UNIVERSITY OF GAZIANTEP

GRADUTE SCHOOL OF

NATURAL & APPLIED SCIENCE

THE EFFECT OF DATA SIZE ON DETECTING TREND: A CASE STUDY OF FILYOS RIVER (TURKEY)

M.Sc. THESIS

IN

CIVIL ENGINEERING

BY

RUQAYA MAHMOOD JASIM

DECEMBER 2014

The Effect of Data Size on Detecting Trend: A Case Study of Filyos River (Turkey)

M.Sc. Thesis

In Civil Engineering

University of Gaziantep

Supervisor

Assoc. Prof. Dr. Nermin ŞARLAK

By

Ruqaya Mahmood JASIM

December 2014

REPUBLIC OF TURKEY
UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: The Effect of Data Size on Detecting Trend: A Case Study of Filyos River (Turkey)

Name of the student: Ruqaya Mahmood JASIM

Exam date: 16 December 2014

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Metin BEDİR
Director

I certify that this thesis satisfies all the requirements as thesis for the degree of Master of Science.

Prof. Dr. Mustafa GÜNAL
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Nermin ŞARLAK
Supervisor

Examining Committee Members	Signature
Prof.Dr. Mustafa Y. KILINÇ	
Assoc. Prof. Dr. Aytaç GÜVEN	
Assoc. Prof. Dr. Nermin ŞARLAK	

I hereby declare that all information in this document been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ruqaya Mahmood JASIM

ABSTRACT

THE EFFECT OF DATA SIZE ON DETECTING TREND: A CASE STUDY OF FILYOS RIVER (TURKEY)

JASIM, Ruqaya Mahmood

M. Sc. in Civil Engineering

Supervisor: Assoc. Prof. Dr. Nermin ŞARLAK

December 2014, 53 pages

Scaling effect on detecting trend from different segments or different extends from the same time series is a well known problem. A highly significant increasing trend may be found in a given segment, while a highly significant decreasing trend may be found in a different segment. The reconstructed series obtaining from tree ring data which is extended from 1657 to 1997 for a length of 341 years is considered as well as observed data from 1964 to 1997 to discuss this effect. Mann-Kendall trend analysis is used to detect trend on both data series. The main objective of this study is to illustrate the effect of scaling on detecting trend. The present study clearly reveals that both observed and reconstructed data nearly throughout exhibit persistence behaviors. Similar decreasing trend patterns are observed at the different time scales although the trend result for observed time series is not statistically significant. As a result, it can be concluded that trend results can be changed under the effect of scaling and it affects making stationarity and climate change interpretations which are very important to time series model.

Keywords: Trend analysis, scaling effect, tree – ring, Mann – Kendall

ÖZET

TREND TESPİTİNDE ÖRNEK BÜYÜKLÜĞÜNÜN ETKİSİ: UYGULAMA FİLYOS NEHRİ (TÜRKİYE)

JASIM, Ruqaya Mahmood

Yüksek lisans tezi, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Doç. Dr. Nermin ŞARLAK

Aralık 2014, 53 sayfa

Aynı zaman serisinin farklı dilimleri veya farklı zaman aralıklarından gidiş eğilimi tespitinde ölçekleme etkisi bilinen bir problemdir. Göz önüne alınan zaman diliminde oldukça yüksek artış eğilimi bulunabilirken, farklı bir dilim seçildiğinde oldukça yüksek azalış eğilimi bulunabilmektedir. Söz konusu etkiyi tartışmak için 1657’den 1997 yılına 341 yıl uzatılan ağaç halkaları verisi kullanılarak yeniden oluşturulan seri ile 1967 den 1997 yıllına kadar gözlemlenen veri değerlendirildi. Mann Kendall trend yöntemi her iki veri serisindeki gidiş eğiliminin tespitinde kullanıldı. Bu çalışmanın asıl amacı gidiş eğiliminin tespitinde ölçeklendirme etkisini gösterebilmektedir. Bu çalışma hem gözlemlenmiş hem de yeniden oluşturulmuş serilerin neredeyse baştan başa kararlı davranış sergilediğini ortaya koymuştur. Gözlenmiş serilerden istatistiksel olarak anlamlı olmasada farklı zaman ölçeklerinde benzer azalış eğilimi gözlemlenmiştir. Sonuç olarak ölçeklendirme etkisi altında gidiş eğilim sonuçları değişebilmekte ve bu zaman serisi modelleri için önemli olan kararlılık ve iklim değişikliği yorumlarının yapılmasını etkilemektedir.

Anahtar kelimeler: Gidiz analizi, ölçekleme etkisi, ağaç halkası, Mann – Kendall

This thesis dedicated it to my father and my mother. To all my family and all those who contributed to my upbringing and my education.

ACKNOWLEDGEMENTS

First of all, great thanks to Allah his Majesty for enabling me to complete this work.

I would like to express my sincerest thanks and deepest respect to my supervisor Assoc. Prof. Dr. **Nermin Şarlak** for her fantastic guidance, continuous support and unlimited trust at every stage of this study. She is not only a good advisor and a teacher but also a very good friend. She has always been very patient with me during the course of this study. We have talked and discussed not only about courses, the thesis, we also talked about my personal problems. She is my model at academic life. Thank you so much.

I would like to show my deep gratitude to my father and my mother who brought me up and helped me in all my life and I always felt their support beside me in each step of my thesis from the beginning till the end.

Finally but the most, I send my very special thanks to my family. I would like to show my sincere gratitude to my dear husband **HAFED AHMAD** and my lovely kids **TEBA**, **ABDUL RAHMAN** and **ABDULLAH**. I have spent many times at university to work on the thesis instead of having time with them. My dear husband HAFED always encouraged and motivated me throughout this study. His support and sensibility gave me extra strength to overcome the difficulties I faced during my study.

CONTENTS

page

LIST OF FIGURES

LIST OF TABLES

Page

CHAPTER 1

INTRODUCTION

1.1 Climate Change and its General Effects

Changes in climate are due to both natural and human activities, especially, the activities which lead to changes in the atmosphere. Climate change itself is manifested by a complex mix of stressors that involve elevated atmospheric greenhouse gas (GHG) concentrations, increased frequencies and intensities of extreme weather conditions and change in temperature, precipitation, and hydrologic cycles (Durdu, 2010). There are instances of human anthropogenic activities that have played an important role in the elevated GHG which include; deforestation, industrial activities, processes related to agriculture and most importantly the burning of fossil fuels (UNFCCC, 2007). Increased concentrations of carbon-dioxide in the atmosphere were documented from the start of the industrial revolution. Since that time, great changes in the agricultural, manufacturing, mining, transportations and the technological sectors have occurred and that led to increased burning of fossil fuels (UNFCCC, 2007). It was generally noticed that conditions like these cause an increase in temperatures (Scavia et al., 2002). The most recent assessment conducted by the Intergovernmental Panel on Climate Change (IPCC) reported an increase in the mean surface temperature, which ranged between 0.56 ^{o}C and 0.92 ^{o}C from 1906 to 2005 (IPCC, 2007). This increase is larger than what was mentioned in the previous IPCC report, which concluded that the global mean surface temperature has increased from 0.3 to 0.6 ^{o}C from 1901-2000 (IPCC, 2001). At the time the temperature is prophesy to increase anywhere over land, precipitation is expected to increase globally (IPCC, 2007). In many river basins and the precipitation is expected to increase, but in many others a decrease is expected instead of that (IPCC, 2007). Moreover, a precipitation intensities increase in some seasons or areas, but they decrease in others (IPCC, 2007). All these changes in the climate could threaten the global freshwater system and increase the uncertainty in relation to the hydrological processes (IPCC, 2007; Koutsouris et al., 2010). The IPCC (2007) documented undoubtedly that the effects of the change of climate on freshwater systems and their management mostly resulted in increases in temperature, sea level and precipitation variability that were noticed. A lot of studies all over the world have been conducted to deal with and to prophesy the impacts of the change of climate on the hydrological variables, like precipitation and streamflow. For instance, Beyene et al. (2010) simulated the effects of the change of climate on the hydrology of the Nile River basin and concluded that the basin could have larger streamflow up to 2039, because of the increased precipitation; though from 2040 to 2099, a decrease is predicted to be found. Austin et al. (2010) used the Biophysical Capacity to Change and Cubic Conformal models altogether with different climate change views to forecast the effects of the climate change on Murray-Darling Basin in Australia. Their work revealed that by the year 2070, the mean annual rainfall could be insufficient and the potential evapotranspiration may arise for both by 25% (Austin et al., 2010). Shepherd et al. (2010) forecasted river flows in the Oldman River Basin draining in the North American Rocky Mountains by means of using projection analyses and hydroclimatic technique. When using six different GCMs, both methods indicated similar results: an increase in the flow in the spring and winter, and decrease of the flow in the summer. The recent report by the IPCC (2007) (Fourth assessment) provides a full assessment of the potential effects in terms of the change of climate on many aspects of freshwater systems.

In Canada, many spots are also known to be sensitive to precipitation changes because they are related to the climatic change (Environment Canada, 2004). For instance, a decrease in the mean annual flow with respect to the Great-Lakes-St. Lawrence watershed in the USA and Canada is predicted to be between 4% and 24% during the next 90 years to come, due to increased evaporation (Croley, 2003). When analysis is conducted using the Canadian General Circulation Model (CGCM I) where the concentration of CO_2 is doubled, the sea ice in Hudson Bay vanished practically (Gough and Wolfe, 2001). Roy et al. (2001) also took into consideration the seasonal flooding which is closely relevant to the change in climate in the Chateauguay River Basin, which is located in southern Quebec. They predicted that there would be a major increase in the amount of runoff, maximum discharge (up to 250%), and water level by 2080-2100 relying on the result from the CGCM I and a coupled hydrology-hydraulics model (Roy et al., 2001). Dery and Wood (2005) calculated the total annual discharge in 64 rivers in Canada for the period 1964-2003 at time of drainage in high-latitude oceans (Arctic and North Atlantic). They noticed about 10% decreases in the discharge from 1964 to 2003, which is associated with a decrease in the amount of precipitation for the period of 1964 to 2000 for the areas in the north part of Canada (Dery and Wood, 2005).

1.2 Trends in Hydro climatic Indices

There is no doubt that the effects of the climatic changes attracted a great deal of interest within the fields of hydrology, meteorology and climatology. Most of the studies concluded that the climate change will have a side effect (or at least suppose dangerous challenges) on water resources, both on quality and quantity. Therefore, it is worth to know how the effects of climate change on the water resources are affecting the nature and society. Canada holds a special role because it has approximately one tenth of the world's renewable water; hence, changes in its quantity and/or quality will have results beyond Canada's boundary (Environment Canada, 2004). Since the climate is permanently altered, the investigation of climate change is connected directly with respect to fields in various climatic indices. A huge number of studies have been applied in the scopes of hydro-climatology and hydro-meteorology to show and quantify the existence of trends. Some of the most common sets included in these studies are temperature (Piŝoft et al, 2004; Prokoph and Patterson, 2004; Mohsin and Gough, 2010), streamflow (Zhang et al., 2001; Burn and Hag Elnur, 2002; surface runoff (Labat et al., 2004; Liu, et al., 2010); Anctil and Coulibaly, 2004; Zume and Tarhule, 2006, Partal, 2010), precipitation (Kim, 2004; Mishra and Singh, 2010), and snowpack (Hamlet et al., 2005) Most past studies related to trends in climatic variables surface in Turkey focused on temperature and precipitation patterns. For example, Türkes et al. (1995) used different non-parametric tests to determine sudden changes and trends in the long-term mean temperature of both individual stations and geographical areas in Turkey during the period 1930–1992. The researchers found that the climate tends to be warmer in the eastern Anatolia and to be cooler, especially in the areas of Marmara and the Mediterranean Sea using a series of regional temperatures. Türkes (1996) worked with the area-averaged annual rainfall series during the period 1930–1993 and indicated to the minor insignificant decreases were noted in overall Turkey especially in the Black Sea and Mediterranean regions. Kadioğlu (1997) tested trends in the mean annual temperature archives during the period 1939–1989 in the eighteen stations all over Turkey and found insignificant increasing trends in the mean annual temperatures. He also pointed out that a regional increase in mean minimum temperatures, and that could be refer to the urban heat island impact, occurred about 1955. The results were indecisive for the presence of long-term trends. On the other hand Tayanc¸ et al. (1997) found statistically significant cooling in mean temperatures particularly in northern Turkey and warming in particularly in large civilized locations. In the same case, Karaca et al. (1995) showed the intensity of the urban heat island in Istanbul though it is enclosed by the Black Sea and the Marmara Sea. To emphasize the importance of analyzing trends of hydrologic variables (streamflow as the most attracting variable), in a watershed which is supposed not to be exposed to anthropogenic effects; the following interpretations are based on the work of Zhang et al. (2001). Under some geomorphic circumstances, the river nature reflects the integrated watershed response to climatic forcing. Cayan and Peterson noticed this sensitive point previously (1989); Kahya and Dracup (1993) in the search for the connections between surface hydroclimatic variables and the large-scale atmospheric circulation. Since the development of geomorphologic of watershed is very slow in compare with the change of climate, the changes which can be detected in the hydrologic regimes of stable, unorganized watersheds may be considered as the reflection of the climate changes. Then the hydrologic variables might be used as index to discover and observe the change of climate. The majority of the studies revealed that trends – positive or negative – have been variously due to climate change. It is worth mentioning to differentiate between climate change and climate variability. Climate variability is the natural process of climate variation happening within a period of time, whereas climate change refers to a long-term change in the climate itself (Kundzewicz and Robson, 2004). Alterations would occur as a trend little by little, unexpectedly, or in a more complex form (Xiong and Guo, 2004; Zhang et al., 2010). Climate variability may form highly noticeable effects on hydrological measures, which result in: (i) proof of trends existing as the length of data used is short, but these trends may vanish if longer data are used, (ii) large climatic diversity can effectively conceal changes that are occurred by climate change (Kundzewicz and Robson, 2004). As climatic changes usually continue to occur, one should expect to see more statistically significant trends in hydro-climatic data. This would give evidence that the hydrologic regime will continue to change in the future; therefore, it is not a stationary system.

