STUDY ON CLIMATE VARIABILITY, CLIMATE EXTREMES OVER DHAKA CITY AND PEOPLE'S PERCEPTION ABOUT ITS IMPACT

Farzana Mahbub
University of Dhaka
2 PUBLICATIONS 3 CITATIONS

Md. Marufur Rahman
University of Dhaka
7 PUBLICATIONS 83 CITATIONS

Md. Abdul Mannan
Storm Warning Centre
60 PUBLICATIONS 221 CITATIONS

Fatima Akter
University of Dhaka
9 PUBLICATIONS 155 CITATIONS

STUDY ON CLIMATE VARIABILITY, CLIMATE EXTREMES OVER DHAKA CITY AND PEOPLE'S PERCEPTION ABOUT ITS IMPACT

Farzana Mahbub[1], Md. Marufur Rahman[1], Md. Abdul Mannan[2] and Fatima Akter[3]

ABSTRACT

Under the present global warming scenario, area specific analysis of climate variability and extremes are in high demand especially for an ever-growing urban place like Dhaka city, having huge exposure of people and property. A successful urban planning of the city prerequisites a profound study about its vulnerabilities where climatic extremes play a significant role. Trend and anomaly analysis of climate variability and extremes of Dhaka city during 1981-2017 disclosed that the annual rainfall is decreasing at a rate of -9.87mm (-11.71 Sen's slope) per year while both maximum and minimum annual temperature are increasing about 0.017ºC and 0.028ºC per year respectively, which will be 30.6°C and 25.9°C by 2075 according to projection. Recent decades showed higher standard deviations, shifting of distribution (rainfall) and mean (temperature) and also sudden increases of both parameters. Thus the city climate is becoming extreme and threatened by more frequent heat waves while rainfall is becoming extreme in July and August making the southern part of Dhaka city vulnerable to flooding situations. Due to the negative correlation between parameters, rainfall extremes are less likely to take places in the years of temperature extremes. In spite of some contradictory findings with scientific analysis; survey result of perception study reveals that the climate variability and extremes are well perceived by the city people who also wisely depicted the factors of changes, affected sectors, and requirements for better preparedness as well as disaster management.

Introduction

Climate variability means the annual or seasonal deviation or fluctuations of climatic parameters (rainfall, temperature etc.) from the mean. The range of the variability reveals characteristics of extremes in terms of intensity and shape of frequency distribution (Solomon and Qin, 2013; Loo, Billa, & Singh, 2015; Rahman & Lateh, 2017). Such changes may often be statistically significant that persist for a long period of time or over a specific area, which can be defined as temporal or spatial variability of climate respectively; both are analyzed to characterize a climate and to deduce evidence of climatic change at local to global scale (Priyan, 2015). The IPCC (2013) (intergovernmental panel on climate change) in their AR5 report predicted that- "extreme precipitation events over wet tropical regions will very likely (90-100% probability) become more intense and more frequent as global mean surface temperature increases. Changes in local extremes on daily and sub-daily timescales are expected to increase by roughly 5 to 10% per 1°C of warming (medium confidence)." Islam (2009) has predicted on his study that at least 5.3% annual rainfall in Bangladesh will be increased by 2018. While most of the climate change studies conducted over Bangladesh agree on increasing trend of annual rainfall, the central seem to show opposite changes but with more extreme climatic behavior. Study regarding Dhaka city shows increasing trend (2.7 mm/year for 1979-2009, mostly influenced by last 10 years) of annual maximum daily rainfall and extremes(more events in last 5 years) from both observed data analysis and projection (used Regional climate modelling- PRECIS) (Murshed, Islam and Khan, 2011). The city has a humid sub-tropical monsoon climate and receives approximately 2000mm of rainfall annually (lower than country average of 2456.38 mm), more than 80% of which falls during the monsoon season from June to September (Pramanik and Stathakis, 2016). Again, almost 60% of the greater Dhaka city lies below the mean annual maximum water level from the surrounding rivers and as the ever growing urbanization is taking place towards north and eastern flood prone area of the city, there is a strong possibility that in near future Dhaka might strike by continual water logging events if extreme/erratic rainfall events tend to accelerate and are accompanied by mismanagement of storm water drainage. For instance, 40% of the Dhaka west region was inundated by the highest ever recorded daily rainfall (about 341mm/day) on September 2004; the study further claims that extreme rainfall event will increase with time and >10mm/day amount of rainfall can cause water logging by obstructing surface runoff (Murshed, Islam and Khan, 2011). Majority of the rainfall studies used station based data that are sparsely distributed all over the country and only one station in Dhaka; therefore, to get better spatial variation at macro level, gridded data can be utilized.

