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Flood Risk and Vulnerability of Addis Ababa City Due to Climate Change and Urbanization

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Abstract

Since 1988 Addis Ababa is increasingly affected by flooding. The rapid economic growth of the city increases the urbanization rate significantly, furthermore, an increase in summer season precipitation is expected with a possible risk of flooding. In this research, we analysis the flood risk and vulnerability due to climate change and urbanization using Soil and Water Assessment Tool. The change on peak flow is quantified after careful calibration/validation and uncertainty analysis considering two landsat images and General Circulation Models. The model result indicated that a 10% and 25% increase in peak flow due to climate change and urbanization respectively.

*Keywords:*Flooding; urbanization; climate change; vulnerability; SWAT

1. Introduction

For the past 50 years' flood-related disasters in Africa shows an increasing trend [1]and since 1981, floods account about 50 % of the disaster recorded in Sub-Saharan Africa [2]. Addis Ababa (the capital of Ethiopia and Africa) is habitat to one-fourth of the urban population and contributes about half of the national Gross domestic product (GDP) growth of the country [3]. Despite the rapid economic growth and urbanization, flooding is the major development challenge facing the city. Urban flooding is more intensified by dramatic changes in the impervious area, in addition to heavy rainfall and extreme climatic events [4]. According to a remote sensing analysis of the

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study area (Fig.1.), Akaki catchment, the urbanization rate increased by 10% only from 1993 to 2002.

Addis Ababa is vulnerable to riverine as well as flash floods due to extreme climatic events and upper catchment activities and the vulnerability to flooding is more aggravated due to a poor drainage system, rapid housing development along river banks and using inappropriate construction materials [3]. Over one century of rainfall analysis, particularly considering the rainy season (June to September: JJAS) showed an increasing trend of rainfall approximately by 18 mm per decade from 1951 to 2002 [5]. According to the Intergovernmental Panel on Climate Change (IPCC) report, eastern Africa annual rainfall is expected to increase [6]. A recent study by [7] on Ethiopian summer (Kiremt) season using high-resolution models participating in coupled Model Intercomparison Project Phase 5 (CMIP5) under the Representative Concentration Pathway (RCP) 4.5 scenario also shows an increase in precipitation.

Due to rapid urbanization and population increase, low-income communities are forced to settle in flood-prone areas additionally the poor drainage systems of the city also intensify the risk of flooding as well [8]. The reduction of green structures and the increase in the impervious area in urban areas generates more surface runoff even from regular storms [4] and the situations will be more worst when poor people settle in areas which are vulnerable to flooding such as riverine and low-lying floodplains [9]. Considering the flooding risk of Addis Ababa city, in this research we assess the flooding due to climate change and urbanization using Soil and Water Assessment Tool (SWAT) hydrological model. Particularly, the impact of climate change on peak flow (July-August) is quantified using two General Circulation Models (GCMs) participating in the CMIP3 considering SRES A1B emissions scenarios and the urbanization effect is also assessed using remote sensing data of 1993 and 2002 taken from the United States Geological Survey (USGS). Keeping the main objectives of the paper, section 1 presents, a detail background information about the flooding problem in Addis Ababa. Section 2 and 3 describes the study area, the data used and approach followed. Section 4 presents the quantified results of the two scenarios including a discussion about climate and land use change assessment based on the model output. Finally, in section 5 conclusions is drawn by carefully analyzing the quantified results of climate change and urbanization impacts on flooding.

