EPiC Series in Engineering
Volume 3, 2018, Pages 252–257
HIC 2018. 13th International Conference on Hydroinformatics

Extreme flooding in Alexandria: Can anticipatory flood management be a solution?

Biswa Bhattacharya, Chris Zevenbergen, Adele Young, Mohanasundar Radhakrishnan

IHE Delft Institute for Water Education, Westvest 7, 2601 DA Delft, The Netherlands.

Corresponding author: B.Bhattacharya@un-ihe.org

Abstract Alexandria experienced heavy rainfall in October 2015 resulting in wide spread flooding, huge damages and seven deaths. This paper presents the analysis of the hydro-meteorological data to characterise the extremity of the event. The flood map of the city and its adjoining area prepared with LANDSAT-8 satellite images shows the extent of flooding. The analysis with the rainfall forecast from the ECMWF clearly demonstrated that the extreme event could have been predicted days ahead. It is proposed to implement Anticipatory Flood Management in Alexandria (AFMA), which will allow using the extreme rainfall forecast to start pumping out water from Lake Maryot and Airport Lake before the event starts. This will enable extra storage space to accommodate some of the flood water from subsequent rain. An analysis of the October flood showed that 50% of the flood water due to the heavy rainfall could have been stored in the lakes had the AFMA been implemented. The study shows that the existing data allows us to implement AFMA to reduce flood consequences and pave the way to critically decide upon additional mitigation infrastructure. The recommendation of this study is currently being implemented.

Keywords: AFMA, Alexandria, anticipatory flood management, early warning, Egypt, flood risk.

1 Introduction

Alexandria in Egypt and its neighbouring region experienced a heavy shower of about 32 mm in a short duration in October 2015, which resulted in a major flood of historical proportion. Different areas of the city were flooded, transportation was stopped for days, seven persons were electrocuted and as a follow up the electrical power was cut off for days [1]. The damage was immense. The city is not at all prepared for extreme weather events. No flood forecasting and warning system is available. As a result no warning based on forecasted inclement weather is provided. Alexandria is also predicted to be one of worst hit cities due to climate change [2]. The difficulty of finding hydro-meteorological data for the region delimits the possibility of a systematic analysis of hydro-meteorological events, for example, in associating probabilities to events and characterising extremity of floods. For the October flood in Alexandria the areal rainfall for the city, as gathered from its three gauging stations, was about 32 mm. This rainfall tentatively was of 50 years return period. It is anticipated that Alexandria and many other Arab cities will suffer from more frequent extreme weather events [2]. This paper presents an analysis of the October flood event, proposes the development of a flood early warning system and presents the concept of Anticipatory Flood Management in Alexandria (AFMA).

2 Methodology

Identifying flooding extent from satellite images serves as one of the established ways of providing evidence of flood extent [3]. In the absence of hydraulic models the flood extent was delineated using the multiband satellite derived index Modified Normalised Differenced Water Index (MNDWI). MNDWI is a band-ratio approach using two multispectral bands, suitable for enhancing and extracting water features in built-up land areas due to its advantage in reducing and removing built-up land noise [4]. Landsat-8 images for October 26, 2015 at 8:30 am with 4% cloud coverage were used. MODIS images were also considered but finally not used due its low spatial resolution. Among other data products Sentinel 1 & 2 images were not available for the period of flood occurrence. Images were pre-processed including atmospheric corrections. Threshold values were manually applied to classify the images into two classes: water and non-water. Suitable thresholds were determined through visual interpretation, trial and error, and comparison with a single band multispectral image. Existing water bodies were removed by overlaying with an image in which no flooding occurred.

As the time series data of gauge rainfall from Alexandria was unavailable so the rainfall estimates from Tropical Rainfall Measuring Mission (TRMM) [5] was used in the analysis. The gauge rainfall of the day of flooding and the monthly gauge rainfall were compared with the TRMM rainfall to estimate the accuracy of the TRMM data and the severity of the flooding event. Furthermore, the rainfall forecast from the European Centre for Medium Range Weather Forecast (ECMWF) was used to explore the possibility of using rainfall forecast in forecasting future flood events. As a mitigation measure it is proposed to implement anticipatory flood management in Alexandria (AFMA). In AFM actions are anticipated based on forecast information. AFM is typically implemented with forecast information of rainfall (from numerical weather models) and/or water level / discharge (from hydrological/ hydraulic models). With AFM when an extreme rainfall and consequent high flow is predicted then actions such as pumping, opening of sluices/ gates, etc. are taken before the extreme event starts. Such anticipated actions provide extra storage space in the system when the extreme event does arrive. The shortcoming of AFM is possible wrong actions due to the uncertainty associated with model forecasts. For Alexandria, the usefulness of the AFMA was investigated with the October 2015 flood.

