HIGH-RESOLUTION GRIDDED CLIMATE DATASET FOR DATA-SCARCE REGION

MOHAMED SALEM MOHAMED HASSAN NASHWAN

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

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JUNE 2020

DEDICATION

To my wife Esraa, my children Salem and Leen, and family.

ACKNOWLEDGEMENT

"*.. my success is not but through Allah. Upon Him I have relied, and unto Him I return*". *The Quran, Surah Hud, 88*

I am grateful to Allah who guided me to my mentor Professor Shamsuddin Shahid who enlightened my study path with his enormous support, guidance, and teaching. My sincere thanks to him for an unforgettable academic journey as he a true image of an outstanding supervisor.

My sincere thanks continue to Dr Tarmizi Ismail for his support and encouragement through my studies. I obliged to appreciate his guidance not only in my studies but also in Malaysia. I am thankful to Dr Noraliani Alias for being my co-supervisor. Special thanks to Prof. Eun-Sung Chung (Seoul National University of Science and Technology, South Korea), Prof. Ashraf Dewan (Curtin University, Australia), and Prof. Xiao-Jun Wang (Nanjing Hydraulic Research Institute, China) for contributing in drafting some of this study outcomes. I acknowledge the late Prof. Norhan Abdrahman for being a co-supervisor at the early months of this study. My sincere gratitude continues to Prof. Tamer A. Gado (Tanta University, Egypt) and Prof. Ahmed El Kenawy (Mansoura University, Egypt) for providing the stations' data of the Egyptian Meteorological Authority. Lastly, I would like to acknowledge NOAA GSOD dataset for providing most meteorological data of Egypt.

I feel highly indebted to my wife Dr Esraa Aldaly for her inestimable love and care, for being with me in Malaysia, for all the late nights and early mornings, and for keeping me sane during my downs. Thank you for being my muse, cheerleader, proof-reader, and protagonist of my life. But most of all, thank you for being my best friend.

To my family, particularly my parents, thank you for your love, support, and unwavering belief in me. To my mother, thank you for your endless care. To my father, I am extremely grateful for persuading me to work and have a PhD degree. Also, I am grateful for your full financial support. Without my family, I would not be the person I am today.

To my second family, Prof. Shahid and Mrs Ripa, extensive gratitude for your cordiality to me, wife, and son since day one in Malaysia. Mrs Ripa, your love, care, food, and friendship will never be forgotten.

Lastly, I thank Universiti Teknologi Malaysia for partially funding my tuition fee through the International Doctoral Fellowship program.

ABSTRACT

The knowledge of spatiotemporal distribution of climate variables is essential for most of hydro-climatic studies. However, scarcity or sparsity of long-term observations is one of the major obstacles for such studies. The main objective of this study is to develop a methodological framework for the generation of high-resolution gridded historical and future climate projection data for a data-scarce region. Egypt and its densely populated central north region (CNE) were considered as the study area. First, several existing gridded datasets were evaluated in reproducing the historical climate. The performances of five high-resolution satellite-based daily precipitation products were evaluated against gauges records using continuous and categorical metrics and selected intensity categories. In addition, two intelligent algorithms, symmetrical uncertainty (SU) and random forest (RF) are proposed for the evaluation of gridded monthly climate datasets. Second, a new framework is proposed to develop high-resolution daily maximum and minimum temperatures (Tmx and Tmn) datasets by using the robust kernel density distribution mapping method to correct the bias in interpolated observation estimates and WorldClim v.2 temperature climatology to adjust the spatial variability in temperature. Third, a new framework is proposed for the selection of Global Climate Models (GCMs) based on their ability to reproduce the spatial pattern for different climate variables. The Kling-Gupta efficiency (KGE) was used to assess GCMs in simulating the annual spatial patterns of Tmx, Tmn, and rainfall. The mean and standard deviation of KGEs were incorporated in a multi-criteria decision-making approach known as a global performance indicator for the ranking of GCMs. Fourth, several bias-correction methods were evaluated to identify the most suitable method for downscaling of the selected GCM simulations for the projection of high-resolution gridded climate data. The results revealed relatively better performance of GSMaP compared to other satellite-based rainfall products. The SU and RF were found as efficient methods for evaluating gridded monthly climate datasets and avoid the contradictory results often obtained by conventional statistics. Application of SU and RF revealed that GPCC rainfall and UDel temperature datasets as the best products for Egypt. The validation of the 0.05°×0.05° CNE datasets showed remarkable improvement in replicating the spatiotemporal variability in observed temperature. The new approached proposed for the selection of GCMs revealed that MRI-CGCM3 gives the best performance and followed by FGOALS-g2, GFDL-ESM2G, GFDL-CM3 and lastly MPI-ESM-MR over Egypt. The selected GCMs projected an increase in Tmx and Tmn in the range of 2.42 to 4.20°C and 2.34 to 4.43°C respectively for different scenarios by the end of the century. Winter temperature is projected to increase higher than summer temperature. For rainfall, a 62% reduction over the northern coastline is projected where rain is currently most abundant with an increase of rainfall over the dry southern zones. Linear and variance scaling methods were found suitable for developing bias-free high-resolution projections of rainfall and temperatures, respectively. As for the CNE, the high-resolution projections showed a rise in maximum (1.80 to 3.48°C) and minimum (1.88 to 3.49°C) temperature and change in rainfall depth (-96.04 to 36.51%) by the end of the century, which could have severe implications for this highly populated region.

ABSTRAK

Pengetahuan mengenai agihan ruang-masa bagi pemboleh ubah iklim adalah penting untuk kebanyakan kajian hidro-iklim. Walau bagaimanapun, kekurangan atau jarangnya pemerhatian jangka panjang merupakan salah satu halangan utama bagi kajian sedemikian. Objektif utama kajian ini adalah untuk membangunkan rangka kerja metodologi bagi penjanaan data sejarah dan unjuran iklim masa depan yang bergrid pada resolusi tinggi untuk rantau yang kekurangan data. Mesir dan kawasan utara tengah yang padat penduduknya (CNE) dipilih sebagai kawasan kajian. Pada peringkat pertama kajian, beberapa set data bergrid yang sedia ada dinilai dalam penghasilan semula sejarah iklim di kawasan kajian. Prestasi lima produk curahan harian bersumberkan dari satelit dinilai terhadap data curahan yang direkodkan dengan meggunakan metrik berterusan dan berkategori dan kategori keamatan pilihan. Sebagai tambahan, dua algoritma pintar, *Symmetrical Uncertainty* (SU) dan *Random Forest* (RF) dicadangkan untuk penilaian set data iklim bulanan bergrid. Kedua, satu kerangka kerja baru telah dicadangkan untuk membangunkan data suhu harian maksimum dan minimum (Tmx dan Tmn) beresolusi tinggi dengan menggunakan kaedah pemetaan agihan ketumpatan kernel yang utuh. Ini bagi membetulkan kecerungan dalam anggaran interpolasi menggunakan pemerhatian dan menyesuaikan kebolehubahan ruang dalam suhu menggunakan suhu iklim WorldClim v.2. Ketiga, rangka kerja baru dicadangkan untuk pemilihan *Global Climate Models* (GCMs) berdasarkan keupayaannya untuk menghasilkan corak ruang bagi pemboleh ubah iklim yang berbeza. Kaedah Kecekapan Kling-Gupta (KGE) telah digunakan untuk menilai GCMs dalam mensimulasikan corak ruang tahunan Tmx, Tmn, dan hujan. Purata dan sisihan piawai KGE telah dipertimbangkan dalam membuat keputusan penyenaraian kedudukan GCMs dengan pendekatan berpelbagaian kriteria yang dikenali sebagai penunjuk prestasi global. Keempat, beberapa kaedah pembetulan bias dinilai untuk mengenal pasti kaedah yang bersesuaian dalam pengunjuran simulasi GCMs terpilih untuk unjuran data iklim bergrid pada resolusi tinggi. Hasil menunjukkan prestasi GSMaP secara relatifnya adalah lebih baik berbanding produk hujan berasaskan satelit yang lain. SU dan RF didapati sebagai kaedah yang cekap untuk menilai data iklim bulanan dengan mengelakkan kekeliruan yang timbul daripada keputusan yang bercanggah yang sering diperoleh daripada statistik konvensional. Aplikasi SU dan RF menunjukkan data hujan GPCC dan suhu UDel sebagai produk terbaik untuk Mesir. Pengesahan data pada grid beresolusi 0.05°×0.05° CNE menunjukkan peningkatan yang luar biasa dalam mengreplikasi kebolehubahan ruang-masa dengan suhu yang direkodkan. Pendekatan nobel untuk pemilihan GCMs yang diperolehi menunjukkan MRI-CGCM3 memberikan prestasi terbaik diikuti oleh FGOALS-g2, GFDL-ESM2G, GFDL-CM3 dan terakhir MPI-ESM-MR. GCM terpilih, bersertakan senario terpilih, mengunjurkan peningkatan dalam Tmx dan Tmn, masing-masing dalam julat 2.42 hingga 4.20°C dan 2.34 hingga 4.43°C menjelang akhir abad ini. Suhu pada musim sejuk diunjurkan meningkat lebih tinggi daripada suhu musim panas. Bagi hujan, penurunan 62% adalah dijangkakan dalam kawasan zon pantai utara yang kini mengalami hujan paling banyak, manakala peningkatan hujan pula dijangkakan berlaku di zon kering di selatan. Kaedah penskalaan selari dan varians didapati sesuai untuk membangunkan unjuran pengembalian tinggi bebas kecerungan, masing-masing untuk hujan dan suhu. Bagi CNE pula, unjuran resolusi tinggi menunjukkan kenaikan suhu maksimum (1.80 hingga 3.48°C) dan minimum (1.88 hingga 3.49°C) dan perubahan kedalaman hujan (-96.04 hingga 36.51%) menjelang akhir abad, yang mungkin mempunyai implikasi yang buruk untuk rantau berpopulasi tinggi ini.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APHRODITE	-	Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation
AR5	-	Fifth Assessment Report
ARC	-	African Rainfall Climatology
BWh	-	Hot Desert Climate
CCD	-	Cold Cloud Duration
CDF	-	Cumulative Density Function
CFSR	-	Climate Forecast System Reanalysis
CHELSA	-	Climatologies at High-resolution for the Earth's Land Surface Areas
CHG	-	Climate Hazard Group
CHIRP	-	Climate Hazard group InfraRed Precipitation
CHIRPS	-	Climate Hazard group InfraRed Precipitation with Stations
CMIP	-	Coupled Model Intercomparison Project
CNE	-	Central North region of Egypt
CONUS	-	Conterminous United States
COOP	-	Cooperative Observer Network
CORDEX	-	COordinated Regional climate Downscaling Experiment
CPC	-	Climate Prediction Centre
CRU TS	-	Climate Research Unit Time Series
CSI	-	Critical Success Index
DTR	-	Diurnal Temperature Range
eCDF	-	Empirical Cumulative Density Function
EMA	-	Egyptian Meteorological Authority
E-OBS	-	European ensembles of gridded data
EQM	-	Empirical Quantile Mapping
ERA	-	European Centre for Medium-Range Weather Forecasts
ESGF	-	Earth System Grid Federation
FAO	-	Food and Agriculture Organization

FAR	-	False Alarm Ratio
GCM	-	Global Climate Model
GHCN+CAMS	-	Global Historical Climatology Network + Climate Anomaly Monitoring System
GHCN-D	-	Global Historical Climatology Network-Daily
GPCC	-	Global Precipitation Climatology Centre
GPI	-	Global Performance Indicator
GSMaP	-	Global Satellite Mapping of Precipitation
GSOD	-	Global Surface Summary of Day
GTS	-	Global Telecommunication System
IR	-	InfraRed
IDW	-	Inverse Distance Weighting
IMERG	-	Integrated Multi-satellite Retrievals for Global precipitation measurement
IPCC	-	Intergovernmental Panel on Climate Change
JAXA	-	Japan Aerospace Exploration Agency
JST	-	Japan Science and Technology Agency
KDDM	-	Kernel Density Distribution Mapping
KGE	-	Kling-Gupta Efficiency
LST	-	Land Surface Temperature
MENA	-	The Middle East and North Africa
MERRA	-	Modern-era Retrospective-analysis for Research and Applications
MFG	-	Meteosat First Generation
MI	-	Mutual Information
MME	-	Multi-Model Ensemble
MODIS	-	Moderate Resolution Imaging Spectroradiometer
MOS	-	Model Output Statistics
MSG	-	Meteosat Second Generation
mTm	-	Monthly Mean Temperature
mTmn	-	Monthly Mean of Minimum Temperature
mTmx	-	Monthly Mean of Maximum Temperature
NCAR	-	National Centre for Atmospheric Research

NCDC	-	National Climatic Data Center
NCEP	-	National Centres for Environmental Prediction
NDVI	-	Normalized Difference Vegetation Index
NOAA	-	National Oceanic and Atmospheric Administration
NRMSE	-	Normalized Root Mean Square Error
NSE	-	Nash–Sutcliffe Efficiency
P2P	-	Pear to Pear
PDF	-	Probability Distribution Function
PDFss	-	Probability Distribution Function skill score
PERSIANN-CCS	-	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Cloud Classification
PGF	-	Princeton Global Forcing
PMW	-	Passive Microwave
POD	-	Probability of Detection
PREC/L	-	Precipitation Reconstruction over Land
PRISM	-	Parameter-elevation Regression on Independent Slopes Model
PT	-	Power Transform
R	-	Rainfall
r	-	Correlation
R^2	-	Co-efficient of determination
RCP	-	Representative Concentration Pathway
RF	-	Random Forest
RMSE	-	Root Mean Square Error
SC	-	Similarity Co-efficient
SD	-	Statistical Downscaling
Sdv	-	Standard Deviation
SR	-	Success Ratio
SS	-	Skill Score
SU	-	Symmetrical Uncertainty
T	-	Temperature

TAMSAT	-	Tropical Applications of Meteorology using Satellite data and ground-based observations
TIR	-	Thermal InfraRed
Tm	-	Mean Temperature
Tmn	-	Minimum Temperature
TMPA	-	Tropical rainfall measuring mission Multi-satellite Precipitation Analysis
Tmx	-	Maximum Temperature
TRMM	-	Tropical Rainfall Measuring Mission
UDel	-	University of Delaware
Var	-	Variance Scaling
WMO	-	World Meteorological Organization

LIST OF SYMBOLS

W/m^2	-	Watt per square metre
%	-	Per cent

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The knowledge of the spatiotemporal distribution of precipitation and temperature is essential for most of the hydro-climatic studies (Beck et al., 2019, Tapiador et al., 2012). However, the unavailability of long-term quality-controlled observation data is one of the major obstacles for such studies (Prein and Gobiet, 2017). Even if gauge records are reliable and available for an adequately long period, the sparse spatial distribution hinders their use (Prakash et al., 2015a). With the development of remote-sensing technologies and climate modelling, the estimation of climatic variables based on the combination of station data and other multi-source data enabled the generation of more reliable climate data, particularly in areas where long-term reliable observation data is not available or the gauges are sparsely distributed (Maidment et al., 2017). These datasets are spatially gridded and often temporally complete. Several gridded climate datasets have been developed in the last decade on regional and global scales. The regional datasets were developed for specific regions or countries such as the datasets for Europe (Haylock et al., 2008b), Asia (Yatagai et al., 2012), South America (Liebmann and Allured, 2005), Spain (Herrera et al., 2019), and Switzerland (Schiemann et al., 2010). Also, several global datasets are available such as the Climate Research Unit Time Series (CRU TS) datasets (Harris et al., 2014), the Global Precipitation Climatology Centre (GPCC) (Schneider et al., 2014), and the Climate Hazards Infrared Precipitation with Stations (CHIRPS) (Funk et al., 2015).

