PARAMETER ESTIMATION METHODS FOR NON-STATIONARY DATA USING L-MOMENTS AND TL-MOMENTS APPROACHES

NUR AMALINA BINTI MAT JAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Science
Universiti Teknologi Malaysia

APRIL 2021

DEDICATION

This thesis is dedicated

To my beloved parents

My father, Hj. Mat Jan bin Hj. Abu Bakar

My mother, Hjh. Asiah bt Hj. Hanapi

To my lovely family members

Nur Amirah bt Hj. Mat Jan

Nur Amanina bt Hj. Mat Jan

Muhammad Firdaus bin Azman

Muhammad Aqil Iman bin Muhammad Firdaus

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Assoc. Prof. Dr. Ani bin Shabri, for encouragement, guidance, critics and friendship. I am also very thankful to Dr Ruhaidah Samsudin for her advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for provide nice facilities and places to study and Ministry of Higher Education, Malaysia for funding my Ph.D study. Special thanks to Department of Irrigation and Drainage, Ministry of Natural Resources and Environment, Malaysia and Universiti Teknologi Malaysia for being my primary sources of relevant information for my study.

My sincere appreciation also extends to my parents who always pray for my success and also my beloved sisters, who continuously support me in this journey. To all my fellow friends, members of Lab C22, members of Lab T05, and others who have provided assistance at various occasions and created beautiful memory along this journey, thank you so much. Their views and tips are useful indeed.

ABSTRACT

Non-stationary flood frequency analysis (NFFA) plays an important role in defining the probabilities of flood occurrences by taking into account of the non-independence and non-stationary aspects of hydrological extreme events data. This analysis overcomes the issue of the stationary assumptions (independent and identically distributed flood series) applied in flood frequency analysis (FFA), which are no longer valid in infrastructure-designed methods. This is because ignoring the non-stationarity of hydrological records may result in inaccurate future flood event predictions. Flood estimation is one of the important components in frequency analysis. Thus, an appropriate parameter estimation method should be established to deal with flood frequency analysis in the likely case of non-stationary. The objective of this study is to propose a parameter estimation method to estimate the parameter of non-stationary distribution model. The proposed methods are Trimmed L-moments (TL-moments) method and performance comparison of TL-moments with L-moments method in NFFA study. The TL-moments method was applied to the Generalized Extreme Value (GEV) distribution model with time as covariate. Four GEV distribution models examined in this study were stationary model (GEV0) and three non-stationary models (GEV1, GEV2, and GEV3). Comparisons of the parameter estimation methods were carried out using Monte Carlo simulation and bootstrap techniques. The simulation study showed that TL-moments performed better than L-moments method for GEV1 and GEV3 models. Streamflow data for three of eleven rivers in Johor, Malayis were found to exhibit non-stationary behaviour in the annual maximum streamflow. These rivers showed decreased trend in the flood series based on the Mann-Kendall trend test and Spearman's Rho test. From the bootstrap analysis, the TL-moments method performed better as compared to the L-moments method for GEV0, GEV1, and GEV3 models. The overall result concluded that the TL-moments method could provide an efficient prediction of the flood event estimated at quantiles of the higher return periods.

ABSTRAK

Analisis frekuensi banjir tidak pegun (NFFA) memainkan peranan penting dalam menentukan kebarangkalian kejadian masa hadapan dengan mengambil kira aspek ketidakbersandaran dan tidak pegun bagi data hidrologi kejadian ekstrim. Analisis ini mengatasi isu andaian data pegun (siri banjir bebas dan tersebar sama) yang diterapkan dalam analisis frekuensi banjir (FFA), yang tidak lagi sah dalam sistem pembangunan infrastruktur. Ini kerana pengabaian ciri tidak pegun dalam rekod data hidrologi boleh menghasilkan ramalan banjir masa depan yang tidak tepat. Penganggaran banjir adalah salah satu komponen penting dalam analisis frekuensi. Oleh itu, kaedah anggaran parameter yang sesuai harus dibentuk untuk menangani analisis frekuensi banjir bagi kes data tidak pegun. Objektif kajian ini adalah untuk mencadangkan kaedah penganggaran parameter bagi menganggar parameter model taburan tidak pegun. Kaedah yang dicadangkan adalah kaedah Trim L-momen (TL-momen) dan pembandingan prestasi kaedah TL-momen dengan kaedah L-momen di dalam kajian NFFA. Kaedah TL-momen telah digunakan ke atas model bagi taburan Nilai Ekstrim Teritlak (GEV) dengan masa sebagai kovariat. Empat model bagi taburan GEV yang dikaji dalam kajian ini adalah model pegun (GEV0) dan tiga model tidak pegun (GEV1, GEV2, dan GEV3). Perbandingan kaedah penganggaran parameter dijalankan melalui teknik simulasi Monte Carlo dan bootstrap. Kajian simulasi telah menunjukkan kaedah TL-momen adalah lebih baik berbanding dengan kaedah L-momen bagi model GEV1 dan GEV3. Data aliran sungai bagi tiga daripada sebelas sungai di Johor, Malaysia didapati mempamerkan ciri tidak pegun dalam aliran sungai maksimum tahunan. Sungai-sungai ini menunjukkan aliran menurun dalam siri banjir berdasarkan ujian tren Mann-Kendall dan ujian Spearman’s Rho. Daripada analisis bootstrap, kaedah TL-momen menunjukkan prestasi yang lebih baik berbanding dengan kaedah L-momen bagi model GEV0, GEV1, dan GEV3. Hasil keseluruhan keputusan menyimpulkan bahawa kaedah TL-momen dapat memberikan anggaran kejadian banjir yang cekap dalam penganggaran kejadian banjir pada kuantil aliran tinggi.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	**iii**
	DEDICATION	**iv**
	ACKNOWLEDGEMENT	**v**
	ABSTRACT	**vi**
	ABSTRAK	**vii**
	TABLE OF CONTENTS	**viii**
	LIST OF TABLES	**xiii**
	LIST OF FIGURES	**xv**
	LIST OF ABBREVIATIONS	**xviii**
	LIST OF SYMBOLS	**xix**
	LIST OF APPENDICES	**xxi**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Introduction	1
1.2	Problem Statement	3
1.3	Research Objectives	4
1.4	Research Scope	5
1.5	Research Contribution	7
1.6	Organization of the Thesis	8
CHAPTER 2	**LITERATURE REVIEW**	**11**
2.1	Introduction	11
2.2	Flood Frequency Analysis	11
2.3	Non-stationary Flood Frequency Analysis	12
	2.3.1 Generalized Extreme Values (GEV) Distribution	14
	2.3.2 Time-varying Moments Method	16
	2.3.3 Parameter Estimation Method	21

2.4	Monte Carlo Simulation	27
2.5	Bootstrap Technique	30
2.6	Selection of Best Model	34
2.7	Summary	38
CHAPTER 3	**RESEARCH METHODOLOGY**	**41**
3.1	Introduction	41
3.2	Operational Framework	42
3.3	Probability Distribution Function	44
	3.3.1 Generalized Extreme Value (GEV) Distribution	44
3.4	L-moments Method	47
	3.4.1 Background of L-moments	47
	3.4.2 Sample Estimates of L-moments	50
3.5	TL-moments Method	52
	3.5.1 Background of TL-moments	52
	3.5.2 Sample Estimates of TL-moments	54
3.6	Model Structure for Stationary and Non-stationary GEV Model	56
3.7	Parameter Estimation for Stationary and Non-Stationary GEV Model	59
	3.7.1 Parameter Estimation for GEV0 Model	61
	i. L-moments Method	61
	ii. TL-moments (1,0) Method	63
	iii. TL-moments (2,0) Method	65
	iv. TL-moments (3,0) Method	66
	v. TL-moments (4,0) Method	67
	3.7.2 Parameter Estimation for GEV1 Model	69
	i. L-moments Method	69
	ii. TL-moments (1,0) Method	70
	iii. TL-moments (2,0) Method	71
	iv. TL-moments (3,0) Method	72
	v. TL-moments (4,0) Method	73

3.7.3 Parameter Estimation for GEV2 Model 75
i. L-moments Method 75
ii. TL-moments (1,0) Method 77
iii. TL-moments (2,0) Method 78
iv. TL-moments (3,0) Method 80
v. TL-moments (4,0) Method 81
3.7.4 Parameter Estimation for GEV3 Model 83
i. L-moments Method 83
ii. TL-moments (1,0) Method 84
iii. TL-moments (2,0) Method 85
iv. TL-moments (3,0) Method 86
v. TL-moments (4,0) Method 87
3.7.5 Simplified Parameter Estimation of L-Moments and TL-Moments 88
3.8 Simulation Study 96
3.9 Bootstrap Technique 99
3.10 Non-stationary Analysis 101
3.10.1 Augmented Dickey-Fuller (ADF) test 101
3.11 Trend Detection Test 102
3.11.1 Mann-Kendall Test 102
3.11.2 Spearman's Rho Test 104
3.12 Selection of Best Model 105
3.12.1 Akaike Information Criterion (AIC) 105
3.12.2 Bayesian Information Criterion (BIC) 105
3.12.3 Diagnostic Plot 106
i. Probability Plot 106
ii. Quantile Plot 107
3.13 Performance Criteria 108
3.14 Summary 109