1.3 Problems Faced in Time Series Analysis to Determine Trends

The essential part of studies that attempt to detect trends and changes in Hydro-meteorological processes are data. Hydro-meteorological data are usually characterized by non-stationary features, and are made up of trendy, periodic, autoregressive, and random residual elements (Kite, 1993). The trend is always a result of changes in the structure that are executed by natural or anthropogenic activities (e.g., climatic variability, land-use changes, etc.). Primarily, periodicities are related to astronomical phenomena such as the earth's rotation around the sun. Autoregressive components appear that the knowledge of the time series probably depends on the magnitude of the preceding events. Since hydrological processes might be influenced by factors such as weather, vegetation cover, infiltration and evapotranspiration, they comprise stochastic constituents, and multi-time measure and nonlinear properties (Wang and Ding, 2003). Trend detection (identification) and evaluation in the existence of all these stochastic elements is a main part of hydrological researches. Other matters in trend detection studies might be shown caused by the existence of data mistakes in the records, and the presence of outliers and autocorrelation (Lattenmaier, 1988). To take this into consideration, many authors have applied the use both of parametric and non-parametric statistical tests. Shao et al. (2010) pointed out that most of the methods used in the literature are incapable of detecting both long-term trends and unexpected changes simultaneously. The familiar non-parametric approaches, like the Mann-Kendall, the Wilcoxon–Man Whitney, t-test, and Pettitt's, can only show a monotonic trend or a single abrupt alteration (Shao et al., 2010). So the result that the trends in hydrological time series cannot be efficiently detected by the use of any one of these tests alone. This is due to hydrological time series are recognized to often show multiple abrupt changes and various trends, happening in miscellaneous periods, that are acted by inter-annual and decadal variability associated with the climate system (Peel and McMahon, 2006). Besides, classical trend tests do not handle very well the impacts of persistence and seasonality (Cluis et al., 1989).

Some authors have also endeavoured to find out the trend and sudden change components in a time series disconnectedly (e.g., Zhao et al., 2008), but this approach is not statistically satisfied as the conclusions gained from the different tests may not be harmonized (Shao et al., 2010). Despite a single trend test is regarded suitable to trend testing and detection with specific start and end times, it does not show whether any changes are because of gradual or sudden actions (Zhang et al., 2010).

Yue et al. (2002) and Mohsin and Gough (2010) proved that a number of trend-related studies composed of some flaws did not include testing for autocorrelation when using trend detection tests (as what happens with the Mann-Kendall test). They simply assumed that the notices included in the time series being analyzed are serially independent. The effect of one data view on the next one (serial correlation) in a successive time series can result in a misleading explanation (type I error) – the unacceptability of the null hypothesis will be more likely to simulate when in fact it has to be accepted (Kulkarni and von Storch, 1995; Hamed and Rao, 1998; Partal, 2010). The positive serial correlation would result in an increase in type I error (Douglas et al., 2000), but the existence of negative serial correlation would lead to an increase in type II error (i.e., misleadingly accepting the null hypothesis) (Yue and Wang, 2002). Accordingly, it is inevitable to handle the condition of serial correlation in a time series prior to applying a trend test.

1.4 Reconstructed data from tree-rings

The streamflow observation period recorded is usually short in compare with the period desired for dependable water resources planning and management. The flow gaging period is mostly much less than the design period. Having obtained dependable models to extend the observed records will presented a simple picture of the potential streamflow patterns which are not clear in the historical record. In recent years, tree ring reconstructions of sreamflow have proven valuable information for water resources planning and management. Tree-rings data considered as indirect archives of climate provide information about streamflow and other surface waters for the period prior to the gauged records (Meko et al., 1995). Robust reconstructions of past streamflow from tree-rings depend on strong relationship between annual increments of tree growth and streamflow.

1.5 Research Objectives

A number of studies have recommended studying the trends for different hydroclimatic variables, so as to understand the relationship between hydrology and climate. In light of this, the main aim of this study is to analyze the trends that may exist at the time series of streamflow. Streamflow inclines to embody how a catchment area thoroughly has been sensitive to the variability in the conditions of weather all over the year (Gaucherel, 2002). Zhang et al. (2009) also pointed out that so as to know the impacts of the change of climate on global and regional water resources. To realize the main objective as for this study, the specific aims are to:

1. discuss the scaling effect on detecting trend from the reconstructed data as well as observed data. The main objective of this study is to clarify the effect of scaling on detecting trend,

2. study the trend results for time series whether is statistically significant or not and the effects of this results on stationarity and climate change interpretations.

1.6 Structure of Thesis

This thesis consisted of five chapters; the first one is a general introduction about the thesis.

The second chapter includes a concentrated review of previous studies, which specializes in studying the detection and analysis of trends and methods used, such as Mann Kendall trend test.

The third chapter revealed the main characteristics of the trend analysis by using Mann-Kendall trend test.

In the fourth chapter, the Mann-Kendall trend test applied on Filyos River streamflow in the Black Sea region (Turkey). Then the results were discussed.

The fifth chapter included the conclusions which were reached by the study and the most important recommendations in this field.

CHAPTER 2

LITERATURE REVIEW

2.1 General

In this section, relevant methods used in trend detection in hydro climatic studies are discussed and reviewed

2.2 General effects of climate change on hydrology

Changes in the earth's climate would get multiple significant inspirations for hydrologic ways. Increasing concentrations of greenhouse gas (GHG) effects will unfortunately lead to a great deal of the solar radiation to be trapped inside the earth for a long time, hence raising its temperature (Trenberth, 1998). Elevating global temperatures will cause alterations (changes) in the features of the hydrologic cycle – reacting to spatiotemporal characteristics of precipitation and rainfall, runoff, and potential evapotranspiration (IPCC, 2007). For instance, the intensification of the hydrologic cycle that has been identified would lead to a decrease in precipitation in subtropical areas, which increases the probability of drought later on (Dai et al., 1998; Huntington, 2006). On the other hand, increased yearly precipitation in the tropics and at high latitudes would result in an increasing expectation of overflowing of water (Huntington, 2006). The jeopardy of melted glaciers and rising sea levels would threaten fresh water supplies as intelligibly because of climate change (Jackson et al., 2001). The general changes are potential to have a strong effect on the environment as a whole, including water resources availability and accessibility, and thus the assumption of problems with respect to water resources planning and management is under inevitable discussion.

As far as the general scale is concerned, the thorough pattern of climate change has been studied quite extensively and is no longer very thorny matter in the scientific world (Oreskes, 2004). However, climate change has noticeably varying effects in different geographical regions (i.e., it is not spatially uniform) (Clark et al., 2000; Burn and Hag Elnur, 2002), and the nature of these variations has a high level of suspicion. Having said this, hydro- climatological parameters can serve to be signed in finding out and monitoring climate change since these variables are going to have the inclination to reflect climatic changes (Burn and Hag Elnur, 2002). Thereby, the research in this scope is very useful in understanding the relationships between hydrology and climate.

The proof of the vulnerability of water resources as to changes in temperature and precipitation characteristics has embodied by recent studies (Lahmer et al., 2001; Ampitiyawatta and Guo, 2009). Water resources react greatly to the environment, economy and society; so, changes in the series of events involved in the hydrological cycle can undoubtedly have great effects on the environment and socioeconomic profile (Arnell, 1999). Studies have in addition detected that since hydrologic conditions are comparatively different as two different regions, the effects of climate change on local hydrological processes are expected to make different within localities, even under the same climate environments (Zhang et al., 2001). Therefore, it is an undeniable truth for policy and decision makers to carefully test changes caused by climate change in the course of managing water resources. The results and risks related to climate change must be properly controlled, not only at the local and regional level, but also at a smaller and more localized measure (Durdu, 2010).

2.3 Detection and Analysis Trend in Hydro Climatic Variables

The analysis of trend in the variables of hydro climatic can be regarded as one way to evaluate how the climate has evolved through time. Trend detection indicates that the methods used to extract an underlying behavioural pattern in a time series that would otherwise be partly or fully not seen by the noise. The detection of sudden and gradual changes in hydrological and meteorological records has been investigated in elaborate detail by researchers. Information about spatiotemporal variability in hydro climatic time series is undoubtedly of great significance from both of scientific and workable points of view. The accounted significance of the trends found in the yearly maximum (flood), mean, and low flows in rivers are very valuable for flow regulation for instance (Tharme, 2003). This is due to take into account in the course of designing flood mitigation structures, flood-protection systems, and water storage reservoirs. Trend detection and forecasting of low flow is very important due to the quantity of water to be freed downstream of a dam, so as to maintain ecological integrity and sustainability (Smakhtin, 2001).

To understand the potential future changes caused by factors that affect climate change, we must take into account the detection and estimation of past trend changes and variability in hydro-climatic variables. This applies especially to the high- latitude regions which are good examples in this regard (such as Canada), where climate change signals are noticed to be stronger, and where the effects of climate change are probably more severe (Nicholls et al., 1996). Boyer et al. (2010) noted that the hydrological system of rivers at higher latitudes in the northern hemisphere (including Canada) could be dramatically restricted for the reason that the changes in temperature and precipitation during the current century, especially in the course of winter and spring. These modifications may contain a reduction in the annual mean of discharge (Arora and Boer, 2001), increased evaporation (Croley, 2003), increased winter runoff (Payne et al., 2004), as well as less snowpack accumulation (Whitfield et al., 2003; Hamlet et al., 2005).

Research undertaken in hydro climatic fields proves a systematic landscape for the sake of the study of how local and global space / time variations in the hydrologic cycle are affected by the climate system (IPCC, 2007). It is pivotal to analyze their importance and to assure whether these trends took place as a result of stochastic or more deterministic processes if it is actually the condition that trends presence in a hydroclimatic time series. All in all, an assumption of stationarity is implied by the data used in planning and designing water resources and engineering projects (Partal and Küçük, 2006; Burn et al., 2010). For example, for a long period of time, hydrologists took into account repeatedly overflowing of water to be events that resulted from stationary, independent and random processes. Like these assumptions may no longer be integrated into the planning and design actions of water resources works if the discussed global climate change (more specifically, because of anthropogenic-induced factors) is actually happening (Beyene et al., 2010).

To determine the main causes affecting these trends is, of course, one of the goals of trend detection (Yu et al., 1993). It must be remembered to recognize the effects of climatic variability/change on hydrological processes (with growing demand for water and problems related to water resources), as they are signals of how the climate has changed over time (Burn, 1994). Furthermore, analyzing and predicting the likely effects of the change of climate on water resources availability is very important to reinforce sustainable water control as well as its future planning (Durdu, 2010). It is important to investigate elaborately the hydrological process of the area so as to manage and understand the causes of water shortages for instance (Durdu, 2010). Moreover, a thorough understanding of how changes in climate affect the hydrological processes in a watershed is required to carry out work such as storm water planning, water quality management, river restoration projects, or anything like that (Coats, 2010). In regard to the hydrological processes in a watershed, one way to identify the changes by analyzing the trends involved in these processes, for example, precipitation and streamflow. Trends in climate are not fully caused by the concentration increasing of GHGs in the atmosphere. Having said this, natural cycles of climate indicators like the North Atlantic Oscillation (NAO), El Niño Southern Oscillation (ENSO), Pacific North American (PNA) – which are noticeable in the Northern hemisphere – have been concluded to affect also the trends in temperature, precipitation, and streamflow (Wettstein and Mearns, 2002; Coulibaly and Burn, 2004; Anctil and Coulibaly, 2004; Bonsal et al., 2006; Damyanov et al., 2012; Fu et al., 2012).

One must pay to attention to the inherent variability of hydrologic time series in the course of attempting to detect trends in a natural series. To make a comparison between natural variability and distinct trends is not always straightforward (Askew, 1987; Burn, 1994). Also, analyzing hydroclimatic time series data is controversial as it can be non- normally formed in distribution; have serial dependency, uneven spacing and timescale uncertainties (Koutsoyiannis and Montanari, 2007); and can also be topic related to shifts and sudden changes. The interest of trend analysis in hydrology is on determining the accurate evolution of these hydroclimatic conditions and variables in the course of time. However, problems can arise because of the availability of data that are usually: (i) limited in length, (ii) reacted to background noise (errors), and (iii) can contain multiple indicators, sections of increasing and decreasing trends, and sometimes discontinuities (Adamowski et al, 2009).

The acquisition of long-term data is a useful approach to adopt if we are going to be able to draw useful and accurate conclusions about these alterations (De Jongh et al., 2006; Pekarova and Pekar, 2007). A great deal of studies conducted by many authors in analyzing hydroclimatic trends have used different lengths of data. Kahya and Kalayci (2004) and Burn and Hag Elnur (2002) take into account a minimum of 31 and 25 years worth of data, respectively, to make a valid mean statistic in analyzing trends in their flow data. Nevertheless, Kundzewicz and Robson (2004) argue that because of the variation in climate, data composing of 30 years or less of records are somehow insufficient for trend detection related to climate change. Approximately four decades worth of data would be sufficient to know the existence of possible trends in annual streamflow series as well as their prevailing periodicities (Ampitiyawatta and Guo, 2009; Partal, 2010). In regard to this information as for this study, we used 341 years of reconstruction data from (1657 to 1997) and the observation data for 34 years from (1964 to 1997).

2.4 Methods to Analyze Trend of Hydro Climatic Variables

Trends in hydro climatic variables can be tested in many different ways. Land- based data, satellite data, statistical tests, computer-intensive approaches and models play vital roles in dismissing the misunderstanding of the complex time and space variations in hydro-climatic systems, it is important to take into account the characteristics of the data before selecting the methods that are going to be used to study trends, such as data length and distribution, the structure of the sample, the possible types of existing trends (monotonic or stepwise), and also, the existence of persistence and seasonal fluctuations in general (Cluis et al., 1989).

Some of the more orderly arrangements used for trend investigation in hydroclimatic research involve the use of the bootstrap method (e.g. Douglas et al., 2000; Di Stefano et al., 2000; Chingombe et al., 2005), Monte Carlo simulation (e.g. Yue et al., 2002b), the Spearman’s rho (SR) test (e.g. McLeod et al., 1991; Yue et al., 2002a), regression models (e.g. Svensson et al., 2005; Shao et al., 2010; Timofeev and Sterin, 2010), the Mann-Kendall (MK) trend test (e.g. Burn and Hag Elnur, 2002; Yue et al., 2003; Partal and Küçük, 2006; Partal, 2010), and non-parametric statistical tests (e.g. Birsan et al., 2005; Zhang et al., 2009; Durdu, 2010; Zhang et al., 2010; Liu et al., 2010), among others. Some of these commonly used methods are being discussed in the following sections, in addition to their strength and shortcomings.

Recently, a number of studies have also had the use of wavelet analysis (WA) approaches in finding out and guessing trends in hydroclimatic time series (e.g. Kirkup et al., 2001; Anctil and Coulibaly, 2004; Kim, 2004; Prokoph and Patterson, 2004; Partal and Küçük, 2006; Adamowski et al., 2009; Partal, 2010). There is no doubt that the use of wavelet transforms in detecting trends is usually associated with statistical tests as in the case of regression models or the MK test in order to make these trends under discussion (e.g., Partal and Küçük, 2006; Zume and Tarhule, 2006; Xu et al., 2009; Adamowski et al., 2009; Partal, 2010).