In the context of global climate change, spatial datasets of historical climate and projections of climate change have become increasingly important for resource managers, scientists, and policy makers (Wang et al., 2011). Gridded data usually have longer, quality controlled, and complete records. Therefore, their use can achieve reliable analysis of climate over a longer period at local, regional and global scales.

Gridded datasets provide credible estimates of climate variables at locations away from observing stations, thereby allowing studies of local climate in data-sparse regions. Area average indices, often used for monitoring of climate change, are easier to calculate using data of equal-area grids. Global Climate Model (GCM) and Regional Climate Model (RCM) are most widely used for climate change analysis. The evaluation of GCM or RCM over a region can be better conducted using gridded climate data (Ahmed et al., 2019c). Projections of climate at regional scale using GCMs require correction of bias in GCM simulations which can be better achieved using gridded data. Besides, climate change impact assessment can be better conducted using gridded data.

The success of big data analytics in different fields recently has prompted the expectation in better modelling, and thus solving, the environmental and socio-economic problem arisen from climate change. The big data generated from different sources contain a large amount of useful information. A better understanding of the interactions of the climate system with its drivers is important for complete monitoring of climate. It is important to know that the changes in climate occur due to global warming and the changes in micro-climate due to the change in land use and cover, water bodies, local topography and land-sea interactions. Such analysis needs a very high-resolution gridded climate data. Besides, it is not only required to know the change in mean and variability of climate but also the changes in climatic extremes as the major effect of climate change in society and economy comes from climatic extremes. This urges the need for daily or sub-daily gridded data. High temporal resolution is essential for the calculation of many variables required for engineering and agricultural applications — such as growing degree-days or the length of the frost-free period — or the probability of extreme climate events that structures have to bear or that may jeopardize crop yield (Xie et al., 2019). High spatial resolution climate data are important for ecological research where species compositions may change considerably at fine scales and elevations (Thellmann et al., 2019). The importance of high-resolution daily gridded climate data has introduced the concept of big data in climate change research. The high-resolution gridded datasets can be used for providing data-driven evidence of climate change impacts and effectiveness of adaptation measures for decision making which can have breakthrough implications in finding solutions to climate change challenges.

1.2 Problem Statement

Knowledge of climatic characteristics in many regions is limited due to unavailability of in situ observations. Setting up a dense network of gauging stations or radar systems to provide adequate high-resolution data is costly for many emerging economies (Nikolopoulos et al., 2013). Several satellite-based rainfall datasets have recently emerged as an alternative source of dense observation data. However, these datasets often contain large uncertainties – errors – posing concerns for using them. The magnitude and structure of estimation errors vary between the available datasets (Dezfuli et al., 2017), thus identifying the datasets performance in data-scarce regions can increase the confidence in their use. Conventional statistical metrics are generally used for the assessment of the performance of gridded climate datasets by comparing them with reliable ground observation data. However, these metrics are designed to assess the ability of gridded datasets in replicating a particular characteristic such as variability, distribution and extremes of observed data, and thus, not enough to evaluate the similarity in all characteristic of a time series. Furthermore, the use of different metrics often results in contradictory conclusions which make the decision-making a difficult task (Salman et al., 2019, Beck et al., 2019). This highlights the need for a robust statistical tool for the assessment of the performances of gridded datasets.

Although global gridded temperature datasets provide long-term time series over large domains, they lack the fine spatial resolution required for regional and local scale analysis. Available reanalysis gridded temperature datasets show limitations in the representation of several weather patterns (Bosilovich et al., 2008) and the satellite datasets are often restricted by specific cloud cover conditions (Sharifnezhadazizi et al., 2019). Therefore, high-resolution datasets are often developed by interpolating temperature observations from a high-density network (Isotta et al., 2014). However, the lack of dense observation stations network in most countries restricts the development of gridded datasets with sufficient spatial resolution and temporal consistency. Therefore, the development of credible high spatial resolution gridded temperature dataset for station-sparse and -scarce region remains a great challenge in climate data science.

The assessment of climate and its change not only require high-resolution historical climate data but also high-resolution projections of future climate. A large number of GCMs are available for the projection of climate. Selection of an appropriate set of GCMs based on their capability to simulate the historical climate is one of the important steps for the reduction of uncertainty in climate projections of the region (Lutz et al., 2016). But, selection of GCMs is not straightforward (Lutz et al., 2016). Challenges originate from the fact that the credibility of GCMs varies with the evaluation metrics used, temporal (i.e., annual and seasonal) and spatial scales examined, and region under consideration (Weigel et al., 2010, McSweeney et al., 2015). Successive efforts have been made to assess GCM performance to simulate spatial climate variability. Studies emphasised the importance of simulating spatial patterns only considered the mean annual or seasonal spatial patterns and ignored annual variations. A fidelity assessment of the temporal variability of spatial patterns of climatic variables is necessary to study the impact of climate change on hydrology and water resource management in a given study area.

Climate change vulnerability assessments and adaptation planning at local or regional scales require high-resolution climate change projections (Sa'adi et al., 2017, Sachindra et al., 2018b). The coarse-resolution GCMs outputs are downscaled to a fine scale for this purpose. The reliability of high-resolution climate projections not only depends on the selected GCMs and the high-resolution historical climate datasets used but also on the downscaling method used. A robust downscaling method is expected to be able to correct all form of biases presented in GCM simulations including biases in the mean, variability, distribution and extremes. However, the selection of suitable downscaling method is a challenging task as their performance significantly varies according to climate variables, regional climate, and types of bias in GCMs. There is a lack of a robust methodological framework for the selection of suitable downscaling method for the reliable projection of climate at fine resolution.

1.3 Research Objectives

The main objective of this study is to develop a methodological framework for the generation of high-resolution gridded historical and future climate projection of a data-scarce region. This main objective was achieved by fulfilling the following specific objectives:

1. To derive robust methods for the evaluation of the performance of existing gridded climate datasets.

2. To derive a methodology for the development of high-resolution daily gridded temperature dataset in a data-scarce region.

3. To develop a credible framework for the selection of GCMs based on their ability to simulate the changes in the historical climatic pattern of a region for the reliable projection of climate.

4. To generate high-resolution gridded climate projections using the most suitable downscaling method of GCM simulations.

1.4 Scope of the Study

This study aimed at developing high-resolution historical and projection datasets for rainfall and temperatures for the data-scarce region. The developed methodologies can be applied for any part of the world, but the present study encompassed Egypt and its central-north region as study areas.

Several gridded temperature and precipitation data are available for hydro-climatic study in data-scarce region. The scope of this study is to evaluate the performance of high-resolution (i.e. $\leq 0.1°$) satellite-based daily rainfall gridded datasets, gauge-based daily temperature gridded datasets, and gauge-based monthly temperature and rainfall gridded datasets. The gridded datasets were limited to only those which has spatial coverage to the study areas and temporally spans for a sufficient period to the targeted purpose of use. Therefore, other products currently available such as the Integrated Multi-satellitE Retrievals for Global precipitation measurement (IMERG), was not included in this study due to its relatively short temporal span.

This temperature datasets developed in this study were spatially and temporally exclusive for the Central North region of Egypt (CNE) during 1981 – 2017 due to the limited availability of station data. However, the methodology proposed for the developed of the datasets can be applied elsewhere.

Out of more than forty-five CMIP5 GCMs, thirty-one GCMs which have daily estimations and projections for two Representative Concentration Pathway (RCP) scenarios namely 4.5 and 8.5 were considered for the selection of GCMs for Egypt. This criterion ensured the use of the highest number of GCMs having common characteristics.

The future projections of rainfall and temperatures generated in this study were spatially exclusive for the CNE due to the limited spatial coverage of the high-resolution gridded temperature datasets.

1.5 Significance of the Study

This study evaluated different satellite-based datasets for the identification of the best-performing dataset to provide fine resolution measurements of rainfall for the study area. The ability to acquire reliable and high-resolution estimates of rainfall for a given study area is expected to significantly improve the to design and implement mitigation measures to counter water-stress and hydro-meteorological disasters (Abutaleb et al., 2018).

The present study proposed new methodologies for evaluation of monthly gauge-based gridded climate datasets which shall reduce the uncertainty in the selection of the best performing gridded dataset for a given region due to the contradictory results often obtained using different conventional statistics. The method can be used for any other climatic variable for systemic assessment of the performance of gridded data. The identification of the best performing monthly rainfall and temperature datasets for the study area shall provide more confidence in their use for many applications such as assessment of the historical changes in climatic characteristics.

The methodology proposed in this study for the development of high-resolution data can be replicated in any region to solve the problem of data-scarcity. The developed datasets have a wide range of applications such as better understanding of temperatures extremes in the study area which can help policymakers to understand the vulnerable zones and planning adaptation measures. The range of application can be widened by combing the use of the developed temperatures datasets with high-resolution rainfall dataset for water resources management operations such as determining the optimum water allocation to crops, estimation of hydrological hazard potential, investigation of climatic water availability and agricultural potential, and planning and management of water resources.

This study proposed a new framework for the selection of GCMs in a systemic manner which can help in the reduction of uncertainty in the projection of climate change in any region. The GCMs selected in the present study can be used for climate change impact assessment in different sectors in the study area.

The methodologies proposed for downscaling of the rainfall and temperature would reduce uncertainty in projection of high-resolution climate. The downscaled climate for CNE would provide insights into the future possible changes in the characteristics of the climatic variables. The availability of projection datasets will open the way for more studies to understand the impacts of changing climate on various natural systems in a heavily populated region like the CNE. This will be significant in developing appropriate adaptation plans and mitigation measures for adaptation to climate change.

Overall, this study paved the way for future studies through the availability of historical and projected high-resolution gridded rainfall and temperature datasets with different temporal scales. By this, the intention of the study which is to surpass of the scarcity of metrological data, for future research, by the generation of high-resolution gridded dataset was achieved.

1.6 Thesis Outline

The thesis is divided into five chapters. Descriptions of the chapters are given below in brief.

Chapter 1 gives a general introduction comprising of the background of the study, problem statement, and the objectives, scope, and significance of the present study.

Chapter 2 provides a description of the study area followed by a review of available gridded climate datasets, development of high-resolution gridded datasets, factors affecting their quality and methods of their performance evaluation. Furthermore, this chapter explores the recent advances in GCM selection, climate downscaling and projection.

Chapter 3 presents the methods used in the study. The chapter describes the data used and their sources, the novel method proposed for the selection of gridded precipitation and temperature gridded datasets, the development of high-resolution temperature datasets, the novel approach developed for the selection of GCMs, statistical downscaling and projection of climate.

Chapter 4 presents the results obtained in the study followed by a critical discussion of the results. It includes the results of the performances of various temperature and precipitation gridded datasets, the validation of the newly developed dataset, selection of GCMs using a novel framework, the generation of high-resolution gridded climate projections through statistical downscaling of GCM projections.

Finally, the conclusions made from the study are given in Chapter 5. Future research points envisaged from the study are also recommended.

REFERENCES

Aadhar, S. & Mishra, V. 2017. High-resolution near real-time drought monitoring in South Asia. *Sci Data,* 4**,** 170145. doi: 10.1038/sdata.2017.145.

Abbasian, M., Moghim, S. & Abrishamchi, A. 2019. Performance of the general circulation models in simulating temperature and precipitation over Iran. *Theoretical and Applied Climatology,* 135**,** 1465-1483. doi: 10.1007/s00704-018-2456-y.

Abd-Elhamid, H., Javadi, A., Abdelaty, I. & Sherif, M. 2016. Simulation of seawater intrusion in the Nile Delta aquifer under the conditions of climate change. *Hydrology Research,* 47**,** 1198-1210. doi: 10.2166/nh.2016.157.

Abdel-Fattah, M., Saber, M., Kantoush, S. A., Khalil, M. F., Sumi, T. & Sefelnasr, A. M. 2017. A Hydrological and Geomorphometric Approach to Understanding the Generation of Wadi Flash Floods. *Water,* 9**,** 553. doi: 10.3390/w9070553.

Abdulai, P. J. & Chung, E. S. 2019. Uncertainty Assessment in Drought Severities for the Cheongmicheon Watershed Using Multiple GCMs and the Reliability Ensemble Averaging Method. *Sustainability,* 11**,** 4283. doi: 10.3390/su11164283.

Abutaleb, K. a. A., Mohammed, A. H. E.-S. & Ahmed, M. H. M. 2018. Climate Change Impacts, Vulnerabilities and Adaption Measures for Egypt's Nile Delta. *Earth Systems and Environment,* 2**,** 183-192. doi: 10.1007/s41748-018-0047-9.

Abuzied, S., Yuan, M., Ibrahim, S., Kaiser, M. & Saleem, T. 2016a. Geospatial risk assessment of flash floods in Nuweiba area, Egypt. *Journal of Arid Environments,* 133**,** 54-72. doi: 10.1016/j.jaridenv.2016.06.004.

Abuzied, S. M., Ibrahim, S. K., Kaiser, M. F. & Seleem, T. A. 2016b. Application of remote sensing and spatial data integrations for mapping porphyry copper zones in Nuweiba area, Egypt. *Int. J. Signal Process. Syst.,* 4**,** 102-108.

Agrawala, S., Moehner, A., El Raey, M., Conway, D., Van Aalst, M., Hagenstad, M. & Smith, J. 2004. *Development and climate change in Egypt: focus on* *coastal resources and the Nile,* Paris, France, Organisation for Economic Co-operation and Development.

Ahmadalipour, A., Moradkhani, H. & Demirel, M. C. 2017. A comparative assessment of projected meteorological and hydrological droughts: Elucidating the role of temperature. *Journal of Hydrology,* 553**,** 785-797. doi: 10.1016/j.jhydrol.2017.08.047.

Ahmed, K., Sachindra, D. A., Shahid, S., Demirel, M. C. & Chung, E. S. 2019a. Selection of multi-model ensemble of GCMs for the simulation of precipitation based on spatial assessment metrics. *Hydrol. Earth Syst. Sci. Discuss.,* 2019**,** 1-35. doi: 10.5194/hess-2018-585.

Ahmed, K., Sachindra, D. A., Shahid, S., Iqbal, Z., Nawaz, N. & Khan, N. 2020. Multi-model ensemble predictions of precipitation and temperature using machine learning algorithms. *Atmospheric Research,* 236**,** 104806. doi: 10.1016/j.atmosres.2019.104806.

Ahmed, K., Shahid, S., Chung, E. S., Ismail, T. & Wang, X. J. 2017. Spatial distribution of secular trends in annual and seasonal precipitation over Pakistan. *Climate Research,* 74**,** 95-107. doi: 10.3354/cr01489.

Ahmed, K., Shahid, S., Nawaz, N. & Khan, N. 2019b. Modeling climate change impacts on precipitation in arid regions of Pakistan: a non-local model output statistics downscaling approach. *Theoretical and Applied Climatology,* 137**,** 1347-1364. doi: 10.1007/s00704-018-2672-5.

Ahmed, K., Shahid, S., Sachindra, D. A., Nawaz, N. & Chung, E. S. 2019c. Fidelity assessment of general circulation model simulated precipitation and temperature over Pakistan using a feature selection method. *Journal of Hydrology,* 573**,** 281-298. doi: 10.1016/j.jhydrol.2019.03.092.

Ahmed, K., Shahid, S., Wang, X. J., Nawaz, N. & Khan, N. 2019d. Evaluation of Gridded Precipitation Datasets over Arid Regions of Pakistan. *Water,* 11**,** 210. doi: 10.3390/w11020210.