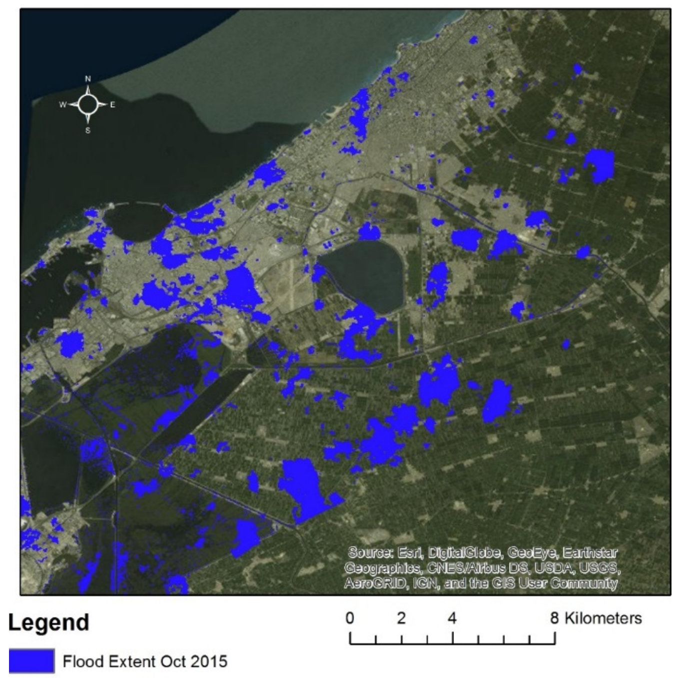

Figure 1. Flood map of Alexandria on October 26, 2015 from LANDSAT-8 images.

3 Results and discussion

The results of the analysis showed that approximately 30% of the city may have been flooded during the October flood (Fig. 1). However, the followed approach gives an underestimation of the actual flooding extent due to the presence of cloud cover in satellite images and the thresholds used in identifying water pixels. Flooded areas with shallow depths (<0.5m) are more likely to be not detected. Additionally, much flooding occurred in localised low topography areas. The limited spatial resolution of the images may have hindered the detection of water in those areas. This issue needs to be investigated further with different image sources. Fig. 2 shows the rainfall forecast from ECMWF with 1, 2, 3 and 4 days lead time. The daily TRMM data also shows a very high rainfall on October 25, 2015. Though the gauge rainfall on the day of the event is lower than the TRMM rainfall and the ECMWF forecast still the extremity of the event is clearly discernible. It can be readily concluded that the October flooding could have been predicted days ahead of the event.

