

Name, place and location data about studied flow observation stations are available in Table 2. In order to represent flood characteristics, this study is performed with maximum flow values. The maximum flow values which are used in this study is obtained from General Directorate of State Hydraulic Works (Turkish abbreviation "DSİ") and it is paid attention for being data used in study is continuous and cover long time period. In addition, selected flow observation stations for studied each dam take place upstream of related dam.

Table 1. Properties of selected dams

Dam	Province	Purpose			Type	Year of Operation Starts	Dam Volume ($10^6 m^3$)	Spillway		
		E*	I*	F*				Type	Number of Gate	Discharge Capacity (m^3/sn)
Çatalan	Adana	x	x	x	Earthfill	1997	14.50	Frontal, gated	6	10055
Demirdöven	Erzurum		x		Earthfill	1996	2.50	Frontal, ungated	-	198
Manavgat	Antalya	x	x	x	Earthfill	1987	1.20	Frontal, gated	3	4000
Oymapınar	Antalya	x			Concrete Arch	1984	0.68	Frontal, gated	4	3600

(E*: Electric Energy, I*: Irrigation, F*: Flood Control)

Table 2. Information of used flow observation stations

Dam	Station ID	Place	Location
Çatalan	E18A018	Adana/Kozan	37:25:25N 35:27:17E
Demirdöven	D24A016	Erzurum/Pasinler	40:02:05N 41:44:07E
Manavgat	E09A901	Antalya/Akseki	36:56:51N 31:31:01E
Oymapınar	E09A901	Antalya/Akseki	36:56:51N 31:31:01E

Flow observation stations are selected primarily depend on length, continuity and reliability of measurements. Observed maximum flow parameters before 1990 are evaluated with previous studies. Later, same analyses are run with the data up to 2012. Possible errors in the data are ignored due to measurement devices and procedures are reliable. Streams that hold the flow observation stations take place at the upstream of related dam and away from the dam's regulation and possible human effect (Yenigun and Ecer, 2012). General statistical properties about data used in this study are available in Table 3.

Table 3. Properties of used data

Dam	Station ID	Station Name	Elevation (m)	Basin Drainage Area (km^2)	Time Interval	Number of Data
Çatalan	E18A018	Seyhan N. (Üçtepe)	148	13740.6	1996-2010	44
Demirdöven	D24A016 D24A097	Tımar Ç. (Demir D.) Tımar Ç. (Tımar)	1738 1801	102.7 97.5	1962-1995 2007-2012	32
Manavgat	E09A901 E09A012	Manavgat (Homa) Manavgat (S.Hoca)	25 245	928.4 625.6	1941-1984 1984-2012	72
Oymapınar	E09A901 E09A012	Manavgat (Homa) Manavgat (S.Hoca)	25 245	928.4 625.6	1941-1984 1984-2012	72

C. Methods

Trend Analysis Methods

Trend analysis methods is used for determining whether there is a tendency (increasing or decreasing) in given data set. There are different trend analysis methods in the literature. These methods can be sorted as non-parametric, parametric and mixed methods (Helsel and Hirsch, 1992). Selection of the non-parametric methods provide advantages because of getting problem independent from statistical distribution of data set. In this study, Mann-Kendall, Spearman's Rho Test are used to determine whether there is a trend in maximum flow values. Coefficients of linear variation of trends are calculated using Sen's slope prediction method. Details about aforementioned methods are available in Yenigün et. al. (2008).

Mann-Kendall Method (Mann, 1945; Kendall, 1975) is one of the most popular trend analysis methods because of providing versatility, even non-standardized data set conditions (Hamed and Rao, 1998; Burn and Elnur, 2002; Xu et al., 2003; Kahya and Kalaycı, 2004; Silva, 2004). For that reason, this method can be used in hydrological analysis suitably. In this method, existence of trend is tested with null hypothesis (H_0). According to result of null hypothesis, existence of trend is determined.

Spearman's Rho Method is also non-parametric method like Mann-Kendall Method and it can be used for determining the existence of trend under specified significance (Yue et al., 2002). Sen's t Test is used for obtaining slope of trend (variation under unit time) under the conditions that trend exists. This method is developed by Sen (1968).

In this study, trend analysis was performed by a computer code named TAFW (Trend Analysis for Windows). Program is first written by Gümüş (2006) and it is developed by Yenigün et al. (2008) later.