CHAPTER 4 DATA DESCRIPTION AND ESTIMATION OF FLOOD QUANTILE **111**

4.1 Introduction 111

4.2 Data Description Study 112

4.2.1 Characteristics of Data 112

4.3 Flood Quantile Estimation for Sungai Sayong 117

4.4 Flood Quantile Estimation in Simulation Study 122

4.5 Flood Quantile Estimation in Bootstrap Study 135

4.6 Choosing Best Model 152

4.7 Summary 154

CHAPTER 5 SIMULATION STUDY **157**

5.1 Introduction 157

5.2 Monte Carlo Simulation 158

5.3 Analysis of Monte Carlo Simulation Study 159

5.3.1 Performance of GEV1 model 159

5.3.2 Performance of GEV2 model 172

i. Case 1: α_1 = -0.02 172

ii. Case 2: α_1 = 0.02 180

5.3.3 Performance of GEV3 model 188

5.4 Conclusion 196

CHAPTER 6 NON-STATIONARY FLOOD FREQUENCY ANALYSIS ON STREAMFLOW DATA **199**

6.1 Introduction 199

6.2 Non-Stationarity Test and Trend Detected Streamflow 200

6.3 Flood Quantile Bootstrap 203

6.4 Selection of Best Model 213

6.5 Conclusion 223

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS **225**

7.1 Introduction 225

7.2 Summary of Research 225

7.3 Research Outcomes 226

7.3.1 Objective I 226

7.3.2 Objective II 227

7.3.3 Objective III 227

7.3.4 Objective IV 228

7.3.5 Objective V 228

7.4 Recommendations for Future Study 229

REFERENCES **229**

APPENDIX A - L **247 - 335**

LIST OF PUBLICATIONS **349**

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Summary of previous works on the trend function of time.	20
Table 3.1	The stationary and non-stationary GEV models	58
Table 3.2	Parameter estimation of GEV0 model by L-moments and TL-moments methods	89
Table 3.3	Parameter estimation of GEV1, GEV2, and GEV3 model by L-moments method	91
Table 3.4	Parameter estimation of GEV1, GEV2, and GEV3 model by TL-moments (1,0) and TL-moments (2,0) method	92
Table 3.5	Parameter estimation of GEV1, GEV2, and GEV3 model by TL-moments (3,0) and TL-moments (4,0) method	94
Table 4.1	Characteristics of gauging sites for annual maximum flow series in Johor	113
Table 4.2	Original data, $x(t)$ and standardized data, $y(t)$ of Sayong station	118
Table 4.3	Quantile function of GEV2 model for Sayong station	121
Table 4.4	Calculated quantile function, $x(F)^C$ of GEV2 model	123
Table 4.5	Generated data, $x(t)$ estimation of GEV2 model	124
Table 4.6	Standardized data, $y(t)$ estimation	126
Table 4.7	Quantile function, $x(F)$ of GEV0 model	129
Table 4.8	Quantile function, $x(F,t)$ estimation of non-stationary GEV2 model	133
Table 4.9	RRMSE and RBIAS result for GEV2 model	134
Table 4.10	Streamflow data, $x(t)$ and standardized data, $y(t)$ of Sayong station	137
Table 4.11	Calculated quantile function, $x(F)^C$ of GEV2 model	142
Table 4.12	Estimation of ‘‘stationary” residuals, $\varepsilon(t)$	143
Table 4.13	Estimation of generated value of $\hat{\varepsilon}(t)$	144
Table 4.14	Estimation of generated value of $\hat{x}(t)$	145
Table 4.15	Standardized data, $y(t)$ estimation of sampling data	147

Table 4.16 Simulated quantile function, $x(F,t)^S$ of GEV2 model 150

Table 4.17 RRMSE and RBIAS result for GEV2 model 151

Table 4.18 Result of AIC and BIC tests at Sayong station 152

Table 4.19 Quantile function of GEV2 model for Sayong station 154

Table 5.1 RRMSE and RBIAS of quantiles are estimated by all methods for the GEV1 model (n = 15, ξ_0 = 0, ξ_1 = -0.2, and α =1). 160

Table 5.2 Performances of TL-moments and L-moments method for simulation on GEV1 model 170

Table 5.3 RRMSE and RBIAS result of quantile estimated for GEV2 model (n = 15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = -0.02). 174

Table 5.4 RRMSE and RBIAS result of quantile estimated for GEV2 model (n =15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = 0.02). 181

Table 5.5 Performances of TL-moments and L-moments methods for simulation on GEV2 model 187

Table 5.6 RRMSE and RBIAS result of quantile estimated for GEV3 model (n = 15, ξ_0 = 0, ξ_1 = 0.2, ξ_2 = 0.2, α = 1). 189

Table 5.7 Performances of TL-moments and L-moments methods for simulation on GEV3 model 195

Table 6.1 The result of the ADF test. 200

Table 6.2 The result of Mann-Kendall and Spearman’s Rho test. 201

Table 6.3 The results of the Mann-Kendall and Spearman’s Rho tests. 202

Table 6.4 The AIC and BIC result for all stations 214

Table 6.5 Model selection from AIC and BIC results for all stations. 215

Table 6.6 Best model for streamflow stations in Johor. 220

Table 6.7 Parameters estimates of the best model for the non-stationary station. 221

Table 6.8 Quantiles estimates of the best model for the non-stationary station. 222

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Monte Carlo simulation	28
Figure 2.2	The flow chart of Bootstrap Technique (Efron, 1979)	31
Figure 3.1	Flowchart of research.	43
Figure 4.1	Location of streamflow stations in Johor, Malaysia. The eleven stations are (1) Sg. Sayong, (2) Sg. Pengeli, (3) Sg. Sembrong, (4) Sg. Bekok, (5) Sg. Kahang, (6) Sg. Muar, (7) Sg. Segamat, (8) Sg. Parit Madirono, (9) Sg. Johor, (10) Sg. Linggui, and (11) Sg. Lenggor	114
Figure 4.2	Plot of the annual maximum flow with the corresponding linear trend for a) Sg. Sayong (1836402), b) Sg. Pengeli (1836403), c) Sg. Bekok (2130422), c) Sg. Kahang (2235401), and e) Sg. Lenggor (2237471).	116
Figure 4.3	GEV fit diagnostics for GEV2 model to the Sayong station	153
Figure 5.1	RRMSE and RBIAS of quantiles are estimated by the comparison methods plotted against the quantile (*F*) for the GEV1 model (n = 15, ξ_0 = 0, ξ_1 = -0.2 and +0.2, α =1, and k = -0.2).	165
Figure 5.2	RRMSE and RBIAS of 0.999 quantile are estimated by the comparison methods plotted against the shape parameter (k) for the GEV1 model (n = 15, ξ_0 = 0, ξ_1 = -0.2 and +0.2, and α =1).	166
Figure 5.3	RRMSE and RBIAS of 0.999 quantile are estimated by the comparison methods plotted against the mean slope in location parameter (ξ_1) for the GEV1 model (n = 100, ξ_0 = 0, k = -0.2 and +0.2, and α =1).	167
Figure 5.4	RRMSE and RBIAS of 0.999 quantile are estimated by the comparison methods plotted against the sample size (n) for the GEV1 model (ξ_0 = 0, ξ_1 = -0.2 and +0.2, k = 0.2, and α =1).	168
Figure 5.5	RRMSE and RBIAS of 0.999 quantiles estimated by the comparison methods plotted against the quantile (*F*) for the GEV2 model (n = 15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = -0.02, and k = -0.2).	177

Figure 5.6 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the shape parameter (k) for the GEV2 model (n = 15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, and α_1 = -0.02). 177

Figure 5.7 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the sample size (n) for the GEV2 model (ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = -0.02, and k = -0.2). 178

Figure 5.8 RRMSE and RBIAS of quantiles estimated by the comparison methods plotted against the quantile (F) for the GEV2 model (n = 15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = 0.02, and k = -0.2). 184

Figure 5.9 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the shape parameter (k) for the GEV2 model (n = 15, ξ_0 = 0, ξ_1 = -0.1, α_0 =1, and α_1 = 0.02). 184

Figure 5.10 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the sample size (n) for the GEV2 model (ξ_0 = 0, ξ_1 = -0.1, α_0 =1, α_1 = 0.02, and k = -0.2). 185

Figure 5.11 RRMSE and RBIAS of quantiles estimated by the comparison methods plotted against the quantile (F) for the GEV3 model (n = 15, ξ_0 = 0, ξ_1 = 0.2, ξ_2 = 0.2, and k = -0.2). 192

Figure 5.12 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the shape parameter (k) for the GEV3 model (n =15, ξ_0 = 0, ξ_1 = 0.2, ξ_2 = 0.2, and α = 1). 192

Figure 5.13 RRMSE and RBIAS of 0.999 quantile estimated by the comparison methods plotted against the sample size (n) for the GEV3 model (ξ_0 = 0, ξ_1 = 0.2, ξ_2 = 0.2, and k = -0.2). 193

Figure 6.1 Performance of L-moments and TL-moments method for RRMSE and RBIAS result on the GEV0 model. 204

Figure 6.2 Performance of L-moments and TL-moments method for RRMSE and RBIAS result on the GEV1 model. 206

Figure 6.3 Performance of L-moments and TL-moments method for RRMSE and RBIAS result on the GEV2 model. 208

Figure 6.4 Performance of L-moments and TL-moments method for RRMSE and RBIAS result on the GEV3 model. 210

Figure 6.5 GEV fit diagnostics for the a) GEV0, b) GEV1, c) GEV2, and d) GEV3 model to the Bekok station. 216

Figure 6.6 GEV fit diagnostics for the a) GEV0, b) GEV1, c) GEV2, and d) GEV3 model to the Kahang station. 217

Figure 6.7 GEV fit diagnostics for the a) GEV0, b) GEV1, c) GEV2, and d) GEV3 model to the Lenggor station. 218

LIST OF ABBREVIATIONS

AIC	-	Akaike Information Criterion
AICc	-	Corrected Akaike's Information Criterion
AMS	-	Annual maximum series
ADF	-	Augmented Dickey-Fuller test
BIC	-	Bayesian Information Criterion
CVM	-	Cramer von Mises test
FFA	-	Flood frequency analysis
GAMLSS	-	Generalized Additive Models for Location, Scale, and Shape
GEV	-	Generalized extreme value distribution
GML	-	Generalized maximum likelihood method
GPA	-	Generalized Pareto Distribution
KS	-	Kolmogorov-Smirnov test
LRT	-	Likelihood ratio test
MMK	-	Modified Mann-Kendall test
MK	-	Mann-Kendall test
MLE	-	Maximum Likelihood Estimator
NFFA	-	Non-stationary flood frequency analysis
OLS	-	Ordinary least square
PML	-	Penalized Maximum Likelihood method
PPCC	-	Probability Plot Correlation coefficient test
PW	-	Pre-Whitening test
PWM	-	Weighted Probability Moments method
RBIAS	-	Relative bias
RRMSE	-	Relative mean square error
SR	-	Spearman's Rho test
TFPW	-	Trend-Free Pre-whitening test
TS	-	Two Stage method
WLS	-	Weighted least square method

