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Determination of flood risk: A case study in the rainiest city of Turkey

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ABSTRACT

This paper combines hydrological and flood models for the purpose of estimating surface and peak flow rates from precipitation storm events occurred in basins of Rize province located in northern Turkey, receiving highest annual average precipitation height over 2300 mm. Two models: (i) Watershed Modeling System for predicting hydrographs and (ii) TuFlow comprised of hydrodynamic model of a one-dimensional river flow and a two-dimensional surface flow model for floodplain delineation were coupled to determine flood risks in the basins of Rize province. A 100-year flood peak discharges are computed based on the historical records and generated records in relation to climate change scenarios using grid-based approach. The influences of resolution of the mesh-size with the same DEM data on automated floodplain delineation are also another concern to investigate in this study. The results of this study could be used in quantitative flood risk assessments in the design of municipal infrastructures in the region. The results of this study showed that İyidere River flooded during the both present and future (tied with three climate change scenarios) conditions and seemed to need rehabilitation whereas Çağlayan and Tahiroğlu rivers flooded only in present condition. Our investigation also showed that coarse grid resolutions might cause overestimation in the floodplain and water depth.

Software and data availability

Name of software Watershed Modeling System (WMS) 9.1
Developer Dr Jim Nelson, Chris Smemoe (Environmental Modeling Research Laboratory, Brigham Young University)
Contact info 242D CB, PO Box 32 Provo, UT 84602, USA
Telephone +1-801-302-1400 (Environmental Modeling Systems, Inc.)
E-mail jimn@byu.edu
Hardware required 1 GB RAM minimum, for all display features to be enabled, Graphics Cards OpenGL 1.5 or higher must be supported
Software required Windows XP, Windows Vista, Windows 7, Windows 8/8.1 or Windows 10
Availability and cost See http://www.aquaveo.com/ for up-to-date pricing information on WMS
Name of software TuFLOW (Two-dimensional Unsteady FLOW)
Developer Developed by BMT WBM; an operating company of the BMT Group
Contact info 3210 N. Canyon Road Suite 300 Provo, Utah 84604, USA
Telephone +01 801 691-5528
E-mail info@aquaveo.com
Hardware required 1 GB RAM minimum, for all display features to be enabled, Graphics Cards OpenGL 1.5 or higher must be supported
Software required Windows XP, Windows Vista, Windows 7, Windows 8/8.1 or Windows 10
Availability and cost See http://www.aquaveo.com/ for up-to-date pricing information on TuFLOW

1. Introduction

In general, hydrological extremes mostly induced by climate change has direct economic and social impacts on society and, thus has long been continuing to be the topic of investigations conducted in a wide spectrum of scientific communities ranging from climatology to public health (e.g., among others, Kalaycı and Kahya, 1998; Şarlak et al., 2009; Kaya et al., 2012; Meral et al., 2014; 2015). Of course, many of the most direct impacts occur by means of the hydrologic cycle for which climate is a driving force. It is becoming increasingly important to be able to accurately predict flooding because it accounts for the greatest losses attributable to natural

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disasters in the world. Pelling et al. (2004) indicated that about 196 million people in more than 90 countries are exposed to catastrophic flooding, resulting in more than 170,000 deaths.

Hydrologic models are mainly employed to provide flow estimations at the regional/watershed scale by considering for various parameters as elevation, soil type, and land use. Bell et al. (2007) divided hydrologic models in two broad categories: lumped and distributed. Lumped hydrologic models use all parameters that are spatially averaged such as precipitation, land use and soil type. Hydrologic parameters are distributed uniformly over the watershed in a lumped modeling method. Grid-based or distributed models account for spatial variability in sub-catchment hydrologic response and can make use of gridded, spatially-distributed climate data obtained from climate models.

Flood inundation modeling has been mostly dominated by one-dimensional (1D) models, which are computationally efficient and are considered by many engineers to yield reasonably accurate water surface profiles (Buchele et al., 2006). However, 1D models do not explicitly show the complex flow behavior that is present in floodplains and urban environments (Knight and Shiono, 1996). The two-dimensional (2D) models have been recently becoming more common to employ as they were developed on the basis of shallow-water equations and have significantly greater ability to determine flow velocity and direction. The National Research Council (2000) has recommended using 2D for flood inundation studies. It is also important to wonder what would come out if 1D and 2D models were compared in the same study; answer to this question was previously well given by Gharbi et al. (2016) who pointed out that 1D models are proved to be easy and fast to build and to run although the results of such models have significant inaccuracies in the floodplains. On the other hand 2D models can correct this problem but it needs much more time for the flows implementation and simulations.

All types of flooding pose serious infrastructure hazard to human populations. According to Federal Emergency Management Agency (FEMA), floods are the second most common and widespread of all natural disasters (Noman et al., 2001). North Carolina is one of those districts in the world, which faces extreme hazards and consequences from flooding. Since 1989, there have been 14 federally declared disasters in North Carolina. Maintaining alone has cost \$3.5 billion (NCCTSMP, 2001).

More recently, Balica et al. (2013) compared physically based and the parametric approaches to compute flood risk under climate change. Smemoe et al. (2004) proposed an automated computing method for Green and Ampt parameters using digital soil and land use data. The developed methodology yielded less time for parameter estimation. Adiyanti et al. (2016) applied TUFLOW-FV to hydrodynamic calculations as simulate the water level, velocity, salinity and temperature distribution, including vertical stratification. Costabile and Macchione (2015) employed the shallow-water equations for detailed inundation modeling, underlining the importance of using 2D fully dynamic unsteady flow equations for flood mapping. Alaghmand et al. (2016) searched the relative impacts of artificial flooding on the flow and solute dynamics of the floodplain aquifer and its ecological implications.

Intensive precipitation events in Rize province usually produce damaging floods. Hence, there is a need for estimating peak flow rates from storm events to develop a detailed floodplain management plan and reliable information to promote proper use and management of flood plains in order to protect property and lives and to work on other development plans (NNDWR, 2002). The purpose of this study is to produce a reliable watershed and floodplain model for the determination of risk for flood prone areas in Rize province using historical data and produced future data based on climate change scenarios. We employed a model consisting of the combination of Watershed Modeling System (WMS) for peak discharge determination and TuFlow for floodplain analysis. TuFlow (Syme, 1991; WBM, 2005), which is 1D/2D hydraulic model based on finite difference approach, is known as one of the

Fig. 1. Overview of sub-basins in Rize Province.