Risk Analysis Methods

Risk analysis methods can be classified by different aspects like efficiency, applicability, computation requirements and precision. At this point, MFOSM (Mean Value First Order Second Moment) and AFOSM (Advanced First Order Second Moment) methods take place at an optimum point from between other risk analysis methods when precision and applicability is considered. Because, capacity and demand functions cannot be defined precisely in engineering problems due to structure of problem and these two methods are based on mean value and variance which can be obtained easier (Yenigün, 2001).

In addition, using Taylor expansion in these methods simplifies obtaining probability density functions for discrete or continuous variables (Goodarzi et al., 2013).

Only difference between MFOSM and AFOSM methods is using mean or actual value in taylor expansion. One point that should be considered using such methods is MFOSM and AFOSM give reasonable results under the data conditions which fit normal distribution. Suitable transformation operations should be apply when data don't fit normal distribution. Mathematical details about both MFOSM and AFOSM methods are available in Yenigün and Erkek (2007).

In this study, risk analyses were performed with computer program named DamRisk which is developed under Java environment. Program is developed by Yenigün (2001).

III. RESULTS AND DISCUSSION

Results of trend analyses performed in context of this study is given in Table 4

Table 4. Trend Analysis Results

Dam	Mann-Kendall Test Results			Spearman's Rho Test Results			Year of Trend is Starting	Sen's Slope Value
	Kendall Correlation Coefficient	Z	Trend	Rho Test Value	Z	Trend		
Çatalan	-0.12	-1.11	-	-0.17	-1.13	-	-	-6.761
Demirdöven	-0.06	-0.50	-	-0.08	-0.47	-	-	-0.062
Manavgat	-0.20	-2.43	▼	-0.34	-2.64	▼	1986	-2.735
Oymapınar	-0.20	-2.43	▼	-0.34	-2.64	▼	1986	-2.735

Being a base point of interpretation trend analyses and outputs of Mann-Kendall Rank Correlation Tests u(t) and u'(t) charts are not presented in this study. However, they are also evaluated.

When trend analyses results given in Table 4 are observed, a trend was not obtained for Çatalan and Demirdöven dams. But, decreasing trend was found for Manavgat and Oymapınar dams. Obtained decreasing trends are suitable with the results of studies which predict the cause of decreasing precipitation is climate change in Turkey (Kahya and Kalaycı, 2004; Cığızoğlu et al., 2005).

Table 5. Previous (Short) term risk analysis results

Dam	MFOSM	AFOSM	Remarks
Çatalan	0.0409^a	0.0000	a: MFOSM risk when m=5 gated closed
Demirdöven	0.0000	0.0000	
Manavgat	0.0003^b	0.0002^c	b: MFOSM risk when m=2 gated closed c: AFOSM risk when Q_{100} situation occur
Oymapınar	0.3745^d	0.001^e	d: MFOSM risk when m=3 gated closed e: AFOSM risk when Q_{100} situation occur

Risk analyses results in this study are represented for period of before and after 1990 in Table 5 and Table 6, separately. Reason of this is risk analyses were already performed by author with data which cover the before 1990 period (Yenigün 2001; 2007; Yenigün and Erkek, 2002a; 2002b). According to this, risk values show decrease for Çatalan, Manavgat and Oymapınar dams when long period considered except Demirdöven dam. Especially, obtained decreasing trends for Manavgat and Oymapınar dams support this situation. Result of study, there is no dam under critical condition when risk analyses were performed with recent data. This indicates selected dams are safe enough.

Table 6. Recent (Long) term risk analysis results

Dam	MFOSM	AFOSM	Remarks
Çatalan	0.0222^a	0.0000	a: MFOSM risk when m=5 gated closed
Demirdöven	0.0000	0.0000	
Manavgat	0.0001^b	0.0002^c	b: MFOSM risk when m=2 gated closed c: AFOSM risk when Q_{100} situation occur
Oymapınar	0.2611^d	0.001^e	d: MFOSM risk when m=3 gated closed e: AFOSM risk when Q_{100} situation occur

IV. CONCLUSIONS AND RECOMMENDATIONS

In this study, possible effects of climate change on maximum flow parameters and impact of variation of maximum flows on dam's spillway risks are studied. To achieve this, trend and risk analyses were performed.

For all studied dams, no trend or decreasing trend were obtained. This situation's major reasons are extreme properties of studied maximum flow values and precipitation decreasing effect of climate change which is stated in the literature.

Dam's spillway risk values are compatible with trend analyses results and they show decrement when long term is considered. This indicates, selected dams are safe enough under such effects.

This study can be expanded investigating upstream flows from directly dam's reservoir volume variation instead of considering only streams. In addition, future risk status of dams can be investigated performing prospective rainfall-runoff analyses (for 25 or 50 years) using different climate change scenarios.

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