Assessment of Climate Change Impact on Urban Heavy Rainfall Extremes Alexandria, Egypt Case Study

Doctor

Mohamed E. Hafez

Assistant professor of Applied Climatology
Department of Geography & GIS, Faculty of Arts
Helwan University

Abstract

Rainfall extremes pose a serious threat to Alexandria in general; especially that precipitated on urban areas. So this study of an assessment of rainfall extremes on Alexandria has been carried out to better understand the potential causes and develop proposals to minimize their serious. The study aims to Analysis rainfall characteristics, trend estimate for historical series of rainfall, extremes rainfall estimate by nested regional climate modeling technique and rainfall extremes impact evaluate on urban for Alexandria to mitigate of damages to infrastructure and economic losses resulting from future rainfall extremes. The study depends on analytical methodology based on Database building, with several processing techniques applied. Those included preprocessing for radar data format (TRMM_3B42_Daily v7), those were coupled with field observations and data analyses with emphasis on the days of rainfall extremes in last years the data of three rainfall stations. The study concluded, that the poor quality of infrastructure and services are the key drivers of these threats. Poor land-use planning against rainfall extremes, absence of building construction standards, and the impact of climate change are some contributing factors to urban drainage vulnerability. The study recommends that Alexandria authorities are taken adequate precautions to protect from rainfall extremes after predictions of rainfall event, put budget allocated to upgrade urban drainage system and develop innovative infrastructure solutions to enhance the flash flooding resilience of Alexandria.

Keywords: Climate change, Rainfall extremes, Urban drainage, Alexandria.

الملخص العربي

تشكل الأمطار الكثيفة الفجائية تهديداً خطيراً للإسكندرية بوجه عام؛ وبخاصة المناطق الحضرية. لذلك تم إجراء هذه الدراسة لتقييم هطول الأمطار الكثيفة الفجائية على الإسكندرية لفهم الأسباب الكامنة لتأثيرها السلبي، ووضع المقترحات للحد من أضررها. وتهدف الدراسة إلى تحليل خصائص الأمطار وتقدير الاتجاه العام طويل المدي للأمطار في الإسكندرية، وتقدير تساقط الأمطار الكثيفة الفجائية بتقنية النمذجة المناخية الإقليمية، وتقييم تأثيرها على المناطق الحضرية في الإسكندرية، للتخفيف من الأضرار التي لحقت بالبنية التحتية والخسائر الاقتصادية الناجمة

عنها، وتفادي ذلك في حالات سقوط الأمطار الكثيفة الفجائية في المستقبل. وتعتمد الدراسة على المنهج التحليلي الكمي القائم على بناء قاعدة البيانات مع تطبيق العديد من تقنيات المعالجة، وشمل ذلك المعالجة المسبقة لبيانات الرادار (TRMM_3B42_Daily v7)، والملاحظات الميدانية وتحليلات البيانات الرصدية مع التركيز على أيام تساقط الأمطار الكثيفة الفجائية في السنوات الأخيرة؛ وبخاصة عامي ٢٠١١ و٢٠١٥م ، وباستخدام بيانات ثلاث محطات أمطار هي: رأس التين والنزهة وأبو قير. وخلصت الدراسة إلى أن سوء نوعية البنية التحتية والخدمات هي العوامل الرئيسية للأضرار التي تعرضت لها بالإسكندرية، ومن العوامل الرئيسة التي تسهم في الضعف في مجال الصرف الصحي في المناطق الحضرية بالإسكندرية ضعف تخطيط استخدامات الأراضي، وغياب معايير تشييد المباني، وتأثير تغير المناخ. وتوصي الدراسة بأن تتخذ سلطات الاسكندرية الاحتياطات الكافية للحماية من الأمطار الكثيفة الفجائية بعد التنبؤات بحدوثها، ووضع الميزانية المخصصة لرفع مستوى نظام الصرف الحضري، وتطوير حلول البنية التحتية المبتكرة لتعزيز مرونة الفيضانات الناتجة عن الأمطار الكثيفة في الإسكندرية.

Introduction

All over the globe, urbanized cities are major sources of economic and human development, Many are also of historical and cultural significance such as Alexandria. Rainfall extremes pose a serious threat to these cities in general and the urban areas in particular. The poor quality of infrastructure and services are the key drivers of these threats. Poor land-use planning against rainfall extremes, absence of building construction standards, and the impact of climate change are some contributing factors to urban vulnerability.

Alexandria is an historical and cultural significance city, located on the southern coast of the Mediterranean sea, and the second largest city of Egypt. For more than a century sewer systems have been constructed at large scale in Alexandria city. These sewer systems have reduced the vulnerability of the city in general, but at present, with this aspect not being considered in development could make them more vulnerable to rainfall extremes, partly due to the lack of consideration to what occurs when the design criteria are exceeded. Next to this increase in the vulnerability, there is strong evidence that due to the global warming the probabilities and risks of sewer surcharge and flooding are changing. In their Fourth Assessment Report the Intergovernmental Panel on Climate Change (IPCC, 2007) indeed reports for the late 20th century a worldwide increase in the frequency of extreme rain storms as a result of global warming. most often Climate change impact estimations on climatic variables including rainfall extremes, are based on the results of simulations with climate models. Regional Climate Models can use initial and boundary conditions from the output of General Circulation Models for selected time periods of the global simulation. However, at present the understanding of the processes involved in rainfall formation is limited, especially at high spatial and temporal resolution (Baker and Peter, 2008).

Previous Studies (Bibliography)

Arnbjerg-Nielsen (2008) This study compared three different downscaling methods on estimation of climate factors Causing rainfall of extreme storms for Denmark and pointed out that those different methods indeed exhibit systematic differences; and found that the rainfall changes obtained by the BLRP method lead to underestimations in comparison with two other methods, one which makes direct use of RCM rainfall results and one based on climate analogs. It was explained by the fact that changes were estimated based on general rainfall extremes properties, such as mean cell intensity, mean cell duration, and rate of rainfall extremes arrival. this requires of impact results are presented based on ensembles of climate models, greenhouse gasses emission scenarios, and a careful evaluation of all other scenario uncertainties within the urban drainage context.

Ntegeka and Willems (2008) Have shown for Belgium that rainfall extremes show multidecadal oscillations, with oscillation peaks in the 1910s–1920s, the 1960s and recently during the past 15 years; when compared quantiles in moving block periods of 5, 10 and 15 years' length, with quantiles derived from the entire series of 10-minute rainfall intensities. For the winter season, the increase in heavy rainfall extremes during the past 15 years could in part be around half of the increase by the climate oscillation and around half by climate change. For the summer season, the increase could entirely be explained by the climate oscillation peak. The climate change contribution was found to be consistent with predictions by regional climate models.