Akhtar, M., Ahmad, N. & Booij, M. J. 2009. Use of regional climate model simulations as input for hydrological models for the Hindukush-Karakorum-Himalaya region. *Hydrology and Earth System Sciences,* 13**,** 1075-1089. doi: 10.5194/hess-13-1075-2009.

Ali, E. M. 2011. Impact of drain water on water quality and eutrophication status of Lake Burullus, Egypt, a southern Mediterranean lagoon. *African Journal of Aquatic Science,* 36**,** 267-277. doi: 10.2989/16085914.2011.636897.

Ali, M. H., Mustafa, A. R. A. & El-Sheikh, A. A. 2016. Geochemistry and spatial distribution of selected heavy metals in surface soil of Sohag, Egypt: a multivariate statistical and GIS approach. *Environmental Earth Sciences,* 75**,** 1257. doi: 10.1007/s12665-016-6047-x.

Almazroui, M. 2019. Temperature Changes over the CORDEX-MENA Domain in the 21st Century Using CMIP5 Data Downscaled with RegCM4: A Focus on the Arabian Peninsula. *Advances in Meteorology,* 2019**,** 1-18. doi: 10.1155/2019/5395676.

Almazroui, M., Abid, M. A., Athar, H., Islam, M. N. & Ehsan, M. A. 2013. Interannual variability of rainfall over the Arabian Peninsula using the IPCC AR4 Global Climate Models. *International Journal of Climatology,* 33**,** 2328-2340. doi: 10.1002/joc.3600.

Almazroui, M., Islam, M. N., Al-Khalaf, A. K. & Saeed, F. 2016. Best convective parameterization scheme within RegCM4 to downscale CMIP5 multi-model data for the CORDEX-MENA/Arab domain. *Theoretical and Applied Climatology,* 124**,** 807-823. doi: 10.1007/s00704-015-1463-5.

Amengual, A., Homar, V., Romero, R., Alonso, S. & Ramis, C. 2012. A statistical adjustment of regional climate model outputs to local scales: application to Platja de Palma, Spain. *Journal of Climate,* 25**,** 939-957.

Aonashi, K., Awaka, J., Hirose, M., Kozu, T., Kubota, T., Liu, G. S., Shige, S., Kida, S., Seto, S., Takahashi, N. & Takayabu, Y. N. 2009. GSMaP Passive Microwave Precipitation Retrieval Algorithm : Algorithm Description and Validation. *Journal of the Meteorological Society of Japan,* 87a**,** 119-136. doi: 10.2151/jmsj.87A.119.

Armanuos, A. M., Negm, A. & Valeriano, O. C. S. 2016. Groundwater Quality Investigation Using Multivariate Analysis--Case Study: Western Nile Delta Aquifer, Egypt. *International Journal of Environmental Science and Development,* 7**,** 1.

Babaousmail, H., Hou, R., Ayugi, B. & Gnitou, G. T. 2019. Evaluation of satellite-based precipitation estimates over Algeria during 1998–2016. *Journal of*

Atmospheric and Solar-Terrestrial Physics, 195**,** 105139. doi: 10.1016/j.jastp.2019.105139.

Basharin, D., Polonsky, A. & Stankūnavičius, G. 2015. Projected precipitation and air temperature over Europe using a performance-based selection method of CMIP5 GCMs. *Journal of Water and Climate Change,* 7**,** 103-113. doi: 10.2166/wcc.2015.081.

Basheer, M. & Elagib, N. A. 2019. Performance of satellite-based and GPCC 7.0 rainfall products in an extremely data-scarce country in the Nile Basin. *Atmospheric Research,* 215**,** 128-140. doi: 10.1016/j.atmosres.2018.08.028.

Basistha, A., Arya, D. S. & Goel, N. K. 2007. Spatial Distribution of Rainfall in Indian Himalayas – A Case Study of Uttarakhand Region. *Water Resources Management,* 22**,** 1325-1346. doi: 10.1007/s11269-007-9228-2.

Batanouny, K. H. 2001. Climatic Aridity in the Deserts of the Middle East. *Plants in the Deserts of the Middle East.* Berlin, Heidelberg: Springer Berlin Heidelberg.

Bayissa, Y., Tadesse, T., Demisse, G. & Shiferaw, A. 2017. Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought for the Upper Blue Nile Basin, Ethiopia. *Remote Sensing,* 9**,** 669. doi: 10.3390/rs9070669.

Beck, C., Grieser, J., Rudolf, B. & Schneider, U. A new monthly precipitation climatology for the global land areas for the period 1951 to 2000. Geophys. Res. Abstr, 2005. 07154.

Beck, H. E., Pan, M., Roy, T., Weedon, G. P., Pappenberger, F., Van Dijk, A. I. J. M., Huffman, G. J., Adler, R. F. & Wood, E. F. 2019. Daily evaluation of 26 precipitation datasets using Stage-IV gauge-radar data for the CONUS. *Hydrology and Earth System Sciences,* 23**,** 207-224. doi: 10.5194/hess-23-207-2019.

Begueria, S., Vicente-Serrano, S. M., Tomas-Burguera, M. & Maneta, M. 2016. Bias in the variance of gridded data sets leads to misleading conclusions about changes in climate variability. *International Journal of Climatology,* 36**,** 3413-3422. doi: 10.1002/joc.4561.

Behar, O., Khellaf, A. & Mohammedi, K. 2015. Comparison of solar radiation models and their validation under Algerian climate – The case of direct irradiance. *Energy Conversion and Management,* 98**,** 236-251. doi: 10.1016/j.enconman.2015.03.067.

Behrangi, A. & Wen, Y. X. 2017. On the Spatial and Temporal Sampling Errors of Remotely Sensed Precipitation Products. *Remote Sensing,* 9**,** 1127. doi: 10.3390/rs9111127.

Belo-Pereira, M., Dutra, E. & Viterbo, P. 2011. Evaluation of global precipitation data sets over the Iberian Peninsula. *Journal of Geophysical Research-Atmospheres,* 116doi: 10.1029/2010jd015481.

Bosilovich, M. G., Chen, J. Y., Robertson, F. R. & Adler, R. F. 2008. Evaluation of global precipitation in reanalyses. *Journal of Applied Meteorology and Climatology,* 47**,** 2279-2299. doi: 10.1175/2008jamc1921.1.

Braganza, K., Karoly, D. J. & Arblaster, J. M. 2004. Diurnal temperature range as an index of global climate change during the twentieth century. *Geophysical Research Letters,* 31doi: 10.1029/2004gl019998.

Breiman, L. 2001. Random forests. *Machine Learning,* 45**,** 5-32. doi: 10.1023/A:1010933404324.

Buser, C. M., Kunsch, H. R., Luthi, D., Wild, M. & Schar, C. 2009. Bayesian multi-model projection of climate: bias assumptions and interannual variability. *Climate Dynamics,* 33**,** 849-868. doi: 10.1007/s00382-009-0588-6.

Cannon, A. J. 2015. Selecting GCM Scenarios that Span the Range of Changes in a Multimodel Ensemble: Application to CMIP5 Climate Extremes Indices. *Journal of Climate,* 28**,** 1260-1267. doi: 10.1175/Jcli-D-14-00636.1.

Cannon, A. J. 2018. Multivariate quantile mapping bias correction: an N-dimensional probability density function transform for climate model simulations of multiple variables. *Climate Dynamics,* 50**,** 31-49. doi: 10.1007/s00382-017-3580-6.

Capmas 2019. *Egypt in Figures 2019 - Census* Cairo, Egypt, Central Agency for Public Mobilization And Statistics (CAPMAS).

Cattani, E., Merino, A., Guijarro, J. A. & Levizzani, V. 2018. East Africa Rainfall Trends and Variability 1983–2015 Using Three Long-Term Satellite Products. *Remote Sensing,* 10**,** 931.

Ceccherini, G., Ameztoy, I., Hernandez, C. P. R. & Moreno, C. C. 2015. High-Resolution Precipitation Datasets in South America and West Africa based on

Satellite-Derived Rainfall, Enhanced Vegetation Index and Digital Elevation Model. *Remote Sensing,* 7**,** 6454-6488. doi: 10.3390/rs70506454.

Chen, C., Chen, Q. W., Duan, Z., Zhang, J. Y., Mo, K. L., Li, Z. & Tang, G. Q. 2018. Multiscale Comparative Evaluation of the GPM IMERG v5 and TRMM 3B42 v7 Precipitation Products from 2015 to 2017 over a Climate Transition Area of China. *Remote Sensing,* 10**,** 944. doi: 10.3390/rs10060944.

Chen, H., Xu, C. Y. & Guo, S. L. 2012. Comparison and evaluation of multiple GCMs, statistical downscaling and hydrological models in the study of climate change impacts on runoff. *Journal of Hydrology,* 434**,** 36-45. doi: 10.1016/j.jhydrol.2012.02.040.

Chen, M. Y., Xie, P. P., Janowiak, J. E. & Arkin, P. A. 2002. Global land precipitation: A 50-yr monthly analysis based on gauge observations. *Journal of Hydrometeorology,* 3**,** 249-266. doi: 10.1175/1525-7541(2002)003<0249:Glpaym>2.0.Co;2.

Chen, X. & Ishwaran, H. 2012. Random forests for genomic data analysis. *Genomics,* 99**,** 323-9. doi: 10.1016/j.ygeno.2012.04.003.

Chiew, F. H. An overview of methods for estimating climate change impact on runoff. 30th Hydrology & Water Resources Symposium: Past, Present & Future, 2006. Conference Design, 643.

Cools, J., Vanderkimpen, P., El Afandi, G., Abdelkhalek, A., Fockedey, S., El Sammany, M., Abdallah, G., El Bihery, M., Bauwens, W. & Huygens, M. 2012. An early warning system for flash floods in hyper-arid Egypt. *Natural Hazards and Earth System Sciences,* 12**,** 443-457. doi: 10.5194/nhess-12-443-2012.

Costa, J. E. 1987. Hydraulics and Basin Morphometry of the Largest Flash Floods in the Conterminous United-States. *Journal of Hydrology,* 93**,** 313-338. doi: 10.1016/0022-1694(87)90102-8.

Dadamouny, M. A. & Schnittler, M. 2015. Trends of climate with rapid change in Sinai, Egypt. *Journal of Water and Climate Change,* 7**,** 393-414. doi: 10.2166/wcc.2015.215.

Dai, A. 2006. Precipitation characteristics in eighteen coupled climate models. *Journal of Climate,* 19**,** 4605-4630. doi: 10.1175/Jcli3884.1.

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., Curtis, J. & Pasteris, P. P. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology,* 28**,** 2031-2064. doi: 10.1002/joc.1688.

Darwish, K. M., Rashad, M., Mohamed, S. Z. & Gad, A. 2015. Spatial distribution analysis of soil variables for agronomic development in El-Omayed Area, North-Coastal of Egypt. *Environmental Earth Sciences,* 74**,** 889-901. doi: 10.1007/s12665-015-4095-2.

Dee, D. P., Balmaseda, M., Balsam, G., Engelen, R., Simmons, A. J. & Thepaut, J. N. 2014. Toward a Consistent Reanalysis of the Climate System. *Bulletin of the American Meteorological Society,* 95**,** 1235-1248. doi: 10.1175/Bams-D-13-00043.1.

Dembele, M. & Zwart, S. J. 2016. Evaluation and comparison of satellite-based rainfall products in Burkina Faso, West Africa. *International Journal of Remote Sensing,* 37**,** 3995-4014. doi: 10.1080/01431161.2016.1207258.

Demircan, M., Demir, Ö., Atay, H., Yazici, B., Eskioğlu, O., Tuvan, A. & Akçakaya, A. 2014. *CLIMATE CHANGE PROJECTIONS FOR TURKEY WITH NEW SCENARIOS*.

Denis, B., Laprise, R., Caya, D. & Cote, J. 2002. Downscaling ability of one-way nested regional climate models: the Big-Brother Experiment. *Climate Dynamics,* 18**,** 627-646. doi: 10.1007/s00382-001-0210-0.

Despotovic, M., Nedic, V., Despotovic, D. & Cvetanovic, S. 2015. Review and statistical analysis of different global solar radiation sunshine models. *Renewable & Sustainable Energy Reviews,* 52**,** 1869-1880. doi: 10.1016/j.rser.2015.08.035.

Dezfuli, A. K., Ichoku, C. M., Huffman, G. J., Mohr, K. I., Selker, J. S., Giesen, N. V. D., Hochreutener, R. & Annor, F. O. 2017. Validation of IMERG Precipitation in Africa. *Journal of Hydrometeorology,* 18**,** 2817-2825. doi: 10.1175/jhm-d-17-0139.1.

Di Luzio, M., Johnson, G. L., Daly, C., Eischeid, J. K. & Arnold, J. G. 2008. Constructing Retrospective Gridded Daily Precipitation and Temperature Datasets for the Conterminous United States. *Journal of Applied Meteorology and Climatology,* 47**,** 475-497. doi: 10.1175/2007jamc1356.1.

Diaz-Nieto, J. & Wilby, R. L. 2005. A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. *Climatic Change,* 69**,** 245-268.

Dinku, T., Ceccato, P., Cressman, K. & Connor, S. J. 2010. Evaluating Detection Skills of Satellite Rainfall Estimates over Desert Locust Recession Regions. *Journal of Applied Meteorology and Climatology,* 49**,** 1322-1332. doi: 10.1175/2010jamc2281.1.

Dinku, T., Connor, S. J., Ceccato, P. & Ropelewski, C. F. 2008. Comparison of global gridded precipitation products over a mountainous region of Africa. *International Journal of Climatology,* 28**,** 1627-1638. doi: 10.1002/joc.1669.

Diodato, N. & Bellocchi, G. 2012. Decadal modelling of rainfall–runoff erosivity in the Euro-Mediterranean region using extreme precipitation indices. *Global and Planetary Change,* 86-87**,** 79-91. doi: 10.1016/j.gloplacha.2012.02.002.

Dirks, K. N., Hay, J. E., Stow, C. D. & Harris, D. 1998. High-resolution studies of rainfall on Norfolk Island Part II: Interpolation of rainfall data. *Journal of Hydrology,* 208**,** 187-193. doi: 10.1016/S0022-1694(98)00155-3.

Domroes, M. & El-Tantawi, A. 2005. Recent temporal and spatial temperature changes in Egypt. *International Journal of Climatology,* 25**,** 51-63. doi: 10.1002/joc.1114.

Dutta, S. & Chaudhuri, G. 2015. Evaluating Environmental Sensitivity of Arid and Semiarid Regions in Northeastern Rajasthan, India. *Geographical Review,* 105**,** 441-461. doi: 10.1111/j.1931-0846.2015.12093.x.

Eden, J. M. & Widmann, M. 2014. Downscaling of GCM-Simulated Precipitation Using Model Output Statistics. *Journal of Climate,* 27**,** 312-324. doi: 10.1175/jcli-d-13-00063.1.

Eghdamirad, S., Johnson, F. & Sharma, A. 2017. How reliable are GCM simulations for different atmospheric variables? *Climatic Change,* 145**,** 237-248. doi: 10.1007/s10584-017-2086-x.

El-Gammal, M. I., Ali, R. R. & Abou Samra, R. M. 2019. GIS-based land degradation risk assessment of Damietta governorate, Egypt. *Egyptian Journal of Basic and Applied Sciences,* 2**,** 183-189. doi: 10.1016/j.ejbas.2015.01.001.