[1] *Dept. of Disaster Science and Management, University of Dhaka, Dhaka, Bangladesh.*
[2] *Bangladesh Meteorological Department, Agargaon, Dhaka, Bangladesh.*
[3] *Dept. of Geography and Environment, University of Dhaka, Dhaka, Bangladesh*
E-mail of corresponding authors: fmhridita@gmail.com, mamannanbmd2015@gmail.com

As rainfall depends on factors like- relief of landmass, direction of humid/moisture wind and temperature; abrupt change of any factor could alter rainfall pattern positively or negatively. The impact of climate change again depends on physiographic settings of a particular area and its interaction with the change(Kabir and Golder, 2017). The combined effect of urbanization and climate change could raise urban temperatures to levels that the city area may have 2-3ºC higher temperature in hot summer than surrounding countryside as a consequence of urban heat island (UHI) (Alam and Rabbani, 2007). Projection exhibits rise of average temperature about 1.3ºC for Bangladesh where more warming of temperature would take place in winter (1.1 ºC) than in summer (0.8 ºC) (Shourav et al., 2016). The vulnerable group (urban poor, children, elderly etc.) would be the worst sufferer towards climate extreme impacts such as frequent heat waves, alteration to infectious disease vectors distributions, scarcity of safe water and productivity. Therefore, this study aims at comprehensive investigation of climate variability to understand the escalating vulnerability implied by extremes in Dhaka city and how people perceive the risk. In order to assist in policy making, Dhaka city and its surrounding (area under DAP) have been taken under consideration.

Materials and Methods

Point observation data of rainfall and temperature for past 37 years (1981-2017) have been collected from Bangladesh Meteorological Department (BMD) and with the help of satellite data (CHIRPS) gridded rainfall data (0.25°x0.25°resolution) has been generated for better spatial analysis. Spatial variability of rainfall is obtained by Kriging interpolation which performs better for monthly data and final output is the weighted average of the nearby stations derived through CHRIPS. Comparison between two datasets is done by percent bias calculation which is explained by following formula:

$$PB = 100\frac{\sum(C-G)}{\sum G} \quad (1)$$

Where, *PB*= Percent bias; *G*= rain gauge rainfall estimation; *C*= CHIRPS-based rainfall estimate. For climate projection, ACCESS 1.0 version of coupled model was incorporated to get Coupled Model Intercomparison Project Phase 5 (CMIP5) data (for RCP 4.5 scenario) from Climate Explorer managed by the Royal Netherlands Meteorological Institute (KNMI). Microsoft Excel 2013, MAKESENS (1.0) and RClimDex (1.0) has been utilized to analyze temporal variability through linear regression (best-fit line considering all variables) which determines existence and degree of monotonic changes (consistently increasing or decreasing trends). The Mann-Kendall test done in MAKESENS (1.0), is a simple non-parametric trend test (applicable for all distributions/assumptions) which follows pair-wise comparison method (each data is compared to all subsequent data) of observed values yi, yj of the random variable. Each pair is then inspected to find out whether yi>yj or yi<yj (if former pair=P & later pair=M); then S statistics is calculated by: S = P−M. The Z statistic is calculated from S statistic and variance, positive or negative value of Z indicates an upward or downward trend. The Sen's estimator of slope shows the magnitude of changes in data where slope of all data value pair is calculated by following formula:

$$Q_i = \frac{x_j - x_k}{j-k}\text{; (Where, j>k)} \quad (2)$$

If there are *n* values *xj* in the time series we get as many as *N = n(n-1)/2* slope estimates *Qi*. The Sen's estimator of slope is the median of these N values of *Qi* (Salmi *et al.*, 2002). The RClimDex (1.0) software is designed to calculate indices of climate extremes according to user delivered threshold values that requires daily time scale data as input and delivers best fit trend lines with magnitude/slope value, slope error and significance (P value). For more comprehensive analysis, Precipitation anomaly percent has been computed through following equation:

$$P_a = \left(\frac{P-\bar{P}}{\bar{P}} \times 100\right)\% \quad (3)$$

Where, *P*= average rainfall of certain period/year and $\bar{P}$= long-term average rainfall. Moreover, standard deviation and Pearson correlation have also been calculated in Microsoft Excel 2013 for this study. The Easy fit 5.6 professional software is used to compute fitted probabilistic distributions by Kolmogorov–Smirnov test (goodness-of-fit test) to analyse rainfall distribution pattern and its changes through decadal periods form 1981-2017 (Mehrannia and Pakgohar, 2014). The test provided fitted distributions for probability density functions and cumulative distribution functions along with mean and standard deviations to investigate level of risk and extremity. Furthermore, a structured questionnaire survey has been materialized to determine the gap between actual information and knowledge, and preferred action to minimize so. Hence, perception study is necessary for understanding practical manifestation of scientific information.

Results and Discussions

The observed rainfall data is taken from Agargaon station while other five distinctive stations were selected for their unique values and relatively even distributions based on the data from CHRIPS. The stations are located in Gazipur, Gulshan, Motijheel, Narayanganj, and Rupganj; in some cases, they show variant results compared to observed data (Agargaon) which may be due to the distance and methodological differences of data acquisition. in comparison with observational data, CHRIPS data has overestimated in pre-monsoon season and underestimated the rainfall of winter as depicted in Figure 1. CHRIPS performs better in cases of annual, monsoon and post-monsoon rainfall estimation and shows least difference (less than 5%) in monsoon season.

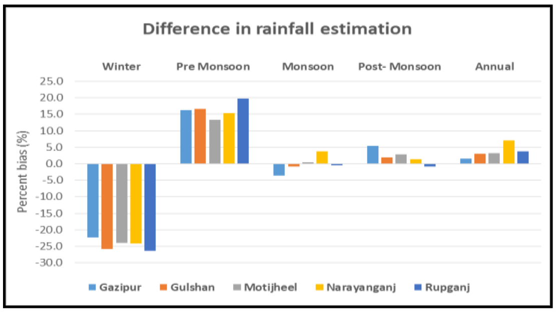

Figure 1. Annual and seasonal difference in rainfall estimation compared with observed rainfall in Dhaka during 1981-2017