2.4.1 Non-parametric Statistical Tests

In order to measuring the significance of trends in a time series, non-parametric (distribution free) statistical tests are used in trend detection. The use of statistical tests involves testing of the null hypothesis which suppose that the data are haphazard and are not mutually related (i.e., no trend will be detected) against the alternative hypothesis, there would be a noticeably trend detected, either positive or negative. When the arguments under discussion of the parametric tests cannot be fully met, non-parametric tests are used. Non-parametric tests have less strict assumptions and have a higher tolerance with respect to missing values and non-normal distribution (Cunderlik and Burn, 2004). Non-parametric tests are usually preferred in exchange for parametric tests in conducting since earth-based scientific phenomena (including hydrological processes) tend to have non-stationary features and non-normal distributions a trend analysis (Hirsch and Slack, 1984; Lattenmaier, 1988). Besides, hydrological data normally exhibit autocorrelation; accordingly, data values are not independent. They may reveal seasonality, which violates the arguments under discussion of permanent distribution (Kundzewicz and Robson, 2004).

It is worth mentioning that both parametric and non-parametric tests still required where the observations are independent, since the existence of serial correlation can noticeably influence on the trend determination leading to inexact conclusions (Adamowski and Bougadis, 2003). Taking this into consideration, the strength of non-parametric tests must be found in their exact level of significance (even if the data show non-normal distributions) (Johnson, 2000). Helsel (1987) concluded that the advantages of non-parametric tests can be embodied as follows:

1. Transformation of data to the normal distributed one is not needed.
2. The results produced should still be dependent confidently, even though data exhibit non-normal distribution.

3. The tests are still effective even though the distribution of samples is not corresponding exactly to each other.
4. The results of non-parametric tests should still be under the use even if there are outliers shown in the data.

2.4.2 The Mann-Kendall (MK) Trend Test

The MK (Mann, 1945; Kendall, 1975) trend test can be regarded as a rank-based test of aimlessness against monotonic trends (Zhang et al., 2001; Déry and Wood, 2005; Kallache et al., 2005; Zume and Tarhule, 2006, Burn et al., 2010). A great deal of studies has executed the MK trend test in their data analysis so as to assess and characterize trends in a time series. It is possibly the most dominantly used non-parametric test for trend detection in hydrological researches (Yue and Pilon, 2004; Hamed, 2008). This is not only because of the simplicity of use, but it is also resilient to skewed distribution, missing values and values that are classified outside the detection boundary, and to the non-stationary nature of the data (Lins and Slack, 1999; Partal and Küçük, 2006). For the reason that it is rank-based, it placed certainty on the order of the rank, and not on the value existing in fact now of the records themselves. Thus, if some values are missing or if an outlier is present, the results would not be influenced much because the ranks would not change a lot. The hypothesis of the MK test is based on the condition of monotonic change, not a break change (Chaouche et al., 2010). The MK test, however, still performs well even if a break is not missing in the time series (Lemaitre, 2002; Chaouche et al., 2010). Chaouche (2010) also assured that changes in a time series that are affected by climate change, should occur step by step (in a more gradual way). Hence, the MK test was deemed to be suitable to be used in our study.

Önöz and Bayazit (2003) compared the power of the t-test and the MK test in analyzing the annual streamflow series at 107 sites across Turkey by Monte Carlo Simulation. They found that the t-test had slightly more power than the MK test in the course of the distribution is normal; whereas for skewed distributions, the MK test was more effective, especially, when the coefficient of skewness is high (Önöz and Bayazit, 2003). In the same way, when Yue and Pilon (2004) made comparison to the power of the parametric t-test, the MK test, the bootstrap-based slope test (BS-slope), and the bootstrap-based MK test (BS-MK), they came up with that the t-test and BS-slope test were more powerful than the rank-based tests for data having a normal distribution, irrespective of the linearity of the trend. As far as the data that are not normally distributed are concerned, the rank-based tests were much more powerful in detecting trends, regardless of their linearity (Yue and Pilon, 2004).

Using the MK test on its own for detecting trends might not always be ideal, although the MK test is robust and very useful in many hydrological studies. That is due to the MK test does not account for the serial correlation that repeatedly exists in a hydrological time series (Hamed and Rao, 1998; Yue et al., 2002b; Partal and Küçük, 2006). The existence of serial correlation in a dataset may result in a falsely result interpretation as it gives support to the probability of finding a noticeable trend, in the course of the actual absence of a significant trend. Accordingly, in regard to this study, each time series was first checked for whether a noticeable autocorrelation (more specifically, lag-1 autocorrelation coefficient) exists or be present. If a time series did not show a significant autocorrelation, the original MK test was going to analyze the data. In the event that a significant autocorrelation was present in a time series, we adopted the modified versions of the original MK test for the reason that these modified MK tests have shown that they are more effective (powerful) and hence, more reasonable for data with significant autocorrelation.

2.4.2.1 Treatment Serial Correlation Problem in Time Series Analysis

Several proposals and efforts which attempt and to deal with the presence of serial correlation in a time series have been made, including: (1) Prewhitening method by Kulkarni and von Storch (1995); (2) modified MK test by Hirsch and Slack (1984); and (3) modified MK test which was applied by Hamed and Rao (1998). The Prewhitening method will be discussed in the following section.

2.4.2.1.1 Pre-whitening Method

Kulkarni and von Storch (1995) proposed the prewhitening method in order to eliminate the autocorrelation from a certain data set. A correlation coefficient which is used on a wide scale (i.e., correlation coefficient between the time series value at time t and its value at time t-1) to decide if an autocorrelation (lag-1 autocorrelation coefficients) exists in a dataset. If the calculated lag-1 autocorrelation coefficients of a time series is significant at a significance level (e.g. the 5% level), then the autocorrelation is eliminated by the prewhitening processes (before the application of the MK trend) via presuming that the autocorrelation of the time series is an AR (1)-process. An autoregressive process of the first order or the AR (1)-process is removed or reduced by subtracting the observation at time t-1 (which was multiplied by its estimated autocorrelation at lag-1) from the observation at time t (Kulkarni and von Storch, 1995). This is performed to create a time series which is sampled independently and identically distributed. Monte Carlo simulations was used by Kulkarni and von Storch (1995) for 1000 prewhitened time series (with an AR (1) process originally) and with α (= 5%), the process of prewhitening resulted in rejection rates for the correct null hypothesis, which were extremely close to the α value. Kulkarni and von Storch (1995) noticed that the method of prewhitening is not efficient with the data involving large autoregressive coefficient values or when the time series length is short. The prewhitening method was employed by Zhang et al. (2001); Burn and Hag Elnur (2002); and Mohsin and Gough (2010), besides others.

Yue and Wang (2002) evaluated the effectiveness of the pre-whitening procedure via a simulation process. That was done by using the estimation of the first order autocorrelation coefficient which was the outcome of a Markov process that was coupled with the trends. They discovered that the pre-whitening procedure is not completely effective in terms of eliminating the effect of autocorrelation in the data when they detected the trends by means of the M-K test (commonly used on pre-whitened data), where the sequence of records manifested trending observations (Yue and Wang, 2002). Additionally, Yue at al. (2002b) reported that by the removal of the positive serial correlation from the time series through the pre-whitening method, the trends that might be present in the series is reduced, and several components of the trend are also removed. Alternatively, removing the negative serial correlation by means of using the same procedure could enhance the magnitude of the trends that exist (Yue et al., 2002b).

2.5 Nonstationarity Approach In Hydrology

A time series in which a trend is identified is considered as nonstationarity. The idea of stationarity (and nonstationarity) is well defined theoretically of stochastic processes (being called a stochastic process stationarity) if its statistical properties are fixed to a shift of time. That is to say, stationarity a process is called that is time invariant.

2.6 Reconstruction Data From Tree-Ring Chronologies With Nonparametric Approaches

There have been several attempts that were made in the past to reconstruct the streamflow before performing the direct measurements by means of the tree-rings. Studies indicated that tree-ring dating provides greater insight to the potential design problems and the possible solutions (Meko et al., 1995). The first dendroclimatological study in Turkey which was conducted in 1942, determined the wet and dry years around Ankara through using the black pine tree rings (Touchan et al., 2003). More comprehensive studies followed it such as (Hughes et al., 2001; Touchan et al., 2003, 2005a, b; Akkemik and Aras, 2005; Akkemik et al., 2005, 2008). Among these studies, Akkemik et al., (2008) reconstructed streamflow using the tree rings in Filyos River region and that was done by using the linear regression method. They discovered that a measure of good suitability (R^2), which stands for the percent of variance, which is explained by their model was 0.28, Sarlak (2014) reconstructed streamflow which are based on the tree-ring for the Filyos River basin with the nonparametric paleo-hydrologic (NPP) method in accordance with the K nearest neighbor (KNN), modified KNN (mKNN), and local polynomial approaches. She mentioned that the purpose of performing the mKNN and local polynomial approaches was to simulate values that were not observed in the historical record.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The data of time series stands for the observations which are measured regularly over time. The time series analysis or the analysis of trend studies conduct on the data of time series over time. Streamflow is considered one of the time series data as observed at the same stream gage stations throughout a long period of time. As for the main objective of the trend analysis, part of the thesis is dedicated to determine whether there are increasing or decreasing trends in the values of the annual streamflow. The analysis of trend is conducted with non-parametric Mann-Kendall tests. The Mann-Kendall test is regarded as non-parametric and does not provide any assumption about the variable distribution. The Mann-Kendall tests were applied in terms of the mean annual stream flow values. Serial correlation at the data of time series if it exists has been removed and trend tests were applied to the residual terms once again. The significance level (=5%) is used for accept or to reject the null hypothesis. The methodological procedures are outlined and shown in Figure 3.1. These steps include: (1) testing the effect of the serial correlation; (2) application the Mann–Kendall test.

3.2 Serial correlation effect

One of the problems that encountered in discovering and explaining the trends in hydrologic data is the confusing effect of the serial correlation. Precisely, if there was a positive serial correlation in the time series the test of non-parametric could imply a significant trend (Kulkarni and Van Storch, 1995). Therefore, Von Storch and Navarra (1995) argued that the time series must be pre- whitened so as to remove the effect of the serial correlation before the application of the Mann–Kendall test.

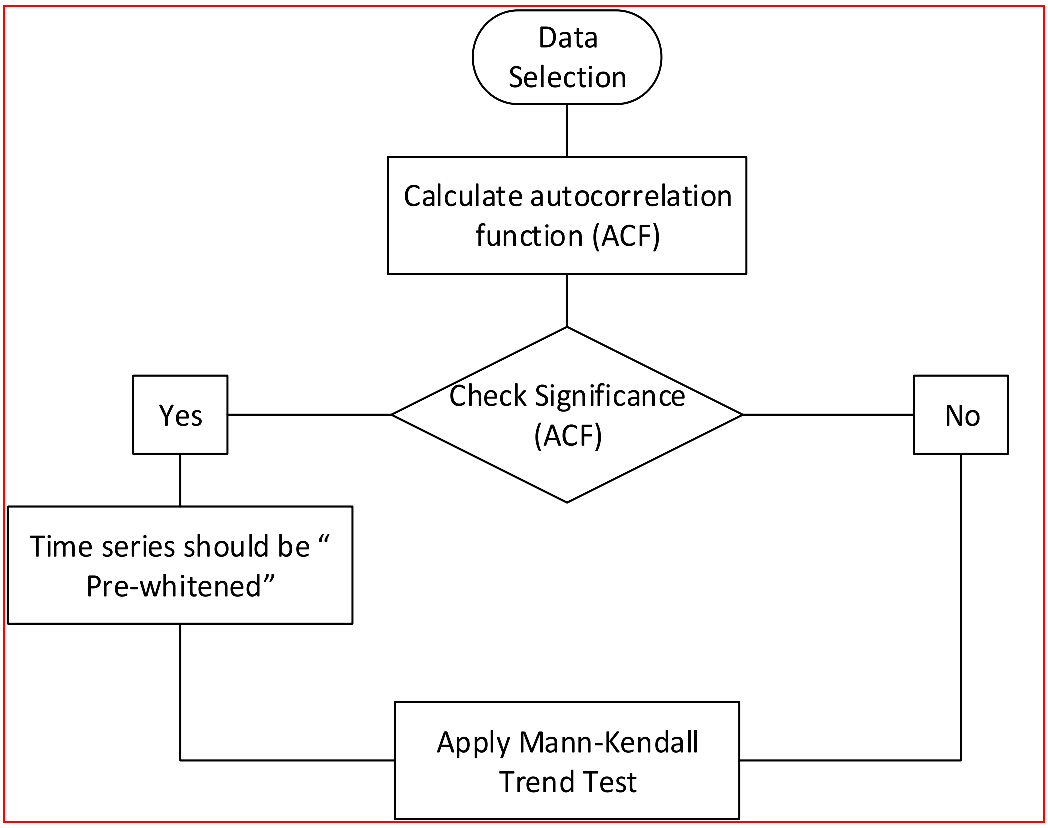

Figure 3.1 Flow chart of methodological procedures

This possible serial correlation, which are significant statistically in a streamflow observations (x_1, x_2, ... x_n), are reviewed by using the following steps:

1. Determining the lag-1 serial correlation coefficient (which is designated by r_1).

$$\boldsymbol{r_1} = \frac{[\sum_{i=1}^{n}(X_i - \bar{X})\ (X_{i+1} - \bar{X})]}{\sum_{i=1}^{n}(X_i - \bar{X})^2} \qquad (3.1)$$

where $\bar{X}$ represents the mean of the data

2. If the r_1 calculated is not significant at the level 5%, then the Mann–Kendall test can be applied to the original values of the time series.

3. If r_1 found is significant, before the application of the Mann–Kendall test, then the 'pre-whitened' time series should be obtained as ($x_2 - r_1 x_1, x_3 - r_1 x_2 ... x_n - r_1 x_{n-1}$).

3.3 Mann–Kendall Test

The Mann Kendall test is a statistical test which is used frequently and widely for the purpose of trend analysis in climatologic and hydrologic time series. The use of this test has two advantages. Firstly, it is a non-parametric test and does not require that the data should be normal distributed. Secondly, the test is characterized with low sensitivity to sudden breaks as a result of the inhomogeneous time series. In accordance with this test, the null hypothesis H_0 presumes that there is no trend (the data is independent and randomly ordered) and this is tested in comparison to the alternative hypothesis H_1, which presumes that there is a trend. The calculation steps for the Mann Kendall test takes into consideration the time series of n data points and x_i and x_j as two subsets of the data where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3,…, n. After that the data values are evaluated as an ordered time series. They are compared to each data value for all subsequent values. If a data value from a later time period was higher than the data value from an earlier time period, then the statistic S would be increased by 1. While if the data value from a later time period was lower than a data value which was sampled earlier, then S would be decreased by 1. The final result of all the increments and decrements leads in the final value of S.