El-Magd, I. A., Hermas, E. & El Bastawesy, M. 2010. GIS-modelling of the spatial variability of flash flood hazard in Abu Dabbab catchment, Red Sea Region,

Egypt. *The Egyptian Journal of Remote Sensing and Space Science,* 13**,** 81-88.
El-Nahry, A. H. & Doluschitz, R. 2010. Climate change and its impacts on the coastal zone of the Nile Delta, Egypt. *Environmental Earth Sciences,* 59**,** 1497-1506. doi: 10.1007/s12665-009-0135-0.
El Afandi, G. 2014. Evaluation of NCEP Climate Forecast System Reanalysis (CFSR) against Surface Observations over Egypt. *American Journal of Science and Technology,* 1**,** 157-167.
El Bastawesy, M., White, K. & Nasr, A. 2009. Integration of remote sensing and GIS for modelling flash floods in Wadi Hudain catchment, Egypt. *Hydrological Processes: An International Journal,* 23**,** 1359-1368.
El Kenawy, A. M., Hereher, M. E. & Robaa, S. M. 2019a. An Assessment of the Accuracy of MODIS Land Surface Temperature over Egypt Using Ground-Based Measurements. *Remote Sensing,* 11**,** 2369.
El Kenawy, A. M., Lopez-Moreno, J. I., Mccabe, M. F., Robaa, S. M., Domínguez-Castro, F., Peña-Gallardo, M., Trigo, R. M., Hereher, M. E., Al-Awadhi, T. & Vicente-Serrano, S. M. 2019b. Daily temperature extremes over Egypt: Spatial patterns, temporal trends, and driving forces. *Atmospheric Research,* 226**,** 219-239. doi: 10.1016/j.atmosres.2019.04.030.
El Kenawy, A. M. & Mccabe, M. F. 2016a. Future projections of synoptic weather types over the Arabian Peninsula during the twenty-first century using an ensemble of CMIP5 models. *Theoretical and Applied Climatology,* 130**,** 173-189. doi: 10.1007/s00704-016-1874-y.
El Kenawy, A. M. & Mccabe, M. F. 2016b. A multi-decadal assessment of the performance of gauge-and model-based rainfall products over Saudi Arabia: climatology, anomalies and trends. *International Journal of Climatology,* 36**,** 656-674.
Elhayed, A. 2019. On World Meteorological Day, learn about its origins in Egypt and its goals. *Al-Wafd*, 13 Mar 2019.
Elmallah, E. S. & Elsharkawy, S. G. 2011. Influence of circulation indices upon winter temperature variability in Egypt. *Journal of Atmospheric and Solar-Terrestrial Physics,* 73**,** 439-448. doi: 10.1016/j.jastp.2010.10.013.

Elnazer, A. A., Salman, S. A. & Asmoay, A. S. 2017. Flash flood hazard affected Ras Gharib city, Red Sea, Egypt: a proposed flash flood channel. *Natural Hazards,* 89**,** 1389-1400. doi: 10.1007/s11069-017-3030-0.

Elshamy, M., Seierstad, I. A. & Sorteberg, A. 2009. Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios.

Ema. 2019. *About the Egyptian Meteorological Authority* [Online]. Egypt: Egyptian Meteorological Authority (EMA). Available: https://www.emaeg.org/about?lang=en [Accessed 12 Dec 2019].

Englund, C. & Verikas, A. 2012. A novel approach to estimate proximity in a random forest: An exploratory study. *Expert Systems with Applications,* 39**,** 13046-13050. doi: 10.1016/j.eswa.2012.05.094.

Esling, P. & Agon, C. 2012. Time-Series Data Mining. *Acm Computing Surveys,* 45**,** 12. doi: 10.1145/2379776.2379788.

Eum, H. I., Dibike, Y., Prowse, T. & Bonsal, B. 2014. Inter-comparison of high-resolution gridded climate data sets and their implication on hydrological model simulation over the Athabasca Watershed, Canada. *Hydrological processes,* 28**,** 4250-4271.

Evans, J. P. 2009. 21st century climate change in the Middle East. *Climatic Change,* 92**,** 417-432. doi: 10.1007/s10584-008-9438-5.

Evans, J. P. 2010. Global warming impact on the dominant precipitation processes in the Middle East. *Theoretical and Applied Climatology,* 99**,** 389-402. doi: 10.1007/s00704-009-0151-8.

Fan, J. L., Wang, X. K., Wu, L. F., Zhang, F. C., Bai, H., Lu, X. H. & Xiang, Y. Z. 2018. New combined models for estimating daily global solar radiation based on sunshine duration in humid regions: A case study in South China. *Energy Conversion and Management,* 156**,** 618-625. doi: 10.1016/j.enconman.2017.11.085.

Farjad, B., Gupta, A., Sartipizadeh, H. & Cannon, A. J. 2019. A novel approach for selecting extreme climate change scenarios for climate change impact studies. *Sci Total Environ,* 678**,** 476-485. doi: 10.1016/j.scitotenv.2019.04.218.

Fenta, A. A., Yasuda, H., Shimizu, K., Ibaraki, Y., Haregeweyn, N., Kawai, T., Belay, A. S., Sultan, D. & Ebabu, K. 2018. Evaluation of satellite rainfall estimates over the Lake Tana basin at the source region of the Blue Nile

River. *Atmospheric Research,* 212**,** 43-53. doi: 10.1016/j.atmosres.2018.05.009.

Fernandez-Blanco, E., Aguiar-Pulido, V., Munteanu, C. R. & Dorado, J. 2013. Random Forest classification based on star graph topological indices for antioxidant proteins. *J Theor Biol,* 317**,** 331-7. doi: 10.1016/j.jtbi.2012.10.006.

Ferro, C. A. 2004. Attributing variation in a regional climate change modelling experiment. *EU Project PRUDENCE Tech. Rep*.

Fick, S. E. & Hijmans, R. J. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology,* 37**,** 4302-4315. doi: 10.1002/joc.5086

Finger, D., Heinrich, G., Gobiet, A. & Bauder, A. 2012. Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent effects on hydropower production during the 21st century. *Water Resources Research,* 48doi: 10.1029/2011wr010733.

Flaounas, E., Drobinski, P., Vrac, M., Bastin, S., Lebeaupin-Brossier, C., Stéfanon, M., Borga, M. & Calvet, J.-C. 2012. Precipitation and temperature space–time variability and extremes in the Mediterranean region: evaluation of dynamical and statistical downscaling methods. *Climate Dynamics,* 40**,** 2687-2705. doi: 10.1007/s00382-012-1558-y.

Floodlist. 2015a. *Egypt – Floods in Alexandria Leave at Least 6 Dead* [Online]. FloodList. Available: http://www.webcitation.org/76IuxIySz [Accessed 23 Sep 2018].

Floodlist. 2015b. *Updated: Egypt – Floods Strike Again – 25 Killed in Beheira and Alexandria* [Online]. Egypt: FloodList. Available: http://www.webcitation.org/76Iuk4xH7 [Accessed 23 Sep 2018].

Floodlist. 2018. *Eastern Mediterranean – Deadly Flash Floods After Heavy Rain* [Online]. FloodList. Available: http://www.webcitation.org/76Iv1Fxmq [Accessed 23 Sep 2018].

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. & Michaelsen, J. 2015. The climate hazards infrared precipitation with stations--a new environmental record for monitoring extremes. *Sci Data,* 2**,** 150066. doi: 10.1038/sdata.2015.66.

Gado, T. A. Statistical characteristics of extreme rainfall events in Egypt. Twentieth international water technology conference, IWTC20. Hurghada, Egypt, 2017.

Gado, T. A., El-Hagrsy, R. M. & Rashwan, I. M. H. 2019. Spatial and temporal rainfall changes in Egypt. *Environ Sci Pollut Res Int,* 26**,** 28228-28242. doi: 10.1007/s11356-019-06039-4.

Gella, G. W. 2019. Statistical evaluation of High Resolution satellite precipitation products in arid and semi-arid parts of Ethiopia: a note for hydro-meteorological applications. *Water and Environment Journal,* 33**,** 86-97. doi: 10.1111/wej.12380.

Genuer, R., Poggi, J. M. & Tuleau-Malot, C. 2010. Variable selection using random forests. *Pattern Recognition Letters,* 31**,** 2225-2236. doi: 10.1016/j.patrec.2010.03.014.

Giorgi, F. & Mearns, L. O. 2002. Calculation of Average, Uncertainty Range, and Reliability of Regional Climate Changes from AOGCM Simulations via the “Reliability Ensemble Averaging” (REA) Method. *Journal of Climate,* 15**,** 1141-1158. doi: 10.1175/1520-0442(2002)015.

Girons Lopez, M., Wennerström, H., Nordén, L. Å. & Seibert, J. 2016. Location and density of rain gauges for the estimation of spatial varying precipitation. *Geografiska Annaler: Series A, Physical Geography,* 97**,** 167-179. doi: 10.1111/geoa.12094.

Gray, K. R., Aljabar, P., Heckemann, R. A., Hammers, A., Rueckert, D. & Alzheimer's Disease Neuroimaging, I. 2013. Random forest-based similarity measures for multi-modal classification of Alzheimer's disease. *Neuroimage,* 65**,** 167-75. doi: 10.1016/j.neuroimage.2012.09.065.

Gupta, H. V., Kling, H., Yilmaz, K. K. & Martinez, G. F. 2009. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. *Journal of Hydrology,* 377**,** 80-91. doi: 10.1016/j.jhydrol.2009.08.003.

Gyalistras, D. 2003. Development and validation of a high-resolution monthly gridded temperature and precipitation data set for Switzerland (1951-2000). *Climate Research,* 25**,** 55-83. doi: 10.3354/cr025055.

Haddeland, I., Heinke, J., Voß, F., Eisner, S., Chen, C., Hagemann, S. & Ludwig, F. 2012. Effects of climate model radiation, humidity and wind estimates on hydrological simulations. *Hydrology and Earth System Sciences,* 16**,** 305-318.

Haerter, J. O., Hagemann, S., Moseley, C. & Piani, C. 2011. Climate model bias correction and the role of timescales. *Hydrology and Earth System Sciences,* 15**,** 1065-1079. doi: 10.5194/hess-15-1065-2011.

Hagemann, S., Chen, C., Haerter, J. O., Heinke, J., Gerten, D. & Piani, C. 2011. Impact of a statistical bias correction on the projected hydrological changes obtained from three GCMs and two hydrology models. *Journal of Hydrometeorology,* 12**,** 556-578.

Hanna, E. G. & Mciver, L. J. 2018. Climate change: a brief overview of the science and health impacts for Australia. *Med J Aust,* 208**,** 311-315. doi: 10.5694/mja17.00640.

Hansen, J., Ruedy, R., Sato, M. & Lo, K. 2010. Global Surface Temperature Change. *Reviews of Geophysics,* 48doi:
10.1029/2010rg000345.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W. & Medina-Elizade, M. 2006. Global temperature change. *Proc Natl Acad Sci U S A,* 103**,** 14288-93. doi: 10.1073/pnas.0606291103.

Harris, I., Jones, P. D., Osborn, T. J. & Lister, D. H. 2014. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *International Journal of Climatology,* 34**,** 623-642. doi: 10.1002/joc.3711.

Hasanean, H. M. 2004. Wintertime surface temperature in Egypt in relation to the associated atmospheric circulation. *International Journal of Climatology,* 24**,** 985-999. doi: 10.1002/joc.1043.

Hasanean, H. M. & Basset, H. A. 2006. Variability of summer temperature over Egypt. *International Journal of Climatology,* 26**,** 1619-1634. doi: 10.1002/joc.1321.

Hassan, A., Ismail, S. S., Elmoustafa, A. & Khalaf, S. 2018. Evaluating evaporation rate from high Aswan Dam Reservoir using RS and GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science,* 21**,** 285-293. doi: 10.1016/j.ejrs.2017.10.001.

Haylock, M., Hofstra, N., Klein Tank, A., Klok, E., Jones, P. & New, M. 2008a. A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. *Journal of Geophysical Research: Atmospheres,* 113.

Haylock, M., Hofstra, N., Tank, A. K., Klok, E., Jones, P. & New, M. 2008b. A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. *Journal of Geophysical Research: Atmospheres,* 113doi: 10.1029/2008JD010201

Hereher, M. E. 2013. The status of Egypt's agricultural lands using MODIS Aqua data. *The Egyptian Journal of Remote Sensing and Space Science,* 16**,** 83-89. doi: 10.1016/j.ejrs.2013.03.001.

Hereher, M. E. 2016. Time series trends of land surface temperatures in Egypt: a signal for global warming. *Environmental Earth Sciences,* 75doi: 10.1007/s12665-016-6024-4.

Herrera, S., Cardoso, R. M., Soares, P. M., Espirito-Santo, F., Viterbo, P. & Gutierrez, J. M. 2019. Iberia01: a new gridded dataset of daily precipitation and temperatures over Iberia. *Earth System Science Data,* 11**,** 1947-1956. doi: 10.5194/essd-11-1947-2019.

Herrera, S., Gutiérrez, J., Ancell, R., Pons, M., Frías, M. & Fernández, J. 2012a. Development and analysis of a 50-year high-resolution daily gridded precipitation dataset over Spain (Spain02). *International Journal of Climatology,* 32**,** 74-85.

Herrera, S., Gutiérrez, J. M., Ancell, R., Pons, M., Frías, M. & Fernández, J. 2012b. Development and analysis of a 50-year high-resolution daily gridded precipitation dataset over Spain (Spain02). *International Journal of Climatology,* 32**,** 74-85. doi: 10.1002/joc.2256

Hertig, E. & Jacobeit, J. 2008a. Assessments of Mediterranean precipitation changes for the 21st century using statistical downscaling techniques. *International Journal of Climatology,* 28**,** 1025-1045. doi: 10.1002/joc.1597.

Hertig, E. & Jacobeit, J. 2008b. Downscaling future climate change: Temperature scenarios for the Mediterranean area. *Global and Planetary Change,* 63**,** 127-131. doi: 10.1016/j.gloplacha.2007.09.003.

Hewitt, A. J., Booth, B. B. B., Jones, C. D., Robertson, E. S., Wiltshire, A. J., Sansom, P. G., Stephenson, D. B. & Yip, S. 2016. Sources of Uncertainty in Future Projections of the Carbon Cycle. *Journal of Climate,* 29**,** 7203-7213. doi: 10.1175/Jcli-D-16-0161.1.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology,* 25**,** 1965-1978. doi: 10.1002/joc.1276.

Hingray, B., Mezghani, A. & Buishand, T. A. 2007. Development of probability distributions for regional climate change from uncertain global mean warming and an uncertain scaling relationship. *Hydrology and Earth System Sciences,* 11**,** 1097-1114. doi: 10.5194/hess-11-1097-2007.

Hobouchian, M. P., Salio, P., Skabar, Y. G., Vila, D. & Garreaud, R. 2017. Assessment of satellite precipitation estimates over the slopes of the subtropical Andes. *Atmospheric Research,* 190**,** 43-54. doi: 10.1016/j.atmosres.2017.02.006.

Hofstra, N., Haylock, M., New, M. & Jones, P. D. 2009. Testing E-OBS European high-resolution gridded data set of daily precipitation and surface temperature. *Journal of Geophysical Research: Atmospheres,* 114.

Hong, Y., Hsu, K. L., Sorooshian, S. & Gao, X. G. 2004. Precipitation Estimation from Remotely Sensed Imagery using an Artificial Neural Network Cloud Classification System. *Journal of Applied Meteorology,* 43**,** 1834-1852. doi: 10.1175/Jam2173.1.

Houmsi, M. R., Shiru, M. S., Nashwan, M. S., Ahmed, K., Ziarh, G. F., Shahid, S., Chung, E.-S. & Kim, S. 2019. Spatial Shift of Aridity and Its Impact on Land Use of Syria. *Sustainability,* 11**,** 7047. doi: 10.3390/su11247047.