Ntegeka et al. (2008) Also, This study has shown for Belgium – based on 31 RCM and about 20 GCM simulations for four IPCC emission scenarios, that the climate change factors strongly depend on the climate model run considered. For a return period of one year, with applied a perturbation approach to historical input time series of hydrological models in the number of events and in the probability distribution of extreme rainfall intensities - at the daily time scale - Found variations from 0.88 (12% decrease) to 1.22 (22% increase) in daily rainfall intensities, while for a return period of 10 years the climate change factor varies between 0.90 and 1.52. Also Nguyen et al. (2008) Found that the use of different GCMs may change the climate change impact estimate on urban drainage design flows from positive to negative.

Semadeni-Davies et al. (2008) This study derived climate factors for 6 hours rainfall intensities in southern Sweden, and found that these factors vary widely from month to month between a 50% decrease and a 500% increase for the period 2071s- 2100s depending on season, duration, intensity level, and rate of rainfall extremes. This confirms that both season and intensity level need to be taken into account.

Larsen et al. (2009) This study Analyzed the impact of climate change on the Intensity-Duration-Frequency-curves for rainfall extremes across Europe. Although the results are clearly very uncertain they confirm the fact that climate change factors do depend on duration, return period, and location.

Sunyer and Madsen (2009) This study derived from compared 3 different stochastic rainfall models for downscaling of rainfall extremes events north of Copenhagen: based on Markov chain semi-empirical models and the Neyman–Scott Rectangular Pulses (NSRP) model, that all 3 models represent well the increase in the number of extreme events, but only the NSRP model reflected well the change in variance.

Willems and Vrac (2010) The study focused on compared historical Intensity-Duration-Frequency relationships with RCM and GCM outputs for central Belgium. The comparison covers a range from 1 to 15 days for 17 GCM runs with the ECHAM5 model, after simulation of the A1B emission scenario. It was found that the difference in spatial scale most likely is the main factor explaining the bias, next to the limited accuracy of the climate model in describing extreme short-duration rainfall.

Willems et al. (2012) This study provides a critical review of the current state-of-the-art methods for assessing the impacts of climate change on rainfall at the urban catchment scale, following an overview of some recent advances in the development of innovative methods for assessing the impacts of climate change on urban rainfall extremes as well as on urban hydrology.

Zevenbergen et al. (2017) The study provides Analyzed the October 2015s storm in Alexandria led to flooding of historical proportions. It was found that the use of rainfall forecasting in rainfall extremes modelling can be one of the first useful and cheap mitigation measures; where The high variability and uncertainty of rainfall call for a robust and flexible strategy for Alexandria, which considers a portfolio of measures able to absorb the negative consequences of extreme events.

Objectives

The study aims to achieve the following objectives:

1- Studying climate features and rainfall characteristics include temperature values, rainfall; especially an average of 24 hours rainfall, Maximum rainfall and probability of rainfall.

2- Trend estimate for historical series of rainfall at Alexandria.

3- Analysis extreme rainfall by nested regional climate modeling technique.

4- Evaluate rainfall extremes impact urban environment at Alexandria.

Methodology

The study depends on analytical methodology based on database building, and several processing techniques applied. Those included preprocessing for radar data format, classification, and time-series analysis. Those were coupled with field observations and data analyses. Used rainfall data from The Egyptian Meteorological Organization and earthdata from nasa (Giovanni). Giovanni provides 24-hourly rainfall forecast, begin from 01-01-1998s and end at 31-05-2017s. During this study, the rainfall forecast from the Egyptian Meteorological Organization was not readily available. So the rainfall forecast from the Giovanni website was downloaded for the months of October, November and Decmber at 2010s & 2015s (https://giovanni.sci.gsfc.nasa.gov/).

A Total daily analysis for accumulated of rainfall Alexandria has been conducted for the period 2010s–2015s. This analysis (based on TRMM Radar platform images) provides quantitative information about rainfall extremes and features such as densification. rainfall total daily maps have been constructed for 12 November 2011s, 25 October 2015s and 4 November 2015s, using the TRMM radar enhanced thematic mapper (TRMM_3B42_Daily v7) for region 28E, 30N, 31E, 32N. Precipitation total daily for every 0.25 deg., has been used for conducting a supervised classification (maximum likelihood), and the changes in urban drainage trends at Alexandria, have subsequently been analysed in ArcGIS (version 10.3). These data were registered to geographical coordinates based on Alexandria topographic map.

Fieldwork was carried out in order to inspect extreme rainfall storms affected areas and to collect additional data regarding flash flood features (intensity, duration, frequency and damages), for assessing the impacts of climate change on urban rainfall extremes. Study illustrates the typical climate in Alexandria, based on a statistical analysis of historical days weather reports and model reconstructions from January 1960s to December 2016s, With emphasis on the days of rainfall extremes in last years by using three rainfall stations where daily rainfall is measured with rain gauges at Alexandria (Table 1 & Figure 1).

Table 1. Rainfall stations in Alexandria

Rainfall Station	Site	Latitude (N) (Decimal degrees)	Longitude (E) (Decimal degrees)
Ras El Teen	West of Alexandria	31.19	29.88
Abu Kir	East of Alexandria	31.33	30.08
Nozha	South of Alexandria	31.19	29.95

Source: Egyptian Metrological Authority.