Although the region experiences a good amount of rainfall annually (observed annual average rainfall 2059.9 mm with standard deviation of 489.08), but trend shows degradation in total amount of annual rainfall at a high rate of -9.86 mm per year (Sen's Slope value -11.731mm per year) which is delineated in Table 1 along with seasonal trend values. Unlike other seasons, monsoon has the highest amount of rainfall (increasing) and HR events of which July and August showed positive rainfall trend and highest number of heavy rainfall (HR≥44mm/day) events. The number of non-rainy days (<1mm/day) showed decreasing to no change for July and increasing to no change for August; hence total rainfall and HR events will spread through July causing prolonged/erratic rainfall and for August, it would be extreme due to increasing intensity of one-day precipitation. Other rainy months (March-October) are heading towards drier weather due to the increasing number of non-rainy days and decreasing trend of annual rainfall and number of HR events. These may affect urban poor by creating water logging in wet season and safe water scarcity in dry season. Also, sudden increase in prolonged heavy amount of rainfall and daily maximum rainfall is depicted in particular years after 2000. The last half of study period (2000-2017) shows consecutive pattern of less and heavy rainfall including sudden extensive high values; for instance, prolonged rainfall (2007 and 2017) and one day maximum rainfall (2004 and 2009) after the year 2000 indicating to an unusual and extreme climatic pattern. In addition, Monthly maximum consecutive 5-day precipitation amount showed an upward trend about 0.507 mm increase of rainfall per year. Even consecutive dry days (relative rainfall<1mm) is increasing significantly at 1.027 rates showing extensive high values found after 2000 and consecutive wet days (relative rainfall≥1mm) decreasing at a rate of -0.083 days per year. Therefore, rainfall will be high in remaining less number of wet days i.e. extensive high values in one-day precipitation will occur. According to Table 2, rainfall pattern is changing with time and shows high variability with occasional extremes which are verified by changes in distribution pattern and also by decreasing mean (μ) with increasing standard deviation (SD,σ) (except for 2011-2017, due to short period data). As in 2001-2010 period, shift from normal to logistic distribution reveals that rainfall pattern was extreme for that period; as long positive tail (positively skewed) denotes larger range (difference between maximum and minimum rainfall) and higher kurtosis (peakedness) results from rare extreme deviations, hence higher SD with lower mean resulted in sudden extreme rainfall as seen in Table 2 for maximum rainfall.

***Table 1**. Seasonal & annual distribution and trend of rainfall in Dhaka city during 1981-*

Time/seasons	Average rainfall	MK Test (Sen's Slope)
Winter	35.3	-0.580
Pre Monsoon	472.1	-7.884 **
Monsoon	1353.6	0.563
Post- Monsoon	196.7	-1.453
Annual	2059.9	-11.713

** if $\alpha = 0.01$ level of significance

Table 2. Decadal variation of distribution of rainfall

Period	Mean □□□	Normal (σ)	Logistic (σ)	Max. rain(mm)
1981-1990	6.04	15.99	8.82	176.0
1991-2000	5.71	15.46	8.52	158.0
2001-2010	5.69	17.08	9.42	341.0
2011-2017	4.90	13.37	7.37	149.0

(shaded block represents best-fitted distribution)

Spatial distribution of rainfall in Figure 2 revealed that south and south eastern regions are exposed to heavy rainfall (≥50 mm per day) and high amount of annual rainfall as well; which resembles with the monsoon rainfall pattern of whole Bangladesh (i.e. south and south eastern part gets the most rainfall than north and north western part).