The Mann-Kendall S Statistic is calculated and determined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(X_j - X_i) \tag{3.2}$$

$$sgn\,(X_j - X_i) = \begin{cases} +1 & if\ (X_j - X_i) > 0 \\ 0 & if\ (X_j - X_i) = 0 \\ -1 & if\ (X_j - X_i) < 0 \end{cases} \tag{3.3}$$

where x_j and x_i are the annual values in years j and i, j > i, respectively. If sample ≤size of data (n) < 10, the value of |S| will be directly comparable to the theoretical distribution of S derived by Mann and Kendall. In this study the two tailed test is used. At certain probability level H_0 is rejected in favor of $H_{1.}$ If the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S having the probability less than α/2 it will show in case of no trend. A positive (negative) value of S refers to an upward (downward) trend. For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows:

E(S) =0

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i\,(i)(i-1)(2i+5)}{18} \qquad (3.4)$$

where t_i is considered as the number of ties up to sample i.

The test statistics Z_c is calcalated as:

$$Z_c = \begin{Bmatrix} \frac{s-1}{\sqrt{Var(s)}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s-1}{\sqrt{Var(s)}} & if\ s < 0 \end{Bmatrix} \qquad (3.5)$$

The test statistic Z_c is used a measure of significance of trend. Actually, this test statistic is used to test the null hypothesis, H_0. If $| Z_c |$ is greater than $Z_{\alpha/2}$, where α represents the chosen significance level (eg. 5% with $Z_{0.025}$ = 1.96) then the null hypothesis is invalid which means that trend is significant.

The another test statistic used to test the null hypothesis H_0 is the p-value test. If the **p-value ≤ α** reject the null hypothesis that means there is a trend in the time series. **P-value** > **α** accept the null hypothesis that there is no trend in the time series.

The other test is Kendall's tau test, which is considered a measure of correlation and therefore it measures the strength of the relationship between the two variables. Kendall's tau, similar to Spearman's rank correlation, is performed on the ranks of the data. This means that each variable are listed in increasing order, where 1 represents the lowest value and 2 stands for the next lower and etcetera. In conformity with other procedures of correlation, Kendall's tau takes values between ±1 and +1. In addition, the positive correlation indicates that the ranks of both variables increase together while the negative correlation indicates that when the rank of one variable increases the other one decreases.

The Mann-Kendall test (Kendall's tau) can be obtained from this equation:

$$\tau = \frac{S}{n(n-1)/2} \qquad (3.6)$$

where S is The Mann-Kendall S Statistic and n is the sample size.

3.4 Methodology for Paleo – Hydrologic Reconstructions

Describing the NPP method according to KNN, mKNN, and local polynomial (LOCFIT) methods are manifested in the next section. It is confirmed that mKNN and local polynomial approaches were put into application as the limitation of retrieval having shorter data overlap (Sarlak, 2014).

3.4.1 NPP-KNN Algorithm

In the past tree - ring studies, principal component analysis (PCA) and multiple linear regression (MLR) methods were used in general to get rid of the drawbacks of the traditional MLR approach. In this approach, principal component analysis (PCA) is used to reduce the set of chronologies and then the leading principle components (PCs) are used in calibrating the MLR model. However, this technique suffers from four main drawbacks: (1) it assumes that the data are normally distributed, (2) it assumes that there is no correlation between the predictor variables, (3) it produces variance compression of the predictand, and (4) outliers can have an undue influence on the fitted MLR model (Gangopadhyay et. al., 2009). The first drawback is a main challenge for almost all valid parametric models. For this drawback, the data must be tested and appropriate method must be used to transform it to normal or near-normal distribution. The second assumption is no correlation between the predictor variables. However, a fairly high level of predictability may exist for one or more predictors from the other predictors when several predictor variables are used in MLR. This condition is referred to as multicollinearity and can lead to instability of the regression coefficients. Multicollinearity refers to a situation in which two or more explanatory variables in a multiple regression model are highly linearly related. Principal component analysis is used to eliminate multicollinearity. To address variance compression in streamflow reconstructions, a noise-added probabilistic approach to interpretation of the reconstructions is proposed by Meko et al. [2001]. The outlier effect is crucial for MLR approach, since this effect cannot be fully eliminated in this approach. The reason of this effect is that MLR approach involves fitting a single function, often linear, to the entire observed data set (Gangopadhyay et. al., 2009).

Gangopadhyay et. al., (2009) proposed nonparametric paleohydrologic (NPP) method based on the K-nearest neighbor (K-NN) bootstrap in empirical orthogonal function (EOF), or principal component (PC) to alleviate the above drawbacks of the traditional MLR approach. They used the advantage of non-parametric method along with PC analysis. However, the method preserved the disadvantages of KNN bootstrap also. The positive characteristics of the KNN approaches are as follows: (1) keeping the marginal distribution; (2) reproducing linear or nonlinear dependence in the historical data; and (3) it provides simplicity in extending to higher order dependence and to multidimensions. However, the KNN approach only generates historical values as it is merely a re-sampling technique. Therefore, the compound values which were not observed in the historical record is not likely to be simulated. The detailed procedure of the methodology is found in Gangopadhyay et al. (2009) (Sarlak, 2014).

3.4.2 NPP-Modified KNN Algorithm

The KNN approach generates historical values only. Therefore, the reconstructed group is confined to the overlap period length. This limitation is important when the overlap period is short just as in our case. To extenuate the limitation a local polynomial (Loader, 1999) can be fit and this fitness can be used for the mean flow estimation. In this approach, the model is represented as:

$$\boldsymbol{Y_t = g\left(X_{1,t}\,, X_{2,t}\,, \dots\dots\dots. X_{mi,t}\right) + e_t} \qquad (\mathbf{3.7})$$

The detailed description of the method can be found in Prairie (2002) and Prairie et al. (2005) who refer to it as the “mKNN.” The same terminology will be used for the rest of this study. The advantages of this technique are as follows: (1) values are simulated other than historical record; (2) any relationship (linear or nonlinear) that is manifested in the data observed is captured. On the other hand, the defects of this method are the following: (1) negative values could be generated because of the error term; (2) the variation generated from this method is limited especially having short overlap datasets (Sarlak, 2014).

3.4.3 NPP-LOCFIT Algorithm

The mKNN method is characterized with the ability to generate values not observed in the historical record unlike the straight bootstrap technique such as KNN (Grantz et al., 2005). However, when the number of overlap observations is very small, then the number of neighbors to bootstrap the residuals will limit the variety in the groups. To deal with this, the terms of the random error with a mean of zero and the standard error deviation are both used. Then they are added to the mean estimates, Y new to generate the groups (Prairie et al., 2006). Singhrattna et al. (2005) refer to that as LOCFIT. The only difference of this approach from mKNN is adding normal random error terms instead of the corresponding error term to the mean estimate, Y is new. This method was implemented and good results were obtained in terms of forecasting Thailand summer rainfall with a smaller sample size (N = 25) by Singhrattna et al. (2005) (Sarlak, 2014).

CHAPTER 4

APPLICATION AND RESULTS

4.1 Introduction

In general, observational and historical data of hydro climatology is used in planning and designing the projects of water resources. There is an implicit supposition, which is called stationarity that implies time-invariant statistical characteristics of the time series in question in all the water resources engineering projects and works. Such an supposition can no longer be valid if the changes assumed in the universal climate go on due the increase of greenhouse gases in the atmosphere. This, of course, leads to great problems (e.g. dislocation and inefficiencies) in the management of the regional water resources. In terms of more specific understanding, for instance, floods are considered to be a result of stationary, independent and identically distributed random process by hydrologists for a long period of time. Nevertheless, several scholars (i.e. Cayan and Peterson, 1989; Lins and Slack, 1999; Jain and Lall, 2000) have submitted evidence of trends (probably due to the anthropogenic influences) and long-term variation of climate. Trend is usually considered the natural variability and change to be small enough to allow for the design based on stationarity. In this study, Mann-Kendall trend test has been used to verify the stationarity approach in fiylos River.

4.2 Study Area

The Filyos River basin is located on the northwestern part of Turkey at the Black Sea. The climate in the Black Sea area is wet and humid (summer 23°C, winter 7°C). The annual precipitation in the coastal area is about 1,000 mm, whereas in the inner parts of the basin it decreases to 500 mm. Monthly mean discharge records for the Filyos River were obtained from the Electrical Power Resources Survey (EIE). The Filyos gaging station (EIE 1335) was selected for use since it is located at the most downstream point of the watershed and can be considered to be representing the whole watershed. Study area and the location of selected streamflow gaging station is shown in Figure 4.1. Thirty-four years of monthly natural streamflow data for the period of 1964-1997 were available.

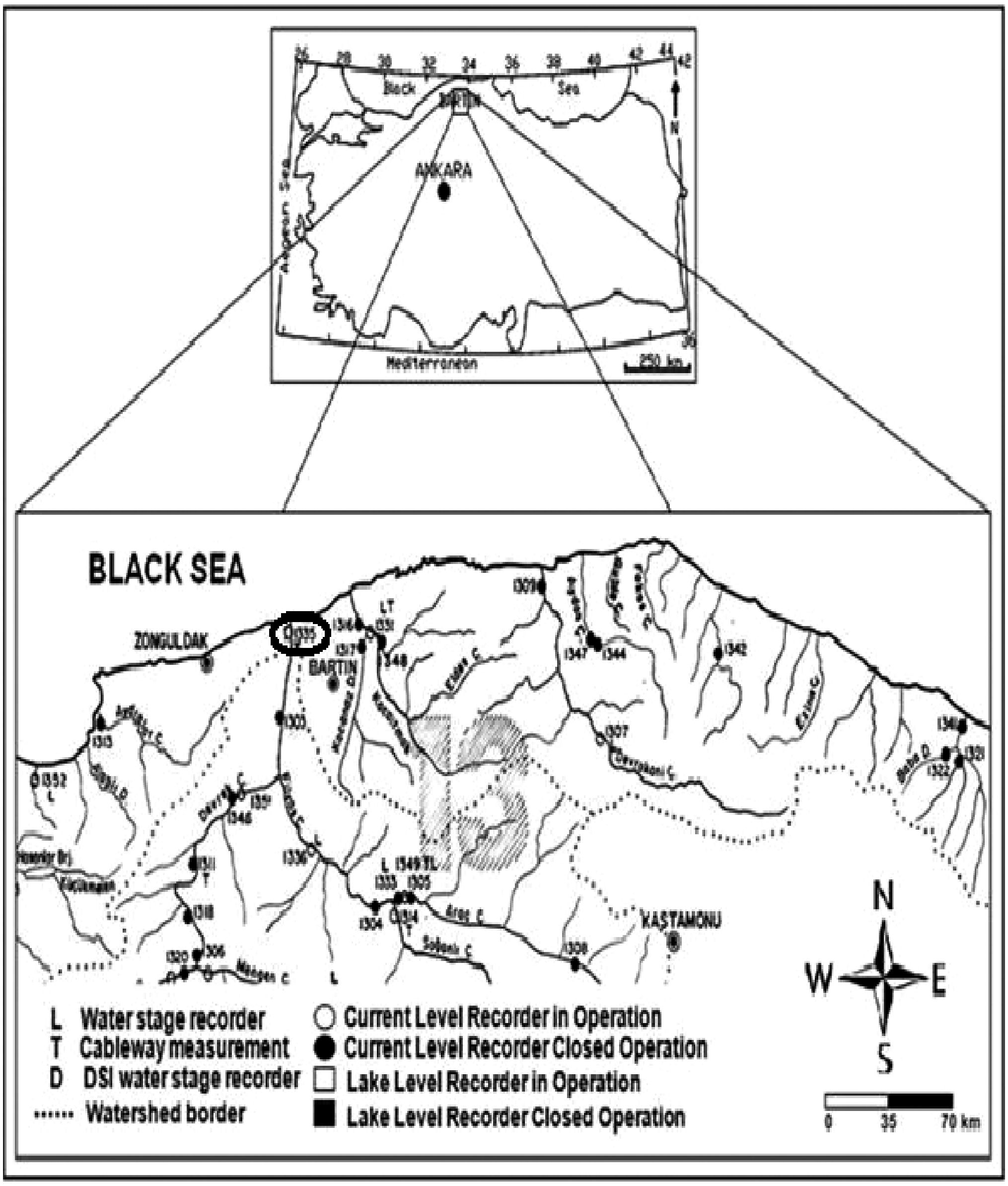

Figure 4.1 Study area and the location of selected stream gaging station on the map

Site information for gaging station including latitude, longitude, and observation period are listed in Table 4.1. Thirty-four years of monthly natural streamflow data for the period of 1964-1997 were available. Mean annual streamflow is 100.7 m^3/s. The highest flow was measured to be 533 m^3/s in April 1997, and the lowest was 6.2 m^3/s in September 1994.

Table 4.1 Site information for EIE 1335

Site Names	Elevation (m)	Latitude (N)	Longitude (E)	Period
Filyos(EIE1335)	2	41 15	29 19	1964 – 1997

4.3 Results and Discussions

4.3.1 Streamflow Reconstruction Data from Tree-Ring Chronologies with Nonparametric Approaches

Sarlak (2014) reconstructed the streamflow data during 1657-1997 for the Filyos River with three different nonparametric models and these are presented in Figures (4.2), (4.3) and (4.4) Sarlak (2014).

Sarlak (2014) indicated that the streamflow reconstructions displayed numerous fluctuations at both the interannual and decadal scales as it can be seen in Figures (4.2), (4.3) and (4.4). The moving average values obtained from LOCFIT method were close to observed streamflow. It indicates that longer term cycles for streamflow reconstruction with smoothing out shortterm fluctuations preserve the observed data pattern. She also used some anecdotal documentation to compare the dendrohydrological reconstruction of this region.