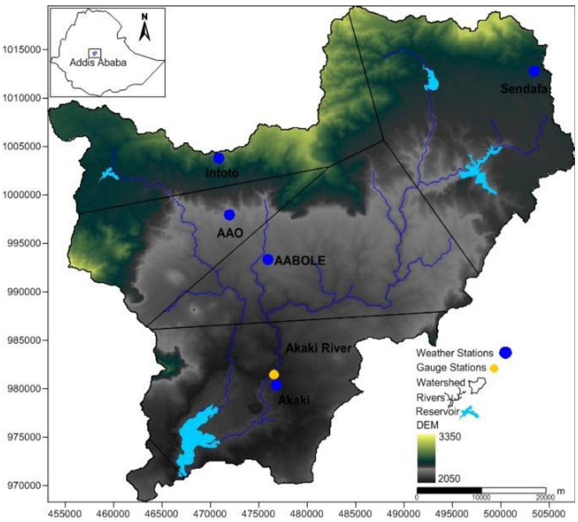

Fig. 1. Study area description

2. Material and methods

2.1. Hydrological Model

The SWAT model is a comprehensive, semi-distributed model, which is designed to assess the impact of land use and management on water, climate change in ungauged watersheds [10]. The model also allows users to quantify different water balance components with unique values at a hydrologic response units (HRUs) level for each subbasin [11]. A detail description of the model can be found in the theoretical documentation and in [12]. SWAT (Fig.2.) model have been applied worldwide in various areas by different scholars and researchers, recently a lot of peer reviewed publication can be found in different research journals [11] [13]. In Ethiopia, the model has been successfully applied at different spatial and temporal scale [14] [15].

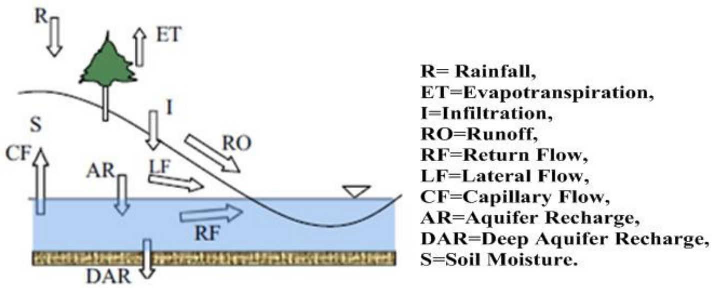

Fig. 2. Schematic illustration of the conceptual water balance model in SWAT [11]

2.2. Databases and model setup

The Akaki catchment hydrological model was constructed using up to data available data taken from different organization in the country and additional data have been taken from open source data providers (Table 1).

Table 1. Databases used for the model set up, calibration, validation and scenario analysis.

Data type	Resolution	Source
Digital Elevation(DEM)	90 m	Shuttle Radar Topography Mission (SRTM) http://www2.jpl.nasa.gov/srtm/
Land use		
1993	30m	Landsat - USGS(http://landsat.usgs.gov/)
2002	15 m	
Soil	30 arc-second	Harmonized World Soil Database v 1.2(http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/)
Climate		
Observed	1985-2004	National Meteorology Agency of Ethiopia (www.ethiomet.gov.et/)
GFDL CM 2.0	2.5^0	Climate Change Data for SWAT
GFDLCM2.1	2.5^0	(CMIP3)(http://globalweather.tamu.edu/cmip)
River discharge	1 Station (20 years)	Ministry of Water, Irrigation & Energy of Ethiopia (www.mowr.gov.et/)

The ArcSWAT 2009 interface, which is an open source code that has been applied in various studies in different spatial and temporal scale is applied to set up the model and represent an appropriate physical parameter in the catchment. The watershed delineation is done by using DEM and detail stream network, watershed (1464km^2), 29 subbasins and 675 HRUs representing a unique combination of land use, soil and slope is created by the model. Water balance computations are made at the HRU level for each subbasin. The total simulation period is from 1985 to 2004 and the first 3 years were used as warm up period, which helps to minimize model error in the initial simulation and the remaining two-third of the data have used for calibration and one-third for validation period. The calibrated model and parameters are used to assess the climate change impact and urbanization effect on the peak flow.

[16] developed SWAT-CUP (Calibration and Uncertainty Procedures), which is used to facilitate the calibration, validation, and sensitivity analysis process. SWAT-CUP includes five different calibration methods; it also allows users to visualize the study area in Bing Map. The SUFI-2 [17] [16] in SWAT-CUP has been used to minimize the computation time significantly [18]. Due to its efficiency, in this study, the SUFI-2 program is used for calibration and uncertainty analysis.