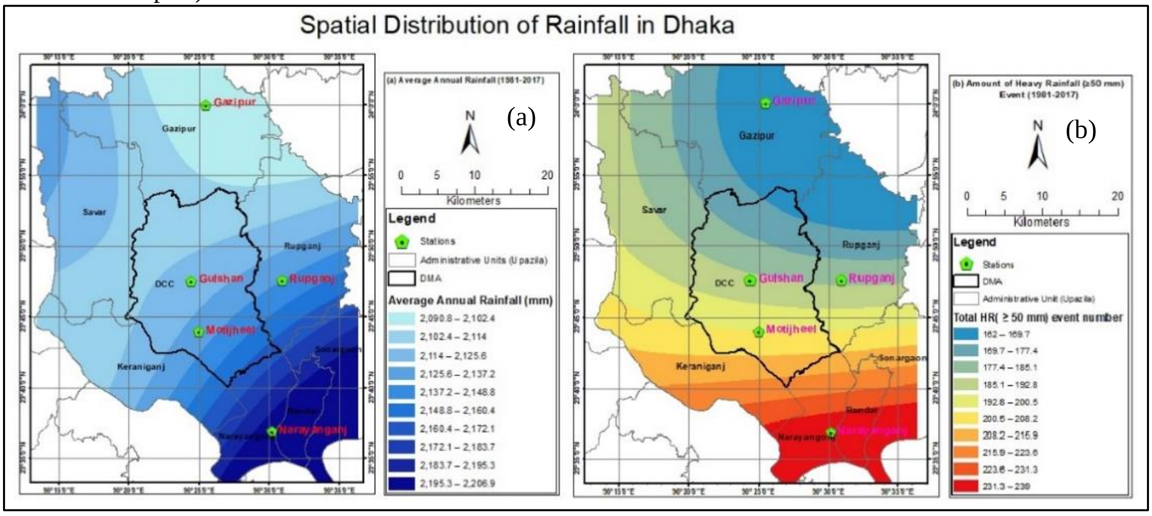

Figure 2. Spatial distribution of (a) average annual rainfall; (b) amount of HR (≥50 mm per day) event in Dhaka during 1981-2017

The average maximum and minimum annual temperatures are 30.83°C and 21.92°C with SD about 0.52°C and 0.47°C respectively. Both day and night time temperatures are increasing significantly at a rate of 0.017°C and 0.028°C; where, monsoon day time (especially May) and winter night time (especially December) showed rapid increase. The change of maximum temperature from the average resembles a consecutive pattern (fluctuates around average in a decadal manner) but change of minimum temperature shows quite obvious shift from below average line to above it. The diurnal temperature variation is decreasing as 99th and 1st percentile value of maximum temperature decreases with increasing percentile values of minimum temperature. It's found that the nights are warming up at a higher rate where day time temperature will show high variation with more possibility of heat wave rather than cold wave. Additionally, warm spell duration indicator shows increasing trend at a rate of 0.17days per year. Although, number of days having high daytime temperature decreases, extensive values in one day maximum temperature would be seen due to the higher standard deviation (see Table 3). Furthermore, due to decreasing SD, minimum temperature would not fluctuate rapidly; however, warm nights would be observed very frequently. Shifting of the average temperature will result in frequent extreme climatic events. For instance, 2011 has lowest daytime temperature about 17.9°C (1st percentile) while its immediate previous year (2010) has 63 days of high daytime temperature (≥35°C) and 42 days of high night time temperature (≥28°C).

***Table 3**. Decadal variability of maximum and minimum temperature in Dhaka during 1981-2017*

Maximum	1981-1990	1991-2000	2001-2010	2011-2017
99th percentile	37.50	37.35	36.80	37.04
1st percentile	22.20	21.60	20.65	19.91
Average	30.77	30.83	30.79	31.02
SD	3.31	3.50	3.60	3.77
Minimum	1981-1990	1991-2000	2001-2010	2011-2017
99th percentile	28.40	28.50	28.70	28.90
1st percentile	10.34	9.60	11.00	10.91
Average	21.74	21.67	22.10	22.39
SD	5.13	5.32	4.83	4.96

There is a negative correlation between temperature and rainfall for all seasons except in post-monsoon season when minimum temperature seems to avail rainfall occurrence (Pearson's r =0.074). Since the annual rainfall is decreasing with increasing temperature (inverse relationship), it can be stated that the wet years / extreme rainfall years may not experience temperature extremes and it is likely to be reversed for dry years. Rainfall seems to act more contrariwise with response to the changes of maximum temperature than with minimum as depicted in Figure 3.

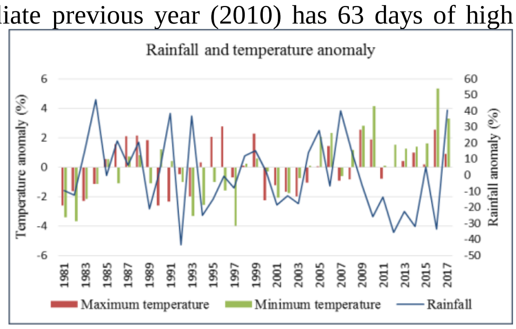

Figure 3. Rainfall and temperature anomaly during 1981-2017 in Dhaka city

Since there is consistency between hindcasts and observed temperature data, projection has been made where maximum and minimum temperature show about 0.04°C and 0.02°C increase of temperature per year respectively as shown in Figure 6. The day and night temperature which are 27.9°C and 24.0°C now (2017), will be 30.6°C and 25.9°C by 2075. Due to the inconsistency of model derived data with observed rainfall (showed opposite trend), the future climate may not uphold the foreseen rainfall condition precisely for future.