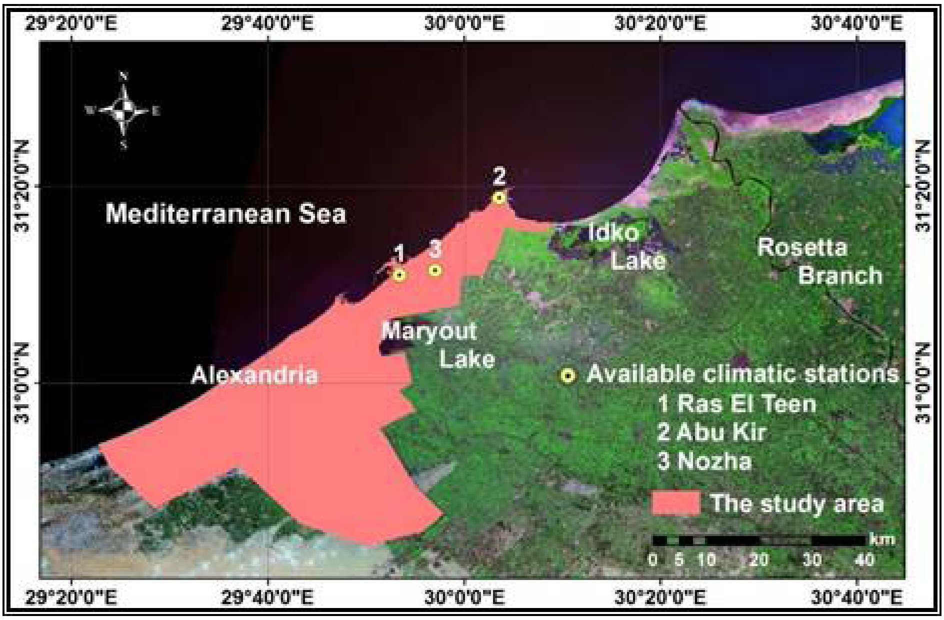

Fig. 1. Location map

Discussions & Analysis

1– Climate Features & Rainfall Characteristics in Alexandria

Alexandria has a borderline hot desert climate (Köppen climate classification: BWh), approaching a hot semi-arid climate (BSh). As the rest of Egypt's northern coast, the prevailing north wind, blowing across the Mediterranean Sea, gives the city a less severe climate from the hinterland desert. Analysis of meteorological data shows that Alexandria is characterized at the summer is warm, arid, and clear and the winter is cool, dry, windy, and mostly clear. Over the course of the year. The temperature typically varies from 10°C to 30°C and is rarely below 5°C or above 35°C. The hot season lasts for four months, from the beginning June to the beginning October, with an average daily high temperature above 30°C. The hottest day of the year is Mid-August, with an average high of 35°C and low of 30°C. The cool season lasts for 3.5 months, from the beginning December to Mid-March, with an average daily high temperature below 20°C.The coldest day of the year is 4-February, with an average low of 10°C and high of 18°C. Its climate is influenced by the Mediterranean Sea, moderating its temperatures, causing variable rainy winters and moderately hot summers that, at times, can be very humid; January and February are the coolest months, with daily maximum temperatures typically ranging from 12 to 18 °C and minimum temperatures that could reach 5 °C. July and August are the hottest and driest months of the year. Alexandria experiences violent storms, rain and sometimes hail during the cooler months; these events, combined with a poor drainage system, have been responsible for occasional flash flooding in Alexandria. The average annual rainfall is around 200 mm but has been reaches more 400 mm (Table 2). As a maximum rainfall.

The chance of rainfall days in Alexandria varies throughout the year. The rainfall season lasts five months, from November to March, with a greater than 6% chance of a given day being a rainy day. The chance of a rainy day peak at 32% on December and January. The arid season lasts seven months, from April to October. To show variation within the months and not just the monthly totals, (see to table 1. and figure 2), show Maximum rainfall accumulated over a study period centered around each day of the year, that December and January are Record the highest values for rainfall extremes. Alexandria experiences some seasonal variation in monthly rainfall; where The rainless season of it lasts for nine months, from September to May According to Average rainfall and Average rainfall days (≥ 0.01 mm). The least rainfalls during September, with an average total accumulation of 0.8 mm in September and Average rainfall days (≥ 0.01 mm) of one day in May. Probability ratio of rainfall on a day over a study period lasts for eight months, from October to May, with a falling 41-day rainfall of at least 9.4 mm. The most rain falls during the 41 days centered around December and January, with an average total accumulation more than 20 mm.

Table 2. Monthly rainfall characteristics in Alexandria during 1960s to 2016s

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max rainfall	47.9	28	21.1	89.9	8.8	0	0	0	22.6	127	64.6	54.3
Average rainfall (mm)	52.8	29.2	14.3	3.6	1.3	0	0	0	0.8	9.4	31.7	52.7
Average rainfall	10	7	4	1	1	0	0	0	0	2	6	10
Average rainfall days (≥ 0.01 mm)	11	8.9	6	1.9	1.0	0.04	0.04	0.2	2.9	5.4	9.5	46.92
Probability of rain-fall on a day (%)	32	25	13	3	3	0	0	0	0	6	20	32

Source: Egyptian Metrological Authority & http://www.alexandria.climatemps.com/precipitation.php

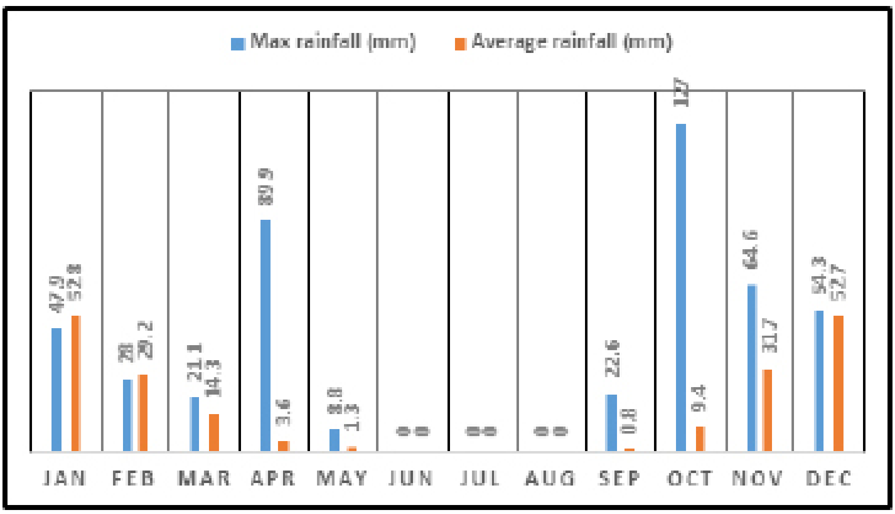

Fig. 2. Average monthly rainfall days and maximum rainfall in one day over the year

As regards the characteristics of climate and rainfall patterns, run-off is managed using a combined drainage system. Although the capacity of the system had been attempt upgraded comparatively, it still remains insufficient. Overflowing of manholes and pumping stations, with the consequent damages, has been observed during heavy rainfall in the recent past (HCWW 2016).

