CLIMATE VARIABILITY AND CHANGES IN THE RAINFALL TRENDS IN THE EAST COAST OF PENINSULAR MALAYSIA

OLANIYAN, OLUSEGUN MAYOWA

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil – Hydraulics and Hydrology)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

AUGUST 2013

Dedicated to my precious Wife - Funmilayo Caroline and my two wonderful Sons - Emmanuel Odunayo and Daniel Akinola

ACKNOWLEDGEMENT

I am forever grateful to Almighty God, the Alpha and the Omega, the Beginning and the End- in whom I live, in whom I move and in whom I have my being for seeing me through this Masters program in Universiti Teknologi Malaysia successfully.

It is with heart of gratitude that I acknowledge the inputs of my supervisor- Associate Professor Dr. Shamsuddin Shahid, the best Supervisor any student can dream of having, for he has not just been a teacher and tutor, but also he has been a guide, a leader and above all a father figure for all his efforts in bringing out the best out of me and giving me the good attention required to have this study concluded. Without his continued support and interest, this thesis would not have been the same as presented here.

I also want to appreciate my parents- Elder and Mrs. Olaniyan for their prayers and good wishes all the time throughout the time of my studying in University Teknologi Malaysia (UTM). My appreciation also goes to my Wife and Children for their understanding and sacrifice in playing supportive roles throughout the long period I was away from the family pursuing this degree. I will not forget also to appreciate my Siblings at home and abroad for their goodwill towards me throughout my stay in Malaysia

I acknowledge the various inputs of all my classmates, course mates, Lecturers and friends at Universiti Teknologi Malaysia (UTM) for being there for me at one time or the other always when it counted most. With you, life is a treasure.

ABSTRACT

The coastlines have been identified as the most vulnerable region with respect to response to hydrological hazards as a result of climate change and variability. The east coast of Peninsular Malaysia is not an exception in this regard considering the evidence of heavy rainfall resulting in floods as an annual phenomenon and also the drought that is brought about as a result of long dry spell in the region. It is envisaged that future climate changes may bring about climatic variability which may in turn produce large changes in the in the probability of occurrence of extreme hydrologic events. A study has been carried out to understand the recent trends in rainfall amount and rainfall related extreme events such as maximum daily rainfall, number of rainy days, average rainfall intensity, heavy rainfall days, extreme rainfall days, and precipitation concentration index in the east coast of Peninsular Malaysia. Long term (1971-2010) data of 40-year daily rainfall records at 55 stations along the east coast of Peninsular Malaysia have been analyzed by using non-parametric Mann-Kendall test and Sen's slope method to understand the trends and estimate the magnitude of change. The study shows that annual rainfall, precipitation concentration index, high rainfall and extreme rainfall have increased significantly at many stations in the east coast of Peninsular Malaysia. The study concluded that the rainfall has become more distributed over the year which has reduced dry spells, however, the extreme rainfall events have increased which may be the cause of extreme hydrologic event of floods that is experienced in the region.

ABSTRAK

Persisiran pantai telah dikenalpasti sebagai rantau yang paling lemah dalam bertindak balas terhadap bahaya hidrologi akibat daripada perubahan dan kepelbagaian iklim. Pantai timur di Semenanjung Malaysia juga tidak terkecuali apabila mempertimbangkan bukti hujan lebat yang mengakibatkan banjir sebagai fenomena tahunan dan juga kemarau akibat daripada musim kering yang panjang di rantau ini. Adalah dijangkakan bahawa perubahan iklim pada masa depan boleh membawa kepelbagaian iklim yang mungkin pula menghasilkan perubahan yang besar dalam kebarangkalian berlakunya peristiwa hidrologi yang melampau. Satu kajian telah dijalankan untuk memahami trend terkini dalam kuantiti hujan dan peristiwa yang melampau berkaitan dengan hujan seperti hujan maksimum harian, bilangan hari hujan, purata keamatan hujan, bilangan hari hujan lebat, hari hujan yang melampau, dan indeks kepekatan hujan di pantai timur Semenanjung Malaysia. Data jangka panjang yang mengandungi 40 tahun rekod hujan harian (1971-2010) di 55 stesen di sepanjang pantai timur Semenanjung Malaysia telah dianalisis dengan menggunakan ujian non-parametric Mann-Kendall dan kaedah Sen’s slope untuk memahami trend dan menganggar magnitud perubahan. Kajian berkenaan menunjukkan hujan tahunan, indeks kepekatan hujan, hujan lebat dan hujan yang melampau telah meningkat secara ketara di banyak stesen di pantai timur Semenanjung Malaysia. Kesimpulannya, hujan menjadi lebih berselerak sepanjang tahun telah mengurangkan musim kering, tetapi hujan yang melampau telah meningkat dan hal ini mungkin merupakan punca kejadian banjir hidrologi yang melampau dialami di rantau ini.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
		DECLARATION	i
		DEDICATION	iii
		ACKNOWLEDGEMENT	iv
		ABSTRACT	v
		ABSTRAK	vi
		TABLE OF CONTENTS	vii
		LIST OF TABLES	ix
		LIST OF FIGURES	x
		LIST OF ABBREVIATIONS AND SYMBOLS	xii
1	**INTRODUCTION**		1
	1.1	Background of Study	1
	1.2	Problem Statement	4
	1.3	Study Objectives	4
	1.4	Scope of Study	4
2	**LITERATURE REVIEW**		6
	2.1	Introduction	6
	2.2	Rainfall Characteristics	18
		2.2.1 Rainfall Intensity	18
		2.2.2 Monsoon Rainfall	19
		2.2.3 Extreme Rainfall	20