LIST OF SYMBOLS

ξ	-	Location parameter
α	-	Scale parameter
k	-	Shape parameter
$\xi(t)$	-	Non-stationary location parameter
$\alpha(t)$	-	Non-stationary scale parameter
t	-	Time
μ	-	Mean
σ	-	Standard deviation
$\mu(t)$	-	Non-stationary in the mean
$\sigma(t)$	-	Non-stationary in the standard deviation
$F(x)$	-	Cumulative distribution function (cdf)
$x(F)$	-	Quantile function
$x(F,t)$	-	Non-stationary quantile function
$x(F)^C$	-	Calculated quantile function
$x(F)^S$	-	Simulated quantile function
$x(t)$	-	Generated quantile function
$x(T)$	-	Quantile of flood at T-year
T	-	Return period, year
U	-	Uniform random numbers
$E[X]$	-	Expectation of order statistic
q	-	Flood
x	-	Random variable
f_i	-	Plotting position
$F(f_i)$	-	Generated cumulative distribution function
Z_i	-	Ordered values for $i = 1,\ldots,n$
$F^{-1}(f_i)$	-	Generated of inverse cumulative distribution function
(t_1, t_2)	-	Smallest and largest trimmed L-moments (TL-moments)
β_r	-	r^{th} probability weighted moments
λ_r	-	r^{th} L-moments

$\lambda_r^{(t_1,t_2)}$	-	r^{th} TL-moments
l_r	-	r^{th} sample L-moments
$l_r^{(t_1,t_2)}$	-	r^{th} sample TL-moments
b_r	-	r^{th} sample probability weighted moments
τ_2	-	L-coefficient of variation (L-Cv)
τ_3	-	L-coefficient of skewness (L-Cs)
τ_4	-	L-coefficient of kurtosis (L-Ck)
$\hat{\tau}_r$	-	r^{th} sample L-moments ratio
$\tau_2^{(t_1,t_2)}$	-	TL-coefficient of variation (TL-Cv)
$\tau_3^{(t_1,t_2)}$	-	TL-coefficient of skewness (TL-Cs)
$\tau_4^{(t_1,t_2)}$	-	TL-coefficient of kurtosis (TL-Ck)
$\hat{\tau}_r^{(t_1,t_2)}$	-	r^{th} sample TL-moments ratio
$\tilde{\tau}$	-	Tau
$\Gamma(\cdot)$	-	Gamma function
$\text{sgn}(\cdot)$	-	Signum function
$\log(\cdot)$	-	Logarithm function
iid	-	Independent and identically distributed
F	-	Non-exceedance Probability
L	-	Likelihood function
n	-	Sample size
N	-	Total number of samples
p	-	Number of parameters
Y	-	Output variable
Z	-	Test statistic

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
APPENDIX A	The codes of Monte Carlo simulation study in R Software	247
APPENDIX B	The codes of bootstrap technique in R Software	251
APPENDIX C	The time series plot of the annual maximum streamflow in Johor	254
APPENDIX D	RRMSE and RBIAS result of quantile estimated at different sample size for GEV1 model in simulation study	258
APPENDIX E	RRMSE and RBIAS result of quantile estimated at different sample size for GEV2 model in simulation study	268
APPENDIX F	RRMSE and RBIAS result of quantile estimated at different sample size for GEV3 model in simulation study	275
APPENDIX G	Parameter estimations of stationary model (GEV0) and non-stationary model (GEV1, GEV2, and GEV3) using L-moments and TL-moments method for streamflow station.	280
APPENDIX H	RRMSE and RBIAS values for different quantiles, F of L-moments and TL-moments method for GEV0 model in bootstrap study	287
APPENDIX I	RRMSE and RBIAS values for different quantiles, F of L-moments and TL-moments method for GEV1 model in bootstrap study	300
APPENDIX J	RRMSE and RBIAS values for different quantiles, F of L-moments and TL-moments method for GEV2 model in bootstrap study	313
APPENDIX K	RRMSE and RBIAS values for different quantiles, F of L-moments and TL-moments method for GEV3 model in bootstrap study	326
APPENDIX L	GEV fit diagnostics for GEV0, GEV1, GEV2, and GEV3 model in streamflow case study	339

CHAPTER 1

INTRODUCTION

1.1 Introduction

Flood is one of the most common natural disasters in Malaysia, especially during the rainy season. US Geological Survey (2013) defined flood as an overflow or inundation that comes from a river or other water body that can cause damages. The primary cause of the river flooding is the presence of heavy rainfall, assisted with waste disposal into the river. This problem has affected the livelihoods and economic development in the country and can lead to serious damage, property losses, and even human life losses. The hydraulic structure such as weir, spillway and dam is an innovative technique in the management of water system for potential energy or flood control. The development of these structures needs information on accurate estimation of flood prediction. The design of the structures is constructed through the maximum flows that exceed a certain level in a given return period (the time period of flood occurrence).

Flood frequency analysis (FFA) suggested by Stedinger *et al*. (1992) is mostly used by engineers and hydrologists all over the world to determine the best probability distribution (or model) that fits streamflow data. It consists of estimating flood peak quantiles (frequency of flood occurrence) (Hosking & Wallis, 1997). The FFA is related to the magnitude of extreme events by determining their frequency of occurrence using probability distributions. The validity of the findings of frequency analysis is based on the classic principles of independence and stationary observations to proceed with the distribution fitting method (Khaliq et al., 2006). It means that the probability distribution parameters are estimated from independent and identically distributed (iid) observations and the flood series free of trends and drastic changes.

However, the assumption of stationary is questionable when the flood is caused by severe storms like climate change, land-use modification, and watershed regulations, acting individually or together (Katz *et al*., 2002; Milly *et al*., 2008; Gilroy & McCuen, 2012; Salas & Obeysekera, 2014; Vasiliades *et al*., 2015) and flood predictions made on that basis would be questionable. The changes of Earth's climate are altering the means and extremes of precipitation and rates of discharge of rivers (Intergovernmental Panel on Climate Change (IPCC), 2007). Thus, these changes cause to the criteria for the frequency of data samples or the statistical characteristics (e.g. mean and variance) of the related data may have changed over time (i.e. inconstant pattern) (Khaliq *et al*., 2006) which is known as non-stationary data.

In flood frequency analysis, the analysis implies the annual extreme flood with time-invariant (or 1-year-periodic) on probability density function (pdf) (Milly et al., 2008). The pdf is used to evaluate and manage risks to water infrastructure; water supplies and floodplains. Thus, handling FFA by taking into account the presence of non-stationary behaviour in data will make the distribution parameter model changes over time and the distribution get more complicated (Gado & Nguyen, 2016a). Recent flood frequency studies showed the seriously bias the result of estimated frequency of flood occurrence for future events when ignoring the non-stationary behaviour in the streamflow series (Cunderlik & Ouarda, 2006). Therefore, the standard parameter estimation method in FFA studies which assuming the parameter distribution as a constant parameter cannot be applied to non-stationary data records. New estimation procedures need to be used to allow modelling distribution parameters as a function of time. Thus, this study aims to estimate parameter and predict frequency of flood occurrence by suitable parameter estimation method in the application of non-stationary flood frequency analysis (NFFA).

In order to analyse hydrological extreme events such as annual maximum series of floods, the prediction of flood magnitude is usually estimated in large return period (flood occurrence in a high time period) such as 100 years and above (Wang 1990). Hence, it is advantageous to find a suitable parameter estimation method that intentionally censors (or eliminate) low-value observations because using only the larger value flood ensures that the extrapolation to large return periods flood is carried out by exploring the trend of these larger flows only. Trimmed L-moments (TL-moments) method is a parameter estimation method which works by trimming a predetermined percentage of the extreme values from the samples (Elamir & Seheult, 2003). Sample of this method assigned no weight to the extreme value since censoring data from below value (i.e. smaller value) may remove a nuisance value in the upper quantile estimation (high return period) (Wang, 1990). The TL-moments method has been applied successfully as parameter estimation method in flood frequency analysis study in several case studies from Malaysia (Ahmad et al., 2011a, 2011b, 2011c; Shabri et al., 2011a, 2011b), Czech Republic (Bílková, 2014a, 2014b, 2014c, 2014d), Pakistan (Ishfaq Ahmad et al., 2015, 2016), East India (Bora & Borah, 2017), Texas (Asquith, 2007). Thus, the application of TL-moments method will be carried out in this research to investigate the parameter estimation in non-stationary flood frequency analysis.

1.2 Problem Statement

The motivation to carry out this study arises from the need to estimate the parameter of the non-stationary model which is a time-dependent parameter and predict the frequency of flood occurrence. Before dealing with this research, a few issues need to be considered.

In flood frequency analysis for stationary data, the parameter distribution is a constant parameter. However, non-stationary flood frequency analysis is dealing with time-dependent parameters of flood frequency distribution which means the distribution parameter model changes over time. Thus, the technique of parameter estimation using the TL-moments method for non-stationary distribution model need to be discovered.

In order to evaluate the performance of the proposed parameter estimation method in non-stationary flood frequency analysis for real data, the proposed method should be applied to non-stationary streamflow data station. Hence, the non-stationary behaviour of streamflow series for each case study is needed to be known.

Since TL-moments method is the extension of L-moments method, the third issue is how the performance of TL-moments method in handling the non-stationary model compare with the non-stationary model and stationary model estimated by L-moments method.

Therefore, in this study, the non-stationary distribution model will be estimated by TL-moments method since there is no further research that has investigated the non-stationary flood frequency analysis of trimming sample. Hence, this research will provide further investigation and more comprehensive evaluation of TL-moments approach in non-stationary flood frequency analysis, especially on evaluating the performance of TL-moments compared to L-moments.

1.3 Research Objectives

The main objective of this study is to evaluate the application of non-stationary flood frequency analysis based on the GEV distributions by investigating the performance of non-stationary model in L-moments and TL-moments approaches. In achieving this, the following specific objectives were outlined:

i. To develop the parameter estimation for non-stationary model of L-moments and TL-moments $(t_1,0)$, t_1 = 1,2,3,4 for GEV distribution.

ii. To investigate the performance of TL-moments $(t_1,0)$, t_1 = 1,2,3,4 compared to L-moments for non-stationary of GEV distribution model based on Monte Carlo simulation when the data are generated from parent distribution.

iii. To evaluate the non-stationarity of the annual maximum streamflow over stations in Johor, Malaysia and detect significant floods trend for each station.

iv. To evaluate the performance of L-moments and TL-moments (t_1,0), t_1= 1,2,3,4 in the context of a stationary and a non-stationarity approach using real data analysis of annual maximum streamflow data of Johor, Malaysia.

v. To analyze the suitable model in the prediction of flood peak quantiles (frequency of flood occurrence) using the L-moments and TL-moments methods for annual maximum streamflow data in Johor, Malaysia.