2- Trend Estimate for Historical Series of Rainfall at Alexandria

General aim of statistical trend analysis is to investigate whether recent historical changes in the Intensity, Duration, Frequency and amplitude of the rainfall extremes can be detected, and whether these can be considered statistically significant in comparison with the natural temporal variability of rainfall intensities. Most classical trend tests are the Mann–Kendall test, and non-parametric tests based on rank statistics, but other methods have also been employed such as time series. One of the main difficulties of the trend testing is that the effect of clustering in time on the temporal variability of the intensity, Frequency and amplitude of the rainfall extremes has to be taken into account on both temporal and spatial scales. Most trend testing techniques indeed assume independence from year to year. When short or long-term persistence is present in the series, trend testing techniques cannot be correctly applied. Whatever method is applied for trend testing, the interpretation of the result is difficult because there is no objective way to discriminate trends among natural climatic trends, anthropogenic caused changes. Due to the strong temporal variability of daily rainfall intensities, time series indeed have to be of sufficient length.

Figure 3, show time-series data, in which a series of points representing annual observations are connected, are useful for showing changes in a rainfall over times. Also, from identifying the nature of rainfall (represented by the sequence of observations) found out characterize by randomness and lack of clear direction. In addition to show predicting future values of the time series variable. Time series model has been the basis for study of metrics over a period of time (1960s - 2030s), in analysis that involve factor of uncertainty of the future. Most often, future course of actions and decisions for such processes will depend on what would be an anticipated result. Also, this model can be combined with other data mining techniques to help understand the behavior of the data and to be able to predict future trends and patterns in the nature of rainfall.

As Alexandria had not experienced flash floods with significant impacts in the recent past (Excepting 2011s and 2015s). Figure 4, which is prepared with the rainfall data by satellite, provides relevant

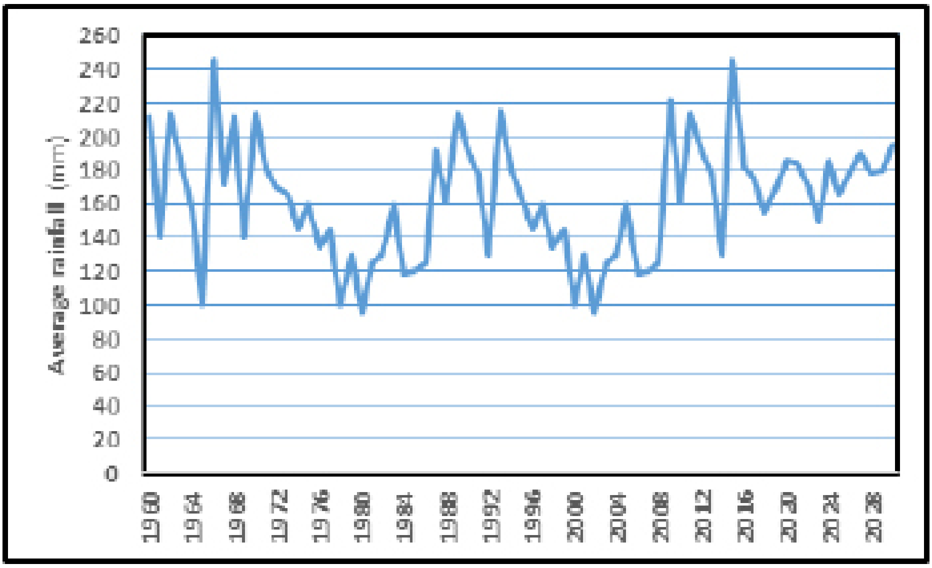

Fig. 3. Rainfall change trend in the future at Alexandria (1960s -2030s)

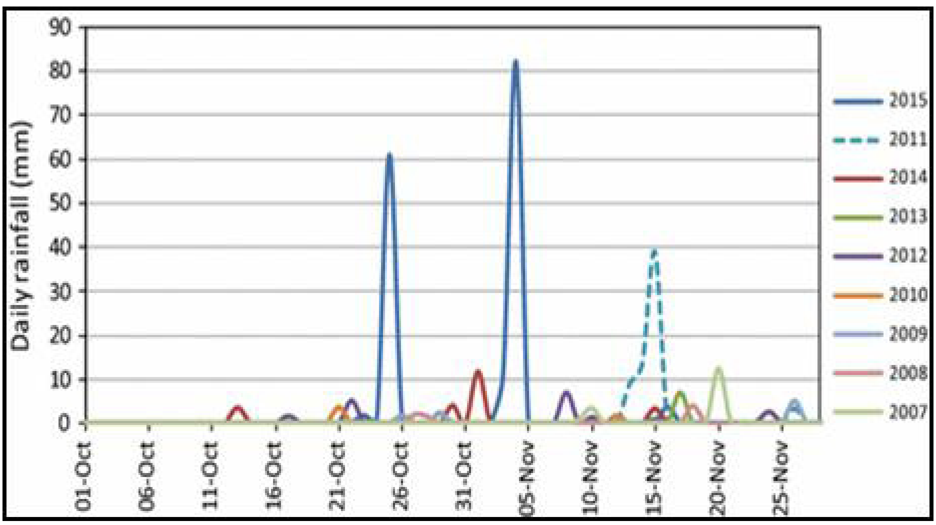

Fig. 4. Comparison of TRMM rainfall at a daily time scale in October and November at Alexandria (2007s - 2015s)

Source: Alexandria Sanitary and Drainage Company

information regarding the extremity of the rainfall event in October and November from 2007s to 2015s. The intensity, duration, and frequency chart of Alexandria is shown in Figure 5, for the 32 mm of rainfall in 30 min on 25-October, the frequency could only be estimated by extrapolation and the frequency of this rainfall seemed to be of the order of 50 years. The meteorological data revealed that the individual storm events in October and November 2015s were low probability events. Additionally, the persistence and clustering of the observed two consecutive peaks of extensive rainfall storm was exceptional, leading to flooding in Alexandria of historical proportions. The probability of occurrence of this type of clustered storm event is hard to predict and associated with large uncertainties (Zevenbergen, et al., 2017).