		2.2.4 Precipitation Concentration Index	21
3	**RESEARCH METHODOLOGY**		23
	3.1	Introduction	23
	3.2	Study Area	25
	3.3	The Methods	28
		3.3.1 Rainfall Characteristics Analysis	28
		3.3.2 Trend Analysis	28
		3.3.3 Mapping with GIS	29
4	**DATA ANALYSIS**		30
	4.1	Data Sources	30
	4.2	Data Quality	31
	4.3	Trend Analysis	32
5	**RESULTS AND DISCUSSION**		33
	5.1	The Time Series	33
		5.1.1 Time Series of Rainfall indices in Kelantan	34
		5.1.2 Time Series of Rainfall indices in Terengganu	41
		5.1.3 Time Series of Rainfall indices in Pahang	48
	5.2	Mapping with GIS	55
	5.3	Correlation	63
6	**CONCLUSION**		65
	REFERENCES		66
	APPENDIX		73

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Definitions of Precipitation indices	28
4.1	List and locations of Rainguage Stations used in the Study	30
5.1	Trend Significance of Rainfall Indices in the Study Area	33
5.2	The Z-Values obtained from the Trend analysis of the Rainfall Index of 55 Rainguage Stations used for the GIS Mapping	55
5.3	Kendall-Tau Correlation Matrix of the Rainfall Indices of the 55 Stations in the Study Area	64

LIST OF FIGURES

FIGURES	TITLE	PAGE
3.1	Flowchart of the Methodology used for the Study	24
3.2	Map of East Coast of Peninsular Malaysia showing the Study Area	26
3.3	Map of Study Area showing the Rainfall Stations	27
5.1	Time series of Annual Rainfall in Kelantan	34
5.2	Time series of Annual Rainfall in Kelantan	35
5.3	Time series of Annual Rainfall in Kelantan	35
5.4	Time series of Annual Rainfall in Kelantan	36
5.5	Time series of Annual Rainfall in Kelantan	36
5.6	Time series of Annual Rainfall in Kelantan	37
5.7	Time series of Annual Rainfall in Kelantan	37
5.8	Time series of Annual Rainfall in Kelantan	38
5.9	Time series of Annual Rainfall in Kelantan	38
5.10	Time series of Annual Rainfall in Kelantan	39
5.11	Time series of Annual Rainfall in Kelantan	39
5.12	Time series of Annual Rainfall in Kelantan	40
5.13	Time series of Annual Rainfall in Kelantan	40
5.14	Time series of Annual Rainfall in Terengganu	41
5.15	Time series of Annual Rainfall in Terengganu	42
5.16	Time series of Annual Rainfall in Terengganu	42
5.17	Time series of Annual Rainfall in Terengganu	43
5.18	Time series of Annual Rainfall in Terengganu	43