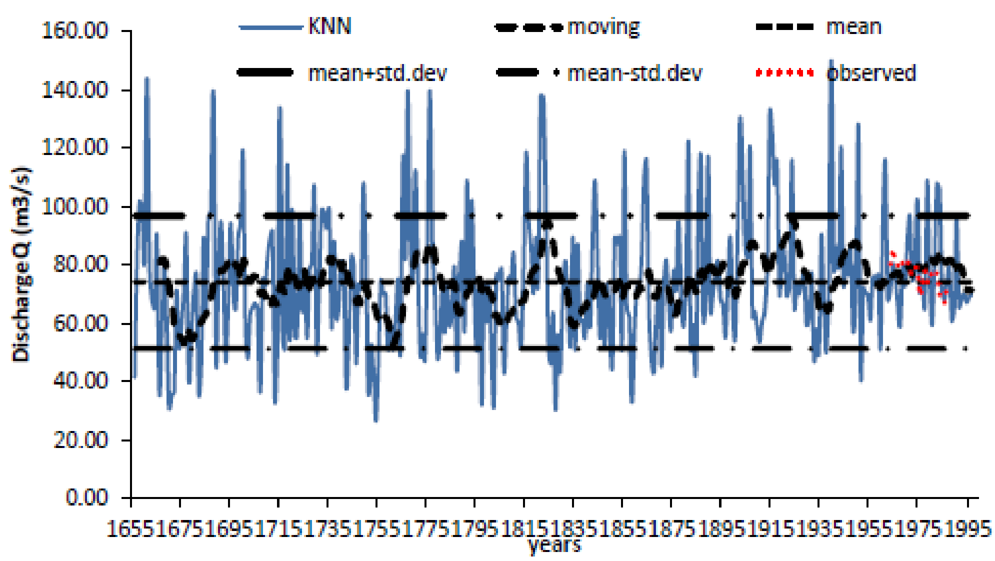

Figure 4.2 Paleo-hydrologic reconstructions during 1657-1997 obtained from NPP-KNN model

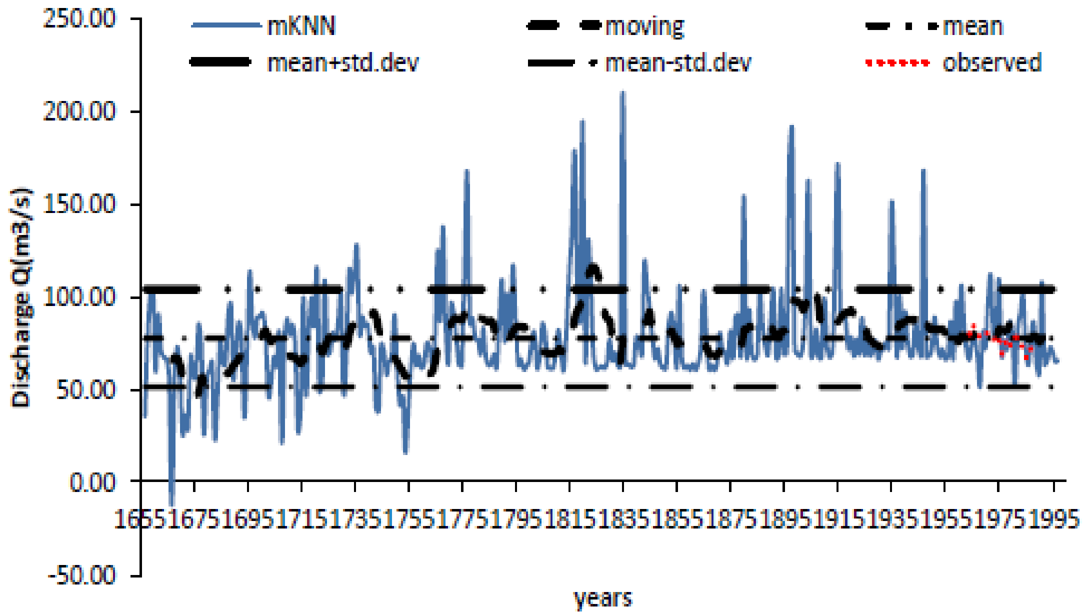

Figure 4.3 Paleo-hydrologic reconstructions during 1657-1997 obtained from NPP-mKNN model

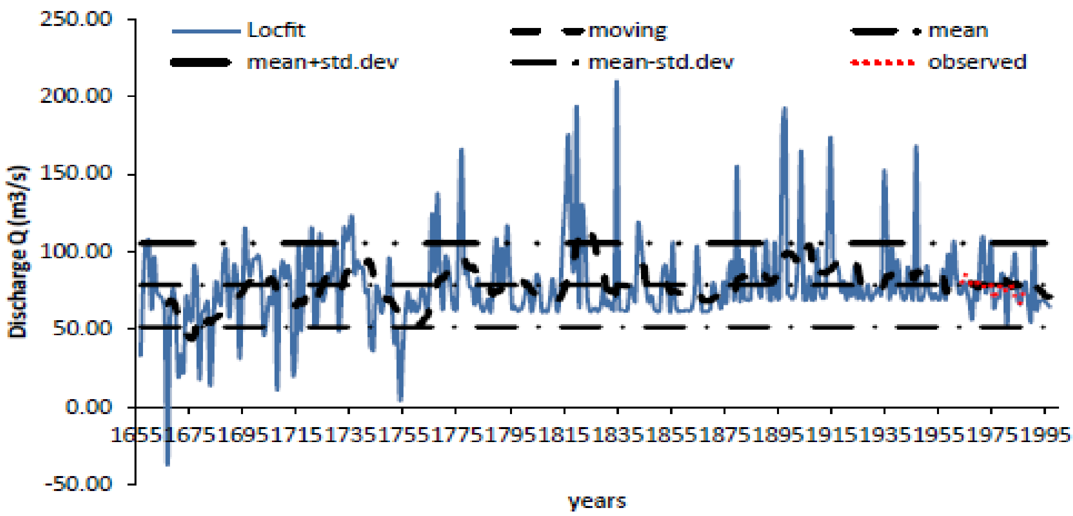

Figure 4.4 Paleo-hydrologic reconstructions during 1657-1997 obtained from NPP-LOCFIT model

Since she emphasized that NPP-LOCFIT method exhibits better performance capturing the features present in the observed data than the others, the reconstructed data series obtained from NPP-LOCFIT method is utilized in the following part of this study.

4.3.2 Mann-Kendall Test on Observed Annul Data

At the first, the trend analysis for annual series was made in order to get an overview of the potential changes in streamflow procedures. The Mann-Kendall trend test (Mann, 1945 and Kendall, 1975) was used to determine whether the trends found are significant or not. Mann-Kendall test is based on the null hypothesis that a sample of data is independent and identically distributed, which means that there is no trend or serial correlation among the data points. That means that the serial correlation effect should be removed before applying Mann-Kendall.The effect of serial correlation was explained in Section 3.2. Since the correlograms or autocorrelation plots characterize the autocorrelation functions of the time series, this method was used to check the serial correlation effect. In this method, if an autocorrelation coefficient values are within the upper and lower confidence limits, we can say that data is independent from each other. Otherwise the correlation effect should be removed. Autocorrelation function as well as partial autocorrelation function are obtained and shown in Figures 4.5 and 4.6. Partial autocorrelation function method was also utilized because it is another way of representing the time dependence structure of a series. Both the autocorrelation and partial autocorrelation coefficients are within upper and lower confidence limits as it can be seen in Figures 4.5 and 4.6. It means that serial correlation effect is not significant at 95% level. Therefore, Mann-Kendall test was applied directly on the original annual observation data.

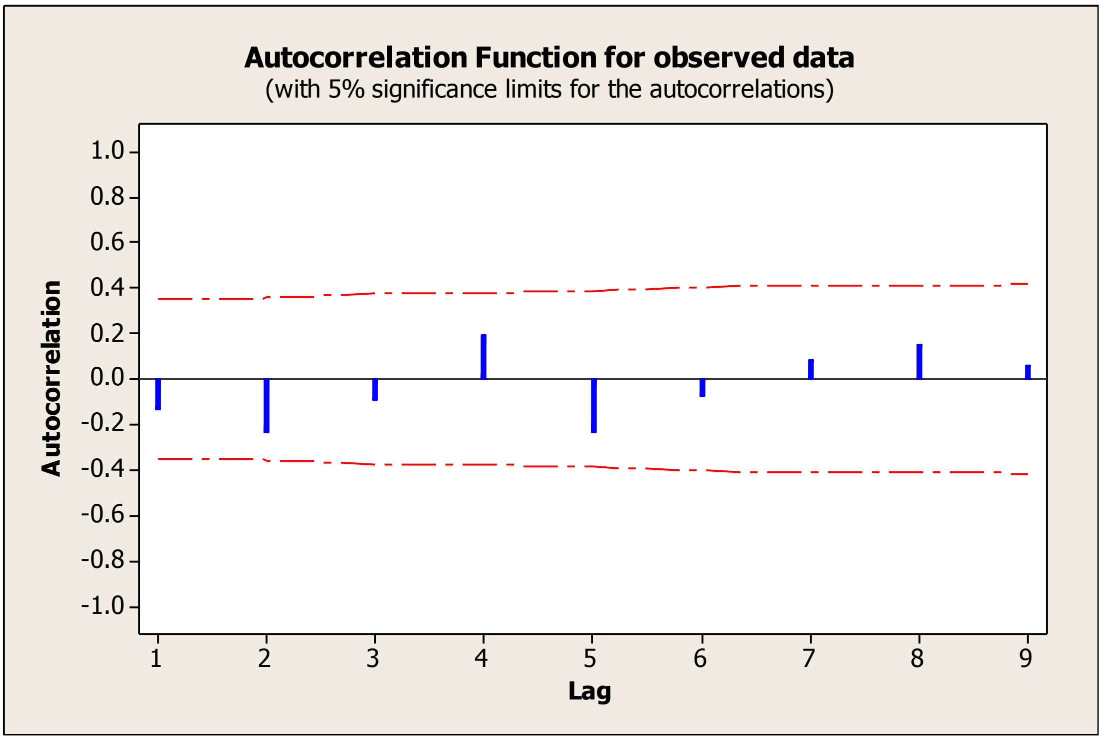

Figure 4.5 Autocorrelation function of observed data

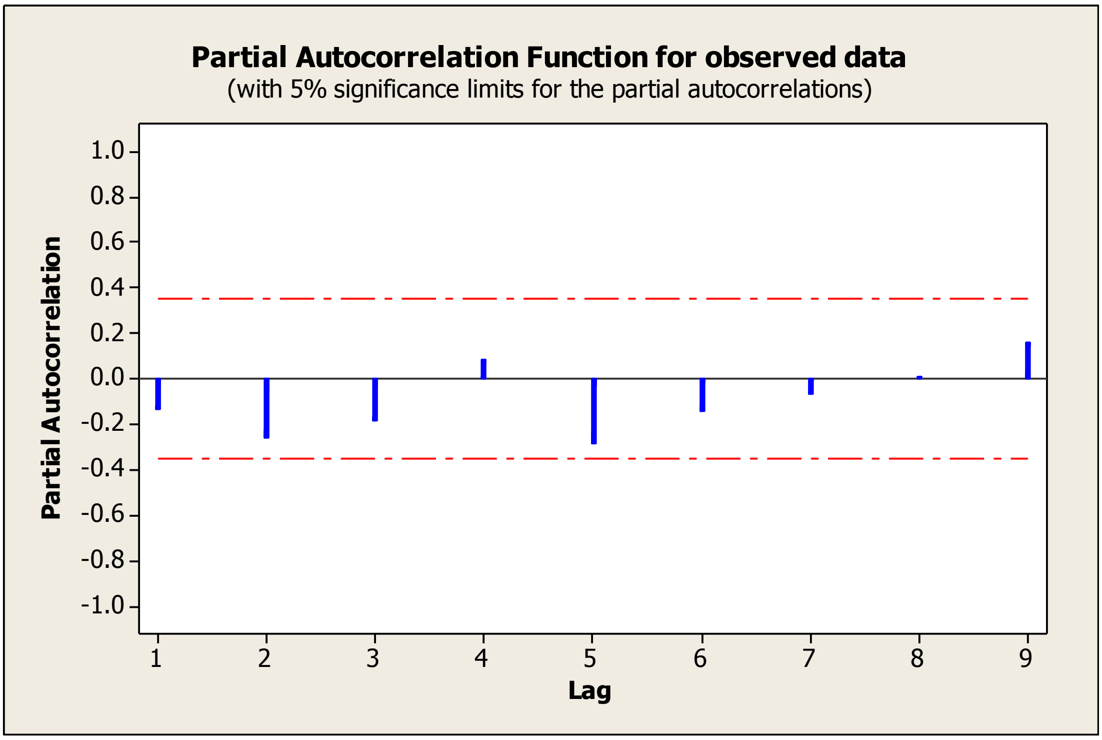

Figure 4.6 Partial autocorrelation function for observed data

The Mann-Kendall test results are given in Table 4.2. If p value is greater than the significance level $\alpha = 0.05$, H_0 will be not rejected. Since the calculated p value (=0.35) is greater than 0.05, we can say that there is no trend in our time series. Although the result indicates that there is a decreasing trend in the time series, it is not statistically significant.

Table 4.2 Results of Mann- Kendall test for observation data

Mann-Kendall Statistic S	**Kendall's Tau**	**Var (S)**	**Mean**	**P-Value (two tailed test)**	**Alpha**	**Test Interpretation**
-64	**-0.114**	**4549.333**	**76.54853**	**0.35028**	**0.05**	**Accept H_0**

4.3.3 Mann-Kendall Test on Mean (spring-summer) Data

In this section, we utilized the mean spring-summer observed data for 34 years from 1964 to 1997.The first step is to find the mean of spring-summer data for months from May to August for each year in the time series data. The reason of this is that Sarlak (2014) reconstructed mean spring-summer data. Because she indicated statistically significant relationship was found between the mean spring-summer data and tree ring chronologies. The second step is to determine the trend of mean spring-summer data by using the Mann-Kendall trend test. Before applying MK test the serial correlation at the data of time series has been removed if it exists. This check is done by examining the autocorrelation and partial autocorrelation function whether it is significant or not as explained in Section 3.2. We found that the autocorrelation and partial autocorrelation values are not significant at 95% level. It can be seen in Figures 4.7 and 4.8. That Mann-Kendall test should be applied directly on the mean spring-summer observed data.

