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Numerical modeling techniques for flood analysis

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ABSTRACT

Topographic and climatic changes are the main causes of abrupt flooding in tropical areas. It is the need to find out exact causes and effects of these changes. Numerical modeling techniques plays a vital role for such studies due to their use of hydrological parameters which are strongly linked with topographic changes. In this review, some of the widely used models utilizing hydrological and river modeling parameters and their estimation in data sparse region are discussed. Shortcomings of 1D and 2D numerical models and the possible improvements over these models through 3D modeling are also discussed. It is found that the HEC-RAS and FLO 2D model are best in terms of economical and accurate flood analysis for river and floodplain modeling respectively. Limitations of FLO 2D in floodplain modeling mainly such as floodplain elevation differences and its vertical roughness in grids were found which can be improve through 3D model. Therefore, 3D model was found to be more suitable than 1D and 2D models in terms of vertical accuracy in grid cells. It was also found that 3D models for open channel flows already developed recently but not for floodplain. Hence, it was suggested that a 3D model for floodplain should be developed by considering all hydrological and high resolution topographic parameter's models, discussed in this review, to enhance the findings of causes and effects of flooding.

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1. Introduction

Environmental changes have always been a keen concern for researchers. Increment in precipitation, urbanization and topographic changes have lead to a sharp rise in the occurrence of natural hazards. Flooding is a very common hazard found in large parts of the Earth. However, according to United Nation's report (UNISDR), flood strike in Asia and Africa more than other countries. The analysis also highlights that since 1995, floods accounted for 47 percent of all weather-related disasters, affecting 2.3 billion people, killing 1.57 lacs and damages about US$19.3 billion and US$0.83 billion for Asia and Africa respectively (Nkwunonwo et al., 2015).

Earth processes in which changes occur in land, air and ocean, are very complex. These changes are interrelated to each other causing climatic changes. Significant urbanization during the past several years explains some important effects of land use changes on water management such as replacement of permeable to impermeable surface, reduction in infiltration and rise in overland flows (Wheater and Evans, 2009). Neupane and Kumar (2015) discussed the combined effects of climate and land use changes on water budget and predicted that the scale and intensity of flood events will increase with continuation of these processes.

The processes have been estimated by researchers by either applying in situ methods or laboratory approaches. However, these methods are limited by the fact that they cannot predict spatial and temporal changes over large areas. Therefore, to estimate accurate spatial and temporal changes over large areas, researchers use numerical modeling techniques, which are powerful tools for visualizing the dynamic behavior of physical systems in science and engineering fields and provide simplification of a complex reality. Numerical modeling includes four main steps; construction of a mathematical model according to physical problems, with suitable assumptions; development of a suitable numerical model; obtaining the results by implementing the model; and interpretation of the results with the help of tables, graphs, charts and animations and finally proposing a feasible solutions.

With the advancement of computational technology, many one dimensional (1D), two dimensional (2D), coupled 1D/2D and 3D numerical models and software have been developed for various scientific and engineering practices (Dimitriadis et al., 2016; Bladé et al., 2012; Carbonneau et al., 2006; Stoesser et al., 2003; Wu et al., 2000). Dimitriadis et al. (2016) used 1D and 2D models for uncertainity assessment in floodplain hydrological modeling. Bladé et al. (2012) studied the conservation of mass and momentum by coupling of 1D and 2D models for river channels and floodplain respectively. The use of mixed approach of 1D and 2D numerical models increases the quality of results (Horritt, 2006; Dimitriadis et al., 2016) and also save time and computer memory which can be limiting factors for the application of 2D models (Bladé et al., 2012). Results of these models also affected by the complexity and quality of topographic and input data (Cook and Merwade, 2009; Neal et al., 2012).

Many studies related to hydrological modeling have been done in several countries which have good record of quality data but in data sparce region or lack of attention towards hydrological modeling, in some developing countries, often prevent researchers to have an interest and accurate prediction of causes and effects of flooding. Nkwunonwo et al. (2015) discussed the gaps of flooding and flood risk reduction in Nigeria and found lacking of flood data and poor attention towards flood modeling and assessment vulnerability to flooding as compared to other developing countries. However, Samela et al. (2015) obtained flood inundation map by using 2D hydrologic simulation in an ungauged basin of Ethiopia. Fernández et al. (2016) also uses a 2D hydraulic model in data sparse region to simulate spatio-temporal patterns in northern Cameroon by assuming uniform maning's roughness coefficient, precipitation and evaporation. They suggested the limitation of 2D model that it is unable to predict elevation differences in floodplain modeling which has its own significance in accurate results. Here is the need of 3D model for floodplain modeling to enhance the limitations. However, very few studies uses 3D modeling technique for river channel modeling (Stoesser et al., 2003; Wu et al., 2000; Ye and McCorquodale, 1998). It is also the need to discuss the models related to input data and complexity along with the limitations of both 1D and 2D numerical models to enhance the quality of results.

In this review, flood generated parameters with their simulation techniques were considered to know the accurate spatial and temporal land, air and climatic changes on flooding. This review includes (i) the role of physically based widely accepted 1D & 2D numerical models with their parameters which were used in flood analysis simulations in recent studies, (ii) the type of their models used and the limitations in recent floods analysis studies are presented. Furthermore, the necessity of 3D model for floodplain simulation based on the limitations of 1D and 2D numerical models was also discussed. The aim of this study is to grasp the importance of physical modeling and its effectiveness in improving the accuracy of spatio-temporal flood analysis in flood event studies.

2. Hydrological modeling

Hydrological modeling can be defined as the characterization of real hydrologic features and system by the use of small-scale physical models, mathematical analogues, and computer simulations (Allaby and Allaby, 1999). The aim of hydrological modeling is to focus on individual flows of a hydrological system with various parameters controlling the intensity of the flows and the soil, land,