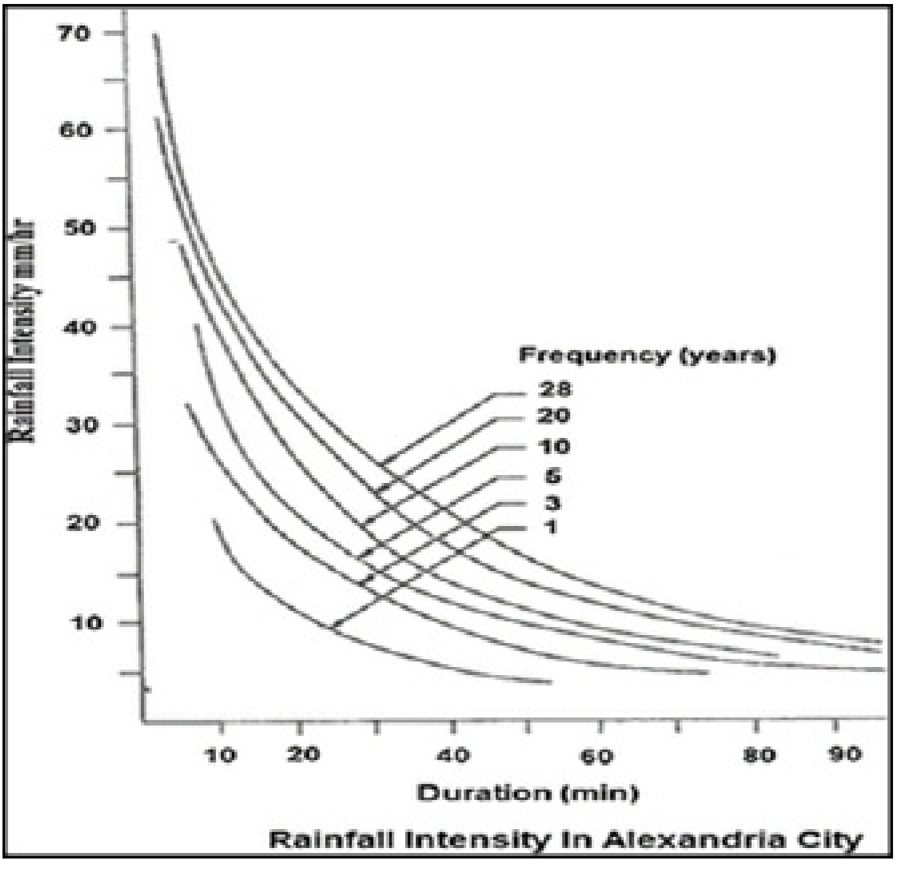

Fig. 5. Intensity–duration–frequency chart of Alexandria

Given that this analysis was based on relatively short historical periods, these trends were not significant. An analysis of the same dataset including data until year 2016s indicated that the change in number of occurrences of precipitation extremes were significant in 2015s with and without inclusion of variables to describe the multi-decadal variation due to the south Mediterranean Oscillation, while changes in the rate of rainfall were much less apparent in the data set, and overall concluded that the 55-year time series available are short for meaningful trend detection for single extremes rainfall series. The predictand variables can be considered as time series, such that the value in each time step can be downscaled to obtain a time series of rainfall, to be used in urban drainage impact that are based on continuous time series simulation and post-processing of simulation results.

3- Analysis Extreme Rainfall by Nested regional climate modeling technique

The recent trends in the rainfall intensities could be used for extrapolation into the future. However, it is clear that such extrapolation would be highly uncertain, because there is no natural basis for selecting the type of extrapolation curve. Climate change impact estimations on climatic variables including extreme rainfall, therefore, are most often based on the results of simulations with climate models [General Circulation Models (GCMs) and Regional Climate Models (RCMs)]. RCMs can use initial and boundary conditions from the output of GCMs for selected time periods of the global simulation. Ability to model processes in global and regional climate models is limited. Local, short duration precipitation generating mechanisms cannot be resolved because of numerical stability and computation efficiency considerations, hence limiting the time and space scales in the models. This means that at present there is a limit to how much dynamic downscaling can be applied and still yield realistic results. In any case nested regional climate modeling technique often results in systematic bias (underestimation) in the estimated extreme precipitation intensities (Dibike et al., 2008 and Baguis et al., 2009).

The medium range rainfall forecast data from the Hadley Center of the British Meteorological Agency (metoffice.gov.uk/climate-change) was downloaded for the study period. Alexandria is expected to experience mainly rainfall declines, common to the Mediterranean, where the 20% decline is expected to occur, which is strongly consistent with the comparison of the mean forecast rainfall from ECMWF with the TRMM and measure rainfall. it can be concluded that the October and November 2015 flash flood could have been predicted forecast. The high values of the forecast rainfall at all forecast lead times are discernible. The forecast amount matched more or less from measure rainfall by satellite. The gauge rainfall was less than the forecast rainfall and satellite rainfall by about 50%. Unless the time series of rainfall data is available, the forecast rainfall data and the TRMM rainfall data cannot be corrected. However, even with the uncorrected forecast rainfall data shows that the high rainfall event of 25-October and 4-November could have been predicted many days ahead of the event. Up to now, this approach is one-way; there are no feedback mechanisms from climate models. In this simulation scheme, the role of the General Circulation Models is to simulate the response of the global circulation to large scale forcing. The Regional Climate Models accounts for finer scale forcing, like topographic features, in a physical manner, and enhances the simulation of the climatic variables at such extent scales. However, at present the understanding of the processes involved in precipitation formation is limited, especially at high spatial and temporal resolution (Baker and Peter, 2008).

From Figures 6, 7, and 8; the rainfall on 4-November, 2015s was very high. This rainfall event had caused flash flooding, but it was less severe compared to the two in 12-November, 2011s and 25-October, 2015s mainly because the rainfall intensity was less. The daily total rainfall in the three times was as follows:

- The daily total rainfall on 12-November, 2011s from the three rainfall stations was: Ras El Teen 12 mm, Abu Kir 9 mm, Nozha 12 mm.
- The daily total rainfall on 25-October, 2015s from the three rainfall stations was: Ras El Teen 27 mm, Abu Kir 22 mm, Nozha 27 mm.
- The daily total rainfall on 4-November, 2015s from the three rainfall stations was: Ras El Teen 60 mm, Abu Kir 70 mm, Nozha 60 mm.

