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PRECIPITATION TREND ANALYSIS FOR THE LANGAT RIVER BASIN, SELANGOR, MALAYSIA

NARGES PALIZDAN

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PRECIPITATION TREND ANALYSIS FOR THE LANGAT RIVER BASIN, SELANGOR, MALAYSIA

By

NARGES PALIZDAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATED

TO

My Mother

A strong and gentle soul who thought me to trust in Allah, believe in hard work and that so much could be done with little

My Father

For earning and honest living for us and for supporting and encouraging me to believe in myself

My Parents-in-law

For being my guardian, their support and encouragement

My Husband

Without whom none of my success would be possible

And finally my lovely Siblings

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement of the degree of Master of Science

PRECIPITATION TREND ANALYSIS FOR THE LANGAT RIVER BASIN, SELANGOR, MALAYSIA

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NARGES PALIZDAN

April 2014

Chairman: Professor Ir. Lee Teang Shui, PhD

Faculty: Engineering

Almost all the hydrological and meteorological variables such as rainfall and temperature etc are affected by global climate change. Precipitation is one significant climate factor that affects the state of the environment and contributes significantly towards the natural hydrological process. Its temporal fluctuation is significant both in terms of the scientific knowledge and practical applications, such as in water resources planning and management. It is necessary to evaluate the regional precipitation trend to improve water management strategies for a given region. A study was conducted to analyse the annual and seasonal precipitation trends of 30 stations in the Langat River Basin, located in the state of Selangor, Malaysia, at both the stationary and on regional scales. On an at site scale the rainfall trends were detected using the Mann-Kendall (MK) test, the Sen's Linear Regression analysis for the period 1982-2011. The lag-1 approach was utilized at the 95% significance level to test the serial correlation of the data series. Then the autocorrelated time series were pre-whitened. On the annual scale, it was found that most of the stations in the basin were characterized with insignificant precipitation trends. The significant trends were found only at the four stations, namely stations 44301, 44305, 44320 and 2719001. The results of the seasonal precipitation trend analysis showed that most of the stations, during the North East Monsoon (NEM) and Inter Monsoon 1 (INT1) seasons, and half of the stations in South West Monsoon (SWM) season, experienced insignificant positive trends. To the contrary, for the Inter Monsoon 2 (INT2) season, the majority of the stations showed negative trends. It was found that during NEM season the station 44301, for INT1 the stations 44301, 2719001 and 3118069 were established as having significant changes, while in SWM, the station 2917001 and during INT2 the stations 2615131and 44301 showed significant trends.

In the regional study, the regional annual and seasonal precipitation trends for the period 1982-2011 were examined at the 95% level of significance, using the Regional Average Mann-Kendall (RAMK) test and the Regional Average Mann-Kendall coupled with bootstrap (RAMK-bootstrap) method. In order to identify the homogeneous regions respectively for the annual and seasonal scales, firstly, at- site mean total annual and separately at site mean total seasonal precipitation were

spatialized into 5 km × 5 km grids using the inverse distance weighting (IDW) algorithm. Next, the optimum number of homogeneous regions (clusters) is computed using the Silhouette Coefficient approach. Next, the homogeneous regions were then formed using the K-mean Clustering method. The applied homogenous region analysis method in the present study is a new approach. From the annual scale perspective, all three regions showed positive trends. However, the application of the two methods at this scale showed a significant trend only in the region AC1. The region AC2 experienced a significant positive trend using only the RAMK test. On a seasonal scale, all regions showed insignificant trends, except the regions I1C1 and I1C2 in the Inter Monsoon 1 (INT1) season which experienced significant upward trends. In addition, it was proved that the significance of trends has been affected by the existence of serial and spatial correlations.

