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Impacts of land use and land cover changes on hydrology of the Gumara catchment, Ethiopia

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ABSTRACT

Land use and land cover (LULC) changes are continuous phenomena, often driven by natural and anthropogenic factors. In Ethiopia, a conversion of forest and grass lands into cultivated and urbanized lands has been reported. While such changes are known to have multidirectional impacts on river flows, erosion and sedimentation, and the socio-economic situation within a catchment, there is a lack of assessment on the scale and rate of these changes, and consequent impacts. This study quantifies the rate of LULC in the Gumara catchment (1413 km^2), an important tributary to Lake Tana in northwest Ethiopia. Landsat images of three years (1986, 2001 and 2015) were processed using the supervised classification method. An extensive field survey generated over 150 ground truth points, which were used in the classification and accuracy assessment process. Then, a conceptual rainfall-runoff model (HBV) was calibrated and validated to assess the impacts of LULC changes on water balance components - evapotranspiration, soil moisture, groundwater recharge and runoff. Additionally, the decadal means and trends of precipitation and discharge were analysed to further examine and quantify the observed changes (if any).

A reasonably reliable LULC classification was achieved, with an overall accuracy of 90%. The results indicated that the catchment area under forest and grass land was about 11 and 18%, respectively, in 1986, which reduced to 5 and 10%, respectively, in 2015. In contrast, cultivated land increased from 70% in 1986 to 82% in 2015. Contrary to the expected impact of these LULC changes on hydrology, the HBV model, indicated only a slight change in the water balance components (± 5%). Runoff and all other water balance components remained more or less stable despite considerable LULC changes. However, the uncertainties encountered in the modelling process (e.g. model structure, LULC representation) could have masked the LULC impacts on hydrology. This was supported by the significant increase in the observed discharge indicated by the statistical analysis, even in view of no substantial changes in precipitation. Therefore, LULC could cause considerable increase in discharge, which needs further testing (e.g. through physically based modelling with detailed inclusion of LULC processes).

1. Introduction

The hydrological behaviour of a catchment is mainly controlled by climate, land use, soil and topography (Elfert and Bormann, 2010). Establishing reliable relationships among these factors is one of the main challenges in hydrological research (Getachew and Melesse, 2012). LULC change may be triggered by various factors. It can be caused by the interaction of socio-economic and demographic changes as well as biophysical conditions (Alemayehu et al., 2009; Bewket, 2002; Jacob et al., 2015; Yalew et al., 2016; Zeleke and Hurni, 2001).

At the one hand, LULC changes provide social and economic benefits, while generating unintended multi-directional impacts on water balance components. For instance, a study conducted in Ethiopia and Eritrean highlands by Hurni et al. (2005) found an increase in runoff when natural forest was converted to farmland. Other studies reported a reduction of infiltration and groundwater recharge associated with increased surface runoff (Bewket and Sterk, 2005; Gebresamuel et al., 2010; Pan et al., 2011).

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The impacts of LULC changes on hydrology can be studied by hydrological modelling, statistical analysis and experimental catchments' comparative analysis (Elfert and Bormann, 2010). The statistical analysis can be carried out when a good quality and long-term data on LULC and hydro-climatic variables is available. For instance, Saraiva Okello et al. (2015) argued that the observed trends in streamflows were caused by the LULC changes and water infrastructure (reservoir) development in the Incomati basin in Southern Africa. Similarly, Gebremicael et al. (2017) used statistical analysis and found that there was no significant change on precipitation, while there were significant changes (mostly decreasing trends) in stream flow in the Upper Tekeze-Atbara basin, Ethiopia. The LULC change was considered a likely driver among other factors such as surface and groundwater abstractions for irrigated agriculture, and the flow regulations due to dam construction. Another way of studying the LULC impacts is thorough a comparative assessment of hydrological behaviour of experimental catchments (Gebresamuel et al., 2010). This method has been rarely used due to lack of such experimental catchments. Applications of hydrological modelling for the assessment of LULC change impacts on hydrology is the most widely used method, and several applications could be found in literature (Fohrer et al., 2001; Hurni et al., 2005; Liu et al., 2008; Masih et al., 2011; Ott and Uhlenbrook, 2004).

The main objective of this study was to investigate the LULC changes and the consequent impact on hydrology of the Gumara catchment in Lake Tana Basin, Upper Blue Nile, Ethiopia by using a combination of remote sensing, hydrological modelling and statistical methods. The following research questions are investigated in this paper.