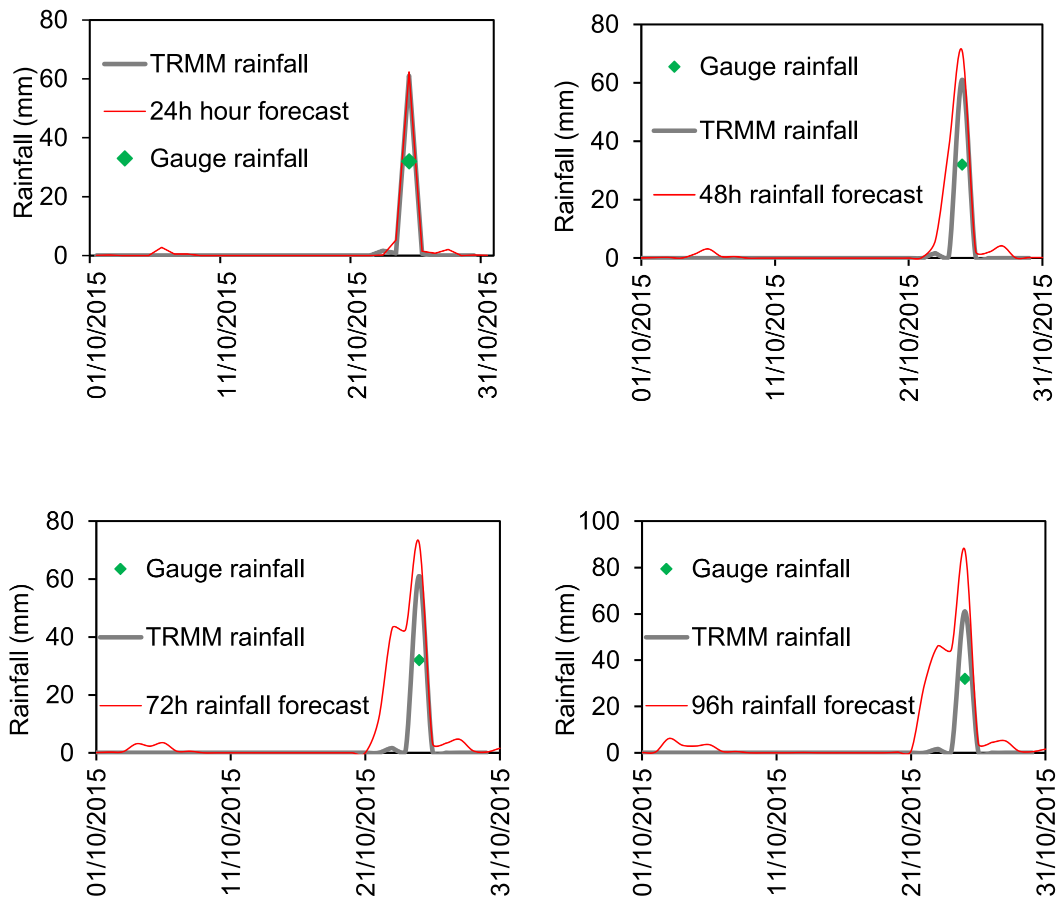

Figure 2. Rainfall forecast from ECMWF for Alexandria and along with the daily TRMM rainfall.

Fig. 3 conceptually presents the application of AFMA for the October flood. It presents the daily rainfall data of a week around the flood event. Note that the gauge rainfall data was available only for the event date. As TRMM data showed zero rainfall for other days of the week so gauge rainfall in other days was considered as zero as well. The total daily load from the mixed sewer system that reaches the end point (Max Point) and needs to be pumped out to the Mediterranean is presented as well. Note that this data was gathered during the discussion with the Alexandria Sanitary and Drainage Company and from Zevenbergen et al. [1]. The estimation of the total load needs to be corroborated further with evidences. Nonetheless, the increase in the load and the consequent flooding has been observed.