We also aimed to determine the most dominant periodic components that affect the trends in each homogeneous region for the period 1982-2011. The combination of wavelet analysis and Mann-Kendall test at regional scale was used for the first time in this study. In each region the areal precipitation series were computed using the Thiessen polygon method. In the method using wavelet transformation, the mother wavelet type and the number of decomposition levels were assessed based on two criteria. The first one is the Mean Relative Error (MRE) between the wavelet approximation component and the original data set and the second one is the relative error of the MK Z-value (e_r) between the approximation series and the original data series. The Discrete Wavelet Transform (DWT) coupled with the Mann-Kendall (MK) test and the sequential MK analysis were utilized in order to find out which time scale are affecting the trends observed in each homogenous region. On annual scale it was found that DWT1 in region AC1 and AC2 and DWT2 in region AC3 were the periodic modes responsible for trends. On seasonal scale, in regions NC1, I1C1, I1C2, I1C3, SC1, SC2, I2C1 and I2C2, DWT1, in region NC2, DWT2 and DWT3, in region I2C3, DWT2 were the most influential periodicity for trends, respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS KECENDERUNGAN HUJAN BAGI KAWASAN TADAHAN SUNGAI LANGAT, SELANGOR, MALAYSIA

Oleh

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Hampir semua perubah hidrologi dan meterologi seperti hujan, suhu dan lain-lain dipengaruhi oleh perubahan iklim global. Hujan adalah satu faktor iklim yang ketara yang menjejaskan tahap persekitaran alam sekitar dan banyak menyumbang kepada proses semulajadi hidrologi. Turun naik semasanya adalah penting dari segi ilmu saintifik dan penggunaan praktikal seperti dalam bidang pengurusan dan perancangan sumber air. Keperluan untuk menilai trend taburan hujan adalah bagi meningkatkan strategi pengurusan air bagi sesebuah kawasan. Satu kajian telah dijalankan untuk menganalisa trend taburan hujan mengikut tahun dan musim bagi 30 stesen di kawasan tadahan Sungai Langat, Selangor, Malaysia, pada kedua-dua skala pegun dan kawasan tersebut. Pada skala di tapak, trend taburan hujan dikesan menggunakan Ujian Mann-Kendall (MK), Penaksir Cerun Sen dan Analisis Linear Regression bagi tempoh 1982-2011. Pendekatan Lag-1 diguna pada tahap kepentingan 95% untuk menguji korelasi bersiri pada siri data. Kemudian, auto-korelasi masa bersiri di pra-putihkan. Pada skala tahunan, kebanyakan stesen dalam kawasan tadahan disifatkan sebagai tidak cenderung kepada corak taburan hujan. Trend kecenderungan ketara ditemui hanya di empat stesen, iaitu stesen 44301, 44305, 44320 and 2719001. Keputusan analisis bagi corak taburan hujan bermusim menunjukkan kebanyakan stesen pada musim Monsun Timur Laut (NEM) dan Pertengahan Monsun 1 (INT1), dan sebahagian daripada stesen di musim Monsun Barat Daya (SWM) mengalami trend tidak cenderung positif. Sebaliknya, bagi musim Pertengahan Monsun 2 (INT2), majoriti stesen menunjukkan trend kecenderungan negatif. Didapati semasa musim NEM bagi stesen 44301 dan INT1 bagi stesen 44301, 2719001 dan 3118069 mengalami kecenderungan perubahan yang ketara, manakala pada SWM, stesen 2917001 dan INT2 di stesen 2615131dan 44301 menunjukkan trend yang berkecenderungan ketara.

Dalam kajian kawasan serantau, trend taburan hujan tahunan dan bermusim bagi tahun 1982-2011 diperiksa pada tahap bermakna 95%, menggunakan ujian Regional Average Mann-Kendall (RAMK) dan Regional Average Mann-Kendall digabungkan dengan bootstrap (RAMK-bootstrap) method. Demi mengenal pasti kawasan homogen masing-masing bagi skala tahunan dan bermusim, pertamanya, jumlah

purata di kawasan tahunan dan jumlah purata kawasan bermusim secara berasingan di spatialkan kepada grid 5 km x 5 km menggunakan algoritma Inverse Distance Weighting (IDW). Kemudian, nombor optimum bagi kawasan homogenus (gugusan) dihitung menggunakan pendekatan Silhouette Coefficient. Selepas itu, kawasan homogenus dibentuk menggunakan kaedah K-mean Clustering. Daripada perspektif skala tahunan, ketiga-tiga kawasan menunjukkan trend yang positif. Walau bagaimanapun, penggunaan kedua-dua kaedah tersebut pada skala menunjukkan trend yang berkecenderungan ketara pada kawasan AC1. Kawasan AC2 mengalami trend kecenderungan ketara yang positif dengan hanya menggunakan ujian RAMK. Pada skala bermusim, semua kawasan menunjukkan trend kecenderungan tidak ketara, kecuali kawasan I1C1 dan I1C2 pada musim Pertengahan Monsun 1 (INT1) yang mengalami trend kecenderungan ketara menaik. Sebagai tambahan, terbukti bahawa trend kecenderungan ketara telah terjejas hasil daripada kewujudan korelasi bersiri dan spatial.