5.19	Time series of Annual Rainfall in Terengganu	44
5.20	Time series of Annual Rainfall in Terengganu	44
5.21	Time series of Annual Rainfall in Terengganu	45
5.22	Time series of Annual Rainfall in Terengganu	45
5.23	Time series of Annual Rainfall in Terengganu	46
5.24	Time series of Annual Rainfall in Terengganu	46
5.25	Time series of Annual Rainfall in Terengganu	47
5.26	Time series of Annual Rainfall in Terengganu	47
5.27	Time series of Annual Rainfall in Pahang	48
5.28	Time series of Annual Rainfall in Pahang	49
5.29	Time series of Annual Rainfall in Pahang	49
5.30	Time series of Annual Rainfall in Pahang	50
5.31	Time series of Annual Rainfall in Pahang	50
5.32	Time series of Annual Rainfall in Pahang	51
5.33	Time series of Annual Rainfall in Pahang	51
5.34	Time series of Annual Rainfall in Pahang	52
5.35	Time series of Annual Rainfall in Pahang	52
5.36	Time series of Annual Rainfall in Pahang	53
5.37	Time series of Annual Rainfall in Pahang	53
5.38	Time series of Annual Rainfall in Pahang	54
5.39	Time series of Annual Rainfall in Pahang	54
5.40	Maps showing the Spatial Distribution of Rainfall based on the Rainfall indices used in the Study	63

LIST OF ABBREVIATIONS AND SYMBOLS

AnnRain	-	Annual Rainfall
CDD	-	Consecutive Dry Days
CDR<1	-	Low Rainfall Days
CWD	-	Cumulative Wet Days
C5DPT	-	Cumulative 5-Day Precipitation Total
DJF	-	December-January-February
ENSO	-	El-Nino Southern Oscillation
GCMs	-	Global Climate Models
GIS	-	Geographic Information System
HPE	-	Heavy Precipitation Models
ITCZ	-	Inter-Tropical Convergence Zone
Max1DR	-	Maximum 1-Day Rainfall
MonRain	-	Monsoon Rainfall
M5DR	-	Maximum 5-Day Rainfall
NEM	-	North East Monsoon
OLR	-	Outgoing Long-wave Radiation
P	-	Annual Precipitation
PCI	-	Precipitation Concentration Index
P_i	-	Precipitation of i-th Month
Rain>20m	-	High Rainfall Days
Rain>95pctl	-	Extreme Rainfall Days
RegHCM-PM	-	Regional Hydroclimate Model of Peninsular Malaysia
RI	-	Rainfall Intensity
SIO	-	Southern Indian Ocean
SON	-	September-October-November

SWM	-	South West Monsoon
TWD	-	Total Wet Days
WNP	-	Western North Pacific
%	-	Percentage
Σ	-	Total

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Hydrologic changes are the most significant potential impacts of climate change in many regions of the world (IPCC, 2007). Future climate changes may involve modifications in climatic variability as well as changes in averages (Mearns *et al.*, 1996). As the primary impacts of climate change on society results from extreme events (Rodrigo, 2002), it might have severe negative consequences in the regions which are already under stress. Coastal regions of Peninsular Malaysia are more vulnerable to climate change compared to others parts of the country. Among the coastal regions, the east coast of Malaysia is considered as the most vulnerable to climate change (Yusuf and Francisco, 2009). The future projections of climate by means of Global Climate Models (GCMs) revealed that annual rainfall in the east coast of Malaysia will increase by 10% in the end of this century. High variability in inter-annual and inter-seasonal rainfall and river discharge is also projected by climate models. In some parts of the east coast of peninsular Malaysia, the frequency of long dry periods tended to be higher with a significant increase in the mean and variability of the length of the dry spells (Deni et al., 2008). The coastal zone of Peninsular Malaysia is already vulnerable to hydrological hazards. Floods triggered by heavy rainfall are almost every year phenomena in the region (Malaysian Meteorological Department, 2009). Unlimited industrial enlargement, extensive agricultural irrigation, and the continuing improvement of living standards constitute the main factors in the human dimension that influence the changing balance between water supply and demand in the region. Variability in inter-annual and inter-seasonal rainfall and river discharge will cause more hydrologic extremes in the east coast of Malaysia and make the livelihood and infrastructure more vulnerable.