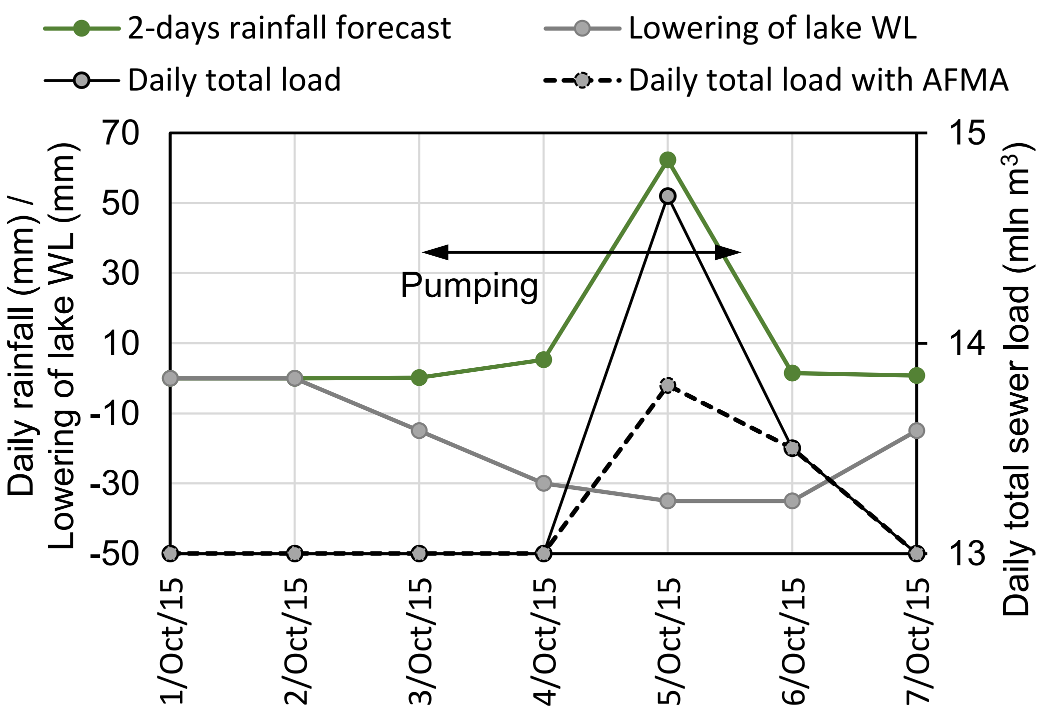

Figure 3. Conceptual figure illustrating the usefulness of the proposed AFMA.

Fig. 3 further exemplifies the efficacy of the AFMA principle. Based on the rainfall forecast pumping out water from Maryot Lake and Airport Lake to the Mediterranean was considered 2 days before the flood event. With a combined pumping capacity of 5 m^3/s the extra storage in the lakes was computed as 0.88 mln m^3. This will lower the lake water level by about 40 mm. Fig. 3 further shows the lowering of the daily total load by 0.88 mln m^3, which is about 7% of the daily total load and a considerable percentage of the extra flood water of the October flood event. The consequence of this lowering of the load to the sewer system needs to be further studied with the help of a hydraulic model of the sewer system. The consequences to lake water quality also needs to be investigated. The uncertainty associated with the model forecasts and consequent wrong actions need to be studied further. The AFMA principle perhaps is ideal for cities like Alexandria, which are not regularly flooded and are not at all prepared for extreme events. The AFMA is a low investment option that allows buying time to implement additional and perhaps more expensive mitigation measures for lowering flood risks and avoiding further build-up of risks.

4 Conclusions

Alexandria experienced extreme flooding in October 2015. More extreme events are likely to occur in Alexandria and comparable Arab cities. Due to the low level of preparedness of the city(s) to extreme events the consequences are likely to be high as well. With the rainfall forecast data from ECMWF it was possible to predict the October flooding days ahead of the event. Developing a stormwater model will further provide information about when and where flooding may happen. Therefore, it is recommended to establish a flood forecasting and warning system for the city. It was further presented that with the existing data AFMA can be implemented as a mitigation measure. It was shown that the pluvial flooding in October 2015 could have been, at least largely, avoided had the AFMA principle followed to pump out water beforehand. AFMA is a low-cost investment with a relatively large gain and can be utilised to buy time to critical analyse more expensive mitigation measures that need to be implanted. Currently, the AFMA is being implemented. Future studies will focus on hydro-meteorological data analysis, hydraulic modelling, early warrning and uncertainty quantification to strengthen AFMA.

References

[1] C. Zevenbergen, B. Bhattacharya, R.A. Wahaab, W.A.I. Elbarki, T. Busker, C.N.A. Salinas Rodriguez, In the aftermath of the October 2015 Alexandria Flood Challenges of an Arab city to deal with extreme rainfall storms, Natural Hazards (2016).

[2] S. Hallegatte, C. Green, R.J. Nicholls, J. Corfee-Morlot, Future flood losses in major coastal cities. Nat Clim Change 3 (2013) 802–806.

[3] G.Di Baldassarre, G. Schumann, P.D. Bates, J. E. Freer, K.J. Beven, Flood-plain mapping: a critical discussion of deterministic and probabilistic approaches, Hydrological Sci. J. 55 (3) (2010).

[4] H. Xu, Modification of Normalised Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery, Int. J. of Remote Sensing. 27-14 (2006) 3025–33.

[5] G. J. Huffman, R.F. Adler, D. T.Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, Y. Hong, E.F. Stocker, D.B. Wolff, The TRMM Multisatellite Precipitation Analysis (TMPA): Quasiglobal, multiyear, combined-sensor precipitation estimates at fine scales, Hydrometeorology. 8 (2007) 38–55.

[6] M. Arias-Hidalgo, B. Bhattacharya, A.E. Mynett, A. Van Griensven, Experiences in using the TMPA-3B42R satellite data to complement rain gauge measurements in the Ecuadorian coastal foothills, Hydrol. Earth Syst. Sci. 17 (2013) 2905–2915.

[7] C.J. Kok, B.G.J. Wichers Schreur, D.H.P. Vogelezang, Meteorological support for anticipatory water management, Atmospheric Res. 100(2–3) (2011) 285–295..