Kami juga berazam untuk menentukan komponen berkala yang paling dominan yang menjejaskan trend setiap kawasan homogenus bagi tahun 1982-2011. Di setiap kawasan bahagian hujan bersiri dikira menggunakan kaedah poligon Thiessen. Dalam kaedah menggunakan transformasi gelombang, gelombang jenis induk dan bilangan tahap penguraian dinilai berdasarkan dua kriteria. Kriteria pertama adalah Ralat Purata Relatif (MRE) antara komponen gelombang anggaran dan set data asal dan yang kedua adalah ralat relatif MK nilai-Z (e_r) antara siri anggaran dan siri data asal. Discrete Wavelet Transform (DWT) digandingkan dengan ujian Mann-Kendall (MK) dan analisis berurutan MK digunakan untuk mengetahui mana skala masa yang terkesan dengan trend yang diperhatikan di setiap kawasan yang homogenus. Pada skala tahunan didapati DWT1 dikawasan AC1 dan AC2 dan DWT2 dikawasan AC3 adalah trend mod berkala. Pada skala bermusim, di kawasan NC1, I1C1, I1C2, I1C3, SC1, SC2, I2C1 dan I2C2, DWT1 di kawasan NC2, DWT2 dan DWT3, di kawasan I2C3, DWT2 masing-masing merupakan trend jangka masa yang paling berpengaruh.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

cdf	Cumulative Distribution Function
Co	Correlation
CWT	Continues Wavelet Transform
db	Daubechies wavelet
DID	Department of Irrigation and Drainage
DWT	Discrete Wavelet Transform
EMA	Exponential Moving Average
ESS	Effective Sample Size
IDW	Inverse Distance Weighting
INT1	Inter Monsoon 1
INT2	Inter Monsoon 2
MAP	Mean Annual Precipitation
MK	Mann-Kendall
MMD	Malaysian Meteorology Department
MRE	Mean Relative Error
MSE	Mean Square Error
NEM	North East Monsoon
OLS	Ordinary Least Square
PMW	Pettitt Mann-Whitney
RAMK	Regional Average Mann-Kendall
RAMK-bootstrap	Regional Average Mann-Kendall coupled with bootstrap
SMA	Simple Moving Average
STFT	Short –Time Fourier Transformation
SWM	South West Monsoon

LIST OF NOTATIONS

n_a	Number of “a” in Run test
n_b	Number of “b” in Run test
U	Sum of series “a” and “b”
n	Number of data
b	Slope in Linear regression
x	Sample data
t	time
L_{XY}	Sum of deviation square of variable X
U	Regression sum of square in regression analysis
Q	Error sum of square in regression analysis
S	S statistic in MK test
Var(S)	Variance of S in MK test
Z	Standard normal variable
r_1	Lag-1 serial correlation coefficient
Y_t	Pre-whitened series
Q_i	Slope in Sen’s Slope Estimator
C_α	Confidence interval in Sen’s Slope Estimator
W	Weight function of IDW
P	Precipitation value at unmeasured point
S(i)	The silhouette coefficient at point i
SC	Silhouette coefficient
$\bar{S}_m$	Regional Average Kendall’s S in RAMK
m	Number of stations in RAMK
H_0	Null hypothesis

H_1	Alternative hypothesis
ψ	Mother wavelet
S_0	Dilation step
γ_0	Location variable
u(t)	Sequential value of MK test

CHAPTER 1

INTRODUCTION

1.1 Background

Precipitation is the resultant production in condensation of atmospheric water vapor that falls under gravity. It can also be defined as water in various forms that fall back to the earth from the atmosphere. There are different forms of precipitation; these include rain, snow, sleet, hail and mist. Precipitation is the most important factor that has a direct impact on hydrology cycle. The average amount of precipitation on the whole earth has been reported at 1050 mm, and this amount changes in different regions of the earth (Pidwirny, 2006). It can be zero in some deserts such as Sudan Desert in Africa to more than 12 meter in some places such as the Himalayan Heights. In each of these regions, there is a specific distribution of precipitation over time. For instance, the distribution of precipitation in wet areas is in a good order and the rain falls almost throughout the whole year. However, in arid and semi-arid areas this distribution can be unbalanced and it is possible that approximately 50 percent of annual precipitation occurs in just one event.