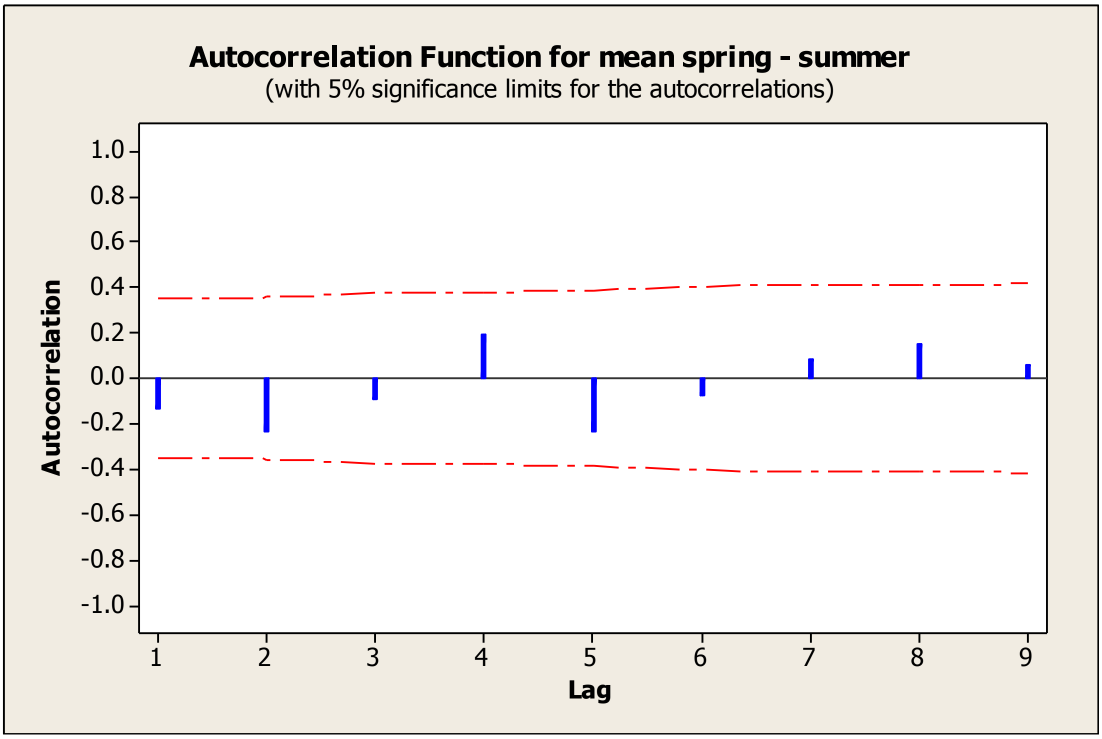

Figure 4.7 Autocorrelation function for mean spring-summer data

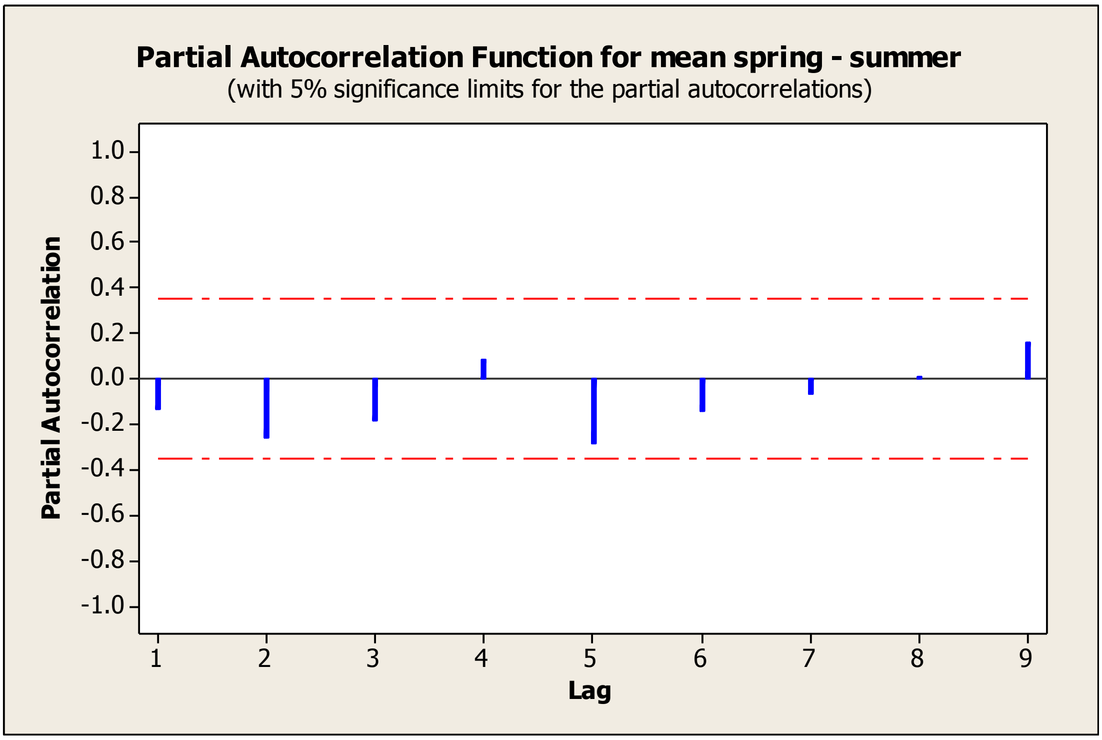

Figure 4.8 Partial autocorrelation function for mean spring-summer data

The Mann-Kendall results of mean spring- summer data for months (May-August) are shown in Table 4.3. We should note that the results obtained from the Mann-Kendall trend test for mean spring-summer data are same with the results obtained from observed annual data exactly. Since the calculated p-value is greater than the significance level, H_0 is not rejected.

Table 4.3 Results of Mann- Kendall test for mean spring-summer data

Mann-Kendall Statistic S	**Kendall's Tau**	**Var (S)**	**Mean**	**P-Value (two tailed test)**	**Alpha**	**Test Interpretation**
-64	**-0.114**	**4549.333**	**76.54706**	**0.35028**	**0.05**	**Accept H_0**

4.3.4 Mann-Kendall Test on Reconstruction Data

Trend analysis of reconstructed data obtained from LOCFIT method has been done in this study with 341 years of reconstruction data from 1657 to 1997. First of all, the serial correlation effect is checked with autocorrelation and partial autocorrelation function method.

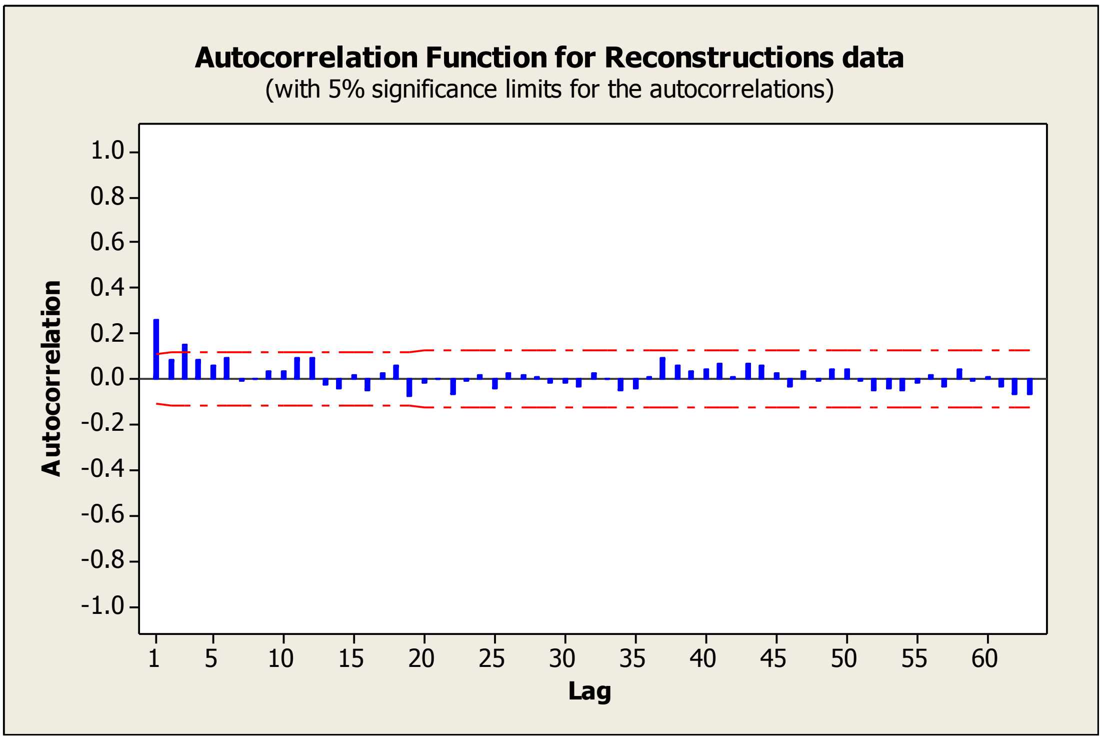

Figure 4.9 Autocorrelation function for reconstruction data

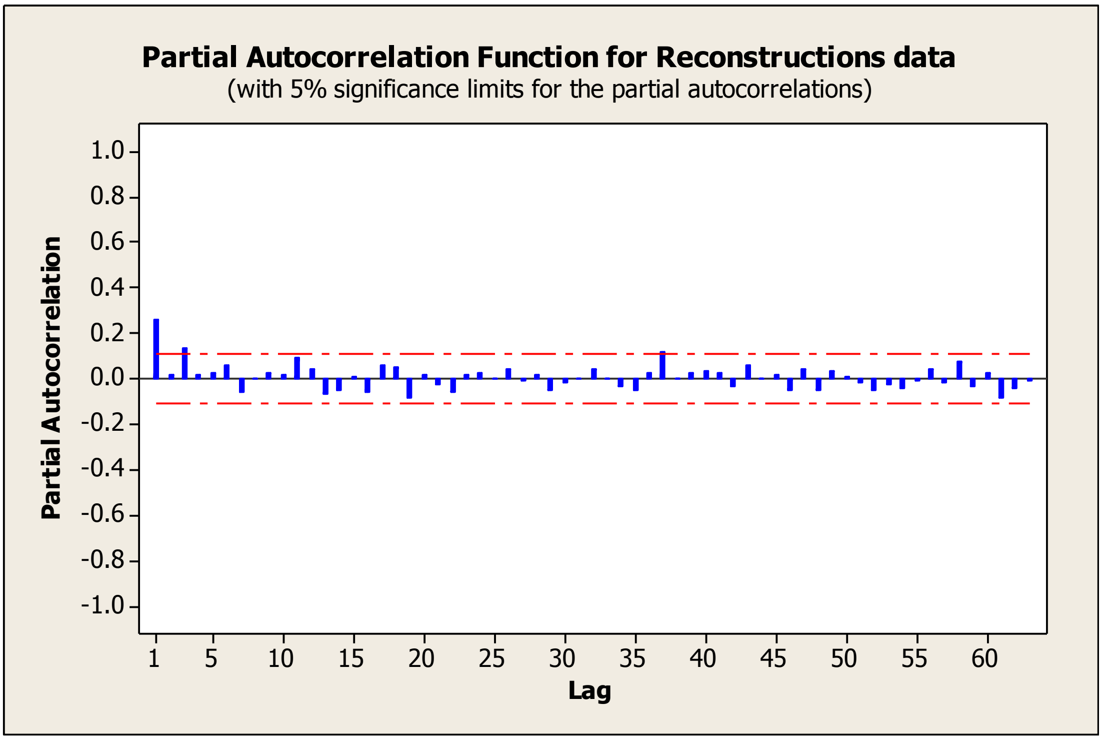

Figure 4.10 Partial autocorrelation function for reconstruction data

The Figures 4.9 and 4.10 show that serial correlation effect in the time series is statistically significant. To eliminate this effect the time series must be pre-whitened before applying the Mann–Kendall test. The procedure explained in Section 3.2 was followed to find the pre-whitened series.

After removing the first order correlation effect on the time series, we checked the serial correlation effect. Figures 4.11 and 4.12 indicate that serial correlation effect was managed to eliminate at 95% level.

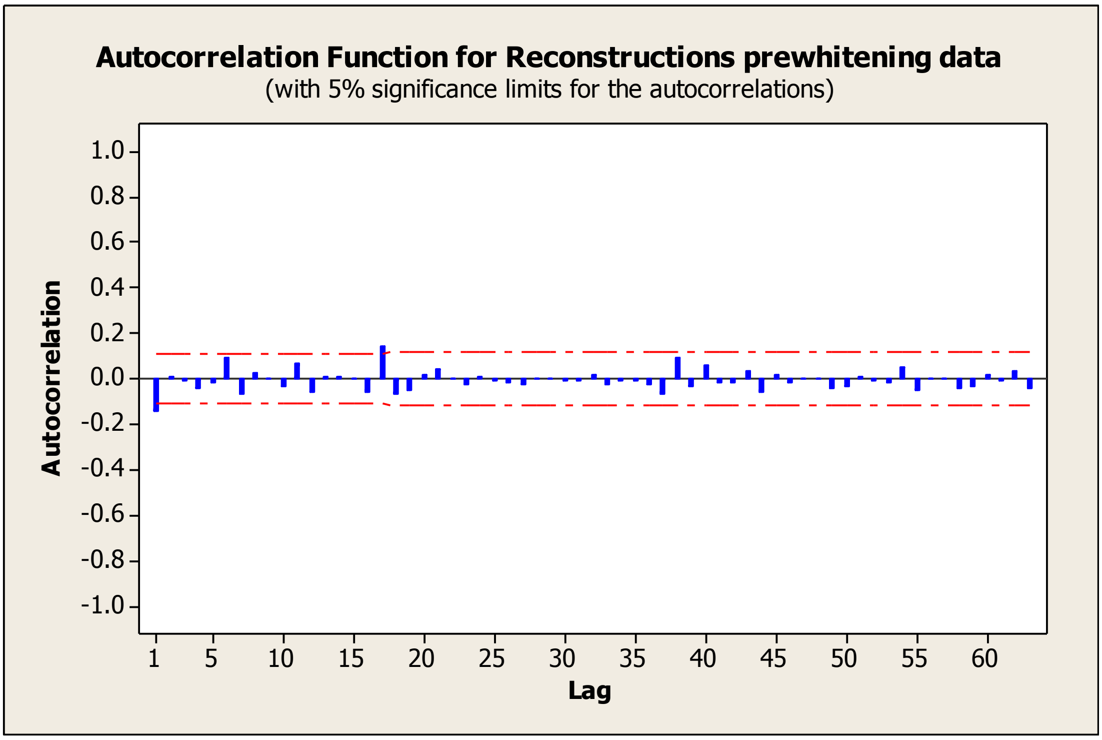

Figure 4.11 Autocorrelation function for reconstruction data after Prewhitening data