In the line of global warming, Peninsular Malaysia is also experiencing a warming trend for the past few decades (Begum et al., 2011). Though Malaysia is considered as moderately vulnerable to climate change, the vulnerability is not evenly distributed over the country (Yusuf and Francisco, 2009). Coastal regions of Peninsular Malaysia are more vulnerable to climate change compared to others parts of the country. Among the coastal regions, the east coast of Peninsular Malaysia is considered as the most vulnerable to climate change (NAHRIM, 2006; Yusuf and Francisco, 2009). The coastline of East Malaysia is 2,607 km long and passed through the states of Kelantan, Terengganu, Pahang and Johor. According to Yusuf and Francisco (2009), hydrologic extremes are the most sever consequences of climate change in the east coast of Malaysia. The future projections of climate by means of Global Climate Models (GCMs) revealed that annual rainfall in the east coast of Malaysia will increase by 10% in the end of this century (NAHRIM, 2006). An increase in mean monthly rainfall in the northeast coastal region is also predicted. In term of river discharge, the maximum monthly flow is projected to increase by 11% to 43% from the base years (1961-1990). High variability in inter-annual and inter-seasonal rainfall and river discharge is also projected by climate models (Shaaban et al., 2008; NAHRIM, 2006). In some parts of the east coast of peninsular Malaysia, the frequency of long dry periods tended to be higher with a significant increase in the mean and variability of the length of the dry spells (Deni et al., 2008). At the same time, there will be significant increase in the overall mean monthly streamflow in the watersheds of Kelantan and Pahang and the high flow conditions will be magnified in Kelantan, Terengganu, Pahang and Perak River watersheds during the wet months (Shaaban et al., 2008).

The coastal zone of east Malaysia is already vulnerable to hydrological hazards. Floods triggered by heavy rainfall are almost every year phenomena in the region (Malaysian Meteorological Department, 2009). On the other hand, the northern coastal state is suffering from an extremely serious water deficiency for decades (Toriman et al., 2009). Unlimited industrial enlargement, extensive agricultural irrigation, and the continuing improvement of living standards constitute the main factors in the human dimension that influence the changing balance between water supply and demand in the region. Variability in inter-annual and inter-seasonal rainfall and river discharge will cause more hydrologic extremes in the east coast of Malaysia and make the livelihood and infrastructure more vulnerable. Most of the areas of east coast of Peninsular Malaysia are low-lying areas that are less than 0.5 m above the highest tide or are within 100 m inland of the high-water mark (DID, 2011). Therefore the region is highly vulnerable to sea level rise leading to coastal erosion, inundation, coral bleaching, saltwater intrusion, soil salinity, reduced productivity in crop lands, etc. National Coastal Erosion Study revealed that about 29% coastline of Malaysia facing erosion (DID, 2011). According to INC (2000), the rise in sea level is about 13-94 cm in 100 years in the east coast of Malaysia. Therefore, study the changing pattern of climate and climate related hydrologic extremes; assess the impacts of these changes on different sectors which are already under stress, and explore the possible adaptation responses are necessary to reduce the risks and challenges posed by climate change on coastal livelihood and infrastructure in the east coast of Peninsular Malaysia.

Rainfall extremes will bring huge disaster to human society and nature ecosystem. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) pointed out that the heavy precipitation events (HPE) in many mid-latitudes were likely to increase, and the total area affected by drought since the 1970s has been likely to increase (Alexander et al., 2006; IPCC, 2007; Li et al., 2010). Water is the foundation of composition, development and stability of oasis ecosystems in arid areas and determines the evolution of the ecological environment (Chen et al., 2007)

1.2 Problem Statement

According to Toriman et al. (2012), the future impacts of climate change on the hydrology of a geographical region needs to be studied in order to quantify in details the potential changes which may occur in hydrological water balances in that region due to such a climate change. Extreme precipitation events can influence flood and soil erosion differently with changes in frequency versus intensity. Assessing changes in extreme rainfall events at the regional scale can identify indicators that cause environmental and other problems and help us to obtain positive information for rational countermeasures (Wang et al., 2012). Therefore, the study of climate variability and changes in the rainfall trends and related extreme events in the East Coast of Peninsular Malaysia is needed to understand and assess the impact of climate changes toward the hydrologic changes in the coastal zones of Peninsular Malaysia.

1.3 Study Objectives

The following are the objectives of the study:

1. To assess the changing pattern of rainfall and rainfall-related extreme events in the east coast of Peninsular Malaysia
2. To study the characteristics and trends of rainfall in East Coast of Peninsular Malaysia.