It is important to follow the development of climate models closely, and critically evaluate their output with respect to reproduction of local rainfall extremes at Alexandria and in turn applicability for urban climate change impact assessment. It should be noted, however, that

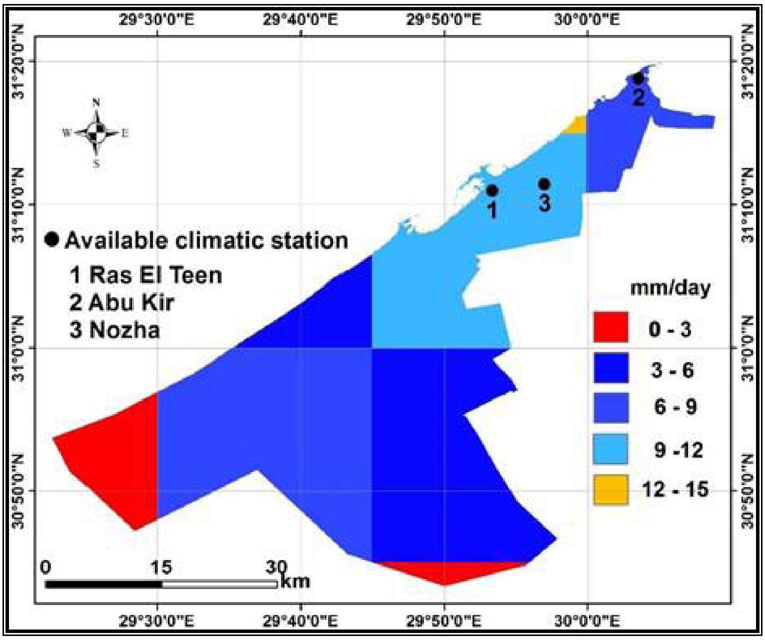

Fig. 6. Rainfall Rate at 12-11-2011s (TRMM TRMM_3B42_Daily v7) mm

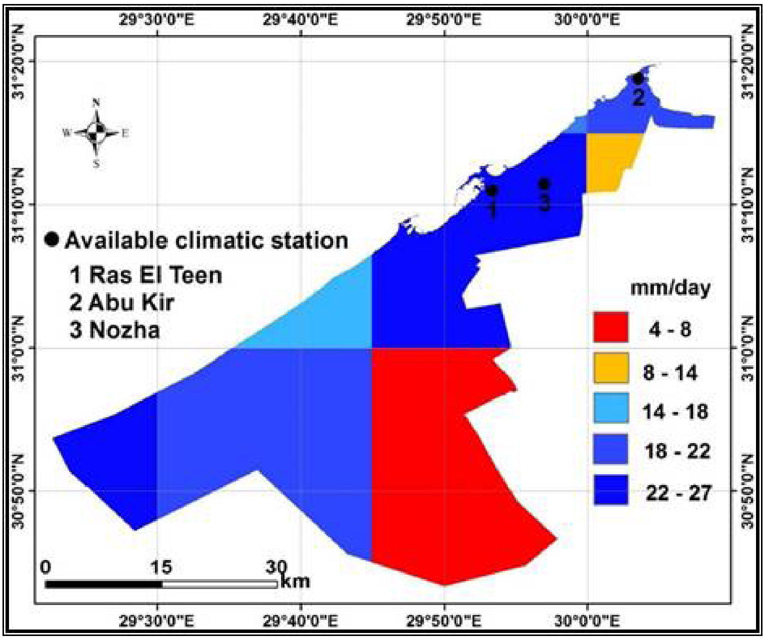

Fig. 7. Rainfall Rate at 25-10-2015s (TRMM TRMM_3B42_Daily v7) mm

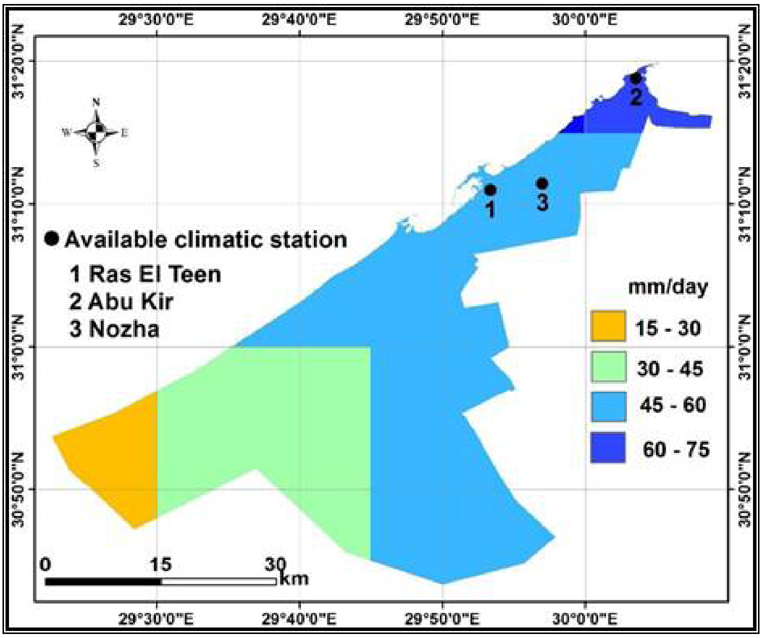

Fig. 8. Rainfall Rate at 04-11-2015s
(TRMM TRMM_3B42_Daily v7) mm

due to lack of a complete natural understanding of the rainfall generating processes at a small scale, both dynamic and statistical downscaling methods are necessary in the search for a more accurate downscaling method for high-quality climate-related impact assessment studies. Due to these difficulties and uncertainties, caution must be exercised when interpreting the climate change scenarios and their impact on urban drainage. However, the cases studies indicate that rather severe impacts can be expected in some times, while other times are likely to experience little or no impact to rainfall extremes due to climate change.

4- Rainfall Extremes impact evaluate on urban at Alexandria

Alexandria is extending about 32 km along the coast of the Mediterranean Sea in the north central part of Egypt. It is geographical coordinates are latitude 30°45′, 31°20′N, longitude 29°22′, 30°08′E, and elevation ranges from less zero to 9 m with a total Area 2,679 km2. The topography within 4 km of Alexandria from North to South contains only modest variations in elevation, with a maximum elevation change of 150 m and an average elevation above sea level of 1-9 m on the coast. Within 80 km also contains only modest variations in elevation, above sea level of 40 - 60 m (Figure 9). Traditionally, storm water management in cities uses grey infrastructure to move water away from the city as soon as possible through a series of underground pipes (Brown et al. 2009; Ashley et al. 2013). Very often, these conveyance systems have insufficient capacity, which causes flooding during storm events. This was the case of Alexandria; where it witnesses flash floods on almost on a yearly basis. Last two years, floods wreaked havoc on the city for several days. At this time, Alexandria was lacked a storm water management plan.