Water is the most valuable material on the earth and fresh water is the reason for human survival, where upon precipitation is the main source. There is no doubt that precipitation is one significant climate factor that affects the environmental and natural processes. Precipitation is an essential component of the hydrological cycle and any change in its distribution may have a significant effect on the hydrosphere, biosphere and the society at large. In addition, changes in the pattern of precipitation may lead to floods and droughts in different areas (Ahani et al., 2012). Precipitation plays an important role in the agricultural production; the significance of precipitation can be obviously seen when applied in dry land agriculture. This is because in dry land agriculture it is expected that the entire moisture required for plant is provided through precipitation, either through irrigation facilities or through direct rain fed options.

Changes in the hydro-meteorological series can take place in many different ways. A change can occur abruptly (step changes) or gradually (trend) or in more complex forms. In general, trend analysis is used to obtain information and in studying whether it is possible to detect a pattern or trend from the information. According to Rana et al. (2011) information about the trends of rainfall is important because it is connected to the water related issues of a region, its associated problems and environment and water management purposes. This information will be the most valuable to researchers studying climate change and its effects on water management. The detection of rainfall trends has been one of the main activities for both hydrologists and climatologists in pursuing climate change studies and research (Rana et al., 2011). Furthermore, studying the climate change needs the information of trends in different indices because climate change is continuously changing.

Climate is the pattern or cycle of weather conditions such as temperature, wind, rain, snowfall, humidity and clouds including extreme or occasional ones, over a large area and averaged over many years. Climate parameters can be affected by some factors such as place, the type and the area of green cover like forest and grassland, local land feature like mountains and human activities (burning fossil fuel, forming or cutting down forest). Climate change is a considerable change in weather patterns in the world over a long period of time. There are many factors that cause climate change including those oceanic processes like oceanic circulation, variation in solar system, plate tectonics and human activities which have increased global warming due to carbon dioxide emission etc.

In recent years concerns about the impact of climate change have increased. Therefore, researchers have utilized various methods and techniques to identify trends and shifts in hydrological series at different scales and places (Caloiero et al., 2011). Trends in hydro-climate data can be investigated at individual sites and regional scales (Sadri et al., 2009). Regional trend analysis has some advantages over at-site analysis. For instance, according to Yue and Hashino (2003) a regional trend analysis provides a better representation of a time series over a wide area. Also, it is more suitable to study the effect of global phenomena such as climate change. There are different methods for detecting trends such as parametric and non- parametric methods. Some researchers have utilized parametric tests to analyze trends in hydrological series. For example Longobardi and Villani (2009) applied the t-test (parametric method) for trend analysis in annual and seasonal rainfall time series in the Mediterranean area. Caloiero et al. (2011) used a parametric method for trend detection in annual and seasonal precipitation in Calabria (southern Italy). The hydrologic components such as precipitation are not constant and they change spatially and temporally. Therefore even over small areas, the parametric methods could not always be appropriate for detecting the precipitation trend. As such many researchers have turned to non-parametric tests such as the Mann-Kendall, the Spearman, the Sen's slope estimator, and so on.

The Mann-Kendall (MK) test has been utilized by many researchers because it has several advantages. For instance, when the data series are non-normal (skewness), the MK test is a suitable choice (Basistha et al., 2009). Another advantage of the MK test is that it has a low sensitivity to inhomogeneous time series (Ahani et al., 2012). Another non-parametric method is the Sen's Slope Estimator. This method estimates the slope if a linear trend exists in time series. Ahani et al. (2012) applied the MK test and Sens's slope estimator to investigate the trend in precipitation volume in different regions of Fars province, Iran. They concluded that the Sen's slope estimator was in a good agreement with MK test. Although the MK test is very popular for analyzing trend, it is sensitive to serial correlation. It has been suggested that before applying the MK test, it is necessary to test the serial correlation of data series (Ahani et al., 2012; Kumar et al., 2009; Matalas and Langbein, 1962; Oguntunde et al., 2011).

