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Predicting urban storm water-logging for Chittagong city in Bangladesh

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Abstract

In recent years, rainfall induced 'urban storm water-logging' (USWL) events are experiencing in Chittagong city like other urbanized parts of Bangladesh. To mitigate this there is an urgent need to predict the USWL beforehand and a numerical model could help. Thus, this paper aimed to use a hydrological model i.e. HEC-HMS through field survey during 2013–2014 and a questionnaire survey. With the support of secondary data source viz. daily newspaper, intensive questionnaire survey and field visits identified 13 most vulnerable USWL locations and based on these a USWL depth–duration–frequency curve was developed. This showed during water logging (i.e. May–July), the depth of logged water rises 0.3–1.27 m causing adjacent dwellers sufferings upto 13 times per year and the inundation period is up to 48 h. Using these, HEC-HMS model was setup and the correlation obtained with the field measurement as R^2 values 0.83 and 0.77 during calibration and verification period respectively. Once a real time hydrological dataset is available, the validated model supposed to provide useful information in the decision support system.

Keywords: Urban storm water-logging (USWL); Depth–duration–frequency curve; Rainfall; Model

1. Background

Recently 'urban storm water-logging' (USWL) becomes an unavoidable experience during wet season for the city dwellers in Chittagong city like other parts of Bangladesh. The USWL pose difficulties on social life through heavy casualties and traffic paralysis, thus causes national economic losses. Rapid urbanization along with climate changes, the USWL was already identified as a common issue around the world, for instance USA, Canada, Europe, Australia, Philippines, Sri Lanka, Japan and China (Li, 2012; Zhang and Pan, 2014; Han et al., 2006; Djordjević et al., 2011). The USWL causes due to (i)change in hydrological cycle i.e. uneven distribution of precipitation in time and space, (ii) land use changes viz. decreasing green areas, occupying water bodies for land developments, and last but not least (iii) absence of proper management, for example, improper maintenance of stormwater drainage system and inadequate emergency response systems (Sanyal et al., 2014; Zhang and Pan, 2014; Han et al., 2006; Djordjević et al., 2011; Suriya and Mudgal, 2012). Among these three issues, details knowledge on the first two, i.e., hydrological cycle and land use/land cover could only ensure the required management measures. In these regards, few attempts were made around the world, viz. storm tracking based on raingauge data compare to radar

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information (Carbone et al., 2014), considering variation in rain storm Han et al. (2006) had carried out a risk analysis on the disasters from USWL using mathematical simulation through probability investigation and statistics, Smith et al. (2015) developed a new hydrodynamic model aimed to design and assessment of sustainable drainage systems, and urban flood modeling with porous shallow-water equations was described by Kim et al. (2015). On the other hand, impact of changing land use on surface runoff using HEC-HMS (Ali et al., 2011; Suriya and Mudgal, 2012) and determination of inundation conditions using geographic information systems (GIS) based urban storm-inundation simulation method (USISM) (Zhang and Pan, 2014).

Chittagong, the second largest and well known port city in Bangladesh, has a tropical monsoon climate. Historical data from the Bangladesh Meteorological Department (BMD) showed an average increasing trend in temperature almost every month compare to earlier year during last three decades (1982–2013). Again the change in precipitation during this period showed a considerable increment in precipitation during January to July while the decreasing trend persists in precipitation from August to December. However, some individual occurrences were recorded for the uneven precipitation, for instance heavy precipitation during July 2009 in contrast to a very low precipitation in July 2010 (Details can be available on Mohit and Akter (2013)). Also in recent years, the reported USWL occurrences in June to July (Majumder et al., 2007) experiences earlier i.e. from May to July (Dey, 2013b) or prolonged up to August (Das, 2014).On the other hand, Chittagong City Corporation (CCC) showed that Chittagong city has a total surface area of 157 km^2 in December 2004 comprises of forest area was 1.34 km^2 (i.e. 0.85% of the total area) in 1990 and 1.21 km^2 (i.e. 0.77% of the total area) in 2004 (Hashemi et al., 2006). Thus, the declination of forest coverage during 1990–2004 is 9%. Again, 8% reduction was recorded in agricultural lands during 1990 (47.1 km^2) to 2004 (34.54 km^2) (Hashemi et al., 2006). As, land covered with vegetation and forest lands have a higher infiltration capacity than the bare lands, the existing land use changes are placing challenges in the hydrological cycle through reducing infiltration capacities. In addition to this, two different studies can also be mentioned, those are survey on water bodies in Chittagong city by District Fisheries Department in 1991 (19250 water bodies) and Chittagong Development Authority during 2006–2007 (4523 water bodies), i.e., the decreasing rate is 920 water bodies per year. So, along with modified hydrological cycle there is a growing threat observed in terms of excess water draining. In this regard, proper urban drainage system incorporating with the changes on detail hydrological cycle and management enforcement were discussed by Hashemi et al. (2006) and Ashraf and Chowdhury (2009). However, there are no published literatures covering history of USWL in Chittagong city and not even a historical database is available on the corresponding depth–duration–frequency. As these events are experiencing in recent years more than a single location around the city, intensive studies are required. To understand the details USWL process, while there is a limitation with dataset, there is an urgent need for a hydrological model which can provide useful information.

The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff process of a watershed system through featuring in an integrated environment (Scharffenberg, 2013). This model is widely used by the researchers and practitioners due to the simplicity and suitability not only with the wide range of geographic areas but also even with minimum data requirement (Zhang and Pan, 2014). For the USWL featuring, the whole area can be represented in HEC-HMS as a basin or a catchment comprises of sub-basins, sinks, junctions, diversion as well as reaches, i.e., lined or unlined drains. Thus, HEC-HMS model application in peak urban runoff frequencies based on changing rainfall were studied (Markus et al., 2007; Seyoum et al., 2013), runoff simulations in a tropical catchment were carried out (Halwatura and Najim, 2013) and also to analyze the impact of land use changes on storm runoff at the event scale (Ali et al., 2011; Sanyal et al., 2014; Suriya and Mudgal, 2012). So, for USWL prediction HEC-HMS can be a useful tool for Chittagong city. Unfortunately, there is no such attempt was taken to feature USWL for Bangladesh so far for Chittagong.

2. Materials and method

Chittagong city corporation area comprised of about 2.5 million of population was selected in this study and the whole work was conducted mainly in three steps (Fig. 1), i.e., Field survey, secondary data collection followed by a questionnaire survey and model setup. First two steps were run simultaneously. Due to absence of identified USWL vulnerable areas in Chittagong city, locations were preliminary identified from secondary sources i.e. available local newspapers (Dey, 2013a,b, 2011 Islam, 2009; Alamgir, 2008, 2012; Das, 2011, 2014; Barua, 2010; Rahman, 2014). Then, based on visual inspection during field survey verification of the USWL vulnerable areas were confirmed. During field study along with visual inspections/observations and accessible measurements, a questionnaire survey was carried out in two consecutive years 2013 and 2014. There were 12 questions in this questionnaire, among them three major sectors were focused on USWL, those are: depth–duration–frequency of USWL, respondents' experiences and views on USWL and rest on urban drainage issues. The whole questionnaire considered 10% closed and 90% open questions. Based on questionnaire survey a statistical analysis were carried out to acquire vulnerable area wise USWL depth–duration–frequency. To figure out the cause and effect of USWL in terms of respondents' experiences were summarized in acceptable ranges (Table 1). Secondary data i.e. spatial

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