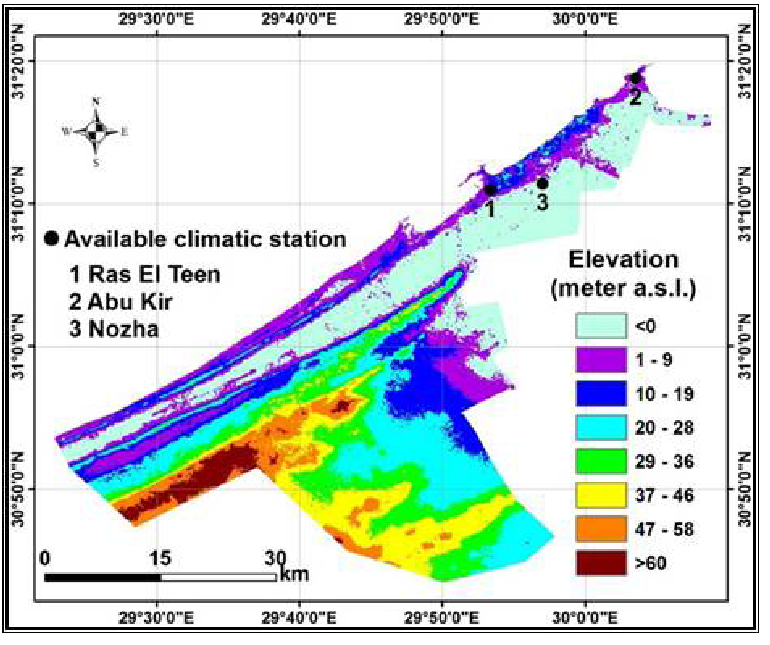

Fig. 9. Surface Elevation

On 12-November 2011s, 25-October and 4-November 2015s, Alexandria experienced an unexpected severe rainfall event; Especially 2015s. where more than 50 mm in one hours was recorded in some places causing flash flooding in these areas. This flash flooding has been described as the worst flash flooding of Alexandria over the past decades in terms of the number of people affected and the amount of economic damage. And because it was the long duration of the Alexandria rainfall storm event was not expected. In addition, the existing urban hydraulic network of canals and drainage infrastructure has not been designed to accommodate the large volumes of water resulting from rainfall extremes such as this. This resulted about 60% of the Alexandria area was flooded from 0.5 up to 1.0 m, and in event low lying areas (Figure 9), and stagnant flood water on the roads remained for more than 15 days (HCWW, 2016). The huge and unexpected water volumes were beyond the pumping capacity of Alexandria.

On October and November 2015s, rainfall extremes persisted in some areas for more than 15 days, resulted in a total of seven deaths and affected Thousands of people. The largest number of affected people consisted of the urban poor living in slum areas covering over 26% of the total Alexandria. The responsible national and local authorities did not anticipate this extreme rainfall event, and hence no protective and emergency measures were taken in advance, nor were citizens forewarned (HCWW, 2016). Major roads and Entire streets of Alexandria were completely submerged by the rainfall for several days, such as Cornish Road (Figure 10). Apart from the direct impacts to the local economy, the rainfall extremes also indirectly affected Human activities as well as the disruption of services such as of electricity, water supply and sanitation, and direct damage to buildings. There are no data available regarding indirect damages.

Fig. 10. Cars in flood water after a rainfall extreme in the Rushdie neighborhood of Alexandria on 25/10/ 2015s

Fig. 10 (contin.). Cars in flood water after a rainfall

In the district of El Mandara alone, 400 buildings showed severe structural damages and in the district of Wadi El Kamar the lives of 100,000 people were threatened by destruction of their homes, and damaged infrastructure (HCWW 2016). Major concerns also included the danger of electrocution: at several locations of Alexandria the overhead power supply line of the tram line snapped and electrocuted four people due to the collapse of the supporting pillars. As a response to these electrocutions, the Alexandria government had cut the electric supply for 10 days, and as a consequence some tunnels were closed (such as Sidi Bishr tunnel) causing Material and moral damages amongst the citizens.

A large fraction of Alexandria urban drainage and infrastructure dates back to the 1980s and is currently in a poor condition. In the existing and newly built-up areas, investments in infrastructure have not kept pace with its rapidly growing demand. A significant part of the buildings in newly built-up areas are deemed illegal. These illegal houses lead to further densification of Alexandria city and result in an increase in direct run-off of rainfall falling on that area. The extra run-off provides an extra load on the pipe network and puts additional strain on the pumping stations. Alexandria has a combined storm water conveyance system. This combined system transmits rainfall water and sewage water in the same pipe sending it to the waste water treatment plant before it reaches the water receiving frame. During high rainfall events, combined sewer overflows occur, and considerable amounts of sewage water is released into waterways, which represents serious environmental concerns. Next to the inability to meet its original purpose during rainfall storm events and obvious inflexibility, grey infrastructure also implies high capital and maintenance costs. During the flash flooding 2015, the Army and Ministry of Housing provided assistance. Actions to alleviate the impact of rainfall extremes included the installation of extra pumps and the removal of parts of the flood protection wall along the city coast. There is no detailed information to what extent the water supply was affected by flooding

A range of proposals and solutions, ranging from flash flooding emergency measures including rainfall extremes forecasting and warning, evacuation and protection plans, to hard measures and land use planning controls such as flash flooding mitigation works, including capacity increase of urban drainage systems. Flash flooding protection such as minimum flood levels and flood Management Unit is be established to ensure long term flood resilience.

These protection measures include short-term flood mitigation actions, which ease the discharge of run-off water to the sea, such as the removal of the flood protection walls and the installation of extra pump capacity and drains at some low lying sections in Alexandria along the coastal road (Figure 9). As an immediate response to rainfall extremes 2015s, some of these measures have already been implemented. The effectiveness of these short-term actions is unknown as a detailed hydraulic analysis has so far been lacking. Other short-term actions include cleaning the urban drainage systems and protecting critical infrastructure.

Conclusions & Recommendations

Based on this study, the main climatic features of rainfall in Alexandria can be summarized as follows:

- Alexandria is accord an average of 195.8 mm of rainfall per year, or 16.3 mm per month.
- On average there are 41 days per year with more than 0.1 mm of rainfall or 3.4 days per month.
- On average there are 94 days per year with more than 0.01 mm of rainfall or 7.8 days per month.
- The arid climate is in June, July & August when an average of 0 mm of rainfall.
- The rainy climate is in December and January when an average of 52 mm of rainfall.
- The difference in rainfall between the driest month and the wettest month is 52 mm.

An analysis of the meteorological data reveals that the observed consecutive individual rainfall storm events are low probability events and that the persistence of this rainfall storm events have been exceptional. The probability of the occurrence of this type of rainfall storm event is hard to predict: they are associated with many factors. Verification of the extent climate model results under the present climate is needed. Urban drainage design and analysis are largely based on considering probabilities of event and exceeding rainfall extremes, and thus it is important that rainfall exceedance probabilities and related probabilistic results are captured well by the extended climate model results.