1.4 Research Scope

This study involved major tasks as follows:

i. The selection of eleven streamflow stations located in Johor, Malaysia. The period of the flow series varies from 15 – 49 years starting from 1960 – 2009. The data were obtained from the Department of Irrigation and Drainage, Malaysia. An annual maximum series (AMS), a series that contains only the streamflow level with the largest magnitude that occurred in each year is used. The selection is due to the data availability and the theoretical basis for extrapolating outside the range of the observations.

ii. This study focus on the prediction of flood magnitudes in high frequency of flood occurrence which involving extreme events. The extreme events are more suitable modelled with heavy tails, which is characterised in the Generalized Extreme Values (GEV) distribution (Martins & Stedinger, 2000; Otiniano et al., 2019). Hence, this research covers the derivation of parameters estimation non-stationary models for GEV distribution based on TL-moments approach.

iii. In non-stationary modelling, the number of parameters to be estimated from fixed-length time-series will increase. Thus, the time-dependent parameters estimated from extreme flow data should be expressed as the functions with the smallest possible number of parameters (simple model function, such as linear and quadratic) (Strupczewski et al., 2016). Thus, the non-stationary GEV model in this analysis consisted of three types of GEV model, which are location parameter is a linear function of the time as a covariate (GEV1), location and scale parameters are a linear function of the time as a covariate (GEV2), and location parameter is a quadratic function of the time as a covariate (GEV3).

iv. This study addressed models with time as a covariate for non-stationary flood frequency analysis for GEV distribution. Due to the lack of information and data on climate changes in Malaysia, this study only focuses on the time-varying model for GEV distribution.

v. TL-moments with various levels of trimming trimming the smallest conceptual sample value, (t_1,0) are investigated in this research ranging from t_1 = 1, 2, 3, and 4. This is because the use of t_1 higher than 4 produced large sampling variability and will affect the tail fitting of distribution (Wang, 1997).

vi. The selection of the best fitted model for the streamflow station is based on the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and diagnostic plot.

1.5 Research Contribution

Although many studies have been conducted in the prediction of flood quantiles in flood frequency analysis (FFA), there are very few studies that used TL-moments method in the prediction of non-stationary flood quantiles (i.e. frequency of flood occurrence in future). This study attempts to use TL-moments method as a tool to predict flood quantile in non-stationary flood frequency analysis (NFFA). The expected contributions of this study are:

i. This research contributes to the development of the NFFA model with three-parameter GEV distribution; GEV1, GEV2, and GEV3 based on TL-moments parameter estimation method.

ii. By investigating TL-moments with trimming smallest values, t_1 ranging from 1 to 4, readers will have some ideas in choosing the suitable trimming values to improve the estimation of extreme events particularly in high return period events in NFFA studies.

iii. The results of this study contributed to the understanding of the hydrological behaviour of the study areas as far as the extreme values are concerned. The direct beneficiaries of the study are the engineers and hydrologists working in the research areas of applications from the results of specifying the probability distribution of extreme events (i.e. flood). The application of the TL-moments method could be widened especially for modelling time series under non-stationary conditions for the flood management and comprehensive response to extreme climate events.

iv. The identification extreme value of the non-stationary probabilistic model was improved in this study in order to evaluate its acceptability for the frequency analysis of floods in the Johor state and investigated changes occurring in the extreme discharge.

1.6 Organization of the Thesis

This thesis consists of seven chapters, followed by references and appendices. Chapter 1 defines the background of the study, problem statement, objectives, scopes, the significance of the study and thesis organization.

Chapter 2 presents a review of this study's literature. The reviews consist of non-stationary flood frequency analysis and the common non-stationary models used for non-stationary flood frequency analysis. Other than that, the reviews also include the TL-moments method for estimating parameter. The simulation application parameter estimator in non-stationary frequency analysis is also reviewed. Lastly, the review of the best model selection method for a non-stationary model is also highlighted.

Chapter 3 presents in detail the related theories and methodologies for the development of non-stationary flood frequency analysis. The chapter begins with the analysis of non-stationary and trend detection used. Then, the background of L-moments and TL-moments are defined by explaining their population and sample theories. The development of the GEV model in the stationary and non-stationary environment are also discussed. Next, the parameter estimation using the methods of L-moments is revisited, and parameter estimation using the methods of TL-moments are derived for each GEV model.

Chapter 4 discusses the calculation procedure of simulation and bootstrap analysis. The L-moments and TL-moments(1,0) methods are used as parameter estimation method in this calculation. For real data application in bootstrap analysis, Sayong station is presented to estimate parameter and flood quantile prediction.

Chapter 5 presents the results of Monte Carlo simulation study to examine the sampling properties of the proposed parameter estimation methods of L-moments and TL-moments. The analyses of the simulations for each model are discussed.

Chapter 6 develops the procedures of non-stationary flood frequency analysis on streamflow data. The procedures include non-stationary test and trend detection for 11 stations in Johor, Malaysia, flood quantile bootstrap, parameter estimation of GEV models, and flood quantile estimation at recurrence intervals of interest using the bootstrap technique. This chapter ends with a conclusion of the best model for flood quantile.

Chapter 7 presents the summary and conclusion of this research. This chapter also suggests recommendations for future works.

REFERENCES

Abdul-moniem, I. (2010). TL-moments and L-moments estimation for the Weibull distribution. *Advances and Applications in Statistics*, *15*(1), 83–99.

Abdul-moniem, I., & Selim, Y. M. (2009). TL-Moments and L-Moments Estimation for the Generalized Pareto Distribution. *Applied Mathematical Sciences*, *3*(1), 43–52.

Ahmad, I., Abbas, A., Saghir, A., & Fawad, M. (2016). Finding Probability Distributions for Annual Daily Maximum Rainfall in Pakistan Using Linear Moments and Variants. *Polish Journal of Environmental Studies*, *25*(3), 925–937. doi:10.15244/pjoes/61715

Ahmad, I., Fawad, M., & Mahmood, I. (2015). At-site flood frequency analysis of annual maximum stream flows in Pakistan using robust estimation methods. *Polish Journal of Environmental Studies*, *24*(6), 2345–2353. doi:10.15244/pjoes/59585

Ahmad, I., Tang, D., Wang, T., Wang, M., & Wagan, B. (2015). Precipitation trends over time using Mann-Kendall and spearman's Rho tests in swat river basin, Pakistan. *Advances in Meteorology*, *2015*. doi:10.1155/2015/431860

Ahmad, I., Waqas, M., Almanjahie, I. B., Saghir, A., & Haq, E. U. (2019). Regional flood frequency analysis using linear moments and partial linear moments: A case study. *Applied Ecology and Environmental Research*, *17*(2), 3819–3836.

Ahmad, U. N., Shabri, A., & Zakaria, Z. A. (2011a). Flood frequency analysis of annual maximum stream flows using L-Moments and TL-Moments approach. *Applied Mathematical Sciences*, *5*(5), 243–253.

Ahmad, U. N., Shabri, A., & Zakaria, Z. A. (2011b). TL-moments and L-moments estimation of the Generalized Logistic Distribution. *Journal of Mathematics Research*, *3*(1), 97–106.

Ahmad, U. N., Shabri, A., & Zakaria, Z. A. (2011c). Trimmed L-moments (1,0) for the generalized Pareto distribution. *Hydrological Sciences Journal*, *56*(6), 1053–1060. doi:10.1080/02626667.2011.595719

Ahmad, U. N., Shabri, A., & Zakaria, Z. A. (2013). An Analysis of Annual Maximum Streamflows in Terengganu , Malaysia using using TL-moments approach. *Theoretical and Applied Climatology*, *111*, 649–663. doi:10.1007/s00704-012-0679-x

Asquith, W. H. (2007). L-moments and TL-moments of the generalized lambda distribution. *Computational Statistics & Data Analysis*, *51*, 4484–4496. doi:10.1016/j.csda.2006.07.016

Barr, M., Bean, R., Berger, M. T., Yi, C. C., Chong, T., & Al., E. (2008). *World and Its Peoples: Malaysia, Philippines, Singapore, and Brunei.*

Bhattarai, K. P. (2004). Partial L-moments for the analysis of censored flood samples / Utilisation des L-moments partiels pour l ' analyse d ' échantillons tronqués de crues Partial L-moments for the analysis of censored flood samples. *Hydrological Sciences Journal*, *49*(5), 855–868. doi:10.1623/hysj.49.5.855.55138

Bhuyan, A., Borah, M., & Kumar, R. (2010). Regional Flood Frequency Analysis of North-Bank of the River Brahmaputra by Using LH-Moments. *Water Resources Management*, *24*, 1779–1790. doi:10.1007/s11269-009-9524-0

Bílková, D. (2014a). Alternative Means of Statistical Data Analysis : L-Moments and TL-Moments of Probability Distributions. *Statistika*, *94*(2), 77–94.

Bílková, D. (2014b). L-Moments and TL-Moments as an alternative tool of statistical data analysis. *Journal of Applied Mathematics and Physics*, *2*, 919–929.

Bílková, D. (2014c). Robust Parameter Estimation Methods : L-Moments and TL-Moments of Probability Distributions. *Journal of Applied Mathematics & Bioinformatics*, *4*(2), 47–83.

Bílková, D. (2014d). Trimmed L-Moments : Analogy of classical L-Moments. *American Journal of Mathematics and Statistics*, *4*(2), 80–106. doi:10.5923/j.ajms.20140402.05

Blagojevic, B., Plavsic, J., & Mihailovic, V. (2014). Outlier treatment in the flood flow statistical analysis. In *International Conference Contemporary Achievements in Civil ENgineering* (pp. 603–609). 24-25 April 2014. Subotica, Serbia. doi:10.14415/konferencijaGFS2014.081

Bora, D. J., & Borah, M. (2017). Regional analysis of maximum rainfall using L - moment and TL - moment : A comparative case study for the north East India. *Journal of Applied and Natural Science*, *9*(4), 2366–2371.