- What are the main LULC types and their areal coverage in the Gumara catchment?
- What was the scale of LULC changes that could be observed during 1986–2015, and how much were the rates of these changes?
- How LULC may have impacted on hydrology of the Gumara catchment?

2. Material and methods

2.1. Study area

The Gumara catchment, with drainage area of 1413 km^2, is located in the Lake Tana sub-basin of Upper Blue Nile (Fig. 1). The catchment has a rugged topographic feature in the upper part, while it has a plain area in the lower part, with large altitudinal variation ranging from 1761 to 3700 m.a.s.l. Mount Guna is the source of Gumara River and its tributaries. The river eventually flows into Lake Tana in northwest Ethiopia. Geologically, the Gumara catchment is known for igneous rock types of trap series basalts and unconsolidated quaternary sediments formed from lacustrine and fluvial processes (Poppe et al., 2013). Vertisols are the most common soils present in the lower part, while Andosols and Leptosols are found in the upper part (Deckers and Nyssen, 2015). The mean monthly climate and river discharge are shown in Fig. 2.

2.2. Methods and data

The methodological framework used in this research is schematized in Fig. 3. The main elements are briefly described below.

2.2.1. LULC mapping

The LULC maps were prepared for the years 1986, 2001 and 2015 using a supervised classification method (de Mûelenaere et al., 2014; Getahun and Van Lanen, 2015; Webster Gumindoga et al., 2014a,b; Jacob et al., 2015; Rogan and Chen, 2004). The freely available Landsat images, of 30 m spatial resolution, were downloaded from United States Geological Survey (https://earthexplorer.usgs.gov/). All the satellite images used were collected in the month of January to minimise the effect of seasonal vegetation differences, aiding to establish a fair comparison (Table 1). For accuracy assessment, ground truth data were collected from the field during November and December 2016. A total of 150 ground truth data points were collected that represented the most prevalent LULC classes. Accordingly, ground truth data were collected for LULC classes of agriculture (41), grazing land (25), forest (20), built-up (25), barren land (17) and water (22). This data set was collected with the help of Open Data Kit tool, Garmin Handheld GPS, Google Earth and topographic map of 1984. From the collected ground truth data, 121 points were used for the accuracy assessment. These points were selected based on their match with the location of ground truth data and located within the catchment through overlay with Google Earth. The location of the ground truth points is shown in Fig. 4. Various statistics, i.e., user's and producer's accuracy, Kappa coefficient, were computed to objectively assess the accuracy of the produced LULC maps (Congalton, 1991; Congalton and Green, 2008).

2.2.2. Hydrological modelling

The HBV model (HBV-Light version) was used for investigating the impact of LULC changes on hydrology (Bergström, 1992; Seibert, 2005). The model has been successfully applied in many countries (Akhtar et al., 2008; Bergström, 1992; Gumindoga et al., 2018; Love et al., 2010; Masih et al., 2010; Seibert, 2005; Uhlenbrook et al., 1999) including the Upper Blue Nile Basin, Ethiopia (Kim and Kaluarachchi, 2008). The required hydro-climatic data were acquired from the relevant government agencies. The climatic data were collected from Debre Tabor, Kimir Dingay, Mekane Eyesus, Alember, Wanzaye and Woreta meteorological stations. The discharge data used for this study was obtained from the station near to Gumara Town Bridge, which is the outlet of the catchment. After the quality was checked and missing records infilled (where needed), a daily time series data of precipitation, temperature and river discharge were used for the period 1985–2015. One year time series data of precipitation, temperature and river discharge were used as a warm-up period for the model. The timeseries between 1986 and 2015 were used for analysis of LULC impacts on the water balance components. Potential Evapotranspiration was estimated from the temperature data using Hargreeve's method (Allen et al., 1998; Hargreaves and Samani, 1985). The areal precipitation was computed using Theisen Polygon method based on the data of 6 rain gauges located inside and around the catchment.