The review given in this study of climate change impacts on extreme short-duration rainfall, and flash flooding, highlighted particular difficulties at the inaccuracies of climate model simulation results for short-duration extreme rainfalls at a local scale and the difficulties of identifying climate change trends in historical series of rainfall extremes because of short- and long-term persistence. The risks of these rainfall storm water events cannot be properly managed using traditional methods. Although these storms studying are an exceptional event, it could have been predicted it, if an appropriate warning system had been in place, and then measures could have been taken to alleviate its damages.

Based on findings, the following recommendations can be made to the three institutions responsible for flash flooding risk management in Alexandria (Ministry of Irrigation Water Resources- Ministry of Housing- the Holding Company for Water and Waste Water), it is:

- Alexandria authorities are taken adequate precautions to protect from rainfall extremes after predictions of rainfall event.
- Budget should be allocated to upgrade urban drainage system in Alexandria, after fall extreme rainy.
- Develop and implement innovative infrastructure solutions to enhance the flash flooding resilience of Alexandria.
- Map out the future of the urban drainage system across Alexandria over the next two or more decades and to identify the tipping point when upgrading of the existing urban drainage system will be present.

References

Arias-Hidalgo, M., Bhattacharya, B., Mynett, A.E., and van Griensven, A., (2013): Experiences in using the TMPA-3B42R satellite data to complement rain gauge measurements in the Ecuadorian coastal foothills, Hydro. Earth Syst. Sci. 17, pp.2905–2915.

Arnbjerg-Nielsen, K., (2008): Quantification of climate change impacts on extreme precipitation used for design of sewer systems Proceedings of the 11th International Conference on Urban Drainage, 31 August – 5 September, Edinburgh, Scotland.

Ashley, R., Lundy, L., Ward, S., Shaffer, P., Walker, A., Morgan, C., Saul, A., Wong, T., and Moore S., (2013): Water-sensitive urban design: opportunities for the UK. In: Proceedings of the Institution of Civil Engineers: Municipal Engineer. ICE Publishing, pp. 65–76.

Baguis, P., Roulin, E., Willems, P., & Ntegeka, V., (2009): Climate change scenarios for precipitation and potential evapotranspiration over central Belgium, Theoretical and Applied Climatology http://dx.doi.org.dlib.eul.edu.eg/10.1007/s00704-009-0146-5

Baker, M.B., & Peter, T., (2008): Small-scale cloud processes and climate Nature, 451, pp. 299–300.

Brown, R., Keath, N., and Wong, T., (2009): Urban water management in cities: historical, current and future regimes, Water Sci Technol. 59, pp. 847–855.

Dibike, Y.B., Gachon, P., St-Hilaire, A., Ouarda, T.B., & Nguyen V.T., (2008): Uncertainty analysis of statistically downscaled temperature and precipitation regimes in Northern Canada, Theoretical and Applied Climatology, 91, pp. 149–170.

HCWW- Holding Company for Water & Wastewater (2016): interviews with HCWW staff held in Alexandria in July 2016.

http://koeppen-geiger.vu-wien.ac.at/pics/kottek_et_al_2006.gif

https://giovanni.sci.gsfc.nasa.gov/giovanni/#service=TmAvMp&starttime=&endtime=&bbox=-180,90,180,90&data=TRMM_3B42_Daily_7_precipitation&variableFacets=dataProductPlatformInstrument%3ATRMM%3B

Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu, G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker, E.F., and Wolff, D.B., (2007): The TRMM multi satellite precipitation analysis (TMPA): quasi global, multiyear, combined-sensor precipitation estimates at fine scales, Hydrometeorology 8, pp.38–55.

Hughes, D.A., (2006): Comparison of satellite rainfall data with observations from gauging station networks, Hydrology 327, pp.399–410.

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

Larsen, A.N., Gregersen, I.B., Christensen, O.B., Linde, J.J., & Mikkelsen, P.S., (2009): Potential future increase in extreme one-hour precipitation events over Europe due to climate change, Water Science and Technology, 60, pp. 2205–2216 http://dx.doi.org.dlib.eul.edu.eg/10.2166/wst.2009.650

Nguyen, V.T., Desramaut, N., & Nguyen, T.D., (2008): Estimation of urban design storms in consideration of GCM-based climate change scenarios, Proceedings International Conference on 'Water & Urban Development Paradigms: Towards an Integration of Engineering, Design and Management Approaches', Leuven, 15–17 September 2008, CRC Press, Taylor & Francis Group, pp. 347–356.

Ntegeka, V., & Willems, P., (2008): Trends and multi decadal oscillations in rainfall extremes, based on a more than 100 years' time series of 10 min rainfall intensities at Uccle, Belgium Water Resources Research, 44. http://dx.doi.org.dlib.eul.edu.eg/10.1029/2007WR006471

Ntegeka, V., Willems, P., Baguis, P., & Roulin, E., (2008): Climate change impact on hydrological extremes along rivers and urban drainage systems, Summary Report Phase 1 of CCI-HYDR Project by K.U. Leuven and Royal Meteorological Institute of Belgium, for the Belgian Science Policy Office, April 2008.

Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L.G., (2008): The impacts of climate change and urbanization on drainage in Helsingborg, Sweden: Combined sewer system, Journal of Hydrology, 350, pp. 100–113.

Sunyer, M.A., & Madsen, H., (2009): A comparison of three weather generators for extreme rainfall simulation in climate change impact studies, Proceedings of the 8th International Workshop on Precipitation in Urban Areas, 10 13 December 2009, St. Moritz, Switzerland, pp. 109–113.

Tesfagiorgis, K., Mahani, S., Krakauer, N., and Khanbilvardi, R., (2011): Bias correction of satellite rainfall estimates using a radar-gauge product: a case study in Oklahoma (USA), Hydro. Earth Syst. Sci. 15, pp.2631–2647.

Willems, P., & Vrac, M., (2010): Statistical precipitation downscaling for small-scale hydrological impact investigations of climate change, Journal of Hydrology, 402, pp. 193–205.

Willemsa, P., Arnbjerg-Nielsenc, K., Olssond, J., & Nguyene, V.T., (2012): Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcomings, Atmospheric Research, 103, pp. 106–118.

www.metoffice.gov.uk/climate-change/policy-relevant/obs-projections-impacts

Zevenbergen, C., Bhattacharya, B., Wahaab, R.A., Elbarki, W.A., Busker, T., & Salinas Rodriguez, C. N., (2017): In the aftermath of the October 2015 Alexandria Flood Challenges of an Arab city to deal with extreme rainfall storms, Natural Hazards, 86, pp. 901–917.