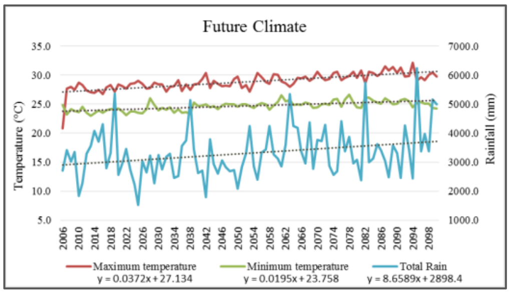

Figure 6. Future climate scenario in

Although most of the people (70%) agreed with the scientific findings (increasing temperature but decreasing rainfall) still they believe that both temperature and rainfall are increasing (76%) and they suspect that it will be extreme (81%) in future. It is perceived by 80% people that anthropogenic factor is playing a vital role in exaggerating the climate change impact in the study area and they pointed out major factors of causation as seen in Figure 4. A significant number of people seem to be unaware about urban heat island (UHI) and among the people who know, 73.3% agreed that UHI exists in Dhaka city and it intensifies the negative impact posed by increasing temperature (63.3%). A large number of people think they are moderately vulnerable to climate extremes and its associated hazards which mostly affects them in following terms as represented in Figure 5.

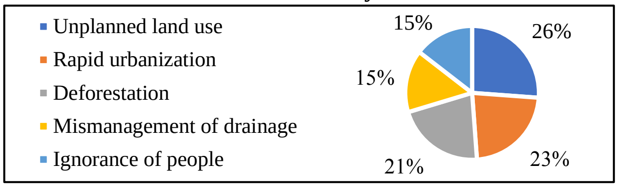

Figure 4. Major anthropogenic factors responsible for enhancing climate impact

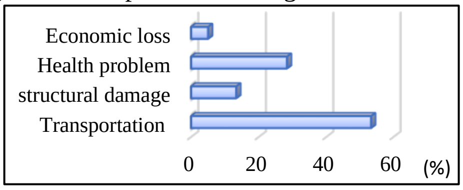

Figure 5. Most affected sectors for climate extremes in Dhaka city

People think that disaster and crisis management, energy and water resource management and urban planning will be the most challenging sectors which can be met by strengthening existing management system in and within those sectors. About 45% responders preferred awareness raising programs for better preparedness while 38% people preferred sharing of latest scientific information/ knowledge on climate extremes. Some major associated hazards have been depicted by the people such as- water logging(24%),health hazards (23%), heat waves (22%), heavy rainfall (15%) etc. Figure 6 gives better picture of such hazards and their sources of information. In most of the cases news broadcasting on television or newspaper are seen to be effective and reliable source of information to people. They also preferred phone or internet as an emerging most effective source.