The HBV model was applied in a semi-distributed mode by dividing the study catchment into 10 elevation bands and 3 vegetation zones (1: Forest and grazing; 2: Agricultural lands; 3: other urban, barren and water). The required data were estimated from the processed LULC maps for this study, and GIS was used to carry out this analysis. The model was calibrated and validated, against the observed discharge, for the periods 1986–1990 and 1991–1995, respectively. The Nash-Sutcliffe Efficiency (NSE) was used as an objective function for parameter optimization, which was done using the Monte Carlo method in the automatic calibration process (available within the used HBV-Light software). Two other commonly used goodness of fit measures (e.g. Coefficient of determination and Percent BIAS) were also computed to further test the model performance. Considering parameter uncertainty issues, the top 30 parameter sets that emerged from 1 million Monte Carlo simulations were used in the LULC change analysis, instead of using only one best performing parameter set. The modelling results reported in this study correspond to the parameter set derived based on the average of top 30 parameter sets. The LULC change impact was assessed on runoff, evapotranspiration, soil moisture and groundwater recharge. The 1986 land use properties were used in the calibration and validation process, thus, forming the base case simulation that was done for the 30 year period (1986–2015). The hydro-meteorological input data of precipitation, temperature, discharge and potential evapotranspiration used in the baseline simulation were kept same under 2001 and 2015 LULC vegetation zone simulations. The HBV model

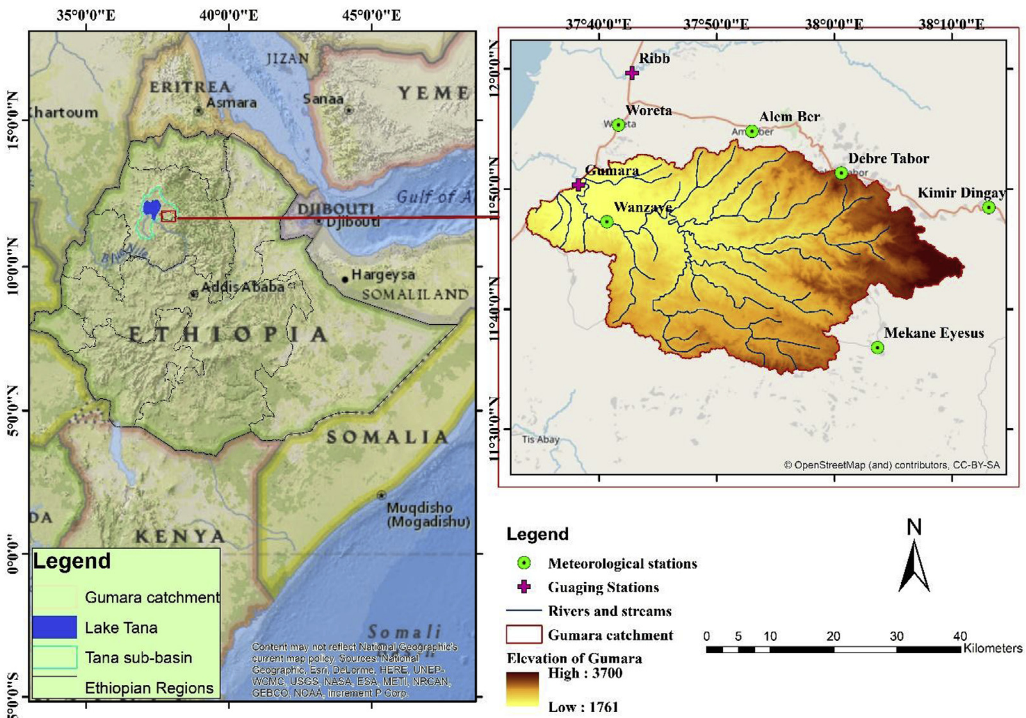

Fig. 1. Location of study area and hydro-meteorological stations used for the study.

parameters of soil moisture routine, response routine and routing routine were calibrated (1985–1990) and validated (1991–1995) based on the 1986 LULC vegetation zone. Then, the value of these parameters kept similar when simulations were done using the 1986, 2001 and 2015 LULC information for the period between 1986 and 2015.

2.2.3. Statistical analysis for detecting changes in hydro-climatic data

Next to the hydrological modelling, precipitation, temperature and discharge data were examined for trends using the Mann-Kendall test at monthly and annual time steps (Yu et al., 1993). Moreover, decadal means were also computed to examine the differences over time.

3. Results and discussion

3.1. LULC change analysis

The overall accuracy of 90% was achieved in the LULC classification process (Table 2). The accuracy statistics presented in Table 2 are well above the recommended value of 80% (Congalton and Green, 2008). Furthermore, the Kappa coefficient (Foody, 2010; Ismail and Jusoff, 2008) was computed as 0.88, which also indicated a very good agreement among the classified and referenced data. These performance statistics demonstrated a successful classification of the 2015 Landsat image. Therefore, a similar approach was used to produce the LULC classification for 1986 and 2001 Landsat images.