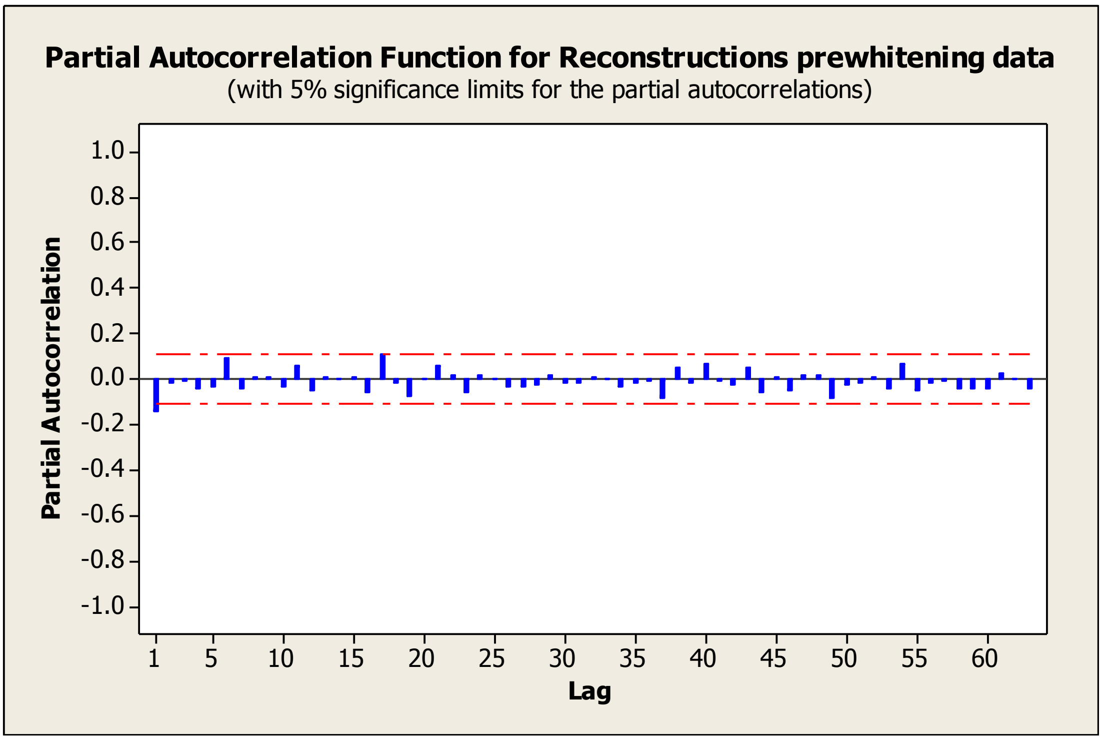

Figure 4.12 Partial autocorrelation function for reconstruction data after Prewhitening data

The Mann-Kendall method was utilized for prewhitening reconstructed data series. The results are represented in Table 4.4

Table 4.4 Results of Mann-Kendall test for reconstruction data

Mann-Kendall Statistic S	**Kendall's Tau**	**Var (S)**	**Mean**	**P-Value (two tailed test)**	**Alpha**	**Test Interpretation**
-5412	**-0.0939**	**4386284**	**141.7105**	**0.0097769**	**0.05**	**Reject H_0**

The calculated p value is less than the significance level α (= 0.05). In this case the null hypothesis, H_0 which there is no trend is rejected. We found statistically significant decreasing trend for reconstructed data.

4.4 Discussion for scaling effect

The smaller the number of available time periods that means became the sample size is smaller, the higher the potential of error. On the other hand, the longest the time period and more information is to accurately determine the patterns of change.

The aim of the following study is to show the effect of data size or scaling on detecting trend. For this aim, different segments from the observed data series are taken into account. The first period is from 1964 to 1967. Discharge values versus considering time together with linear trend is plotted on Figure 4.13. This Figure indicates decreasing trend on the time series. However, we could not detect statistically significant decreasing trend. The Mann-Kendall test results for this period are given in the Table 4.5.

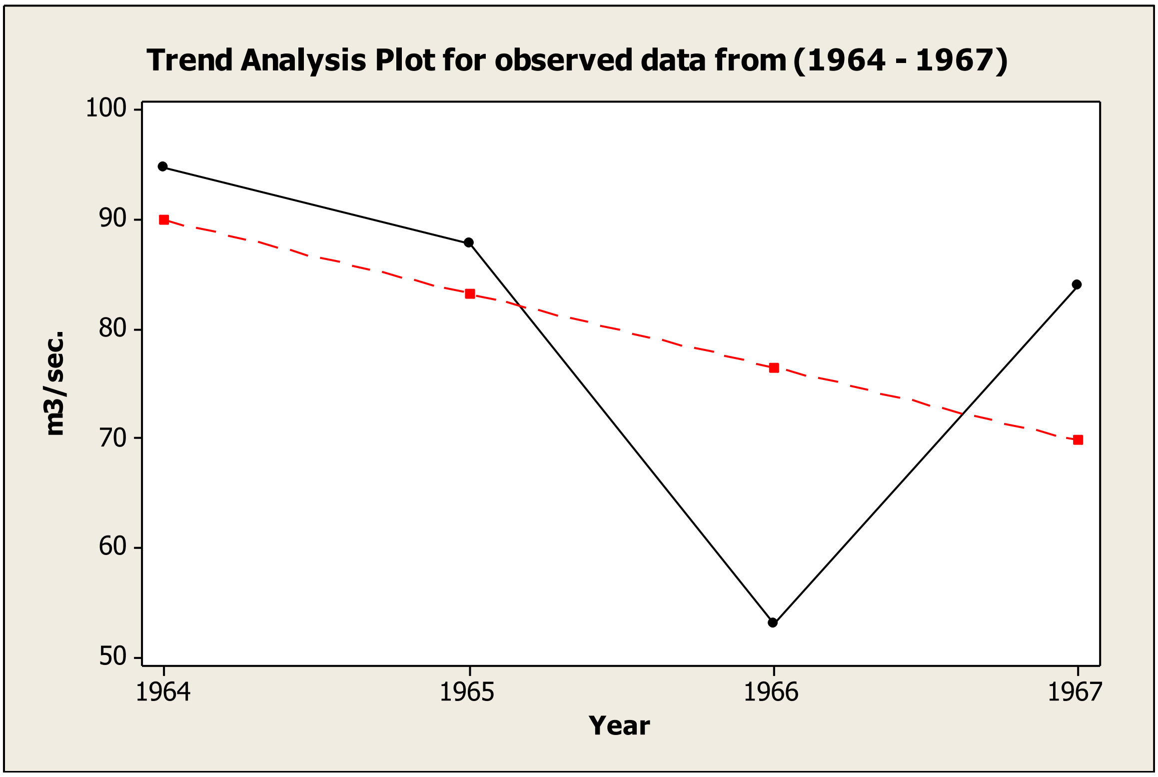

Figure 4.13 Trend analysis for observed data from (1964 – 1967)

Since this period is not enough to confirm the results, the longer time period from 1964 to 1990 is utilized to emphasize the results of trends. Burn and Elnur (2002) also emphasized that minimum record length of 25 years ensures validity of the trend results statistically. Figure 4.14 shows the slope of decreasing trend. The Mann-Kendall test results for period from 1964 to 1990 are represented in Table 4.5.

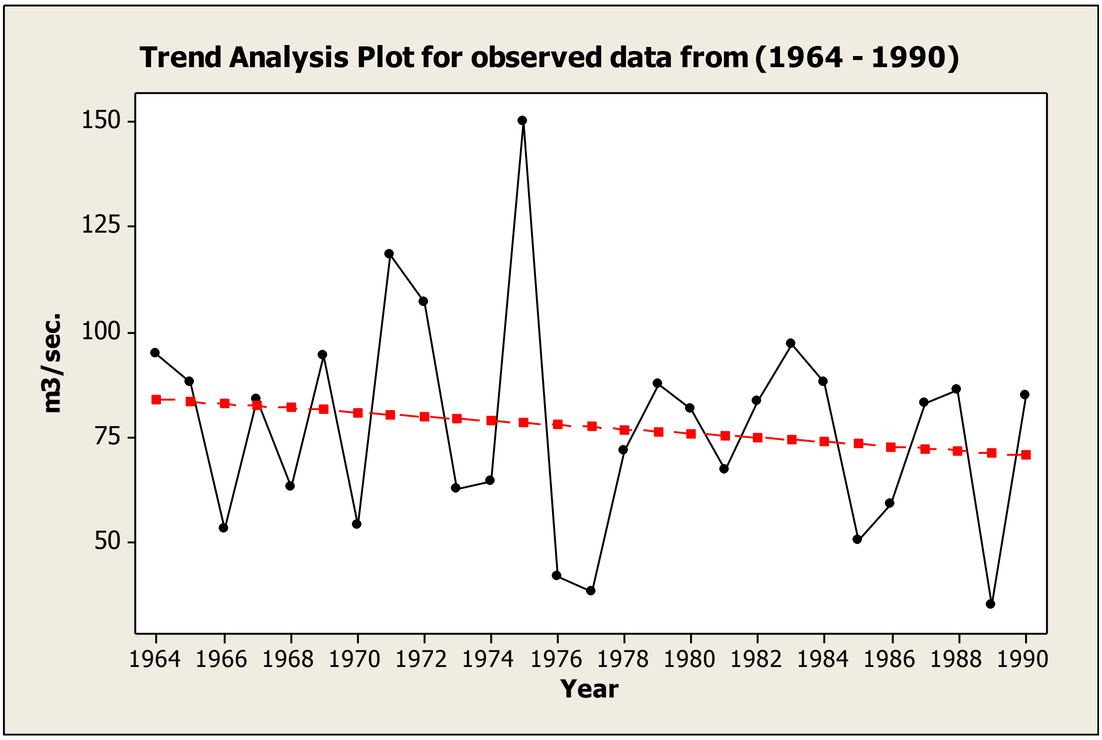

Figure 4.14 Trend analysis for observed data from (1964 – 1990)

The last segment taken into account is from 1964 to 1994. Kahya and Kalayci (2003) found statistically significant decreasing trend from monthly data for same station spanning from 1964 to 1994. Whether there is also significant decreasing trend for annual data or not, the same duration is utilized to conduct Mann-Kendall test. The time series is presented in the Figure 4.15. Mann-Kendall test results are summarized in Table 4.5. Although they concluded that there is a significant decreasing trend on monthly data, our results showed that this decision does not valid for annual data.

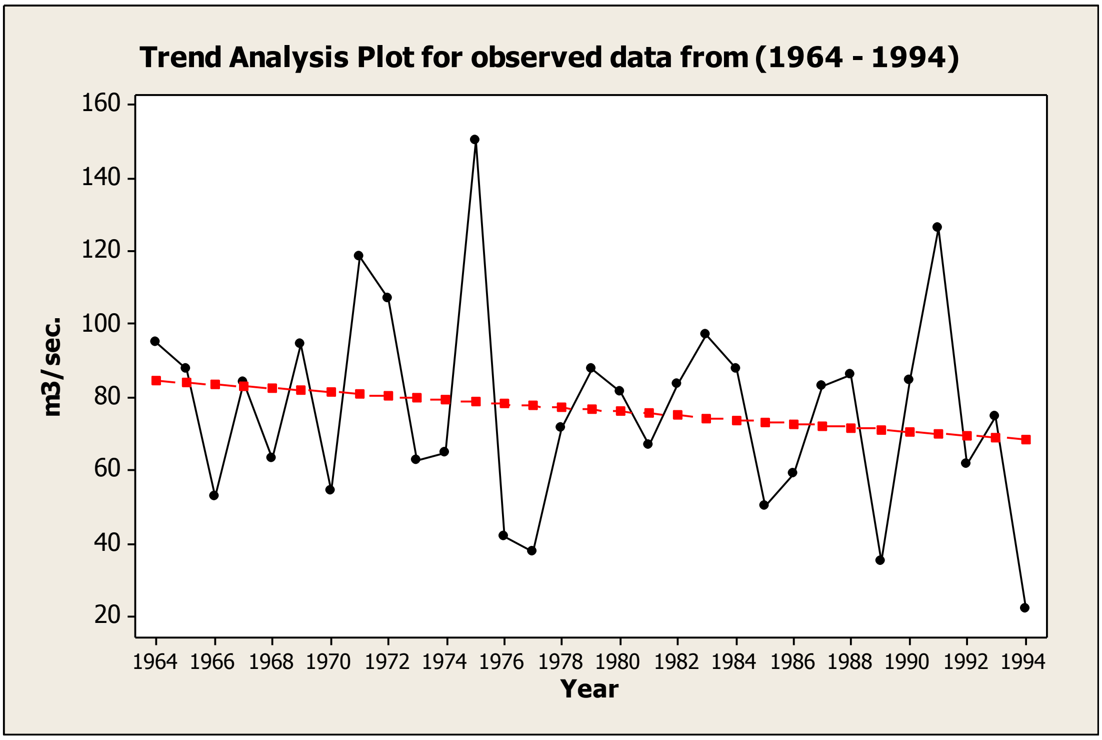

Figure 4.15 Trend analysis for observed data from (1964 – 1994)

Table 4.5 Comparison results from different segments

The period (data size)	Mann-Kendall Statistic S	P-Value (two tailed test)	Alpha	Test Interpretation	Detecting Trend
1964 - 1967	-4	0.30818	0.05	Accept H_0	No Trend
1964 – 1980	-12	0.65046	0.05	Accept H_0	No Trend
1964 – 1990	-34	0.49139	0.05	Accept H_0	No Trend
1964 – 1994	-56	0.34982	0.05	Accept H_0	No Trend
1964 - 1997	-64	0.35082	0.05	Accept H_0	No Trend

The results showed that it was similar in all periods that have been taken as proved that there is a decreasing trend but it is not statistically significant because the calculated p value for each period is greater than significance level $\alpha = 0.05$.

We should note the similarity of the results that there is no trend but the difference is in the value of S statistic summarized in the Table 4.5. The value of S statistic increases with the increasing in the time period. This confirms the effect of data size on detecting trend. That means the data size like existing dependency between data is important to prevent misinterpretation of detecting trend results.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 General

The use of Mann-Kendall (MK) trend test to determine and detect trends in hydroclimatic data has been explored in the literature. This study presents the results of the applications of the MK trend test in examining trends in one of hydroclimatic indices, namely streamflow. In this study, the streamflow data of filyos River in Turkey is selected. At the first, both observed annual streamflow data from 1964 to 1997 and mean spring-summer data are utilized to detect the trend on these time series. Then the reconstructed data from 1657 to 1997 is used. We found same results obtained from the examination of trend by using Mann-Kendall trend test for each of the observed annual data and the mean spring-summer data. The results indicate that there is no statistically significant trend in the time series. As for the reconstruction data, statistically significant decreasing trend is detected.

5.2 Conclusions

The conclusions extracted from this analysis can be summarized as follows:

1. There is consistency in the results obtained from the Mann-Kendall test for each of the observed annual data with the mean spring-summer from May to August from 1964 to 1997.

2. Analysis of the serial correlation effect showed that most of the data have not a significant lag-1 correlation coefficient except for the reconstruction data.

3. The results show having no statistically significant trend in the time series for each of the observed annual streamflow data and the mean spring-summer data

4. As for the reconstruction streamflow data results, it indicates the presence of statistically significant decreasing trend in the time series.

5. The current study clearly shows that both observed and reconstructed data almost over exhibit persistence behaviors. Similar decreasing trend patterns are observed at the different time scales although the trend result for observed time series is not statistically significant.