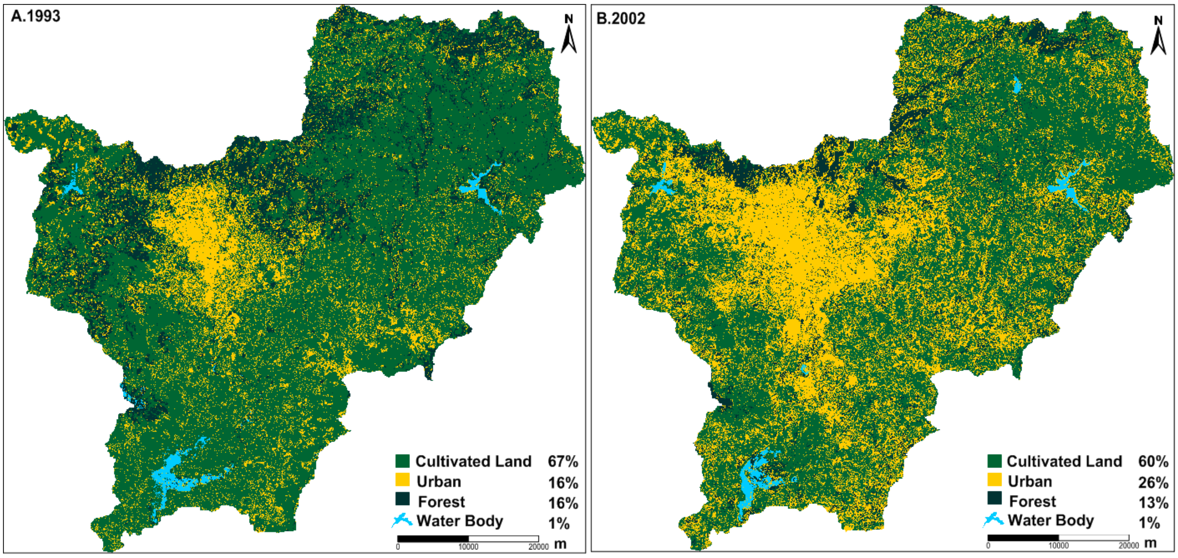

Fig. 3. Land use map of 1993 and 2002 used in the study

The climate change impact on peak flow with possible risk of flooding due to the expected increase in summer season precipitation in the catchment is assessed using two GCMs participating in CMIP3 considering SRES A1B emissions scenarios for a period 2046-2064. Particularly, Geophysical Fluid Dynamics Laboratory Coupled Model (GFDL CM) 2.0 and 2.1 precipitation and temperature data were used to evaluate the potential impact on urban flooding. Additionally, the rapid urbanization effect on flooding is addressed using remote sensing images of 1993 and 2002.

3. Result and discussion

3.1. Calibration and validation of the model

The performance of the model is evaluated using Nash-Sutcliffe (NS) and coefficient of determination (R^2). Accordingly, the model efficiency was found to be satisfactory having a NS 0.79 and R^2 0.79 for calibration period and 0.68 for both criteria in the validation period. The uncertainty analysis is carried out by comparing the recommended values of the percentage of observed data bracketed by the 95PPU (P-factor) and the width of the 95PPU band (R-factors) and both factors were found to be within recommended limits, >0.7 for P-factor and <1.5 for R-factor [11]

3.2. Climate change and urbanization impact on flood

The result of climate change impacts using GFDL CM2.1 indicates that the peak flow is simulated to increase by 10%, however the GFDL CM2.0 model responds differently to a similar scenario. The model response to the rapid urbanization also indicated a rise in peak flow by 25% from 1993 to 2002. Although the two model responds differently, it is evident from a previous study and the IPCC report the possible increase in summer season precipitation [6] [7]. Since our objective is not to compare the performance of the two models, the authors believe that the urbanization impact is more dominant compared to the climate change impact and the combined effect will be much more severe, which intensify the risk of flooding significantly.

3.3. Flood risk and vulnerability of Addis Ababa city

Although flood risk, inundated areas and vulnerability of the city is not quantified for each sub-cities, a significant increase in urban flooding for the past two decades is evident due to the rapid urbanization and climate change impacts. The model result also showed an increase in the peak flow as a result of green structures losses and climate change. In addition, due to economic issues, most people in Addis Ababa are forced to live in flood-prone and vulnerable areas such as riverine, low-lying floodplains and unstable hillsides. "Although no one knows for sure the exact magnitude of slums in Addis Ababa, most international estimates put the proportion of the city’s population that is living in rundown and slum settlements as one of the highest in the world "[19]. A 2005 study conducted to quantify Addis Ababa’s residential areas settlement characterization also indicated that 80 % of the communities are located in slum areas [19]. Unless appropriate adaptations measures are taken by policymakers to reduce the adverse impacts, flood risk and vulnerability of the urban poor who lives in hazardous as well as most impervious areas of Addis Ababa city is expected to rise substantially in the future.