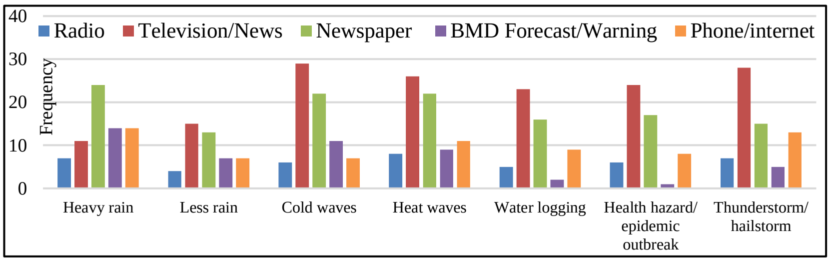

Figure 6. Hazard specific sources of information and warning

Conclusions

Rainfall behavior shows changing tendency with significant indication that the rainfall is becoming extreme in terms of maximum one day precipitation. A comprehensive analysis of rainfall has been conducted for a detail spatial distribution in city domain. A better result can be computed if longer period microclimatic data are available and incorporated in the study. As southern part of the city appears more vulnerable to heavy rain and monsoon shows positive trend with erratic and sudden extreme behavior in July and August, better preparedness measures should be taken especially for that place and time. Again, both day time and night time temperature were seen to be increasing which refers to the shift of average and increases the probability of heat waves; nights are warming at a higher rate as well as the winter season. Recent period shows more extreme behavior (sudden extensive values and consecutive pattern) than previous time for both parameters. As they are inversely related, a sudden increase in temperature may cause a sudden fall in rainfall and viceversa. The concept of climate variability, correlation as well as extremes are well perceived by the people. Unplanned land use is thought to be the major anthropogenic reason that influencing the change while they suggested to enhance capacity of the related fields which are at risk due to the changing climate. The people living in the study area also recommended that taking preparedness will be easier to them if the information is transmitted through quicker and reliable sources such as news broadcast, phone message or internet.

References

Alam, M. and Rabbani, G. M. D. (2007) 'Vulnerabilities and responses to climate change for Dhaka', *Environment and Urbanization*, 19(1), pp. 81–97. doi: 10.1177/0956247807076911.

Islam, M. N. (2009) 'Rainfall and Temperature Scenario for Bangladesh', *The Open Atmospheric Science Journal*, 3(1), pp. 93–103. doi: 10.2174/1874282300903010093.

Kabir, H. and Golder, J. (2017) 'Rainfall Variability and Its Impact on Crop Agriculture in Southwest Region of Bangladesh', *Journal of Climatology & Weather Forecasting*, 05(01), pp. 1–20. doi: 10.4172/2332-2594.1000196.

Loo, Y. Y., Billa, L. and Singh, A. (2015) 'Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia', *Geoscience Frontiers*. Elsevier Ltd, 6(6), pp. 817–823. doi: 10.1016/j.gsf.2014.02.009.

Mehrannia, H. and Pakgohar, A. (2014) 'Using EASY FIT Software for Goodness-Of-Fit Test and Data Generation', *International Journal of Mathematical Archive*, 5(1), pp. 118–124.

Murshed, S. B., Islam, A. S. and Khan, M. S. A. (2011) 'Impact of Climate Change on Rainfall Intensity in', *3rd International Conference on Water & Flood Management (ICWFM?2011)*, pp. 1–8.

Pramanik, M. M. A. and Stathakis, D. (2016) 'Forecasting urban sprawl in Dhaka city of Bangladesh', *Environment and Planning B: Planning and Design*, 43(4), pp. 756–771. doi: 10.1177/0265813515595406.

Priyan, K. (2015) 'Spatial and Temporal Variability of Rainfall in Anand District of Gujarat State', *Aquatic Procedia*. Elsevier B.V., 4(Icwrcoe), pp. 713–720. doi: 10.1016/j.aqpro.2015.02.092.

Rahman, M. R. and Lateh, H. (2017) 'Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model', *Theoretical and Applied Climatology*. Theoretical and Applied Climatology, 128(1–2), pp. 27–41. doi: 10.1007/s00704-015-1688-3.

Salmi, T. et al. (2002) Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Solpe Estimates the Excel Template Application MAKESENS, Finnish Meteorological Institute, Air Quality Research. doi: 456-789X.

Shourav, S. A. *et al.* (2016) 'Historical trends and future projection of climate at Dhaka city of Bangladesh', *Jurnal Teknologi (Sciences & Engineering)*, 78(2), pp. 69–75. doi: 10.13140/RG.2.1.2236.8880.

Solomon, S. and Qin, D. (2013) Climate Change 2007 The Physical Science Basis The, Journal of Chemical Information and Modeling. doi: 10.1017/CBO9781107415324.004.