The Response of Peak Discharge and Sedimentation to the Land Use/Land Cover Change Scenarios in the Upper Awash Basin, Ethiopia

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November 24, 2022

Abstract

Expansion of unplanned agriculture and urbanization increases the danger of extreme flood and sedimentation. The Upper Awash basin has been under tremendous influence of human activities in the last five decades. The historical land use/land cover (LULC) change analysis was made by processing multi-temporal Landsat images and the future LULC was predicted using the Land Change Modeler. The LULC transition between a pair of classified LULC maps and driver variables were combined to predict the future LULC scenario. The five different LULC change and future land management scenarios are LULC 1974, LULC 2014, increase in the urban area, riparian and steep slope afforestation, and predicted future LULC 2045. The LULC change scenarios together with other spatial and climate data were used to simulate the hydrology, and sedimentation at four main subbasins using the calibrated soil and water assessment tool (SWAT) model. The mean monthly change in the water balance components and sedimentation have indicated higher rates of fluctuation due to LULC change. The riparian and steep slope reforestation scenario has reduced the mean annual surface runoff volume by 9.3% and sedimentation yield by 6.1% from the baseline LULC 2014. Moreover, the frequency of estimated 100-year annual extreme daily discharge reveals significant variation among the LULC scenarios. Notably, the future LULC 2045 has indicated a higher increase of extreme daily discharge by 23.5% at Homole subbasin. The study outlined the impact of land management on the flood events and sedimentation in the large basin, and spatial variation of LULC change impact has been presented. It suggests that the increase in deforestation due expansion of cropland and urbanization will intensify floods, whereas, riparian and steep slope reforestation has significantly reduced the peak discharge and sedimentation. Therefore, the future land management plans should consider appropriate vegetative conservation measures in the upland areas.

AGU 100 FALL MEETING Washington, D.C. | 10-14 Dec 2018

H11J-1605

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BACKGROUND

- Long-term land use and land cover (LULC) changes and their associated impacts pose critical challenges to sustaining vital hydrological ecosystem services for future generations.
- The Upper Awash basin is one of the most densely populated and urbanized parts of Ethiopia and the downstream of the basin is suffering from drought, flood and siltation [1].
- In recent years a more frequent flood events have been reported such as Fig. 1.
- Establishing linkages between land use practice and hydrological response can help to formulate potential land management options.

Fig. 1 Extreme flood occurrence on Sept 18, 2017 due to Awash Belo river, near Tefki town in Upper Awash basin.

- The effects of land use on flooding is a major research challenge, when attempting to scale up land use effects from a local to large watersheds scale [2].
- Previous researches mainly focused on the runoff responses to LULC change on annual, seasonal or monthly time scales.

▪Objective

❑ Therefore, the main objective of this study is to evaluate the impact of land use/land cover LULC change scenarios on the annual maximum daily (AMD) peak discharge and sedimentation at subbasins of Upper Awash watershed.

METHODS

Where is Upper Awash watershed?

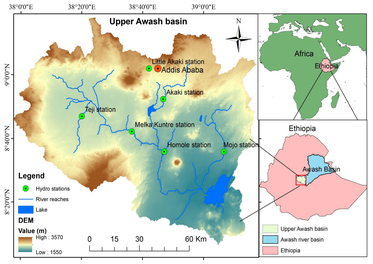

Fig. 2 Location map of Upper Awash basin in Ethiopia

Watershed description

- Upper Awash basin (Fig. 2) has total area: 11720 km^2
- Located in the central part of Ethiopia between latitudes 8°16' and 9° 18' N and longitudes 37° 57' and 39°17' E.
- Elevations range: 3570 to 1550 m asl.
- Number of Subbasins: 77.
- Number of HRUs: 444 for baseline scenario.
- Simulation performed is at four main discharge stations, namely: Akaki, Mojo, Melka-Kuntre and Homole subbasins.

Summarized procedure and model setup

- LULC classifications based on the multi-temporal Landsat images and LULC change detection.
- The future LULC 2045 was projected using the Land Change Modeler (LCM). The LULC transition between a pair of classified LULC maps and driver variables were combined to predict the future LULC scenario.
- Hydrologic modeling with the soil and water assessment tool (SWAT) model which is physically based, semi-distributed continuous time model [3].
- Simulation of hydrological cycle is based on the water balance equation.
- Surface runoff volumes and runoff rates for each hydrologic response unit (HRU) using the SCS curve number method. PET estimated using Penman-Monteith method.
- SWAT uses Modified Universal Soil Loss Equation (MUSLE) method to estimate soil erosion.

Methods Continued…

- Sensitivity analysis, model calibration and uncertainty analysis is performed using SUFI-2 algorithm in the SWAT-CUP [4].
- AMD peak discharge corresponding LULC change scenarios was simulated for a period of year (1980 to 2012).
- The flood frequency is analysed by fitting the annual maximum daily (AMD) discharge for each LULC change scenarios with LP III probability distribution function, and the Hirsch and Stedinger plotting position.

RESULTS

- The LULC change detection revealed that cropland increased from 47.7% in 1974 to 72.1% in 2014 similarly Urban area hiked up from 0.57% to 3.8%. In contrary, the vegetation cover declined from 49% to 22.8% in the same period as shown in the Fig. 3.
- The SWAT model has met the requirements of statistical efficiency criteria at daily and monthly time steps during calibration and validation periods, thus, it can be taken for further hydrologic scenario simulations.
- Simulations of daily and monthly streamflow and sediment yield revealed significant fluctuation due to the change in LULC.