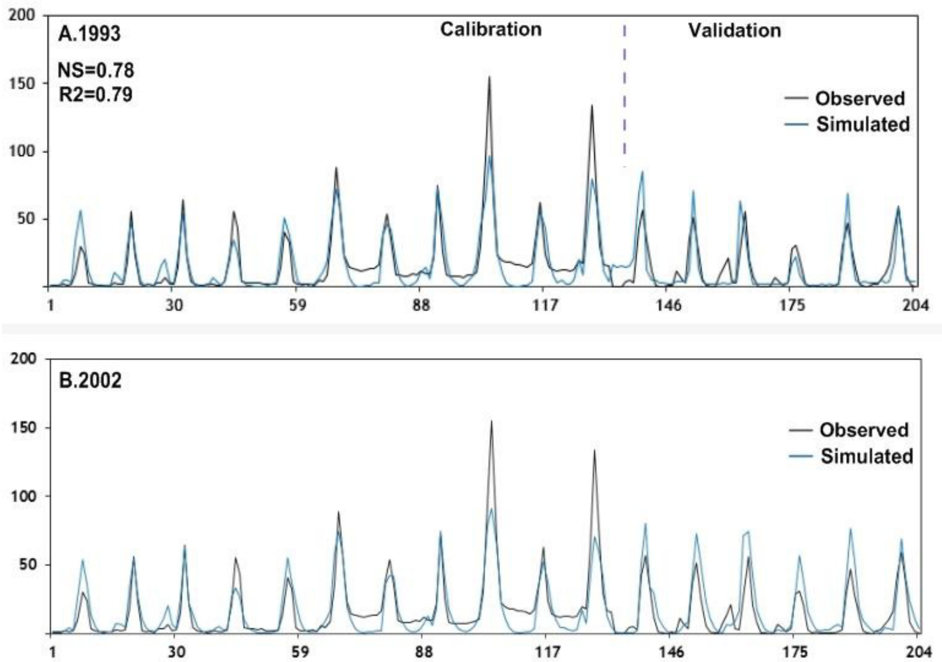

Fig. 4. A. Calibration and validation output of the model using land use 1993 B. Land use change output for 2002 (Date start from month one of 1988)

4. Summary and conclusion

In this study, Akaki catchment model was built, calibrated, and validated using SWAT program considering the available data in the study area. The calibration, validation, sensitivity as well as uncertainty analysis is also facilitated by using the SUFI-2 program in SWAT-CUP. The existing data were used for model setup, calibration as well as validation. The calibrated model is further used to assess flood risk due to the climate change impacts and the rapid urbanization using GFDL CM 2.0 and 2.1 as well as Landsat imagery data of 1993 and 2002. Though the 95% prediction uncertainty of the output satisfies the recommended values, it is also advised to address the major limitations which arise due to lack of data, such as discharge stations, reservoir management, soil moisture and/or deep aquifer percolation and so on which have a significant impact on the model result.

In general, the rapid urbanization and climate change impacts link with flooding in the catchment is quantified on a monthly time step. The assessment provides a valuable information to the country which is one of the highly vulnerable to climate change impacts, it also helps to maintain the rapid economic growth of the city by minimizing the risk of flooding due to the rapid urbanization and climate change. Considering the uncertainties appropriately, the model could be also applied to a wide range of areas including water resources assessment, policy making, and other studies.

Even though there exists a lack of data for a country like Ethiopia, it can be concluded that having the basic data, modeling tools and expertise it is possible to conduct a hydrological as well as other studies in various spatial and temporal scales. However, it is obvious that a good data quality and availability would minimize the risk associated with uncertainty, which assists to make a reliable model prediction and forecasting.

Acknowledgements

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