The produced LULC maps are presented in Fig. 5. The agricultural land use emerged as the most dominant LULC type in the basin (Fig. 5). The LULC map of 1986 showed 70% of the catchment area under cultivation (agriculture) followed by grazing (18%) and forest (11%). The proportion of other LULC types were very small (barren: 0.77%, built up areas: 0.72%, and water: 0.47%). The 2015 LULC map revealed that 82% of the catchment was cultivated followed by grazing (10%) and forest (5%). While, the area under barren, built up and water was estimated at 1.25, 1.46 and 0.35%, respectively.

The comparison of three study periods indicated that cultivated and grazing land cover occupied the largest proportion in the Catchment followed by forest. Cultivated land increased between 1986 and 2015 from 70 to 82%, respectively. On the other hand, a significant decrease

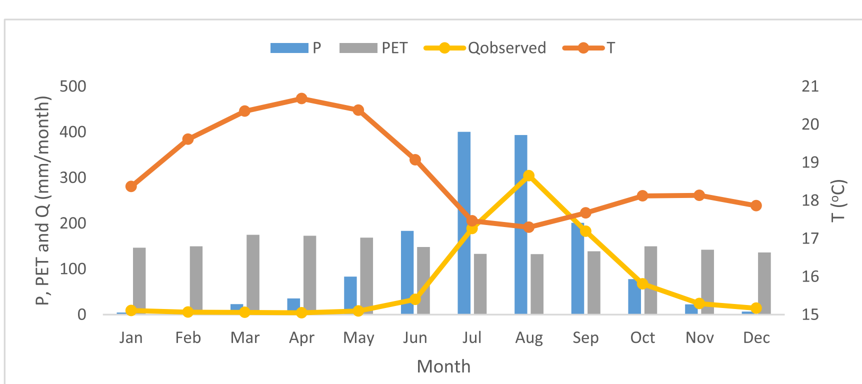

Fig. 2. Mean monthly climate and river discharge for the period between 1985 and 2015. P, PET, Q and T refer to precipitation, Potential evapotranspiration, river discharge and temperature, respectively.