Hu, Z., Chen, X., Chen, D., Li, J., Wang, S., Zhou, Q., Yin, G. & Guo, M. 2019. “Dry gets drier, wet gets wetter”: A case study over the arid regions of central Asia. *International Journal of Climatology,* 39**,** 1072-1091. doi: 10.1002/joc.5863.

Huang, W. R., Wang, S. Y. & Chan, J. C. L. 2011. Discrepancies between global reanalyses and observations in the interdecadal variations of Southeast Asian cold surge. *International Journal of Climatology,* 31**,** 2272-2280. doi: 10.1002/joc.2234.

Huffman, G. J., Adler, R. F., Morrissey, M. M., Bolvin, D. T., Curtis, S., Joyce, R., Mcgavock, B. & Susskind, J. 2001. Global precipitation at one-degree daily resolution from multisatellite observations. *Journal of Hydrometeorology,* 2**,** 36-50. doi: 10.1175/1525-7541(2001)002<0036:Gpaodd>2.0.Co;2.

Hulme, M. 1992. A 1951–80 global land precipitation climatology for the evaluation of general circulation models. *Climate Dynamics,* 7**,** 57-72. doi: 10.1007/bf00209609.

Hurst, H. E. 1951. Long-term storage capacity of reservoirs. *Trans. Amer. Soc. Civil Eng.,* 116**,** 770-799.

Hurst, H. E. 1952. The Roda Nilometer. *Nature,* 170**,** 132-133. doi: 10.1038/170132a0.

Hutchinson, M. F., Mckenney, D. W., Lawrence, K., Pedlar, J. H., Hopkinson, R. F., Milewska, E. & Papadopol, P. 2009. Development and Testing of Canada-Wide Interpolated Spatial Models of Daily Minimum–Maximum Temperature and Precipitation for 1961–2003. *Journal of Applied Meteorology and Climatology,* 48**,** 725-741. doi: 10.1175/2008jamc1979.1.

Ifrc. 2017. *Emergency Plan of Action Final Report, Egypt: Floods* [Online]. International Federation of Red Cross and Red Crescent Societies. Available: https://reliefweb.int/sites/reliefweb.int/files/resources/MDREG013dfr.pdf [Accessed 26 Apr 2018].

Ipcc 2014. *Climate change 2014: impacts, adaptation, and vulnerability - Part B: regional aspects - Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, Cambridge University Press.

Isotta, F. A., Frei, C., Weilguni, V., Perčec Tadić, M., Lassegues, P., Rudolf, B., Pavan, V., Cacciamani, C., Antolini, G. & Ratto, S. M. 2014. The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data. *International Journal of Climatology,* 34**,** 1657-1675.

Isotta, F. A., Vogel, R. & Frei, C. 2015. Evaluation of European regional reanalyses and downscalings for precipitation in the Alpine region. *Meteorologische Zeitschrift,* 24**,** 15-37. doi: 10.1127/metz/2014/0584.

Jiang, Z., Sharma, A. & Johnson, F. 2019. Assessing the sensitivity of hydro-climatological change detection methods to model uncertainty and bias. *Advances in Water Resources,* 134**,** 103430. doi: UNSP 103430
10.1016/j.advwatres.2019.103430.

Johnson, F. & Sharma, A. 2009. Measurement of GCM Skill in Predicting Variables Relevant for Hydroclimatological Assessments. *Journal of Climate,* 22**,** 4373-4382. doi: 10.1175/2009jcli2681.1.

Johnson, F., Westra, S., Sharma, A. & Pitman, A. J. 2011. An Assessment of GCM Skill in Simulating Persistence across Multiple Time Scales. *Journal of Climate,* 24**,** 3609-3623. doi: 10.1175/2011jcli3732.1.

Jones, P. D., Lister, D. H., Osborn, T. J., Harpham, C., Salmon, M. & Morice, C. P. 2012. Hemispheric and large-scale land-surface air temperature variations: An extensive revision and an update to 2010. *Journal of Geophysical Research-Atmospheres,* 117doi: 10.1029/2011jd017139.

Jun, M., Knutti, R. & Nychka, D. W. 2008. Spatial analysis to quantify numerical model bias and dependence: How many climate models are there? *Journal of the American Statistical Association,* 103**,** 934-947.

Karger, D. N., Conrad, O., Bohner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P. & Kessler, M. 2017. Climatologies at high resolution for the earth's land surface areas. *Sci Data,* 4**,** 170122. doi: 10.1038/sdata.2017.122.

Karmalkar, A. V., Thibeault, J. M., Bryan, A. M. & Seth, A. 2019. Identifying credible and diverse GCMs for regional climate change studies—case study: Northeastern United States. *Climatic Change,* 154**,** 367-386. doi: 10.1007/s10584-019-02411-y.

Katsanos, D., Retalis, A. & Michaelides, S. 2016. Validation of a high-resolution precipitation database (CHIRPS) over Cyprus for a 30-year period. *Atmospheric Research,* 169**,** 459-464. doi: 10.1016/j.atmosres.2015.05.015.

Khan, N., Shahid, S., Ahmed, K., Ismail, T., Nawaz, N. & Son, M. 2018. Performance Assessment of General Circulation Model in Simulating Daily Precipitation and Temperature Using Multiple Gridded Datasets. *Water,* 10**,** 1793. doi: 10.3390/w10121793.

Kimura, R., Kato, H. & Iwasaki, E. 2015. Cultivation Features Using Meteorological and Satellite Data from 2001 to 2010 in Dakhla Oasis, Egypt. *Journal of Water Resource and Protection,* 7**,** 209.

Kling, H., Fuchs, M. & Paulin, M. 2012. Runoff conditions in the upper Danube basin under an ensemble of climate change scenarios. *Journal of Hydrology,* 424**,** 264-277. doi: 10.1016/j.jhydrol.2012.01.011.

Koch, J., Demirel, M. C. & Stisen, S. 2018. The SPAtial EFficiency metric (SPAEF): multiple-component evaluation of spatial patterns for optimization of hydrological models. *Geoscientific Model Development,* 11**,** 1873-1886. doi: 10.5194/gmd-11-1873-2018.

Kohler, M. A. 1949. On the use of double-mass analysis for testing the consistency of meteorological records and for making required adjustments. *Bulletin of the American Meteorological Society,* 30**,** 188-189.

Koutsoyiannis, D. 2003. Climate change, the Hurst phenomenon, and hydrological statistics. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques,* 48**,** 3-24. doi: 10.1623/hysj.48.1.3.43481.

Krichak, S. O., Tsidulko, M. & Alpert, P. 2000. November 2, 1994, severe storms in the southeastern Mediterranean. *Atmospheric Research,* 53**,** 45-62. doi: 10.1016/S0169-8095(99)00045-9.

Kuhn, S., Egert, B., Neumann, S. & Steinbeck, C. 2008. Building blocks for automated elucidation of metabolites: Machine learning methods for NMR prediction. *BMC bioinformatics,* 9**,** 1.

Kurbalija, V., Radovanovic, M., Geler, Z. & Ivanovic, M. 2014. The influence of global constraints on similarity measures for time-series databases. *Knowledge-Based Systems,* 56**,** 49-67. doi: 10.1016/j.knosys.2013.10.021.

Kysely, J. & Plavcova, E. 2010. A critical remark on the applicability of E-OBS European gridded temperature data set for validating control climate simulations. *Journal of Geophysical Research-Atmospheres,* 115doi: 10.1029/2010jd014123.

Kyselý, J. & Plavcová, E. 2010. A critical remark on the applicability of E-OBS European gridded temperature data set for validating control climate simulations. *Journal of Geophysical Research,* 115doi: 10.1029/2010jd014123.

Lafon, T., Dadson, S., Buys, G. & Prudhomme, C. 2013. Bias correction of daily precipitation simulated by a regional climate model: a comparison of methods. *International Journal of Climatology,* 33**,** 1367-1381. doi: 10.1002/joc.3518.

Lamptey, B. L. 2008. Comparison of gridded multisatellite rainfall estimates with gridded gauge rainfall over west Africa. *Journal of Applied Meteorology and Climatology,* 47**,** 185-205. doi: 10.1175/2007jamc1586.1.

Lawrimore, J. H., Menne, M. J., Gleason, B. E., Williams, C. N., Wuertz, D. B., Vose, R. S. & Rennie, J. 2011. An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3. *Journal of Geophysical Research-Atmospheres,* 116doi: 10.1029/2011jd016187.

Leander, R. & Buishand, T. A. 2007. Resampling of regional climate model output for the simulation of extreme river flows. *Journal of Hydrology,* 332**,** 487-496. doi: 10.1016/j.jhydrol.2006.08.006.

Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E. & Zittis, G. 2016. Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. *Climatic Change,* 137**,** 245-260. doi: 10.1007/s10584-016-1665-6.

Lenderink, G., Buishand, A. & Van Deursen, W. 2007. Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrology and Earth System Sciences,* 11**,** 1143-1159.

Liebmann, B. & Allured, D. 2005. Daily precipitation grids for South America. *Bulletin of the American Meteorological Society,* 86**,** 1567-1570. doi: 10.1175/Bams-86-11-1567.

Llasat, M. C., Llasat-Botija, M., Prat, M. A., Porcú, F., Price, C., Mugnai, A., Lagouvardos, K., Kotroni, V., Katsanos, D., Michaelides, S., Yair, Y., Savvidou, K. & Nicolaides, K. 2010. High-impact floods and flash floods in Mediterranean countries: the FLASH preliminary database. *Advances in Geosciences,* 23**,** 47-55. doi: 10.5194/adgeo-23-47-2010.

Luo, M., Liu, T., Meng, F. H., Duan, Y. C., Frankl, A., Bao, A. M. & De Maeyer, P. 2018. Comparing Bias Correction Methods Used in Downscaling Precipitation and Temperature from Regional Climate Models: A Case Study from the Kaidu River Basin in Western China. *Water*, 10**,** 1046. doi: 10.3390/w10081046.

Lutz, A. F., Ter Maat, H. W., Biemans, H., Shrestha, A. B., Wester, P. & Immerzeel, W. W. 2016. Selecting representative climate models for climate change impact studies: an advanced envelope-based selection approach. *International Journal of Climatology*, 36**,** 3988-4005. doi: 10.1002/joc.4608.

Ly, S., Charles, C. & Degre, A. 2011. Geostatistical interpolation of daily rainfall at catchment scale: the use of several variogram models in the Ourthe and

Ambleve catchments, Belgium. *Hydrology and Earth System Sciences,* 15, 2259-2274. doi: 10.5194/hess-15-2259-2011.

Ma, L., Zhang, T., Li, Q., Frauenfeld, O. W. & Qin, D. 2008. Evaluation of ERA-40, NCEP-1, and NCEP-2 reanalysis air temperatures with ground-based measurements in China. *Journal of Geophysical Research,* 113doi: 10.1029/2007jd009549.

Mabrouk, M. B., Jonoski, A., Solomatine, D. & Uhlenbrook, S. 2013. A review of seawater intrusion in the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development. *Hydrology and Earth System Sciences Discussions,* 10, 10873-10911. doi: 10.5194/hessd-10-10873-2013.

Mahrooghy, M., Anantharaj, V. G., Younan, N. H., Aanstoos, J. & Hsu, K. L. 2012. On an Enhanced PERSIANN-CCS Algorithm for Precipitation Estimation. *Journal of Atmospheric and Oceanic Technology,* 29, 922-932. doi: 10.1175/Jtech-D-11-00146.1.

Maidment, R. I., Grimes, D., Black, E., Tarnavsky, E., Young, M., Greatrex, H., Allan, R. P., Stein, T., Nkonde, E., Senkunda, S. & Alcantara, E. M. U. 2017. A new, long-term daily satellite-based rainfall dataset for operational monitoring in Africa. *Sci Data,* 4, 170063. doi: 10.1038/sdata.2017.63.

Mamoon, A. A., Rahman, A. & Joergensen, N. E. 2019. Assessment of Climate Change Impacts on IDF Curves in Qatar Using Ensemble Climate Modeling Approach. *In:* SINGH, S. K. & DHANYA, C. T. (eds.) *Hydrology in a Changing World.* Cham: Springer International Publishing.

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., Widmann, M., Brienen, S., Rust, H. W., Sauter, T., Themeßl, M., Venema, V. K. C., Chun, K. P., Goodess, C. M., Jones, R. G., Onof, C., Vrac, M. & Thiele-Eich, I. 2010. Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics,* 48, n/a-n/a. doi: 10.1029/2009RG000314.

Mashaly, J. & Ghoneim, E. 2018. Flash Flood Hazard Using Optical, Radar, and Stereo-Pair Derived DEM: Eastern Desert, Egypt. *Remote Sensing,* 10, 1204. doi: 10.3390/rs10081204.

Masson, D. & Knutti, R. 2011. Climate model genealogy. *Geophysical Research Letters,* 38, L08703. doi: 10.1029/2011gl046864.

Matsuura, K. & Willmott, C. J. 2015. Terrestrial Precipitation: 1900-2014 Gridded Monthly Time Series.

Mccollum, J. R., Gruber, A. & Ba, M. B. 2000. Discrepancy between Gauges and Satellite Estimates of Rainfall in Equatorial Africa. *Journal of Applied Meteorology,* 39**,** 666-679. doi: 10.1175/1520-0450-39.5.666.

Mcginnis, S. 2018. *climod: Bias correction and other tools for climate model output* [Online]. Available: https://rdrr.io/github/sethmcg/climod/ [Accessed 5 May 2018].

Mcginnis, S., Nychka, D. & Mearns, L. O. 2015. A New Distribution Mapping Technique for Climate Model Bias Correction. *In:* LAKSHMANAN, V., GILLELAND, E., MCGOVERN, A. & TINGLEY, M. (eds.) *Machine Learning and Data Mining Approaches to Climate Science.* 1 ed. Cham: Springer International Publishing.

Mcmahon, T. A., Peel, M. C. & Karoly, D. J. 2015. Assessment of precipitation and temperature data from CMIP3 global climate models for hydrologic simulation. *Hydrology and Earth System Sciences,* 19**,** 361-377. doi: 10.5194/hess-19-361-2015.

Mcmillan, H., Krueger, T. & Freer, J. 2012. Benchmarking observational uncertainties for hydrology: rainfall, river discharge and water quality. *Hydrological Processes,* 26**,** 4078-4111. doi: 10.1002/hyp.9384.

Mcsweeney, C. F., Jones, R. G., Lee, R. W. & Rowell, D. P. 2015. Selecting CMIP5 GCMs for downscaling over multiple regions. *Climate Dynamics,* 44**,** 3237-3260. doi: 10.1007/s00382-014-2418-8.

Mega, T., Ushio, T., Kubota, T., Kachi, M., Aonashi, K. & Shige, S. Gauge adjusted global satellite mapping of precipitation (GSMaP_Gauge). General Assembly and Scientific Symposium (URSI GASS), 2014 XXXIth URSI, 2014. IEEE, 1-4.

Mendlik, T. & Gobiet, A. 2016. Selecting climate simulations for impact studies based on multivariate patterns of climate change. *Clim Change,* 135**,** 381-393. doi: 10.1007/s10584-015-1582-0.

Menne, M. J., Durre, I., Vose, R. S., Gleason, B. E. & Houston, T. G. 2012. An Overview of the Global Historical Climatology Network-Daily Database. *Journal of Atmospheric and Oceanic Technology,* 29**,** 897-910. doi: 10.1175/Jtech-D-11-00103.1.

Mildrexler, D. J., Zhao, M. S. & Running, S. W. 2011. A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests. *Journal of Geophysical Research-Biogeosciences,* 116doi: 10.1029/2010jg001486.