1.4 Scope of Study

This paper studies the variability and changes in rainfall trend in response to the climate change in the east coastal states of Terengganu, Kelantan and Pahang of Peninsular Malaysia over a period of forty years (1971-2010). Various indices of rainfall extremes covered by the study include Annual Rainfall, Rainfall Intensity, Total Wet days, Monsoon Rainfall, Consecutive Dry Days, Low Rainfall Days, Consecutive Wet Days, Cumulative 5-Day Precipitation Total, Maximum 1-Day Rainfall, Maximum 5-Day Rainfall, High Rainfall Day, Extreme Rainfall Day and Precipitation Concentration Index (PCI).

REFERENCES

Adler. R. F., Huffman, G. J., Bolvin, D. T., Curtis, S., and Nelkin, E. J. (2000). Tropical Rainfall Distributions Determined Using TRMM Combined with other Satellite and Rain Gauge Information. *Journal of Applied Meteorology*. 39, 2007-2023. doi: http://dx.doi.org/10.1175/1520-0426(2003)20<752:LREITB>2.0.CO;2

Alexander, L.V., et al., 2006.Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res. 111, D05109. doi:10.1029/2005JD006290.

Begum, R.A., Siwar, C., Abidin, R.D.Z.R.Z., and Pereira, J.J. (2011). Vulnerability of climate change and hardcore poverty in Malaysia. *Journal of Environmental Science and Technology, 4*(2), 112-117.

Caesar J, Alexander LV, Trewin B, Tse-Ring K, Sorany L, Vuniyayawa V, Keosavang N, Shimana A, HtayMM, Karmacharya J, Jayasinghearachchi DA, Sakkamart J, Soares E, Hung LT, Thuong LT, Hue CT, Dung NTT, Hung PV, Cuong HD, Cuong NM, Sirabaha S. 2011. Changes in temperature and precipitation extremes over the Indo-Pacific region from 1971 to 2005. International Journal of Climatology 31(6): 791–801. DOI: 10.1002/joc.2118.

Chanyatham, T. and Kirtsaeng, S. (2011). Comparison and Analysis of Remote Sensing-based and Ground-based Precipitation Data Over India. *Chiang Mai Journal of Science*. 38(4), 541-550.

Chen YN, Li WH, Xu CC, Hao XM. 2007. Effects of climate change on water resources in Tarim River Basin, Northwest China. Journal of Environmental Sciences (China) 19(4): 488–493.

Deni, S.M., Jamaludin, S., Zin, W.Z.W., and Jemain, A.A. (2008). Tracing trends in the sequences of dry and wet days over peninsular Malaysia. Journal Environmental Science and Technology, 1: 97-110.

Di Baldassarre G, Castellarin A, Brath A. 2006. Relationships between statistics of rainfall extremes and mean annual precipitation: an application for design-storm estimation in northern central Italy. Hydrology and Earth System Sciences 10(4): 589–601.

DID (2011). Department of Drainage and Irrigation, Ministry of Natural Resources and Environment, Malaysia. Coastal Management – Activities http://www.water.gov.my/index.php?option=com_content&task=view&id=30&Itemid=184/

Dore, M.H.I. (2005). Climate change and changes in global precipitation patterns: What do we know. *Environment International*, 31(8), 1167-1181

Durao RM, Pereira MJ, Costa AC, Delgado J, del Barrio G, Soares A. 2010. Spatial–temporal dynamics of precipitation extremes in southern Portugal: a geostatistical assessment study. International Journal of Climatology 30(10): 1526–1537. DOI: 10.1002/joc.1999.

Endo N, Matsumoto J, Lwin T. 2009. Trends in precipitation extremes over Southeast Asia. Sola 5: 168–171. DOI: 10.2151/sola.2009-043.

Frich, P., Alexander, L.V., Della-Martin, P., Gleason, B., Haylock, M., Klein Tank, A.M.G., Peterson, T., 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim. Res. 19, 193–212.

Gemmer M, Fischer T, Jiang T, Su BD, Liu LL. 2011. Trends in precipitation extremes in the Zhujiang River Basin, South China. Journal of Climate 24(3): 750–761. DOI: 10.1175/2010jcli3717.1.

Goodall, J. L., D. R. Maidment, and J. Sorenson, 2004: Representation of spatial and temporal data in ArcGIS, AWRA GIS and Water Resources III Conference, Nashville, TN.

Hundecha Y, Bardossy A. 2005. Trends in daily precipitation and temperature extremes across western Germany in the second half of the 20th century. International Journal of Climatology 25(9): 1189–1202. DOI: 10.1002/joc.1182.