Besides these two approaches, the wavelet analysis can also be used to investigate trend. The wavelet transform is a strong mathematical tool that provides a time-frequency representation of an analyzed signal in the time domain (Partal and Küçük, 2006). There are two kinds of wavelet transform function, namely the continuous wavelet transform (CWT) and the discrete wavelet transform (DWT). The advantage of the CWT is that all potential scales or frequencies are analyzed, detected and extracted. However it suffers from edge effects. Meanwhile, the advantage of the DWT is that the transform and reconstruction of the signals of the scales available is perfect, but it is restricted to a discrete numbers of scales (Adamowski et al., 2009). Adamowski et al. (2009) applied the CWT to analyze the recorded monthly minimum stream flow series for five different eco-zones in Canada. It was said that the CWT method is more efficient than spectral analysis when reconstructing highly variable time series from a few wave bands. Partal and Kahya (2006) used the DWT to determine the possible trends in annual total precipitation series in the Marmara region (Turkey). They found that the trend of hydro meteorological variables may be better understood using the Wavelet approach.

1.2 Problem Statement

In recent years, detection of the precipitation trends has attracted wide spread interest. This is not only because of the concerns about the global warming, the rising demand for water and economic growth but also due to the role of water in natural hazards such as floods, droughts and severe erosions (López-Moreno et al., 2009; Oguntunde et al., 2011). Furthermore changing in the pattern of precipitation affects the quality and quantity of water resources. Therefore it is important to know how the climate change affects the water resources, the society and the nature. Studying the climate change is linked directly with trends in various climatic variables because climate is continuously changing.

The climate of Malaysia is equatorial (hot and humid) throughout the year. It has been mentioned that the climate change is likely to have a significant impact on Malaysia, such as increasing sea levels, rainfall and flood risks. Therefore, it is necessary to determine the trends of climate variables to understand the effect of climate change on them. Since in Malaysia, a few studies such as Suhaila et al. (2010) and Tangang et al. (2006) have been performed to investigate the trends of climatic variables, in the present study the annual and seasonal precipitation trends at the Langat River Basin, Malaysia will be investigated. The reservoirs located within the Langat River Basin are the Semenyih dam and Langat dam that provide water for about 1.2 million people in the Langat and Klang valleys. Furthermore, there are 8 water treatment plants in the basin that provide clean water for the users. Beside of providing fresh water, the reservoirs are also important to control floods. The Langat reservoir is also used to generate hydroelectric power. Any change in the pattern of rainfall affects the quantity of water in the basin. Therefore, studying the trend of precipitation is essential for the study area.

As it was mentioned the wavelet transform is a strong method for detection trend. However most of researches have used the parametric and non-parametric tests. The parametric methods are easy to apply but they are restricted to the normal distributed series. On the other hand, the non-parametric methods do not have any assumption about the distribution of the series. They are not also sensitive to non-homogenous data series and the existence of outliers in the series. The wavelet transform can assess both the trend and the periods which are mainly responsible for trend in the measurement series. So in this study, beside the parametric and non-parametric tests, the wavelet transform will be applied.

1.3 Objectives

The main objective of this study is to detect the annual and seasonal precipitation trends in the Langat River Basin.

The following are the specific objectives:

1. To determine the annual and seasonal precipitation trends at both at-site and regional scales.
2. To identify the homogenous rainfall regions in the Langat River Basin.
3. To find the most influential periodicity for annual and seasonal precipitation trends in each homogenous region using Discrete Wavelet Transform (DWT).

1.4 Significance of the Study

As mentioned earlier, in recent years concerns about the impacts of climate change have increased. Various environmental variables including rainfall is affected by the global climate change phenomenon. Therefore, researchers have used different methods to detect trends in hydrology series. Changes in the amount of precipitation directly influence water resources, agriculture, hydrology and ecosystems (Cannarozzo et al., 2006). Furthermore, precipitation has an important role in contributing to natural hazards such as floods, droughts and severe erosions. Since the at-site analysis do not have clear conclusions, the regional-scale analysis is also needed which might be more suitable than at-site studies for determination the impact of climate change (Renard et al., 2008). Thus studying and establishing the trends of rainfall can contribute significantly to the study of climate change scenario. While precipitation trends help to certain extent with interpreting climate change responses, the usefulness of the trend analysis as well as the magnitude over time can be seen when water managers need to plan water resources project and their related management well. One example is the management of water resources hydro dams for electricity production and assessment of long time water availability.

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