6. Kahya and Kalayci (2003) conducted study in Filyos station EIE (1335) in western Turkey for 31 years data spanning from 1964-1994 and they found significant downward trends. While when we took the same period, we did not find any statistically significant trend. The reason is that they used monthly data while in our study we used annual data. The monthly data are dependent data if we could not remove these dependency from the data, certainly it will affect the results.

7. It is logical that the hypothesis that decreases trend in mean streamflow in western Turkey attributable probably to decreases in precipitation in the same region (Partal and Kahya 2006)

8. As a result, the scaling effects influence the interpretation of results to detect trends. It certainly affects making stationary and climate change decisions which are very important for time-series model. Since the best way is to use more than one different segments from the same data series to discuss the scaling effect, we used different periods from the same data series to emphasize the results and show the effect of scaling and data size on detecting trend. Considering each periods showed that there was no trend in the time series. However we noticed that the value of S statistic increases with increasing in time period. This confirms the effect of scaling and size of the data on detecting trend. In another case of the current study concludes that comparing the limited observed data series with reconstructed data series is also very useful to confirm the scaling effect.

5.3 Further Recommendations

The following items are recommended for further studies:

1. Studying the trend characteristics for more than one segments taking from reconstructed data series.

2. Discuss the scaling effect on these data series.

REFERENCES

Adamowski, K. and Bougadis, J. (2003). Detection of trends in annual extreme rainfall. *Hydrological Processes*, 17(18): 3547-3560.

Adamowski, K., Prokoph, A. and Adamowski, J. (2009). Development of a new method of wavelet aided trend detection and estimation. *Hydrological Processes,* 23(18): 2686-2696.

Akkemik, U. and A. Aras. (2005). Reconstruction (1689-1994) of April-August Precipitation in Southwestern Part of Central Turkey. *International Journal of Climatology* 25:537-548.

Akkemik, U., N. Dagdeviren, and N. Aras. (2005). A Preliminary Reconstruction (A.D. 1635-2000) of Spring Precipitation Using Oak Tree Rings in the Western Black Sea Region of Turkey. *International Journal of Biometeorology* 49(5):297-302.

Akkemik, U., R. D’Arrigo, P. Cherubini, N. Kose, and G.C. Jacoby. (2008). Tree-Ring Reconstructions of Precipitation and Streamflow for North-Western Turkey. *International Journal of Climatology* 28:173-183.

Austin, J., Zhang, L., Jones, R., Durack, P., Dawes, W. and Hairsine, P. (2010). Climate change impact on water and salt balances: An assessment of the impact of climate change on catchment salt and water balances in the Murray-Darling Basin, Australia. *Climatic Change,* 100(3): 607-631.

Beyene, T., Lettenmaier, D. and Kabat, P. (2010). Hydrologic impacts of climate change on the Nile River Basin: Implications of the 2007 IPCC scenarios. *Climatic Change,* 100(3): 433-461.

Burn, H.B. and Elnur, M.A.H. (2002). Detection of hydrologic trends and variability. *Journal of Hydrology*, 255, 107–122.

Burn, D. H., Sharif, M. and Zhang, K. (2010). Detection of trends in hydrological extremes for Canadian watersheds. *Hydrological Processes*, 24(13): 1781-1790.

Caloiero, T., Coscarelli, R., Ferrari, E. and Mancini, M. (2011). Trend detection of annual and seasonal rainfall in Calabria (Southern Italy). *International Journal of Climatology*, 31(1): 44-56.

Chaouche, K., Neppel, L., Dieulin, C., Pujol, N., Ladouche, B., Martin, E., Salas, D. and Caballero, Y. (2010). Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. *Comptes Rendus Geoscience*, 342(3): 2

Clark, J. S., Yiridoe, E. K., Burns, N. D. and Astatkie, T. (2000). Regional climate change: Trend analysis of temperature and precipitation series at selected canadian sites. *Canadian Journal of Agricultural Economics*, 48(1): 27-38.

Cluis, D., Langlois, C., Coillie, R. and Laberge, C. (1989). Development of a software package for trend detection in temporal series: Application to water and industrial effluent quality data for the St. Lawrence River. *Environmental Monitoring and Assessment*, 13(2): 429-441.

Cunderlik, J. M. and Burn, D. H. (2004). Linkages between regional trends in monthly maximum flows and selected climatic variables. *J. Hydrol. Eng.*, 9(4): 246-256.

Dai, A., Trenberth, K. E. and Karl, T.R. (1998). Global variations in droughts and wet spells: 1900-1995. Geophys. *Res. Lett.*, 25(17): 3367-3370.

Déry, S. J. and Wood, E. F. (2005). Decreasing river discharge in northern Canada. Geophys. *Res. Lett.*, 32(10): L10401.

Douglas, E. M., Vogel, R. M. and Kroll, C.N. (2000). Trends in floods and low flows in the United States: Impact of spatial correlation. *Journal of Hydrology,* 240(1–2): 90-105.

Drapela, K. and Drapelova, I. (2011). Application of Mann-Kendall test and the Sen's slope estimates for trend detection in deposition data from Bílý Kříž (Beskydy Mts., the Czech Republic) 1997–2010. Beskdy Mendel University in Brno 4 (2), 133–146.

Durdu, Ö. F. (2010). Effects of climate change on water resources of the Büyük Menderes River Basin, western Turkey. Turk. *J. Agric. For.,* 34(4): 319-332.

Gangopadhyay, S., B.L. Harding, B. Rajagopalan, J.J. Lukas, and T.J. Fulp. (2009). A Nonparametric Approach for Paleo-Hydrologic Reconstruction of Annual Streamflow Ensembles. *Water Resources Research* 45:W06417, doi: 10.1029/2008WR007201.

Hamed, K. H. and Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology,* 204(1–4): 182-196.

Hamlet, A. F., Mote, P. W., Clark, M. P. and Lettenmaier, D. P. (2005). Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate,* 18: 4546-4561.

Helsel, D. R. (1987). Advantages of nonparametric procedures for analysis of water quality data. *Hydrological Sciences Journal,* 32(2): 179-190.

Hipel, K. W. and McLeod, A. I. (1994). Time series modelling of water resources and environmental systems. Elsevier, Amsterdam. *ISBN* 0-444-89270-2, 1013 pp.

Hirsch, R. M., Slack, J. R. and Smith, R. A. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research,* 18(1): 107-121.

Hirsch, R. M. and Slack, J. R. (1984). A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research*, 20(6): 727-732.

Hughes, M.K., P.I. Kuniholm, G.M. Garfin, C. Latini, and J. Eischeid. (2001). Aegean Tree-Ring Signature Years Explained. Tree- Ring Research 57(1):67-73.

IPCC, (2001). Climate change (2001): the third IPCC scientific assessment. In: J.J. McCarthy, O.F.Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds). Intergovernmental Panel on Climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2007). Climate change (2007): the fourth IPCC scientific assessment. In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds). Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jones, N.K. (2008). On the impact of recent climate change on seasonal floods—A case study from a river basin in southern Quebec. *Canadian Water Resources Journal,* 33(1): 55-72.

Kadioğlu, M. (1997). Trends in surface air temperature data over Turkey. *International Journal of Climatology*, 17(5): 511-520.

Kahya, E. and Kalaycı, S. (2004). Trend analysis of streamflow in Turkey. *Journal of Hydrology*, 289(1–4): 128-144.

Kite, G. (1993). Analysing hydrometeorological time series for evidence of climatic change. *Nordic Hydrology,* 24: 135-150.

Koutsouris, A. J., Destouni, G. and Lyon, S. W. (2010). Hydro-climatic trends and water resource management implications based on multi-scale data for the Lake Victoria region, Kenya. *Environmental Research Letters,* 5(3): 034005.

Kulkarni, A. and von Storch, H. (1995). Monte carlo experiments on the effect of serial correlation on the Mann-Kendall test of trend. *Meteorol. Z.,* 4(2): 82-85.

Kundzewicz, Z. W. and Robson, A. J. (2004). Change detection in hydrological records—A review of the methodology. *Hydrological Sciences Journal,* 49(1): 7-19.

Lettenmaier, D. P. (1988). Multivariate nonparametric tests for trend in water quality. *JAWRA Journal of the American Water Resources Association,* 24(3): 505-512.

Liu, D., Chen, X., Lian, Y. and Lou, Z. (2010). Impacts of climate change and human activities on surface runoff in the Dongjiang River Basin of China. *Hydrological Processes,* 24(11): 1487-1495.

Mann, H. B. (1945). Nonparametric tests against trend. Econometrica, 13(3): 245-259.

Mavromatis T. and Stathis D. (2011). Response of the Water Balance in Greece to Temperature and Precipitation Trends. *Theoretical and Applied Climatology* 104:13-24, DOI 10.1007/s00704-010-0320-9.

McLeod, A. I., Hipel, K. W. and Bodo, B. A. (1991). Trend analysis methodology for water quality time series. *Environmetrics,* 2(2): 169-200.

Meko, D.M., C.W. Stockton, and W.R. Boggess. (1995). The Tree- Ring Record of Severe Sustained Drought. *Water Resources Bulletin* 31:789-801.

Mohsin, T. and Gough, W. (2010). Trend analysis of long-term temperature time series in the Greater Toronto Area (GTA). *Theoretical and Applied Climatology,* 101(3): 311-327.

Neha Karmeshu. (2012). Trend Detection in Annual Temperature Precipitation using the Mann Kendall Test – A Case Study to Assess Climate Change on Select States in the Northeastern United States. Master's thesis, University of Pennsylvania

Oh, H. S., Ammann, C. M., Naveau, P., Nychka, D. and Otto-Bliesner, B. L. (2003). Multi-resolution time series analysis applied to solar irradiance and climate reconstructions. *Journal of Atmospheric and Solar-Terrestrial Physics,* 65(2): 191-201.

Önöz, B. and Bayazit, M. (2003). The power of statistical tests for trend detection. *Turkish Journal of Engineering & Environmental Sciences,* 27(4): 247.

Partal,T. and Kahya, E. (2006). Trend analysis in Turkish precipitation data. *Hydrological Processes.* **20**, 2011–2026

Peel, M. C. and McMahon, T. A. (2006). Recent frequency component changes in interannual climate variability. Geophys. *Res. Lett.,* 33(16): L16810.

Prokoph, A. and Patterson, R. T. (2004). Application of wavelet and regression analysis in assessing temporal and geographic climate variability: Eastern Ontario, Canada as a case study. *Atmosphere Ocean,* 43(2): 201-212.

Roy, L., Leconte, R., Brissette, F. P. and Marche, C. (2001). The impact of climate change on seasonal floods of a southern Quebec River basin. *Hydrological Processes,* 15(16): 3167-3179.

Sarlak, Nermin. (2014). Filyos River Streamflow Reconstruction from Tree-Ring Chronologies with Nonparametric Approaches. *JAWRA Journal of the American Water Resources Association,* JAWRA, 50 (5): 1102.1110.

Scavia, D. et al. (2002). Climate change impacts on U. S. coastal and marine ecosystems. *Estuaries,* 25(2): 149-164.

Shao, Q., Li, Z. and Xu, Z. (2010). Trend detection in hydrological time series by segment regression with application to Shiyang River Basin. *Stochastic Environmental Research and Risk Assessment,* 24(2): 221-233.

Tabari, H., Marofi, S., Aeini, A., Talaee, P. H. and Mohammadi, K. (2011). Trend Analysis of Reference Evapotranspiration in the Western half of Iran. *Agricultural and Forest Meteorology*, 151, 128-136.

Tharme, R. E. (2003). A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*, 19(5-6): 397-441.

Touchan, R., G.M. Garfin, D.M. Meko, G. Funkhouser, N. Erkan, M.K. Hughes, and B.S. Wallin. (2003). Preliminary Reconstructions of Spring Precipitation in Southwestern Turkey from Tree Ring Width. *International Journal of Climatology* 23:157-171.

Touchan, R., G. Funkhouser, M.K. Hughes, and N. Erkan. (2005a). Standardized Precipitation Index Reconstructed from Turkish Ring Widths. *Climatic Change* 72:339-353.

Touchan, R., E. Xoplaki, G. Funkhouser, J. Luterbacher, M.K. Hughes, N. Erkan, U. Akkemik, and J. Stephan. (2005b). Reconstruction of Spring/Summer Precipitation for the Eastern Mediterranean from Tree-Ring Widths and Its Connection to Large-Scale Atmospheric Circulation. *Climate Dynamics* 25: 75-98.

Türkes M, Sümer UM and Kılı¸c G. (1995). Variations and trends in annual mean air temperatures in Turkey with respect to climatic variability. *International Journal of Climatology* **15**: 557–569.

Türkes M. (1996). Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology* **16**: 1057–1076.

Wang, W. and Ding, J. (2003). Wavelet network model and its application to the prediction of hydrology. *Nature and Science*, 1(1): 67-71.

Wettstein, J. J. and Mearns, L. O. (2002). The influence of the North Atlantic–Arctic Oscillation on mean, variance, and extremes of temperature in the northeastern United States and Canada. *Journal of Climate,* 15(24): 3586-3600.

Whitfield, P. H., Wang, J. Y. and Cannon, A. J. (2003). Modelling future streamflow extremes—Floods and low flows in Georgia Basin, British Columbia. *Canadian Water Resources Journal*, 28(4): 633-656.

Xiong, L. and Guo, S. (2004). Trend test and change-point detection for the annual discharge series of the Yangtze River at the Yichang hydrological station. *Hydrological Sciences Journal,* 49(1): 99-112.

Yue, S., Pilon, P., Phinney, B. and Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes,* 16(9): 1807-1829.

Yue, S. and Wang, C. Y. (2002). Assessment of the significance of sample serial correlation by the bootstrap test. *Water Resources Management,* 16(1): 23-35.

Yue S. and Wang, C. (2004). The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. *Water Resources Management,* 18, 201–218.

Zhang, X., Harvey, K. D., Hogg, W. D. and Yuzyk, T. R. (2001). Trends in Canadian streamflow. *Water Resources Research,* 37(4): 987-998.

Zhang, Q., Xu, C. Y., Zhang, Z., Chen, Y. D. and Liu, C. L. (2009). Spatial and temporal variability of precipitation over China, 1951-2005. *Theoretical and Applied Climatology,* 95(1-2): 53-68.

Zhao, F. F., Xu, Z. X., Huang, J. X. and Li, J.Y. (2008). Monotonic trend and abrupt changes for major climate variables in the headwater catchment of the Yellow River Basin. *Hydrological Processes,* 22(23): 4587-4599.

Zume, J. and Tarhule, A. (2006). Precipitation and streamflow variability in Northwestern Oklahoma, 1894-2003. *Physical Geography*, 27(3): 189-205.