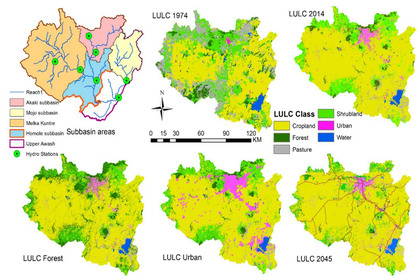

Fig.3 Main subbasins and LULC change scenarios of Upper Awash basin

Table 1 Definitions of LULC change scenarios.

Scenario	Conditions
LULC 2014	Baseline scenario/ recent LULC map of year 2014 from Landsat 8.
LULC 1974	Historical LULC of map of year 1974, Landsat MSS.
LULC urban	Urban sprawl scenario, urban area increased from the baseline 343.2 Km^2 by 200%.
LULC forest	Riparian and steep slope >16% afforestation scenario, area of dense forest increased by 200%.
LULC 2045	Modeled future LULC scenario the considering the disturbance sub-models in the LCM where maximum deforestation is assumed.

Table 2 Annual maximum daily peak discharge based on observation data

			Predicted values (cumecs)		
Stations	Mean	STDEV	Return period in year		
			10	50	100
Homole	452	130.3	616.8	716.1	751.2
Mojo	251.2	103.8	381.4	459.8	487.5
Melka Kuntre	258.2	79.78	358.9	419.6	441
Berga	49.9	23.45	79.2	97.1	103.5
Akaki	231.1	180.75	464.1	599.6	647.4
Holota	28.29	8.05	38.5	44.6	46.8

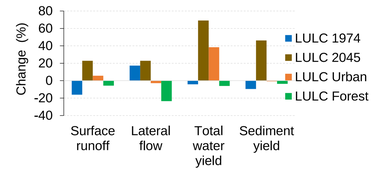

Fig.4 change in mean monthly values from the baseline scenario Upper Awash basin

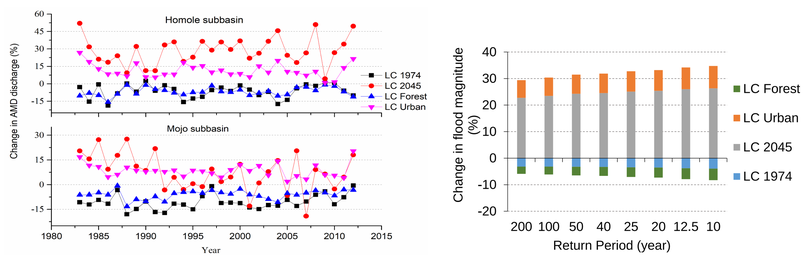

Fig. 5 Change in AMD discharge series and estimated frequency of extreme discharge.

- The future LULC 2045 has indicated a higher increase of AMD discharge by 23.5% whereas, steep slope reforestation reduces the peak discharge by 4.5% as shown in Fig. 5 at Homole subbasin.
- Expansion of unplanned agriculture and urbanization have increased the danger of extreme flood events in the Upper Awash basin.
- The result supports the notion that increasing vegetation cover over upland areas have potential importance in reducing flood risks.
- In contrast, deforestation (LULC 2045) and urbanization largely intensifies the frequency and magnitude of extreme discharges.

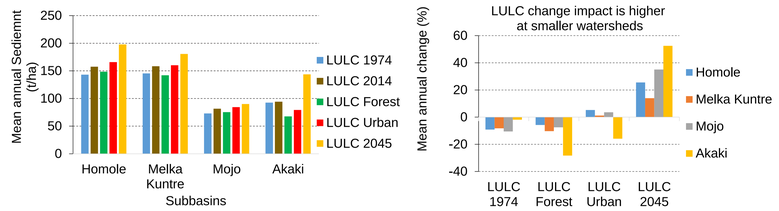

Fig. 6 Mean annual variation in sediment yield due to change in LULC

- The LULC impacts on sedimentation are more pronounced at smaller subbasin level (Fig. 6) where the effects of LULC are not averaged out by the variations contained in the whole watershed.
- Significant change in surface runoff is observed in subbasins where more area converted to urban class, and more sediment yield was generated in when other LULC classes are altered to cropland (Fig. 7).
- Subbasin and HRU level simulation outputs can help to prioritize and address particular watershed problems.

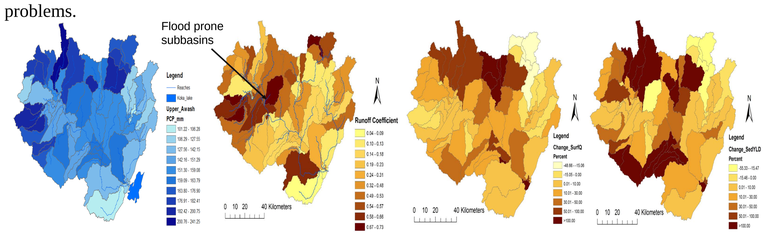

Fig. 7 Subbasin level variations of surface runoff and sediment yield (%) between LULC 1974 and LULC 2014 in Upper Awash basin

CONCLUSIONS

- The impact of LULC on sedimentation is more pronounced on relatively smaller watersheds.
- The impact of urbanization is more on surface runoff and total water yield than sediment yield.
- Expansion of cropland on the expense of native forest, and the swelling trend of urbanization have intensified the magnitude and frequency of peak discharge.
- In contrast, riparian zone and steep slope reforestation significantly reduces the series of AMD peak discharge and sedimentation.
- Therefore, the future land management plans should consider appropriate vegetative conservation measures in the upland and flood plain areas.

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