Borujeni, S. C., & Sulaiman, W. N. A. (2009). Development of L-moment based models for extreme flood events. *Malaysian Journal of Mathematical Science*, *3*(2), 281–296.

Bouza-Deano, R.; Ternero-Rodriguez, M.; and Fernandez-Espinosa, A. J. (2008). Trend study and assessment of surface water quality in the Ebro River (Spain). *Journal of Hydrology*, *361*(3-4), 227–239.

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

Burn, D. H., Cunderlik, J. M., & Pietroniro, A. (2004). Hydrological trends and variability in the Liard River basin. *Hydrological Sciences Journal*, *49*(1), 53–67. doi:10.1623/hysj.49.1.53.53994

Campos-Aranda, D. F. (2018). Fitting with mobile L-moments of the GEV distribution with variable location and scale parameters. *Agrociencia*, *52*(7), 933–950.

Cancelliere, A. (2017). Non Stationary Analysis of Extreme Events. *Water Resources Management*, *31*, 3097–3110. doi:10.1007/s11269-017-1724-4

Cannon, A. J. (2010). A flexible nonlinear modelling framework for nonstationary generalized extreme value analysis in hydroclimatology. *Hydrological Processes*, *24*, 673–685.

Caroni, C., & Panagoulia, D. (2016). Non-Stationary Modelling of Extreme

Temperatures. *REVSTAT - Statistical Journal*, *14*(2), 217–228.

Castillo, E., Hadi, A. S., Sarabia, J. M., Balakrishnan, N., & Castillo, C. R. (2005). *Extreme value and related models with applications in engineering and science*. (E. Castillo, J. M. Sarabia, N. Balakrishnan, & A. S. Hadi, Eds.). New Jersey: Wiley-Interscience.

Charalambous, J., Rahman, A., & Carroll, D. (2013). Application of Monte Carlo Simulation Technique to Design Flood Estimation: A Case Study for North Johnstone River in Queensland, Australia. *Water Resources Management*, *27*(11), 4099–4111. doi:10.1007/s11269-013-0398-9

Chen, P., Wang, Y., You, G. J., & Wei, C. (2017). Comparison of Methods for Non-Stationary Hydrologic Frequency Analysis : Case Study using Annual Maximum Daily Precipitation in Taiwan. *Journal of Hydrology*, *545*, 197–211. doi:10.1016/j.jhydrol.2016.12.001

Chen, X., Ye, C., Zhang, J., Xu, C., & Zhang, L. (2019). Selection of an optimal distribution curve for non-stationary flood series. *Atmosphere*, *10*(31), 1–16. doi:doi:10.3390/atmos10010031

Chen, X., Zhang, L., Xu, C., Zhang, J., & Ye, C. (2013). Hydrological Design of Nonstationary Flood Extremes and Durations in Wujiang River , South China : Changing Properties , Causes , and Impacts. *Mathematical Problems in Engineering*, *2013*, 1–10. doi:http://dx.doi.org/10.1155/2013/527461

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

Coles, S. (2001). *An introduction to statistical modeling of extreme value*. London: Springer-Verlag London.

Condon, L. E., Gangopadhyay, S., & Pruitt, T. (2015). Climate change and non-stationary flood risk for the Upper Truckee River Basin. *Hydrology and Earth System Sciences Discussions*, *11*(5), 5077–5114. doi:10.5194/hessd-11-5077-2014

Council, N. R. (1998). *Decade to Century Scale Climate Variability and Change: A Science Strategy, Panel on Climate Variability on Decade to Century Time Scales)*. Washington, D.C.: National Academy Press. doi:https://doi.org/10.17226/6129

Cunderlik, J. M., & Burn, D. H. (2003). Non-stationary pooled flood frequency analysis. *Journal of Hydrology*, *276*(1-4), 210–223. doi:10.1016/S0022-1694(03)00062-3

Cunderlik, J. M., & Ouarda, T. B. M. J. (2006). Regional Flood-Duration-Frequency Modelling in the Changing Environment. *Journal of Hydrology*, *318*, 276–291.

Cunnane, C. (1987). Review of statistical models for flood frequency estimation. In *Hydrological Frequency Modelling*. The Netherlands.

Davison, A. C., & Hinkley, D. V. (1997). *Bootstrap Methods and Their Application.* Cambridge University Press, Cambridge.

Debanne, S. M. (2000). The planning of clinical studies: bias and precision. *Gastrointestinal Endoscopy*, *52*, 821–822.

Debele, S. E., Strupczewski, W. G., & Bogdanowicz, E. (2017). A comparison of three approaches to non-stationary flood frequency analysis. *Acta Geophysica*, *65*, 863–883. doi:10.1007/s11600-017-0071-4

Delgado, J. M., Apel, H., & Merz, B. (2010). Flood trends and variability in the Mekong river. *Hydrology and Earth System Sciences, 14*, 407–418.

Department of Statistics Malaysia Official Website. (2015). Johor. Retrieved from https://www.dosm.gov.my

Dong, Q., Zhang, X., Lall, U., Sang, Y., & Xie, P. (2019). An improved nonstationary model for flood frequency analysis and its implication for the Three Gorges Dam , China. *Hydrological Sciences Journal*, *64*(7), 845–855. doi:10.1080/02626667.2019.1596274

Douglas, E., Vogel, R. M., States, U., & Kroll, C. (2000). Trends in floods and low flows in the United States : Impact of Spatial Correlation. *Journal of Hydrology, 240,* 90–105. doi:10.1016/S0022-1694(00)00336-X

Durocher, M., Burn, D. H., & Ashkar, F. (2019). Comparison of Estimation Methods for a Nonstationary Index - Flood Model in Flood Frequency Analysis Using Peaks Over Threshold. *Water Resources Research*, *55*, 9398–9416. doi:10.1029/2019WR025305

Efron, B. (1979). Bootstrap methods: another look at the jacknife. *Annal of Statistics*, *7*, 1–26.

El-Adlouni, S., Ouarda, T. B. M. J., Zhang, X., Roy, R., & Bobée, B. (2007). Generalized maximum likelihood estimators for the nonstationary generalized extreme value model. *Water Resources Research*, *43*(3), 1–13. doi:10.1029/2005WR004545

Elamir, E. A. H., & Seheult, A. H. (2003). Trimmed L-moments. *Computational Statistics & Data Analysis*, *43*(3), 299–314. doi:https://doi.org/10.1016/S0167-9473(02)00250-5

El-magd, N. A. T. A. (2010). TL-moments of the exponentiated generalized extreme value distribution. *Journal of Advanced Research*, *1*, 351–359. doi:10.1016/j.jare.2010.06.003

Elsayir, H. A. (2020). On Using Conventional and TL moments for the Estimation of a Mixture of Exponential Distributions , A Theoretical Review. *American Journal of Applied Sciences*, *17*, 88–94. doi:10.3844/ajassp.2020.88.94

Evenson, E. J., Orndorff, R. C., Blome, C. D., Böhlke, J. K., Hershberger, P. K., Langenheim, V. E., … Wood, T. M. (2013). *U. S. Geological Survey Water Science Strategy — Observing, Understanding, Predicting, and Delivering Water Science to the Nation*. Reston, Virginia.

Faulkner, D., Warren, S., Spencer, P., & Sharkey, P. (2020). Can We Still Predict The Future from The Past ? Implementing Non-stationary Flood Frequency Analysis in the UK. *Journal of Flood Risk Management*, *13*(1), 1–15. doi:10.1111/jfr3.12582

Filliben, J. J., & Heckert, A. (2012). Exploratory Data Analysis. In J. J. Filliben, C. Croarkin, B. Hambree, W. Guthrie, P. Tobias, L. Trutna, & J. Prins (Eds.), *e-Handbook of Statistical Methods*. National Institute of Standards and

Technology (NIST). doi:https://doi.org/10.18434/M32189

Gado, T. A., & Nguyen, V. T. Van. (2016a). An at-site flood estimation method in the context of nonstationarity I. A simulation study. *Journal of Hydrology*, *535*, 710–721. doi:10.1016/j.jhydrol.2015.12.063

Gado, T. A., & Nguyen, V. T. Van. (2016b). An at-site flood estimation method in the context of nonstationarity II. Statistical analysis of floods in Quebec. *Journal of Hydrology*, *535*, 722–736. doi:10.1016/j.jhydrol.2015.12.064

Galiano, S. G. G., & Osorio, J. D. G. (2011). Non-stationary analysis of spatial patterns of extreme rainfall events in West Africa. In *Proceedings of IAHS Lead Symposia held during IUGG2011 in Melbourne, Australia, July 2011* (pp. 75–81).

Gilroy, K. L., & McCuen, R. H. (2012). A nonstationary flood frequency analysis method to adjust for future climate change and urbanization. *Journal of Hydrology*, *414-415*, 40–48. doi:10.1016/j.jhydrol.2011.10.009

Giraldo Osorio, J. D., & García Galiano, S. G. (2012). Non-stationary analysis of dry spells in monsoon season of Senegal River Basin using data from Regional Climate Models (RCMs). *Journal of Hydrology*, *450-451*, 82–92. doi:10.1016/j.jhydrol.2012.05.029

Glass, S. (2000). *Performance of bootstrap confidence intervals for L-moments and ratios of L-moments* .

Greenwood, J. A., Landwehr, J. M., Matalas, N. C., & Wallis, J. R. (1979). Probability Weighted Moments: Definition and relation to parameters of several distributions expressable in inverse form. *Water Resources Research*, *15*, 1049–1054.

Guru, N., & Jha, R. (2014). A study on selection of probability distributions for at-site flood frequency analysis in Mahanadi river basin , India, 1813–1819.

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

Hasan, H., Salam, N., & Adam, M. B. (2013). Modelling extreme temperature in Malaysia using Generalized Extreme Value distribution. *International Journal of Mathematical, Computational, Physical, Electrical and Computer Engineering*, *7*(6), 618–624. doi:10.1063/1.4801267

Heidarpour, B., Marseh, B. P., Ekramirad, A., Hosseinnezhad, A., & Langroudi, A. G. (2015). Detection of outlier in flood observations : A case study of Tamer Watershed. *Research Journal of Recent Sciences*, *4*(3), 150–153.