INC (2000). Malaysia initial national communication. Ministry of Science, Technology and the Environment. United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/natc/malnc1.pdf

IPCC (2007). Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of the Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Kayano, M.T., and Sansígolo, C., (2008). Interannual to decadal variations of precipitation and daily maximum and daily minimum temperatures in southern Brazil. Theoretical and Applied Climatology, 97(1-2): 81-90.

Kendall MG. 1975. Rank Correlation Measures. Charles Griffin: London; 202.

Kiktev D, Sexton DMH, Alexander L, Folland CK. 2003. Comparison of modeled and observed trends in indices of daily climate extremes. Journal of Climate 16(22): 3560–3571.

Kioutsioukis I, Melas D, Zerefos C. 2010. Statistical assessment of changes in climate extremes over Greece (1955–2002). International Journal of Climatology 30(11): 1723–1737. DOI: 10.1002/joc.2030.

Li Z, Zheng FL, Liu WZ, Flanagan DC. 2010. Spatial distribution and temporal trends of extreme temperature and precipitation events on the Loess Plateau of China during 1961–2007. Quaternary International 226(1–2): 92–100. DOI: 10.1016/j.quaint2010.03.003.

Mann HB (1945) Nonparametric tests against trend. Econometrica 13:245–259

Mearns, L. O., C. Rosenzweig, and R. Goldberg, 1996: The effect of changes in daily and interannual climatic variability on CERES-wheat: a sensitivity study. *Climatic Change*, **32**, 257-292.

MMD (2009). Report On Heavy Rain Occurrence That Cause Floods in Kelantan and Terengganu. Gong Kedak Forecast Office, Malaysian Meteorological Department (MMD), Ministry of Science, Technology And Innovation. http://www.met.gov.my/images/pdf/weather_report/report_on%20heavy%20rain_in_kelantan_dan_terengganu_%20%2823-27%20november%202009%29.pdf

NAHRIM (2006). Final Report: Study of the Impact of Climate Change on the Hydrologic Regime and Water Resources of Peninsular Malaysia. National Hydraulic Research Institute of Malaysia (NAHRIM) and California Hydrologic Research Laboratory (CHRL), United States.

New M, Hewitson B, Stephenson DB, Tsiga A, Kruger A, Manhique A, Gomez B, Coelho CAS, Masisi DN, Kululanga E, Mbambalala E, Adesina F, Saleh H, Kanyanga J, Adosi J, Bulane L, Fortunata L, Mdoka ML, Lajoie R. 2006. Evidence of trends in daily climate extremes over southern and west Africa. Journal of Geophysical Research—Atmospheres 111(D14). DOI: 10.1029/2005jd006289.

Oliver, J. E., 1980: Monthly precipitation distribution: a comparative index. *Prof. Geogr.*, **32**, 300-309.

Pal I, Al-Tabbaa A. 2011. Assessing seasonal precipitation trends in India using parametric and non-parametric statistical techniques. Theoretical and Applied Climatology 103(1–2): 1–11. DOI: 10.1007/s00704-010-0277-8.

Pavan V, Tomozeiu R, Cacciamani C, Di Lorenzo M. 2008. Daily precipitation observations over Emilia-Romagna: mean values and extremes. International Journal of Climatology 28(15): 2065–2079. DOI: 10.1002/joc.1694.

Rodrigo FS (2002) Changes in climate variability and seasonal rainfall extremes: a case study from San Fernando (Spain), 1821–2000. Theor Appl Climatol 72:193–207

Sen, P. K., 1968: Estimates of the regression coefficient based on Kendall's tau. *J. Amer. Stat. Assoc.*, **63**, 1379- 1389

Shaaban, J.B.A., Chen, Z.Q., Ohara, N., & Amin, M.Z.M. (2008). Regional modeling of climate change impact on peninsular Malaysia water resources. Paper presented at the *World Environmental and Water Resources Congress 2008: Ahupua'a - Proceedings of the World Environmental and Water Resources Congress 2008, 316*

Shaffril, H.A.M., Samah, B.A., Uli, J., and D'Silva, J.L. (2011). The potential impact of climate change environmental hazards on quality of life of fishermen community in Malaysia. *Australian Journal of Basic and Applied Sciences, 5*(7), 507-515.