Mitchell, T. D. & Jones, P. D. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology,* 25**,** 693-712. doi: 10.1002/joc.1181.

Moawad, M. B. 2013. Analysis of the flash flood occurred on 18 January 2010 in wadi El Arish, Egypt (a case study). *Geomatics Natural Hazards & Risk,* 4**,** 254-274. doi: 10.1080/19475705.2012.731657.

Monerie, P. A., Sanchez-Gomez, E. & Boe, J. 2017. On the range of future Sahel precipitation projections and the selection of a sub-sample of CMIP5 models for impact studies. *Climate Dynamics,* 48**,** 2751-2770. doi: 10.1007/s00382-016-3236-y.

Moon, H., Gudmundsson, L. & Seneviratne, S. I. 2018. Drought Persistence Errors in Global Climate Models. *J Geophys Res Atmos,* 123**,** 3483-3496. doi: 10.1002/2017JD027577.

Mostafa, A. N., Wheida, A., El Nazer, M., Adel, M., El Leithy, L., Siour, G., Coman, A., Borbon, A., Magdy, A. W., Omar, M., Saad-Hussein, A. & Alfaro, S. C. 2019. Past (1950–2017) and future (−2100) temperature and precipitation trends in Egypt. *Weather and Climate Extremes,* 26**,** 100225. doi: 10.1016/j.wace.2019.100225.

Mpelasoka, F. S. & Chiew, F. H. S. 2009. Influence of Rainfall Scenario Construction Methods on Runoff Projections. *Journal of Hydrometeorology,* 10**,** 1168-1183. doi: 10.1175/2009jhm1045.1.

Muhammad, M. K. I., Nashwan, M. S., Shahid, S., Bin Ismail, T., Song, Y. H. & Chung, E. S. 2019. Evaluation of Empirical Reference Evapotranspiration Models Using Compromise Programming: A Case Study of Peninsular Malaysia. *Sustainability,* 11**,** 4267. doi: 10.3390/su11164267.

Müller, M. F. & Thompson, S. E. 2013. Bias adjustment of satellite rainfall data through stochastic modeling: Methods development and application to Nepal. *Advances in Water Resources,* 60**,** 121-134.

Murphy, J. M., Sexton, D. M., Barnett, D. N., Jones, G. S., Webb, M. J., Collins, M. & Stainforth, D. A. 2004. Quantification of modelling uncertainties in a large ensemble of climate change simulations. *Nature,* 430**,** 768-72. doi: 10.1038/nature02771.

Muthoni, F. K., Odongo, V. O., Ochieng, J., Mugalavai, E. M., Mourice, S. K., Hoesche-Zeledon, I., Mwila, M. & Bekunda, M. 2019. Long-term spatial-temporal trends and variability of rainfall over Eastern and Southern Africa. *Theoretical and Applied Climatology,* 137**,** 1869-1882. doi: 10.1007/s00704-018-2712-1.

Mwri 2005. Water for the future. National Water Resources Plan 2017. Ministry of Water Resources and Irrigation.

Nabaei, S., Sharafati, A., Yaseen, Z. M. & Shahid, S. 2019. Copula based assessment of meteorological drought characteristics: Regional investigation of Iran. *Agricultural and Forest Meteorology,* 276**,** 107611. doi: UNSP 107611
10.1016/j.agrformet.2019.06.010.

Najafi, R. & Kermani, M. R. H. 2017. Uncertainty Modeling of Statistical Downscaling to Assess Climate Change Impacts on Temperature and Precipitation. *Water Resources Management,* 31**,** 1843-1858. doi: 10.1007/s11269-017-1615-8.

Najmaddin, P. M., Whelan, M. J. & Balzter, H. 2017. Application of Satellite-Based Precipitation Estimates to Rainfall-Runoff Modelling in a Data-Scarce Semi-Arid Catchment. *Climate,* 5**,** 32. doi: 10.3390/cli5020032.

Nalder, I. A. & Wein, R. W. 1998. Spatial interpolation of climatic Normals: test of a new method in the Canadian boreal forest. *Agricultural and Forest Meteorology,* 92**,** 211-225. doi: 10.1016/S0168-1923(98)00102-6.

Nashwan, M. S. & Shahid, S. 2019. Spatial distribution of unidirectional trends in climate and weather extremes in Nile river basin. *Theoretical and Applied Climatology,* 137**,** 1181-1199. doi: 10.1007/s00704-018-2664-5.

Nashwan, M. S., Shahid, S. & Abd Rahim, N. 2019a. Unidirectional trends in annual and seasonal climate and extremes in Egypt. *Theoretical and Applied Climatology,* 136**,** 457-473. doi: 10.1007/s00704-018-2498-1.

Nashwan, M. S., Shahid, S. & Chung, E.-S. 2019b. Central North Region of Egypt (CNE) Maximum and Minimum Temperature Gridded Datasets. *Figshare,* doi: 10.6084/m9.figshare.7504232.

Nashwan, M. S., Shahid, S., Chung, E. S., Ahmed, K. & Song, Y. H. 2018. Development of Climate-Based Index for Hydrologic Hazard Susceptibility. *Sustainability,* 10**,** 2182. doi: 10.3390/su10072182.

Nashwan, M. S., Shahid, S. & Wang, X. J. 2019c. Assessment of Satellite-Based Precipitation Measurement Products over the Hot Desert Climate of Egypt. *Remote Sensing,* 11**,** 555. doi: 10.3390/rs11050555.

Nashwan, M. S., Shahid, S. & Wang, X. J. 2019d. Uncertainty in Estimated Trends Using Gridded Rainfall Data: A Case Study of Bangladesh. *Water,* 11**,** 349. doi: 10.3390/w11020349.

Negm, A. M. & Armanuos, A. M. 2016. GIS-Based Spatial Distribution of Groundwater Quality in the Western Nile Delta, Egypt. *In:* NEGM, A. M. (ed.) *The Nile Delta.* Cham: Springer International Publishing.

New, M., Hulme, M. & Jones, P. 1999. Representing Twentieth-Century Space–Time Climate Variability. Part I: Development of a 1961–90 Mean Monthly Terrestrial Climatology. *Journal of Climate,* 12**,** 829-856. doi: 10.1175/1520-0442(1999)012<0829:Rtcstc>2.0.Co;2.

New, M., Hulme, M. & Jones, P. 2000. Representing Twentieth-Century Space–Time Climate Variability. Part II: Development of 1901–96 Monthly Grids of Terrestrial Surface Climate. *Journal of Climate*, 13**,** 2217-2238. doi: 10.1175/1520-0442(2000)013.

Nikolopoulos, E. I., Anagnostou, E. N. & Borga, M. 2013. Using High-Resolution Satellite Rainfall Products to Simulate a Major Flash Flood Event in Northern Italy. *Journal of Hydrometeorology,* 14**,** 171-185. doi: 10.1175/Jhm-D-12-09.1.

Noor, M., Ismai, T., Shahid, S., Nashwan, M. S. & Ullah, S. 2019a. Development of multi-model ensemble for projection of extreme rainfall events in Peninsular Malaysia. *Hydrology Research,* doi: 10.2166/nh.2019.097.

Noor, M., Ismail, T., Shahid, S., Salem Nashwan, M. & Ullah, S. 2019b. Development of multi-model ensemble for projection of extreme rainfall events in Peninsular Malaysia. *Hydrology Research,* doi: 10.2166/nh.2019.097.

Novella, N. S. & Thiaw, W. M. 2013. African Rainfall Climatology Version 2 for Famine Early Warning Systems. *Journal of Applied Meteorology and Climatology,* 52**,** 588-606. doi: 10.1175/Jamc-D-11-0238.1.

Ogimet. 2018. *SYNOP of Cairo Airport (Egypt) on 04/25/2018 at 00:00 UTC* [Online]. Available: https://www.ogimet.com/cgi-bin/decomet?ind=62366&ano=2018&mes=04&day=25&hora=00&min=00&single=yes&lang=en [Accessed 14 Sep 2019].

Oleson, K. W., Anderson, G. B., Jones, B., Mcginnis, S. A. & Sanderson, B. 2018. Avoided climate impacts of urban and rural heat and cold waves over the U.S. using large climate model ensembles for RCP8.5 and RCP4.5. *Clim Change,* 146**,** 377-392. doi: 10.1007/s10584-015-1504-1.

Omran, E. E. 2012. A Proposed Model to Assess and Map Irrigation Water Well Suitability Using Geospatial Analysis. *Water,* 4**,** 545-567. doi: 10.3390/w4030545.

Onol, B. & Semazzi, F. H. M. 2009. Regionalization of Climate Change Simulations over the Eastern Mediterranean. *Journal of Climate,* 22**,** 1944-1961. doi: 10.1175/2008jcli1807.1.

Onyutha, C., Tabari, H., Rutkowska, A., Nyeko-Ogiramoi, P. & Willems, P. 2016. Comparison of different statistical downscaling methods for climate change rainfall projections over the Lake Victoria basin considering CMIP3 and CMIP5. *Journal of Hydro-Environment Research,* 12**,** 31-45. doi: 10.1016/j.jher.2016.03.001.

Ouyang, F., Zhu, Y. H., Fu, G. B., Lu, H. S., Zhang, A. J., Yu, Z. B. & Chen, X. 2015. Impacts of climate change under CMIP5 RCP scenarios on streamflow in the Huangnizhuang catchment. *Stochastic Environmental Research and Risk Assessment,* 29**,** 1781-1795. doi: 10.1007/s00477-014-1018-9.

Özcan, C. & Önol, B. Intercomparison of Gridded Observation Data Sets over Turkey. EGU General Assembly Conference Abstracts, 2017. 7597.

Ozturk, T., Ceber, Z. P., Turkes, M. & Kurnaz, M. L. 2015. Projections of climate change in the Mediterranean Basin by using downscaled global climate model outputs. *International Journal of Climatology,* 35**,** 4276-4292. doi: 10.1002/joc.4285.

Ozturk, T., Turp, M. T., Turkes, M. & Kurnaz, M. L. 2018. Future projections of temperature and precipitation climatology for CORDEX-MENA domain using RegCM4.4. *Atmospheric Research,* 206**,** 87-107. doi: 10.1016/j.atmosres.2018.02.009.

Panofsky, H. A. & Brier, G. W. 1958. *Some applications of statistics to meteorology,* Mineral Industries Extension Services, College of Mineral Industries, Pennsylvania State University.

Peng, S., Ding, Y., Liu, W. & Li, Z. 2019. 1km monthly temperature and precipitation dataset for China from 1901 to 2017. *Earth System Science Data,* 11**,** 1931-1946. doi: 10.5194/essd-11-1931-2019.

Perkins, S. E., Pitman, A. J., Holbrook, N. J. & Mcaneney, J. 2007. Evaluation of the AR4 Climate Models' Simulated Daily Maximum Temperature, Minimum Temperature, and Precipitation over Australia Using Probability Density Functions. *Journal of Climate,* 20**,** 4356-4376. doi: 10.1175/jcli4253.1.

Perkins, S. E., Pitman, A. J. & Sisson, S. A. 2013. Systematic differences in future 20 year temperature extremes in AR4 model projections over Australia as a function of model skill. *International Journal of Climatology,* 33**,** 1153-1167. doi: 10.1002/joc.3500.

Peterson, T. C., Easterling, D. R., Karl, T. R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Forland, E. J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. & Parker, D. 1998. Homogeneity adjustments of in situ atmospheric climate data: A review. *International Journal of Climatology,* 18**,** 1493-1517. doi: 10.1002/(Sici)1097-0088(19981115)18:13<1493::Aid-Joc329>3.0.Co;2-T.

Piani, C., Haerter, J. O. & Coppola, E. 2010. Statistical bias correction for daily precipitation in regional climate models over Europe. *Theoretical and Applied Climatology,* 99**,** 187-192. doi: 10.1007/s00704-009-0134-9.

Pierce, D. W., Barnett, T. P., Santer, B. D. & Gleckler, P. J. 2009. Selecting global climate models for regional climate change studies. *Proc Natl Acad Sci U S A,* 106**,** 8441-6. doi: 10.1073/pnas.0900094106.

Pitman, A. J. & Perkins, S. E. 2008. Regional Projections of Future Seasonal and Annual Changes in Rainfall and Temperature over Australia Based on Skill-Selected AR4 Models. *Earth Interactions,* 12**,** 1-50. doi: 10.1175/2008ei260.1.

Pokhrel, P. & Gupta, H. V. 2011. On the ability to infer spatial catchment variability using streamflow hydrographs. *Water Resources Research,* 47**,** W08534. doi: 10.1029/2010wr009873.

Poterjoy, J. 2016. A Localized Particle Filter for High-Dimensional Nonlinear Systems. *Monthly Weather Review,* 144**,** 59-76. doi: 10.1175/Mwr-D-15-0163.1.

Pour, S. H., Bin Harun, S. & Shahid, S. 2014. Genetic Programming for the Downscaling of Extreme Rainfall Events on the East Coast of Peninsular Malaysia. *Atmosphere,* 5**,** 914-936. doi: 10.3390/atmos5040914.

Pour, S. H., Shahid, S., Chung, E. S. & Wang, X. J. 2018. Model output statistics downscaling using support vector machine for the projection of spatial and temporal changes in rainfall of Bangladesh. *Atmospheric Research,* 213**,** 149-162. doi: 10.1016/j.atmosres.2018.06.006.

Pouyan, M. B. & Kostka, D. 2018. Random forest based similarity learning for single cell RNA sequencing data. *Bioinformatics,* 34**,** i79-i88. doi: 10.1093/bioinformatics/bty260.

Prakash, S., Gairola, R. M. & Mitra, A. K. 2015a. Comparison of large-scale global land precipitation from multisatellite and reanalysis products with gauge-based GPCC data sets. *Theoretical and Applied Climatology,* 121**,** 303-317. doi: 10.1007/s00704-014-1245-5.

Prakash, S., Mitra, A. K., Momin, I. M., Rajagopal, E. N., Basu, S., Collins, M., Turner, A. G., Rao, K. A. & Ashok, K. 2015b. Seasonal intercomparison of observational rainfall datasets over India during the southwest monsoon season. *International Journal of Climatology,* 35**,** 2326-2338. doi: 10.1002/joc.4129.

Prein, A. F. & Gobiet, A. 2017. Impacts of uncertainties in European gridded precipitation observations on regional climate analysis. *Int J Climatol,* 37**,** 305-327. doi: 10.1002/joc.4706.

Press, W. H., Teukolsky, S. A., Vetterling, W. T. & Flannery, B. P. 1996. *Numerical recipes in C*, Cambridge university press Cambridge.

Prudhomme, C., Reynard, N. & Crooks, S. 2002. Downscaling of global climate models for flood frequency analysis: where are we now? *Hydrological Processes,* 16**,** 1137-1150. doi: 10.1002/hyp.1054.

Qin, Z. H., Dall'olmo, G., Karnieli, A. & Berliner, P. 2001. Derivation of split window algorithm and its sensitivity analysis for retrieving land surface temperature from NOAA-advanced very high resolution radiometer data.

Journal of Geophysical Research-Atmospheres, 106**,** 22655-22670. doi: 10.1029/2000jd900452.

Qutbudin, I., Shiru, M. S., Sharafati, A., Ahmed, K., Al-Ansari, N., Yaseen, Z. M., Shahid, S. & Wang, X. J. 2019. Seasonal Drought Pattern Changes Due to Climate Variability: Case Study in Afghanistan. *Water,* 11**,** 1096. doi: 10.3390/w11051096.