Held, I. M., & Soden, B. J. (2006). Robust responses of the hydrological cycle to global warming. *Journal of Climate*, *19*, 5686–5699.

Heo, J., Shin, H., Nam, W., Om, J., & Jeong, C. (2013). Approximation of Modified Anderson-Darling Test Statistics for Extreme Value Distributions with Unknown Shape Parameter. *Journal of Hydrology*, *499*, 41–49.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., & Kanae, S. (2013). Global Food Risk Under Climate Change. *Natural Climate Change*, *3*, 816–821.

Hosking, J. R. M. (1990). L-Moments : Analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society. Series B (Methodological), 52*(1), 105–124. Retrieved from https://www.jstor.org/stable/2345653

Hosking, J. R. M. (2007). Some theory and practical uses of trimmed L-moments. *Journal of Statistical Planning and Inference*, *137,* 3024–3039. doi:10.1016/j.jspi.2006.12.002

Hosking, J. R. M., & Wallis, J. R. (1997). *Regional frequency analysis: An approach based on L-Moments.* Cambridge, UK: Cambridge University Press.

Hosking, J. R. M., Wallis, J. R., & Wood, E. F. (1985). Estimation of the Generalized Extreme- Value Distribution by the method of Probability-Weighted Moments. *Technometrics*, *27*(3), 251–261.

Hounkpè, J., Afouda, A. A., & Diekkrüger, B. (2016). Use of Climate Indexes As Covariates in Modelling High Discharges Under Non Stationary Condition in Oueme River. In *E-proceedings of the 36th IAHR World Congress* (pp. 1–6). The Hague, the Netherlands USE.

Hounkpè, J., Afouda, A. A., Diekkrüger, B., & Hountondji, F. (2015). Modelling extreme streamflows under non-stationary conditions in Ouémé river basin, Benin, West Africa. *Hydrological Sciences and Water Security: Past, Present and Future*, (June 2014), 143–144. doi:10.5194/piahs-366-143-2015

Hounkpè, J., Diekkrüger, B., Badou, D., & Afouda, A. (2015). Non-stationary flood frequency analysis in the Ouémé River Basin, Benin Republic. *Hydrology*, *2*(4), 210–229. doi:10.3390/hydrology2040210

Ibrahim, H. A., Mahmoud, M. R., Khalil, F. A., & El-kelany, G. A. (2018). TL-Moments for Type-I Censored Data with an Application to the Weibull Distribution. *Mathematical and Computational Application Journal*, *23*(47), 1–21. doi:10.3390/mca23030047

Intergovernmental Panel on Climate Change (IPCC). (2001). *Climate Change 2001: The Scientific Basis.* (J. T. Houghten, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linder, X. Dai, … C. A. Johnson, Eds.). Cambridge University Press, Cambridge.

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science Basis, Contribution of Working Group (WG) 1 to the Fourth Assessment Report of the IPCC (AR4).* (S. Solomon et al., Ed.). Cambridge Univ. Press, New York. Retrieved from www.ipcc.ch/press/index.htm.

Ishak, E. H., Rahman, A., Westra, S., Sharma, A., & Kuczera, G. (2013). Evaluating the non-stationarity of australian annual maximum flood. *Journal of Hydrology*, *494,* 134–145. doi:10.1016/j.jhydrol.2013.04.021

Jenkinson, A. F. (1955). The frequency distribution of the annual maximum (or minimum) values of meteorological elements. *Quarterly Journal of the Royal Meteorology Society*, *87,* 145–158.

Jha, M. K., & Singh, A. K. (2013). Trend analysis of extreme runoff events in major river basins of Peninsular Malaysia. *International Journal of Water*, *7*(1), 142–

158. doi:10.1504/IJW.2013.051995

Jiang, S., & Kang, L. (2019). Flood frequency analysis for annual maximum streamflow using a non-stationary GEV model. In *International Symposium on Architecture Research Frontiers and Ecological Environment (ARFEE 2018)* (Vol. 79, pp. 1–5). 14-16 December 2018. Wuhan, China.

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

Katz, R. W. (2013). Statistical methods for nonstationary extremes. In A. AghaKouchak, D. Easterling, K. Hsu, S. Schubert, & S. Sorooshian (Eds.), *Extremes in a changing climate* (Vol. 65, pp. 15–37). Dordrecht: Springer. doi:10.1007/978-94-007-4479-0

Katz, R. W., Parlange, M. B., & Naveau, P. (2002). Statistics of extremes in hydrology. *Advances in Water Resources*, *25*, 1287–1304.

Kendall, M. G. (1975). *Rank Correlation Methods*. Griffin, London.

Khaliq, M. N., Ouarda, T. B. M. J., Ondo, J. C., Gachon, P., & Bobée, B. (2006). Frequency analysis of a sequence of dependent and/or non-stationary hydro-meteorological observations: A review. *Journal of Hydrology, 329*(3-4), 534–552. doi:10.1016/j.jhydrol.2006.03.004

Khan, S. A., Hussain, I., Hussain, T., Faisal, M., Muhammad, Y. S., & Shoukry, A. M. (2017). Regional Frequency Analysis of Extremes Precipitation Using L-Moments and Partial L-Moments. *Advances in Meteorology*, *2017,* 1–20.

Kim, H., Kim, S., Shin, H., & Heo, J. H. (2017). Appropriate model selection methods for nonstationary generalized extreme value models. *Journal of Hydrology, 547*, 557–574. doi:10.1016/j.jhydrol.2017.02.005

Kim, H., Shin, J., Kim, T., Kim, S., & Heo, J. (2020). Regional frequency analysis of extreme precipitation based on a nonstationary population index flood method. *Advances in Water Resources*, *146*(103757), 1–14.

Kochanek, K., Strupczewski, W. G., Bogdanowicz, E., Feluch, W., & Markiewicz, I. (2013). Application of a hybrid approach in nonstationary flood frequency analysis – a Polish perspective. *Natural Hazards and Earth System Sciences Discussions*, *1*(5), 6001–6024. doi:10.5194/nhessd-1-6001-2013

Kuriqi, A., & Ardiçlioglu, M. (2018). Investigation of Hydraulic Regime at Middle Part of the Loire River in Context of Foods and Low Fow Events. *Pollack Period*, *13*, 145–156.

Kyselý, J. (2008). A cautionary note on the use of nonparametric bootstrap for estimating uncertainties in extreme-value models. *Journal of Applied Meteorology and Climatology*, *47,* 3236–3251. doi:10.1175/2008JAMC1763.1

Laio, F., Baldassarre, G. D., & Montanari, A. (2009). Model Selection Techniques for the Frequency Analysis of Hydrological Extremes. *Water Resources Research*, *45*(7), W07416.

Landwehr, J. M., Matalas, N. C., & Wallis, J. R. (1979). Probability Weighted Moments compared with some traditional techniques in estimating Gumbel parameters and quantiles. *Water Resources Research*, *15*, 1055–1064.

Lee, S. H., & Maeng, S. J. (2003). Comparison and analysis of design floods by the change in the order of LH-moment methods. *Irrigation and Drainage*, *52*(3), 231–245.

Li, L., Zhang, L., Xia, J., Gippel, C. J., Wang, R., & Zeng, S. (2015). Implications of Modelled Climate and Land Cover Changes on Runoff in the Middle Route of the South to North Water Transfer Project in China. *Water Resources Management*, *29*(8), 2563–2579.

Lima, C. H. R., Lall, U., Troy, T. J., & Devineni, N. (2015). A climate informed model for nonstationary flood risk prediction: Application to Negro River at Manaus, Amazonia. *Journal of Hydrology*, *522*, 594–602. doi:10.1016/j.jhydrol.2015.01.009

López, J., & Francés, F. (2013). Non-stationary flood frequency analysis in continental Spanish rivers, using climate and reservoir indices as external covariates. *Hydrology and Earth System Sciences*, *17*(8), 3189–3203. doi:10.5194/hess-17-3189-2013

Luke, A., Vrugt, J. A., AghaKouchak, A., Matthew, R., & Sanders, B. F. (2017). Predicting nonstationary flood frequencies: Evidence supports an updated stationarity thesis in the United States. *Water Resources Research*, *53*, 5469–5494. doi:10.1002/2016WR019676

Maillet, B. B., & Médecin, J. R. (2010). Extreme Volatilities, Financial Crises and L-moment Estimations of Tail-indexes. *Working Paper*, *Department of Economics, Ca' Foscari University of Venice*, *10*, 1–21. Retrieved from http://www.unive.it/pag/fileadmin/user_upload/dipartimenti/economia/doc/Pubblicazioni_scientifiche/working_papers/2010/WP_DSE_maillet_medecin_10_10.pdf

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica*, *13*, 245–259.

Maposa, D., Cochran, J. J., Lesaoana, M., States, U., & Maposa, D. (2016). Modelling Non-stationary Annual Maximum Flood Heights in the Lower Limpopo River Basin of Mozambique. *Journal of Disaster Risk Studies*, *8*(1), 1–9.

Martins, E. S., & Stedinger, J. R. (2000). Generalized maximum-likelihood generalized extreme-value quantile estimators for hydrologic data. *Water Resources Research*, *36*(3), 737–744. doi:10.1029/1999WR900330

Mat Jan, N. A., & Shabri, A. (2017). Estimating distribution parameters of annual maximum streamflows in Johor, Malaysia using TL-moments approach. *Theoretical and Applied Climatology*, *127*, 213–227. doi:10.1007/s00704-015-1623-7

Mat Jan, N. A., Shabri, A., Hounkpè, J., & Badyalina, B. (2018). Modelling non-stationary extreme streamflow in Peninsular Malaysia. *International Journal of Water*, *12*(2), 116–140.

Mehmood, A., Jia, S., Mahmood, R., Yan, J., & Ahsan, M. (2019). Non-stationary Bayesian modeling of annual maximum floods in a changing environment and implications for flood management in the Kabul River Basin, Pakistan. *Water*, *11*(1246), 1–30. doi:10.3390/w11061246

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity Is Dead: Whither Water Management? *Science*, *319*(5863), 573–574. doi:10.1126/science.1151915

Ministry of Natural Resources and Environment Malaysia. (2007). *Flood and drought management in Malaysia*. Retrieved from https://en.wikipedia.org/wiki/Geography_of_Malaysia#cite_note-25

Montanari, A., & Koutsoyiannis, D. (2014). Water Resources Research. *Water Resources Research*, *50*, 9748–9756. doi:10.1002/2014WR016092.Received

Mudholkar, G. S., & Hutson, A. D. (1998). LQ-moments : Analogs of L-moments. *Journal of Statistical Planning and Inference*, *71*, 191–208.