Shahid, S. (2010). Recent trends in the climate of Bangladesh. Climate Research 42:185-193

Shahid, S. (2011a) Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. Climatic Change 105 (304: 433-453

Shahid, S. (2011b) Trends in extreme rainfall events in Bangladesh. Theoretical and Applied Climatology 104(3-4): 489-499

Shahid, S. and Khairulmaini, O.S. (2009) Spatio-Temporal Variability of Rainfall over Bangladesh during the Time Period 1969-2003. Asia-Pacific Journal of Atmospheric Sciences 45(3): 375-389.

Sinclair, S., and Pegram, G. (2005). Combining radar dan rain gauge rainfall estimates using conditional merging. *Atmospheric Sciences Letters*. 6(1), 19-22.

Strangeways, I. *Precipitation: theory, measurement and distribution*. Cambridge: Cambridge University Press. 2007. Tropical Rainfall Measuring Mission, Global Space Flight Center. *Algorithm 3B43 – TRMM and Other Data Precipitation*. Retrieved January 12, 2010, from http://trmm.gsfc.nasa.gov/3b43.html.

Su, B.D., Jiang T., and Jin, W.B. (2006) Recent trends in observed temperature and precipitation extremes in the Yangtze River basin, China. Theoretical and Applied Climatology, 83: 139–151

Suhaila, J., S. M. Deni, and A. A. Jemain, 2008: Detecting Inhomogeneity of Rainfall Series in Peninsular Malaysia, *Asia-Pacific J. Atmos. Sci*., **44**, 369-380.

Swee-Hock (2007) The Population of Peninsular Malaysia. Institute of Southeast Asian Studies. Singapore University Press. pp 1-2

Toriman, M.E., Pereira, J.J., Gasim, M.B., Sharifah Mastura, S.A., and Aziz, N.A.A. (2009) Issues of climate change and water resources in peninsular Malaysia: The case of north Kedah. *Arab World Geographer, 12*(1-2), 87-94.

Tromel S, Schonwiese CD. 2007. Probability change of extreme precipitation observed from 1901 to 2000 in Germany. Theoretical and Applied Climatology 87(1–4): 29–39.

Vaghefi, N., Nasir Shamsudin, M., Makmom, A., and Bagheri, M. (2011) The economic impacts of climate change on the rice production in Malaysia. *International Journal of Agricultural Research, 6*(1), 67-74.

Wang YQ, Zhou L. 2005. Observed trends in extreme precipitation events in China during 1961–2001 and the associated changes in large-scale circulation. Geophysical Research Letters 32(9). DOI: 10.1029/ 2005gl022574.

Wong, C.L., Venneker,R., Uhlenbrook, S., Jamil, A.B.M. and Zhou, Y.(2009) Variability of rainfall in Peninsular Malaysia, Hydrol. Earth Syst. Discuss Vol. No.6, pp 5471-5503

Yilmaz, K. K., Hogue, T. S., Hsu, K. L., Sorooshian, S., Gupta, H. V., and Wagener, T. 2005. Intercomparison of Rain Gauge, Radar, and Satellite-Based Precipitation Estimates with Emphasis on Hydrologic Forecasting. *American Meteorological Society*. 6, 497-517.

You QL, Kang SC, Aguilar E, Yan YP. 2008. Changes in daily climate extremes in the eastern and central Tibetan Plateau during 1961–2005. Journal of Geophysical Research—Atmospheres 113(D7). DOI: 10.1029/2007jd009389.

You QL, Kang SC, Aguilar E, Pepin N, Flugel WA, Yan YP, Xu YW, Zhang YJ, Huang J. 2011. Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961–2003. Climate Dynamics 36(11–12): 2399–2417. DOI: 10.1007/s00382-009-0735-0.

Yusuf, A.A. and Francisco, H.A. (2009). Climate Change Vulnerability Mapping for Southeast Asia. Economy and Environment Program for Southeast Asia (EEPSEA), http://web.idrc.ca/uploads/user-S/12324196651Mapping_Report.pdf

Zhang QA, Xu CY, Zhang ZX, Chen X, Han ZQ. 2010. Precipitation extremes in a karst region: a case study in the Guizhou province, southwest China. Theoretical and Applied Climatology 101(1–2): 53–65.: 10.1007/s00704-009-0203-0.

Zolina O, Simmer C, Kapala A, Bachner S, Gulev S, Maechel H. 2008. Seasonally dependent changes of precipitation extremes over Germany since 1950 from a very dense observational network. Journal of Geophysical Research—Atmospheres 113(D6). DOI: 10.1029/2007jd008393.