Rabeiy, R. E. 2018. Assessment and modeling of groundwater quality using WQI and GIS in Upper Egypt area. *Environ Sci Pollut Res Int,* 25**,** 30808-30817. doi: 10.1007/s11356-017-8617-1.

Radcliffe, D. E. & Mukundan, R. 2017. PRISM vs. CFSR Precipitation Data Effects on Calibration and Validation of SWAT Models. *Journal of the American Water Resources Association,* 53**,** 89-100. doi: 10.1111/1752-1688.12484.

Ragab, O. & Negm, A. 2017. Trend analysis of precipitation data: A case study of Blue Nile Basin, Africa. *Handbook of Environmental Chemistry.*

Raju, K. S. & Kumar, D. N. 2014. Ranking of global climate models for India using multicriterion analysis. *Climate Research,* 60**,** 103-117. doi: 10.3354/cr01222.

Raju, K. S. & Kumar, D. N. 2015. Ranking general circulation models for India using TOPSIS. *Journal of Water and Climate Change,* 6**,** 288-299. doi: 10.2166/wcc.2014.074.

Raju, K. S., Sonali, P. & Kumar, D. N. 2017. Ranking of CMIP5-based global climate models for India using compromise programming. *Theoretical and Applied Climatology,* 128**,** 563-574. doi: 10.1007/s00704-015-1721-6.

Ramirez, F., Bhardwaj, V., Arrigoni, L., Lam, K. C., Gruning, B. A., Villaveces, J., Habermann, B., Akhtar, A. & Manke, T. 2018. High-resolution TADs reveal DNA sequences underlying genome organization in flies. *Nature Communications,* 9**,** 189. doi: 10.1038/s41467-017-02525-w.

Redwan, M. & Elhaddad, E. 2017. Heavy metals seasonal variability and distribution in Lake Qaroun sediments, El-Fayoum, Egypt. *Journal of African Earth Sciences,* 134**,** 48-55. doi: 10.1016/j.jafrearsci.2017.06.005.

Reifen, C. & Toumi, R. 2009. Climate projections: Past performance no guarantee of future skill? *Geophysical Research Letters,* 36**,** L13704. doi: 10.1029/2009gl038082.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N. & Rafaj, P. 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Climatic Change,* 109**,** 33-57. doi: 10.1007/s10584-011-0149-y.

Robaa, S. M. 2013. Some aspects of the urban climates of Greater Cairo Region, Egypt. *International Journal of Climatology,* 33**,** 3206-3216. doi: 10.1002/joc.3661.

Roebber, P. J. 2009. Visualizing Multiple Measures of Forecast Quality. *Weather and Forecasting,* 24**,** 601-608. doi: 10.1175/2008waf2222159.1.

Romanski, P. & Kotthoff, L. 2018. *FSelector: Selecting Attributes v 0.31* [Online]. Available: https://CRAN.R-project.org/package=FSelector [Accessed 16 Apr 2019].

Rosenfeld, D., Rudich, Y. & Lahav, R. 2001. Desert dust suppressing precipitation: a possible desertification feedback loop. *Proc Natl Acad Sci U S A,* 98**,** 5975-80. doi: 10.1073/pnas.101122798.

Rostkier-Edelstein, D., Liu, Y., Wu, W., Kunin, P., Givati, A. & Ge, M. 2014. Towards a high-resolution climatography of seasonal precipitation over Israel. *International Journal of Climatology,* 34**,** 1964-1979. doi: 10.1002/joc.3814.

Roushdi, M., Mostafa, H. & Kheireldin, K. 2016. Present and Future Climate Extreme Indices over Sinai Peninsula, Egypt. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering,* 109**,** 85 - 90.

Rozante, J. R., Vila, D. A., Chiquetto, J. B., Fernandes, A. D. & Alvim, D. S. 2018. Evaluation of TRMM/GPM Blended Daily Products over Brazil. *Remote Sensing,* 10**,** 882. doi: 10.3390/rs10060882.

Sa'adi, Z., Shahid, S., Chung, E. S. & Bin Ismail, T. 2017. Projection of spatial and temporal changes of rainfall in Sarawak of Borneo Island using statistical downscaling of CMIP5 models. *Atmospheric Research,* 197**,** 446-460. doi: 10.1016/j.atmosres.2017.08.002.

Sa’adi, Z., Shiru, M. S., Shahid, S. & Ismail, T. 2019. Selection of general circulation models for the projections of spatio-temporal changes in temperature of Borneo Island based on CMIP5. *Theoretical and Applied Climatology,* doi: 10.1007/s00704-019-02948-z.

Saber, M. & Yilmaz, K. K. 2018. Evaluation and Bias Correction of Satellite-Based Rainfall Estimates for Modelling Flash Floods over the Mediterranean region: Application to Karpuz River Basin, Turkey. *Water,* 10**,** 657. doi: 10.3390/w10050657.

Sachindra, D. A., Ahmed, K., Rashid, M. M., Shahid, S. & Perera, B. J. C. 2018a. Statistical downscaling of precipitation using machine learning techniques. *Atmospheric Research,* 212**,** 240-258. doi: 10.1016/j.atmosres.2018.05.022.

Sachindra, D. A., Ahmed, K., Shahid, S. & Perera, B. J. C. 2018b. Cautionary note on the use of genetic programming in statistical downscaling. *International Journal of Climatology,* 38**,** 3449-3465. doi: 10.1002/joc.5508.

Salguero-Gomez, R., Siewert, W., Casper, B. B. & Tielborger, K. 2012. A demographic approach to study effects of climate change in desert plants. *Philos Trans R Soc Lond B Biol Sci,* 367**,** 3100-14. doi: 10.1098/rstb.2012.0074.

Salih, S. Q., Allawi, M. F., Yousif, A. A., Armanuos, A. M., Saggi, M. K., Ali, M., Shahid, S., Al-Ansari, N., Yaseen, Z. M. & Chau, K. W. 2019. Viability of the advanced adaptive neuro-fuzzy inference system model on reservoir evaporation process simulation: case study of Nasser Lake in Egypt. *Engineering Applications of Computational Fluid Mechanics*, 13**,** 878-891. doi: 10.1080/19942060.2019.1647879.

Salman, S. A., Shahid, S., Ismail, T., Ahmed, K. & Wang, X. J. 2018. Selection of climate models for projection of spatiotemporal changes in temperature of Iraq with uncertainties. *Atmospheric Research,* 213**,** 509-522. doi: 10.1016/j.atmosres.2018.07.008.

Salman, S. A., Shahid, S., Ismail, T., Al-Abadi, A. M., Wang, X. J. & Chung, E. S. 2019. Selection of gridded precipitation data for Iraq using compromise programming. *Measurement,* 132**,** 87-98. doi: 10.1016/j.measurement.2018.09.047.

Salman, S. A., Shahid, S., Ismail, T., Chung, E. S. & Al-Abadi, A. M. 2017. Long-term trends in daily temperature extremes in Iraq. *Atmospheric Research,* 198**,** 97-107. doi: 10.1016/j.atmosres.2017.08.011.

Salvi, K., Kannan, S. & Ghosh, S. Statistical downscaling and bias-correction for projections of Indian rainfall and temperature in climate change studies. 4th

International Conference on Environmental and Computer Science, 2011. 16-18.

Sansom, P. G., Stephenson, D. B., Ferro, C. a. T., Zappa, G. & Shaffrey, L. 2013. Simple Uncertainty Frameworks for Selecting Weighting Schemes and Interpreting Multimodel Ensemble Climate Change Experiments. *Journal of Climate,* 26**,** 4017-4037. doi: 10.1175/Jcli-D-12-00462.1.

Şarlak, N. & Mahmood Agha, O. M. A. 2018. Spatial and temporal variations of aridity indices in Iraq. *Theoretical and Applied Climatology,* 133**,** 89-99. doi: 10.1007/s00704-017-2163-0.

Schiemann, R., Liniger, M. A. & Frei, C. 2010. Reduced space optimal interpolation of daily rain gauge precipitation in Switzerland. *Journal of Geophysical Research-Atmospheres,* 115doi: 10.1029/2009jd013047.

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M. & Rudolf, B. 2014. GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. *Theoretical and Applied Climatology,* 115**,** 15-40. doi: 10.1007/s00704-013-0860-x.

Seo, S. B. & Kim, Y. O. 2018. Impact of Spatial Aggregation Level of Climate Indicators on a National-Level Selection for Representative Climate Change Scenarios. *Sustainability,* 10**,** 2409. doi: 10.3390/su10072409.

Seo, S. B., Kim, Y. O., Kim, Y. & Eum, H. I. 2019. Selecting climate change scenarios for regional hydrologic impact studies based on climate extremes indices. *Climate Dynamics,* 52**,** 1595-1611. doi: 10.1007/s00382-018-4210-7.

Seoane, J. A., Day, I. N., Gaunt, T. R. & Campbell, C. 2014. A pathway-based data integration framework for prediction of disease progression. *Bioinformatics,* 30**,** 838-45. doi: 10.1093/bioinformatics/btt610.

Seto, S., Kubota, T., Iguchi, T., Takahashi, N. & Oki, T. 2009. An Evaluation of Over-Land Rain Rate Estimates by the GSMaP and GPROF Algorithms: The Role of Lower-Frequency Channels. *Journal of the Meteorological Society of Japan,* 87a**,** 183-202. doi: 10.2151/jmsj.87A.183.

Shahid, S. 2011. Trends in extreme rainfall events of Bangladesh. *Theoretical and Applied Climatology,* 104**,** 489-499. doi: 10.1007/s00704-010-0363-y.

Shahid, S., Harun, S. B. & Katimon, A. 2012. Changes in diurnal temperature range in Bangladesh during the time period 1961–2008. *Atmospheric Research,* 118**,** 260-270. doi: 10.1016/j.atmosres.2012.07.008.

Shahid, S., Pour, S. H., Wang, X. J., Shourav, S. A., Minhans, A. & Bin Ismail, T. 2017. Impacts and adaptation to climate change in Malaysian real estate. *International Journal of Climate Change Strategies and Management,* 9**,** 87-103. doi: 10.1108/Ijccsm-01-2016-0001.

Shaltout, M., Tonbol, K. & Omstedt, A. 2015. Sea-level change and projected future flooding along the Egyptian Mediterranean coast. *Oceanologia,* 57**,** 293-307. doi: 10.1016/j.oceano.2015.06.004.

Sharafati, A., Nabaei, S. & Shahid, S. 2019. Spatial assessment of meteorological drought features over different climate regions in Iran. *International Journal of Climatology,* n/a**,** 1– 21. doi: 10.1002/joc.6307.

Sharafati, A. & Pezeshki, E. 2019. A strategy to assess the uncertainty of a climate change impact on extreme hydrological events in the semi-arid Dehbar catchment in Iran. *Theoretical and Applied Climatology,* doi: 10.1007/s00704-019-02979-6.

Sharifnezhadazizi, Z., Norouzi, H., Prakash, S., Beale, C. & Khanbilvardi, R. 2019. A Global Analysis of Land Surface Temperature Diurnal Cycle Using MODIS Observations. *Journal of Applied Meteorology and Climatology,* 58**,** 1279-1291. doi: 10.1175/Jamc-D-18-0256.1.

Sharma, D., Gupta, A. D. & Babel, M. 2007. Spatial disaggregation of bias-corrected GCM precipitation for improved hydrologic simulation: Ping River Basin, Thailand. *Hydrology and Earth System Sciences Discussions,* 11**,** 1373-1390.

Sheather, S. & Chris Jones, M. 1991. *A Reliable Data-Based Bandwidth Selection Method for Kernel Density Estimation*.

Sheffield, J., Goteti, G. & Wood, E. F. 2006. Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. *Journal of Climate,* 19**,** 3088-3111. doi: 10.1175/Jcli3790.1.

Shepard, D. A two-dimensional interpolation function for irregularly-spaced data. Proceedings of the 1968 23rd ACM national conference, 1968. ACM, 517-524.

Shibasaki, R., Azuma, T., Yoshida, T., Teranishi, H. & Abe, M. 2017. Global route choice and its modelling of dry bulk carriers based on vessel movement database: Focusing on the Suez Canal. *Research in Transportation Business and Management,* 25**,** 51-65. doi: 10.1016/j.rtbm.2017.08.003.

Shiru, M. S., Shahid, S., Chung, E. S., Alias, N. & Scherer, L. 2019. A MCDM-based framework for selection of general circulation models and projection of spatio-temporal rainfall changes: A case study of Nigeria. *Atmospheric Research,* 225**,** 1-16. doi: 10.1016/j.atmosres.2019.03.033.

Shokr, M. S., El Baroudy, A. A., Fullen, M. A., El-Beshbeshy, T. R., Ali, R. R., Elhalim, A., Guerra, A. J. T. & Jorge, M. C. O. 2016a. Mapping of Heavy Metal Contamination in Alluvial Soils of the Middle Nile Delta of Egypt. *Journal of Environmental Engineering and Landscape Management,* 24**,** 218-231. doi: 10.3846/16486897.2016.1184152.

Shokr, M. S., El Baroudy, A. A., Fullen, M. A., El-Beshbeshy, T. R., Ramadan, A. R., El Halim, A. A., Guerra, A. J. T. & Jorge, M. C. O. 2016b. Spatial distribution of heavy metals in the middle nile delta of Egypt. *International Soil and Water Conservation Research,* 4**,** 293-303. doi: 10.1016/j.iswcr.2016.10.003.

Shreem, S. S., Abdullah, S. & Nazri, M. Z. A. 2016. Hybrid feature selection algorithm using symmetrical uncertainty and a harmony search algorithm. *International Journal of Systems Science,* 47**,** 1312-1329.

Shukla, J., Delsole, T., Fennessy, M., Kinter, J. & Paolino, D. 2006. Climate model fidelity and projections of climate change. *Geophysical Research Letters,* 33doi:
10.1029/2005gl025579.

Sillmann, J., Kharin, V. V., Zwiers, F. W., Zhang, X. & Bronaugh, D. 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *Journal of Geophysical Research-Atmospheres,* 118**,** 2473-2493. doi: 10.1002/jgrd.50188.

Silverman, B. W. 2018. *Density Estimation for Statistics and Data Analysis,* London, Chapman and Hall/CRC.

Smith, J. B., Hulme, M., Jaagus, J., Keevallik, S., Mekonnen, A. & Hailemariam, K. 1998. Climate change scenarios. *UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Studies,* 2**,** 3-1.

Stanley, D. J. & Warne, A. G. 1993. Nile delta: recent geological evolution and human impact. *Science,* 260**,** 628-34. doi: 10.1126/science.260.5108.628.

Su, B. D., Jiang, T. & 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. doi: 10.1007/s00704-005-0139-y.

Sunyer, M. A., Hundecha, Y., Lawrence, D., Madsen, H., Willems, P., Martinkova, M., Vormoor, K., Burger, G., Hanel, M., Kriauciuniene, J., Loukas, A., Osuch, M. & Yucel, I. 2015. Inter-comparison of statistical downscaling methods for projection of extreme precipitation in Europe. *Hydrology and Earth System Sciences,* 19**,** 1827-1847. doi: 10.5194/hess-19-1827-2015.

Susnik, J., Vamvakeridou-Lyroudia, L. S., Baumert, N., Kloos, J., Renaud, F. G., La Jeunesse, I., Mabrouk, B., Savic, D. A., Kapelan, Z., Ludwig, R., Fischer, G., Roson, R. & Zografos, C. 2015. Interdisciplinary assessment of sea-level rise and climate change impacts on the lower Nile delta, Egypt. *Sci Total Environ,* 503-504**,** 279-88. doi: 10.1016/j.scitotenv.2014.06.111.