Murshed, M. S., Seo, Y. A., & Park, J. (2014). LH-moment estimation of a four parameter kappa distribution with hydrologic applications. *Stochastic Environmental Research and Risk Assessment*, *28*, 253–262. doi:10.1007/s00477-013-0746-6

Nashwan, M. S., Ismail, T., & Ahmed, K. (2019). Non-stationary analysis of extreme rainfall in Peninsular Malaysia. *Journal of Sustainability Science and Management*, *14*(3), 17–34.

Nguyen, V.-T.-V., Tao, D., & Bourque, A. (2002). On selection of probability distributions for representing annual extreme rainfall series. In *Proceedings of the 9th International Conference on Urban Drainage* (pp. 1–10).

O'Brien, N. L., & Burn, D. H. (2014). A nonstationary index-flood technique for estimating extreme quantiles for annual maximum streamflow. *Journal of Hydrology*, *519*(PB), 2040–2048. doi:10.1016/j.jhydrol.2014.09.041

Obeysekera, J., & Salas, J. D. (2013). Quantifying the Uncertainty of Design Floods Under Non-Stationary Conditions. *Journal of Hydrologic Engineering*, *19*(7), 1438–1446. doi:10.1061/(ASCE)HE.1943-5584.0000931

Opere, A. O., Mkhandi, S., & Willems, P. (2006). At-Site Flood Frequency Analysis for the Nile Equatorial Basins. *Physics and Chemistry of the Earth, Parts A, B, C*, *31*(15-16), 919–927.

Otiniano, C. E. G., Paiva, B. S. De, & Martins Neto, D. S. B. (2019). The transmuted GEV distribution : properties and application. *Communications for Statistical Applications and Methods*, *26*(3), 239–259. doi:https://doi.org/10.29220/CSAM.2019.26.3.239

Ouarda, T. B. M. J., & Charron, C. (2019). Changes in the distribution of hydro-climatic extremes in a non-stationary framework. *Scientific Reports*, *9*(8104), 1–8. doi:10.1038/s41598-019-44603-7

Ouarda, T. B. M. J., & El-Adlouni, S. (2011). Bayesian nonstationary frequency analysis of hydrological variables. *Journal of the American Water Resources Association*, *47*(3), 496–505. doi:10.1111/j.1752-1688.2011.00544.x

Panagoulia, D., Economou, P., & Caroni, C. (2014). Stationary and nonstationary generalized extreme value modelling of extreme precipitation over a mountainous area under climate change. *Environmetrics*, *25*(1), 29–43. doi:10.1002/env.2252

Paola, F. De, Giugni, M., Pugliese, F., Annis, A., & Nardi, F. (2018). GEV Parameter Estimation and Stationary vs Non-Stationary Analysis of Extreme Rainfall in African Test Cities. *Hydrology*, *5*(28), 1–23. doi:10.3390/hydrology5020028

Parey, S., Hoang, T. T. H., & Dacunha-Castelle, D. (2010). Different ways to compute temperature return levels in the climate change context. *Environmetrics*, *21*, 698–718.

Plavsic, J., Mihailovic, V., & Blagojevic, B. (2014). Assessment of methods for outlier detection and treatment in flood frequency analysis. In *Proceedings of the Mediterranean Meeting on "Monitoring, modelling and early warning of extreme events triggered by heavy rainfalls".* (pp. 17–28). 26 - 28 June. Cosenza, Italy.

Qu, C., Li, J., Yan, L., Yan, P., Cheng, F., & Lu, D. (2020). Non-Stationary Flood Frequency Analysis Using Cubic B-Spline-Based GAMLSS Model. *Water*, *12*(1867), 1–17.

Rahman, A. S., Rahman, A., Zaman, M. A., Haddad, K., Ahsan, A., & Imteaz, M. (2013). A study on selection of probability distributions for at-site flood frequency analysis in Australia. *Natural Hazards*, *69*(3), 1803–1813. doi:10.1007/s11069-013-0775-y

Rao, A. R., & Hamed, K. H. (2000). *Flood Frequency Analysis.* Boca Raton, London, New York, Washington, D.C: CRC Press.

Raynal-Villasenor, J. a. (2012). Maximum likelihood parameter estimators for the two populatins GEV distribution. *Ijrras*, *11*(3), 350–357.

Razmi, A., Golian, S., & Zahmatkesh, Z. (2017). Non-stationary frequency analysis of extreme water level : Application of annual maximum series and peak-over threshold approaches. *Water Resources Management*, *31*(7), 2065–2083. doi:10.1007/s11269-017-1619-4

Ren, H., Hou, Z. J., Wigmosta, M., Liu, Y., & Leung, L. R. (2019). Impacts of spatial heterogeneity and temporal non-stationarity on intensity-duration-frequency estimates—A case study in a Mountainous California-Nevada Watershed. *Water*, *11*(1296), 1–16. doi:10.3390/w11061296

Rust, H. W., Kallache, M., Schellnhuber, H. J., & Kropp, J. P. (2010). Confidence intervals for flood return level estimates assuming long-range dependence. In J. P. Kropp & H. J. Schellnhuber (Eds.), *Extremis: Disruptive events and trends in climate and hydrology* (p. 61). Berlin: Springer Verlag.

Sadri, S., Kam, J., & Sheffield, J. (2016). Nonstationarity of low flows and their timing in the eastern United States. *Hydrology and Earth System Sciences*, *20*(2), 633–649. doi:10.5194/hess-20-633-2016

Salas, J. D., & Obeysekera, J. (2014). Revisiting the concepts of return period and risk for nonstationary hydrologic extreme events. *Journal of Hydrologic Engineering*, *19*(3), 554–568. doi:10.1061/(ASCE)HE.1943-5584.0000820.

Saw, S.-H. (2007). The population of Peninsular Malaysia. *Institute of Southeast Asian Studies*, 1–2.

Schwarz, G. (1978). Estimating the dimension of a model. *Annal of Statistics*, *6*, 461–464.

Serago, J. M., & Vogel, R. M. (2018). Parsimonious nonstationary flood frequency analysis. *Advances in Water Resources*, *112*, 1–16. doi:10.1016/j.advwatres.2017.11.026

Serinaldi, F., & Kilsby, C. G. (2015). Stationarity is undead: Uncertainty dominates the distribution of extremes. *Advances in Water Resources, 77,* 17–36. doi:10.1016/j.advwatres.2014.12.013

Shabri, A., Ahmad, U. N., & Zakaria, Z. A. (2011). TL-moments and L-moments Estimation of the Generalized Logistic Distribution. *Journal of Mathematics Research*, *3*(1), 97–106. doi:10.5539/jmr.v3n1p97

Shabri, A., Mohd Daud, Z., & Mohd Ariff, N. (2011). Regional analysis of annual maximum rainfall using TL-moments method. *Theoretical and Applied Climatology*, *104*, 561–570. doi:10.1007/s00704-011-0437-5

Shadmani, M., Marofi, S., & Roknian, M. (2012). Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho Tests in Arid Regions of Iran. *Water Resources Management, 26*(1)*,* 211–224. doi:10.1007/s11269-011-9913-z

Shahzad, M. N., & Asghar, Z. (2013). Comparing TL-Moments , L-Moments and Conventional Moments of Dagum Distribution by Simulated data. *Colombian Journal of Statistics*, *36*(1), 79–93.

Silva, V. P. R. (2004). On climate variability in Northeast of Brazil'. *Journal of Arid Environments*, *58*(4), 575–596.

Šimková, T., & Picek, J. (2017). A comparison of L- , Lq- , Tl-moment and maximum likelihood high quantile estimates of the GPD and GEV Distribution. *Journal of Communications in Statistics - Simulation and Computation*, *46*(8), 5991–6010. doi:10.1080/03610918.2016.1188206

Šimková, T., & Republic, C. (2017). Statistical Inference Based on L-Moments. *Statistika : Statistics and Economy Journal*, *97*(1), 44–58.

Singh, J., Singh, T., Vittal, H., & Karmakar, S. (2013). Nonstationary Frequency Estimation of Flood Extremes. In *Proceedings of Hydro 2013 International* (pp. 3–16). 4-6 Dec. IIT Madras, India.

Smyth, P. (2000). Model Selection for Probabilistic Clustering using Cross-validated Likelihood. *Statistics and Computing*, *9*, 63–72.

Sneyers, R. (1990). *On the Statistical Analysis of Series of Observations*. *Tech. note no. 143, WMO no. 415, World Meteorological Organization*. Geneva, Switzerland.

Šraj, M., Viglione, A., Parajka, J., & Blöschl, G. (2016). The Influence of Non-stationarity in Extreme Hydrological Events on Flood Frequency Estimation. *Journal of Hydrology and Hydromechanics*, *64*(4), 426–437. doi:10.1515/johh-2016-0032

Stedinger, J. R., Vogel, R. M., & Foufoula-Georgia, E. (1992). Frequency analysis events of extreme events. In R. Maidment (Ed.), *Handbook of Hydrology* (pp. 18.1–18.66). New York, NY, USA: McGraw-Hill.

Stedinger, J. R., Vogel, R. M., & Foufoula-Georgiou, E. (1993). *Handbook of Hydrology*. New York: Mc Graw Hill.

Strupczewski, W. G., & Kaczmarek, Z. (2001). Non-stationary approach to at-site flood frequency modelling II. Weighted least squares estimation. *Journal of Hydrology*, *248*(1), 143–151. doi:10.1016/S0022-1694(01)00398-5

Strupczewski, W. G., Kochanek, K., Bogdanowicz, E., Markiewicz, I., & Feluch, W. (2016). Comparison of two nonstationary flood frequency analysis methods within the context of the variable regime in the representative Polish Rivers. *Acta Geophysica*, *64*(1), 206–236.