Sylla, M. B., Giorgi, F., Coppola, E. & Mariotti, L. 2013. Uncertainties in daily rainfall over Africa: assessment of gridded observation products and evaluation of a regional climate model simulation. *International Journal of Climatology,* 33**,** 1805-1817. doi: 10.1002/joc.3551.

Tabari, H. & Willems, P. 2018. More prolonged droughts by the end of the century in the Middle East. *Environmental Research Letters,* 13**,** 104005. doi: 10.1088/1748-9326/aae09c.

Taha, M. M. N., Elbarbary, S. M., Naguib, D. M. & El-Shamy, I. Z. 2017. Flash flood hazard zonation based on basin morphometry using remote sensing and GIS techniques: A case study of Wadi Qena basin, Eastern Desert, Egypt. *Remote Sensing Applications: Society and Environment,* 8**,** 157-167. doi: 10.1016/j.rsase.2017.08.007.

Tanarhte, M., Hadjinicolaou, P. & Lelieveld, J. 2012. Intercomparison of temperature and precipitation data sets based on observations in the Mediterranean and the Middle East. *Journal of Geophysical Research-Atmospheres,* 117**,** n/a-n/a. doi: 10.1029/2011jd017293.

Tank, A. K., Wijngaard, J., Können, G., Böhm, R., Demarée, G., Gocheva, A., Mileta, M., Pashiardis, S., Hejkrlik, L. & Kern-Hansen, C. 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *International journal of climatology,* 22**,** 1441-1453.

Tapiador, F. J., Turk, F. J., Petersen, W., Hou, A. Y., Garcia-Ortega, E., Machado, L. a. T., Angelis, C. F., Salio, P., Kidd, C., Huffman, G. J. & De Castro, M. 2012. Global precipitation measurement: Methods, datasets and applications. *Atmospheric Research,* 104**,** 70-97. doi: 10.1016/j.atmosres.2011.10.021.

Tebaldi, C. & Sanso, B. 2009. Joint projections of temperature and precipitation change from multiple climate models: a hierarchical Bayesian approach. *Journal of the Royal Statistical Society Series a-Statistics in Society,* 172**,** 83-106. doi: 10.1111/j.1467-985X.2008.00545.x.

Tebaldi, C., Smith, R. L., Nychka, D. & Mearns, L. O. 2005. Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multimodel ensembles. *Journal of Climate,* 18**,** 1524-1540. doi: 10.1175/Jcli3363.1.

Terink, W., Hurkmans, R., Uijlenhoet, R., Warmerdam, P. & Torfs, P. 2008. Bias correction of temperature and precipitation data for regional climate model application to the Rhine basin. Wageningen Universiteit.

Terink, W., Hurkmans, R. T. W. L., Torfs, P. J. J. F. & Uijlenhoet, R. 2010. Evaluation of a bias correction method applied to downscaled precipitation and temperature reanalysis data for the Rhine basin. *Hydrology and Earth System Sciences,* 14**,** 687-703. doi: 10.5194/hess-14-687-2010.

Teutschbein, C. & Seibert, J. 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. *Journal of Hydrology,* 456**,** 12-29. doi: 10.1016/j.jhydrol.2012.05.052.

Thellmann, K., Golbon, R., Cotter, M., Cadisch, G. & Asch, F. 2019. Assessing Hydrological Ecosystem Services in a Rubber-Dominated Watershed under Scenarios of Land Use and Climate Change. *Forests,* 10**,** 176. doi: 10.3390/f10020176.

Thomson, A. M., Calvin, K. V., Smith, S. J., Kyle, G. P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M. A., Clarke, L. E. & Edmonds, J. A. 2011. RCP4.5: a pathway for stabilization of radiative forcing by 2100. *Climatic Change,* 109**,** 77-94. doi: 10.1007/s10584-011-0151-4.

Tiwari, P. R., Kar, S. C., Mohanty, U. C., Kumari, S., Sinha, P., Nair, A. & Dey, S. 2014. Skill of precipitation prediction with GCMs over north India during winter season. *International Journal of Climatology,* 34**,** 3440-3455. doi: 10.1002/joc.3921.

Tote, C., Patricio, D., Boogaard, H., Van Der Wijngaart, R., Tarnavsky, E. & Funk, C. 2015. Evaluation of Satellite Rainfall Estimates for Drought and Flood Monitoring in Mozambique. *Remote Sensing,* 7**,** 1758-1776. doi: 10.3390/rs70201758.

Trejo, F. J. P., Barbosa, H. A., Penaloza-Murillo, M. A., Moreno, M. A. & Farias, A. 2016. Intercomparison of improved satellite rainfall estimation with CHIRPS gridded product and rain gauge data over Venezuela. *Atmosfera,* 29**,** 323-342. doi: 10.20937/Atm.2016.29.04.04.

Turco, M., Quintana-Segui, P., Llasat, M. C., Herrera, S. & Gutierrez, J. M. 2011. Testing MOS precipitation downscaling for ENSEMBLES regional climate models over Spain. *Journal of Geophysical Research-Atmospheres,* 116doi: 10.1029/2011jd016166.

Unninayar, S. & Olsen, L. 2008. Monitoring, Observations, and Remote Sensing – Global Dimensions. *In:* JØRGENSEN, S. E. & FATH, B. D. (eds.) *Encyclopedia of Ecology.* Oxford: Academic Press.

Ushio, T., Sasashige, K., Kubota, T., Shige, S., Okamoto, K., Aonashi, K., Inoue, T., Takahashi, N., Iguchi, T., Kachi, M., Oki, R., Morimoto, T. & Kawasaki, Z. I. 2009. A Kalman Filter Approach to the Global Satellite Mapping of Precipitation (GSMaP) from Combined Passive Microwave and Infrared Radiometric Data. *Journal of the Meteorological Society of Japan,* 87a**,** 137-151. doi: 10.2151/jmsj.87A.137.

Vano, J. A., Kim, J. B., Rupp, D. E. & Mote, P. W. 2015. Selecting climate change scenarios using impact-relevant sensitivities. *Geophysical Research Letters,* 42**,** 5516-5525. doi: 10.1002/2015gl063208.

Vaze, J., Teng, J. & Chiew, F. H. S. 2011. Assessment of GCM simulations of annual and seasonal rainfall and daily rainfall distribution across south-east Australia. *Hydrological Processes,* 25**,** 1486-1497. doi: 10.1002/hyp.7916.

Wagner, P. D., Fiener, P., Wilken, F., Kumar, S. & Schneider, K. 2012. Comparison and evaluation of spatial interpolation schemes for daily rainfall in data scarce regions. *Journal of Hydrology,* 464**,** 388-400. doi: 10.1016/j.jhydrol.2012.07.026.

Wang, L. & Chen, W. 2014. A CMIP5 multimodel projection of future temperature, precipitation, and climatological drought in China. *International Journal of Climatology,* 34**,** 2059-2078.

Wang, N. Y., Liu, C. T., Ferraro, R., Wolff, D., Zipser, E. & Kummerow, C. 2009. TRMM 2A12 Land Precipitation Product - Status and Future Plans. *Journal of the Meteorological Society of Japan,* 87a**,** 237-253. doi: 10.2151/jmsj.87A.237.

Wang, T., Hamann, A., Spittlehouse, D. L. & Murdock, T. Q. 2011. ClimateWNA—High-Resolution Spatial Climate Data for Western North America. *Journal of Applied Meteorology and Climatology,* 51**,** 16-29. doi: 10.1175/JAMC-D-11-043.1.

Wang, X. J., Zhang, J. Y., Shahid, S., Guan, E. H., Wu, Y. X., Gao, J. & He, R. M. 2016. Adaptation to climate change impacts on water demand. *Mitigation and Adaptation Strategies for Global Change,* 21**,** 81-99. doi: 10.1007/s11027-014-9571-6.

Warren Liao, T. 2005. Clustering of time series data—a survey. *Pattern Recognition,* 38**,** 1857-1874. doi: 10.1016/j.patcog.2005.01.025.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O. & Schewe, J. 2014. The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): project framework. *Proc Natl Acad Sci U S A,* 111**,** 3228-32. doi: 10.1073/pnas.1312330110.

Watson, D. F. 1985. A refinement of inverse distance weighted interpolation. *Geoprocessing,* 2**,** 315-327.

Weigel, A. P., Knutti, R., Liniger, M. A. & Appenzeller, C. 2010. Risks of Model Weighting in Multimodel Climate Projections. *Journal of Climate,* 23**,** 4175-4191. doi: 10.1175/2010jcli3594.1.

Werner, A. T., Schnorbus, M. A., Shrestha, R. R., Cannon, A. J., Zwiers, F. W., Dayon, G. & Anslow, F. 2019. A long-term, temporally consistent, gridded daily meteorological dataset for northwestern North America. *Sci Data,* 6**,** 180299. doi: 10.1038/sdata.2018.299.

Wetterhall, F., Bardossy, A., Chen, D. L., Halldin, S. & Xu, C. Y. 2006. Daily precipitation-downscaling techniques in three Chinese regions. *Water Resources Research,* 42doi:
10.1029/2005wr004573.

Wilby, R. L., Wigley, T. M. L., Conway, D., Jones, P. D., Hewitson, B. C., Main, J. & Wilks, D. S. 1998. Statistical downscaling of general circulation model output: A comparison of methods. *Water Resources Research,* 34**,** 2995-3008. doi: 10.1029/98wr02577.

Wilcke, R. a. I. & Barring, L. 2016. Selecting regional climate scenarios for impact modelling studies. *Environmental Modelling & Software,* 78**,** 191-201. doi: 10.1016/j.envsoft.2016.01.002.

Wilcke, R. a. I., Mendlik, T. & Gobiet, A. 2013. Multi-variable error correction of regional climate models. *Climatic Change,* 120**,** 871-887.

Willmott, C. J. 2013. On the Validation of Models. *Physical Geography,* 2**,** 184-194. doi: 10.1080/02723646.1981.10642213.

Willmott, C. J., Rowe, C. M. & Philpot, W. D. 1985. Small-scale climate maps: A sensitivity analysis of some common assumptions associated with grid-point interpolation and contouring. *The American Cartographer,* 12**,** 5-16. doi: 10.1559/152304085783914686.

Woldemeskel, F. M., Sharma, A., Sivakumar, B. & Mehrotra, R. 2014. A framework to quantify GCM uncertainties for use in impact assessment studies. *Journal of Hydrology,* 519**,** 1453-1465. doi: 10.1016/j.jhydrol.2014.09.025.

Wong, C. L., Venneker, R., Jamil, A. B. M. & Uhlenbrook, S. 2011. Development of a gridded daily hydrometeorological data set for Peninsular Malaysia. *Hydrological Processes,* 25**,** 1009-1020. doi: 10.1002/hyp.7654.

Worner, V., Kreye, P. & Meon, G. 2019. Effects of Bias-Correcting Climate Model Data on the Projection of Future Changes in High Flows. *Hydrology,* 6**,** 46. doi: 10.3390/hydrology6020046.

Wright, D. B., Knutson, T. R. & Smith, J. A. 2015. Regional climate model projections of rainfall from US landfalling tropical cyclones. *Climate Dynamics***,** 1-15.

Wu, W. L., Liu, Y. B., Ge, M., Rostkier-Edelstein, D., Descombes, G., Kunin, P., Warner, T., Swerdlin, S., Givati, A., Hopson, T. & Yates, D. 2012. Statistical downscaling of climate forecast system seasonal predictions for the Southeastern Mediterranean. *Atmospheric Research,* 118**,** 346-356. doi: 10.1016/j.atmosres.2012.07.019.

Wu, Y. F., Zhang, Z. X., Huang, Y. H., Jin, Q., Chen, X. & Chang, J. 2019. Evaluation of the GPM IMERG v5 and TRMM 3B42 v7 Precipitation

Products in the Yangtze River Basin, China. *Water*, 11**,** 1459. doi: 10.3390/w11071459.

Xie, L., Lewis, S. M., Auffhammer, M. & Berck, P. 2019. Heat in the Heartland: Crop Yield and Coverage Response to Climate Change Along the Mississippi River. *Environmental and Resource Economics,* 73**,** 485-513. doi: 10.1007/s10640-018-0271-7.

Xie, P., Chen, M. & Shi, W. 2010. CPC unified gauge-based analysis of global daily precipitation. *24th Conf. on Hydrology, Atlanta, GA, Amer. Meteor. Soc,* 2.

Xue, Y. K., Vasic, R., Janjic, Z., Mesinger, F. & Mitchell, K. E. 2007. Assessment of dynamic downscaling of the continental US regional climate using the Eta/SSiB regional climate model. *Journal of Climate,* 20**,** 4172-4193. doi: 10.1175/Jcli4239.1.

Yang, Z. R. 2010. *Machine learning approaches to bioinformatics,* World scientific.

Yanto, Livneh, B. & Rajagopalan, B. 2017. Development of a gridded meteorological dataset over Java island, Indonesia 1985-2014. *Sci Data,* 4**,** 170072. doi: 10.1038/sdata.2017.72.

Yatagai, A., Arakawa, O., Kamiguchi, K., Kawamoto, H., Nodzu, M. I. & Hamada, A. 2009. A 44-Year Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges. *Sola,* 5**,** 137-140. doi: 10.2151/sola.2009-035.

Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N. & Kitoh, A. 2012. APHRODITE Constructing a Long-Term Daily Gridded Precipitation Dataset for Asia Based on a Dense Network of Rain Gauges. *Bulletin of the American Meteorological Society,* 93**,** 1401-1415. doi: 10.1175/Bams-D-11-00122.1.

Yates, D. N. & Strzepek, K. M. 1998. An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Climatic Change,* 38**,** 261-287. doi: 10.1023/A:1005364515266.

Yip, S., Ferro, C. a. T., Stephenson, D. B. & Hawkins, E. 2011. A Simple, Coherent Framework for Partitioning Uncertainty in Climate Predictions. *Journal of Climate,* 24**,** 4634-4643. doi: 10.1175/2011jcli4085.1.

Youssef, A. M., Pradhan, B. & Hassan, A. M. 2011. Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery. *Environmental Earth Sciences,* 62**,** 611-623.

Yu, L. & Liu, H. Feature selection for high-dimensional data: A fast correlation-based filter solution. Proceedings of the 20th international conference on machine learning (ICML-03), 2003. 856-863.

Zambrano-Bigiarini, M. 2017. *hydroGOF: Goodness-of-fit Functions for Comparison of Simulated and Observed* [Online]. Available: https://CRAN.R-project.org/package=hydroGOF [Accessed 17 Apr 2018].

Zambrano-Bigiarini, M., Nauditt, A., Birkel, C., Verbist, K. & Ribbe, L. 2017. Temporal and spatial evaluation of satellite-based rainfall estimates across the complex topographical and climatic gradients of Chile. *Hydrology and Earth System Sciences,* 21**,** 1295-1320. doi: 10.5194/hess-21-1295-2017.

Zeleny, M. 1973. Compromise programming, multiple criteria decision-making. *Multiple criteria decision making. University of South Carolina Press, Columbia***,** 263-301.

Zhang, L. & Zhou, T. 2011. An assessment of monsoon precipitation changes during 1901–2001. *Climate dynamics,* 37**,** 279-296.

Zhang, Z., Xu, C.-Y., El-Tahir, M. E.-H., Cao, J. & Singh, V. 2012. Spatial and temporal variation of precipitation in Sudan and their possible causes during 1948–2005. *Stochastic environmental research and risk assessment,* 26**,** 429-441.

Zittis, G. 2018. Observed rainfall trends and precipitation uncertainty in the vicinity of the Mediterranean, Middle East and North Africa. *Theoretical and Applied Climatology,* 134**,** 1207-1230. doi: 10.1007/s00704-017-2333-0.