Strupczewski, W. G., Kochanek, K., Feluch, W., Bogdanowicz, E., & Singh, V. P. (2009). On seasonal approach to nonstationary flood frequency analysis. *Physics and Chemistry of the Earth*, *34*(10-12), 612–618. doi:10.1016/j.pce.2008.10.067

Strupczewski, W. G., Singh, V. P., & Feluch, W. (2001). Non-stationary approach to at-site flood frequency modelling I . Maximum likelihood estimation. *Journal of Hydrology*, *248*, 123–142. doi:doi.org/10.1016/S0022-1694(01)00397-3

Strupczewski, W. G., Singh, V. P., & Mitosek, H. T. (2001). Non-stationary approach to at-site flood frequency modelling. III . Flood analysis of Polish rivers. *Journal of Hydrology*, *248*, 152–167. doi:10.1016/S0022-1694(01)00398-5

Sulaiman, N. H., Kamarudin, M. K. A., Mustafa, A. D., Amran, M. A., Azaman, F., Abidin, I. Z., & Hairoma, N. (2015). Trend analysis of Pahang river using non-parametric analysis: Mann kendall's trend test (Analisis corak sungai Pahang menggunakan kaedah bukan parametrik: Ujian corak Mann Kendall). *Malaysian Journal of Analytical Sciences*, *19*(6), 1327–1334.

Sung, J. H., Kim, Y., & Jeon, J. (2018). Application of distribution-free nonstationary regional frequency analysis based on L-moments. *Theoretical and Applied Climatology*, *133*, 1219–1233. doi:10.1007/s00704-017-2249-8

Syafrina, A. H., Norzaida, A., & Ain, J. J. (2019). Stationary and Nonstationary Generalized Extreme Value Models for Monthly Maximum Rainfall in Sabah. *Journal of Physics: Conference Series*, *1366*, 1–9. doi:10.1088/1742-6596/1366/1/012106

Tan, X., & Gan, T. Y. (2015). Nonstationary analysis of annual maximum streamflow of Canada. *Journal of Climate*, *28*(5), 1788–1805. doi:10.1175/JCLI-D-14-00538.1

Totaro, V., Gioia, A., & Iacobellis, V. (2019). Power of parametric and non-parametric tests for trend detection in annual maximum series. *Hydrology and Earth System Sciences Discussions*, (August). doi:10.5194/hess-2019-363

Um, M., Heo, J., Markus, M., & Wuebbles, D. J. (2018). Performance Evaluation of four Statistical Tests for Trend and Non-stationarity and Assessment of Observed and Projected Annual Maximum Precipitation Series in Major United States Cities. *Water Resources Management*, *32*, 913–933.

Vasiliades, L., Galiatsatou, P., & Loukas, A. (2015). Nonstationary frequency analysis of annual maximum rainfall using climate covariates. *Water Resources*

Management, *29*, 339–358. doi:10.1007/s11269-014-0761-5

Villarini, G., Serinaldi, F., Smith, J. A., & Krajewski, W. F. (2009). On the stationarity of annual flood peaks in the continental United States during the 20th century. *Water Resources Research*, *45*(8), 1–17. doi:10.1029/2008WR007645

Villarini, G., Smith, J. A., & Napolitano, F. (2010). Nonstationary modeling of a long record of rainfall and temperature over Rome. *Advances in Water Resources*, *33*(10), 1256–1267. doi:10.1016/j.advwatres.2010.03.013

Villarini, G., Smith, J. A., Serinaldi, F., Bales, J., Bates, P. D., & Krajewski, W. F. (2009). Flood frequency analysis for nonstationary annual peak records in an urban drainage basin. *Advances in Water Resources*, *32*(8), 1255–1266. doi:10.1016/j.advwatres.2009.05.003

Vogel, R. M., & Fennessey, N. M. (1993). L-moments diagrams should replace product moment diagrams. *Water Resources Research*, *29*(6), 1745–1752.

Vogel, R. M., Yaindl, C., & Walter, M. (2011). Nonstationarity: Flood Magnification and Recurrence Reduction Factors in the United States. *Journal of the American Water Resources Association*, *47*(3), 464–474. doi:10.1111/j.1752-1688.2011.00541.x

Walther, B. A., & Moore, J. L. (2005). The concepts of bias , precision and accuracy , and their use in testing the performance of species richness estimators , with a literature review of estimator performance. *Ecography*, *28*(6), 815–829.

Wang, Q. J. (1990). Estimation of the GEV distribution from censored samples by method of Partial Probability Weighted Moments. *Journal of Hydrology*, *120*(1-4), 103–114. doi:10.1016/0022-1694(90)90144-M

Wang, Q. J. (1997a). LH moments for statistical analysis of extreme events. *Water Resources Research*, *33*(12), 2841–2848.

Wang, Q. J. (1997b). Using higher probability weighted moments for flood frequency analysis. *Journal of Hydrology*, *194*, 95–106.

West, M. J. (1999). Stereological methods for estimating the total number of neurons and synapses: issues of precision and bias. *Trends Neuroscience*, *22*, 51–61.

Xavier, A. C. F., Blain, G. C., Morais, M. V. B. de, & Sobierajski, G. da R. (2019). Selecting " the best " nonstationary Generalized Extreme Value (GEV) distribution : on the influence of different numbers of GEV-models. *Agrometeorology*, *78*(4), 606–621.

Xinyi, S., Fan, L., Hao, W., Weihua, X., & Kui, Z. (2018). Penalized Maximum Likelihood Estimators for the Nonstationary Pearson type 3 Distribution. *Journal of Hydrology*, *567*, 579–589. doi:10.1016/j.jhydrol.2018.10.035

Xiong, L., Du, T., Xu, C. Y., Guo, S., Jiang, C., & Gippel, C. J. (2015). Non-stationary annual maximum flood frequency analysis using the norming constants method to consider non-stationarity in the annual daily flow series. *Water Resources Management*, *29*(10), 3615–3633. doi:10.1007/s11269-015-1019-6

Xu, Z. X., Takeuchi, K., & Ishidaira, H. (2003). Monotonic trend andstep changes in

Japanese precipitation. *Journal of Hydrology*, *279*(1-4), 144–150.

Yang, C., & Hill, D. (2012). Modeling stream flow extremes under non-time-stationary conditions. In *XIX International Conference on Water Resources (CMWR)* (pp. 1–8). 17-22 June 2012. Urbana-Champaign.

Yenigün, K., Gümüş, V., & Bulut, H. (2008). Trends in streamflow of the Euphrates basin, Turkey. In *Proceedings of the Institution of Civil Engineers -Water Management* (Vol. 161, pp. 189–198). doi:10.1680/wama.2008.161.4.189

Yilmaz, A. G., & Perera, B. J. C. (2014a). Extreme Rainfall Nonstationarity Investigation and Intensity – Frequency – Duration Relationship. *Journal of Hydrologic Engineering*, *19*(6), 1160–1172. doi:10.1061/(ASCE)HE.1943-5584.0000878.

Yilmaz, A. G., & Perera, B. J. C. (2014b). Extreme Rainfall Nonstationarity Investigation and Intensity – Frequency – Duration Relationship. *Journal of Hydrologic Engineering*, *19*(6), 1160–1172. doi:10.1061/(ASCE)HE.1943-5584.0000878

Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, *259*(1-4), 254–271. doi:10.1016/S0022-1694(01)00594-7

Yue, S., Pilon, P., Phinney, B., & Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Processes*, *16*(9), 1807–1829. doi:10.1002/hyp.1095

Yue, S., Pilon, P., & Phinney, B. O. B. (2003). Canadian streamflow trend detection : impacts of serial and cross-correlation. *Hydrological Sciences Journal, 48*(1), 51–63. doi:10.1623/hysj.48.1.51.43478

Zakaria, Z. A., & Shabri, A. (2013). Regional frequency analysis of extreme rainfalls using partial L-moments method. *Theoretical and Applied Climatology*, *113*, 83–94. doi:10.1007/s00704-012-0763-2

Zakaria, Z. A., Shabri, A., & Ahmad, U. N. (2012). Regional Frequency Analysis of Extreme Rainfalls in the West Coast of Peninsular Malaysia using Partial L-Moments. *Water Resources Management*, *26*, 4417–4433. doi:10.1007/s11269-012-0152-8

Zakaria, Z. A., Sultan, U., Abidin, Z., Shabri, A., Mamat, M., Sultan, U., & Abidin, Z. (2015). Parameter estimation based on partial L-Moments method for censored samples. *Far East Journal of Mathematical Sciences*, *96*(6), 671–684. doi:10.17654/FJMSMar2015

Zalina Mohd Daud, A. H. M. K., Desa, M. N. M., & Vand-Thanh-Van, N. (2002). Statistical analysis of at-site extreme rainfall processes in Peninsular Malaysia. *FRIEND 2002-Regional Hydrology: Bridging the Gap between Research and Practice, Edited by Henny A. J. van Lanen & Siegfried Demuth, IAHS Publication No. 274*, (274), 61–68.

Zalina, M. D., Desa, M. N. M., Nguyen, V. T. V, & Kassim, A. H. M. (2002). Selecting a probability distribution for extreme rainfall series in Malaysia. *Water Science and Technology*, *45*(2), 63–68.

Zhang, T. (2018). Non-stationary flood frequency analysis using univariate and bivariate time-varying models based on GAMLSS. *Water*, *10*(819), 1–13. doi:10.3390/w10070819

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Mat Jan, N. A.**, Shabri, A., & Samsudin, R. (2020). Handling non-stationary flood frequency analysis using TL-moments approach for estimation parameter. *Journal of Water and Climate Change*, 11(4), 966-979. https://doi.org/10.2166/wcc.2019.055. **(Indexed by Science Citation Index Expanded) (Q4, IF: 1.009)**.

Indexed Journal

1. **Mat Jan, N. A.**, Shabri, A., Hounkpè, J., & Badyalina, B. (2018). Modelling non-stationary extreme streamflow in Peninsular Malaysia. *International Journal of Water*, 12(2), 116-140. https://dx.doi.org/10.1504/IJW.2018.091380. **(Indexed by SCOPUS)**.

Indexed Conference Proceedings

1. **Mat Jan, N. A.**, Shabri, A., & Badyalina, B. (2016). Selecting probability distribution for regions of Peninsular Malaysia streamflow. *Advances in Industrial and Applied Mathematics*, AIP Conference Proceedings, 1750, 060014-1–060014-6. https://doi.org/10.1063/1.4954619. **(Indexed by SCOPUS)**.