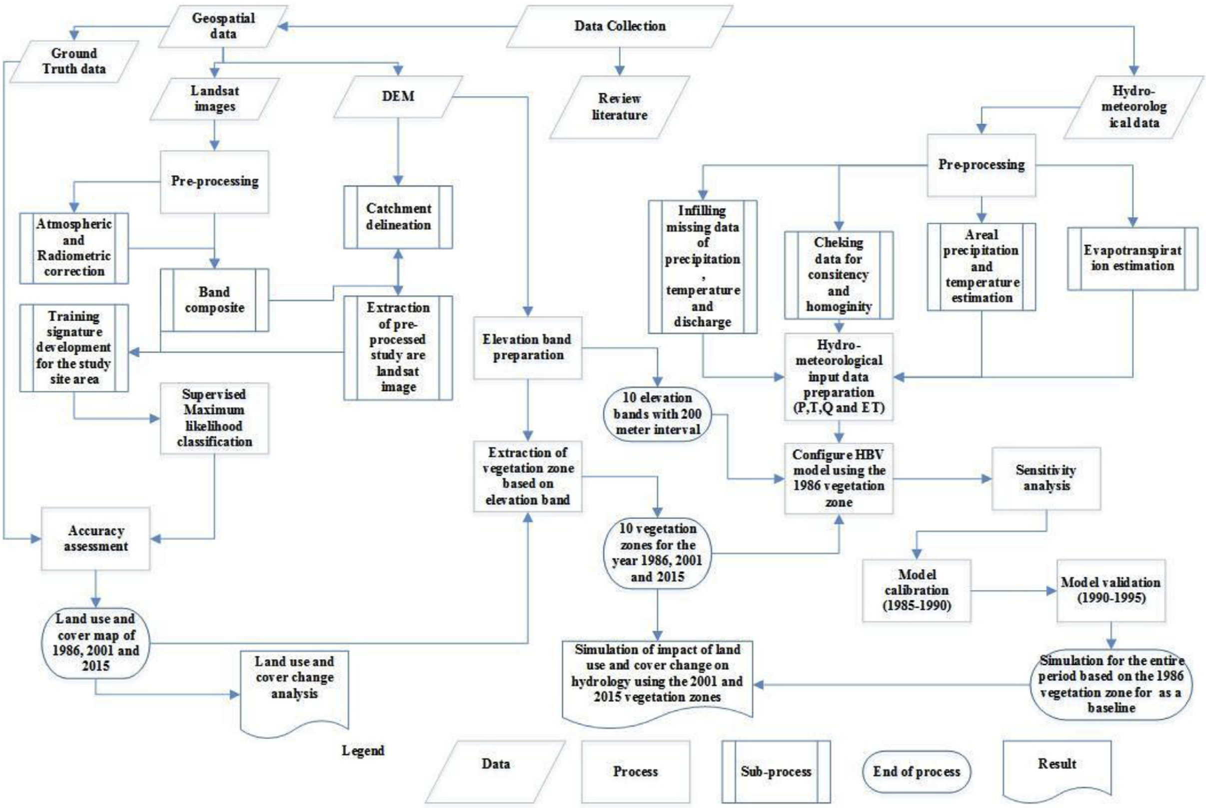

Fig. 3. Methodological framework applied for the land use and cover mapping and hydrological modelling.

Table 1
Summary of satellite data used for the study.

Year	Landsat Sensor	Path	Row	Acquisition date	Spatial Resolution
1986	Landsat TM	169	052	12 January 1986	30 m
2001	Landsat ETM$^+$	169	052	13 January 2001	30 m
2015	Landsat OLI/TIRS	169	052	28 January 2015	30 m

was observed in the catchment area under forest (1986: 11%; 2015: 5%) and grazing land (1986: 18%; 2015: 10%). This indicated a considerable decrease (about 50%) in the area under forest and grazing lands.

Furthermore, the change matrix analysis (Pontius et al. (2004), presented in Table 3, shows the LULC shift from one class to the other. The highest proportion of transition occurred among cultivated, grazing and forest LULC types over the study period. For instance, during the period between 1986 and 2015, about 19% of cultivated land was mainly gained from grazing (11%) and forest (6%). On the other hand, the area under different LULC classes that remained unchanged was estimated as 63, 6 and 4% in case of the cultivated, grazing and forest lands, respectively, during 1986 and 2015. Similarly, 0.11, 0.05 and

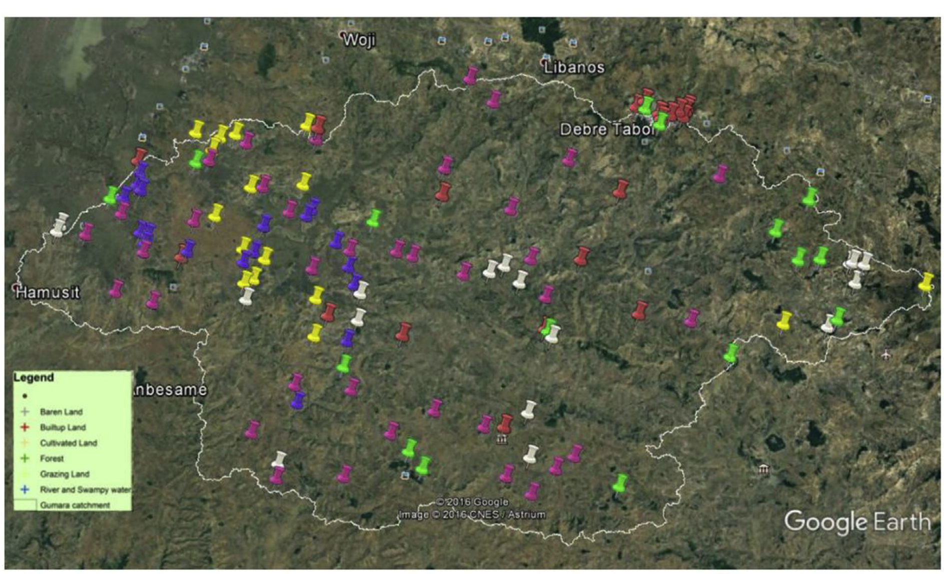

Fig. 4. The location of ground truth data points across the Gumara Catchment.

Table 2
Error matrix for the classified Landsat image of 2015.

LULC class	Number of reference data Points							User's Accuracy (%)
	Forest	Grazing	Barren	Built-up	Water	Cultivated	Total	
Forest	**14**	0	0	0	0	0	14	100
Grazing	1	**12**	0	1	0	0	13	86
Barren	0	0	**16**	0	2	0	18	89
Built-up	0	0	0	**17**	0	1	18	94
Water	0	0	0	0	**15**	0	15	100
Cultivated	0	3	1	2	1	**35**	42	83
Total	15	15	17	20	18	36	120	Overall Accuracy
Producer's Accuracy (%)	93	80	94	85	83	97		= 90%

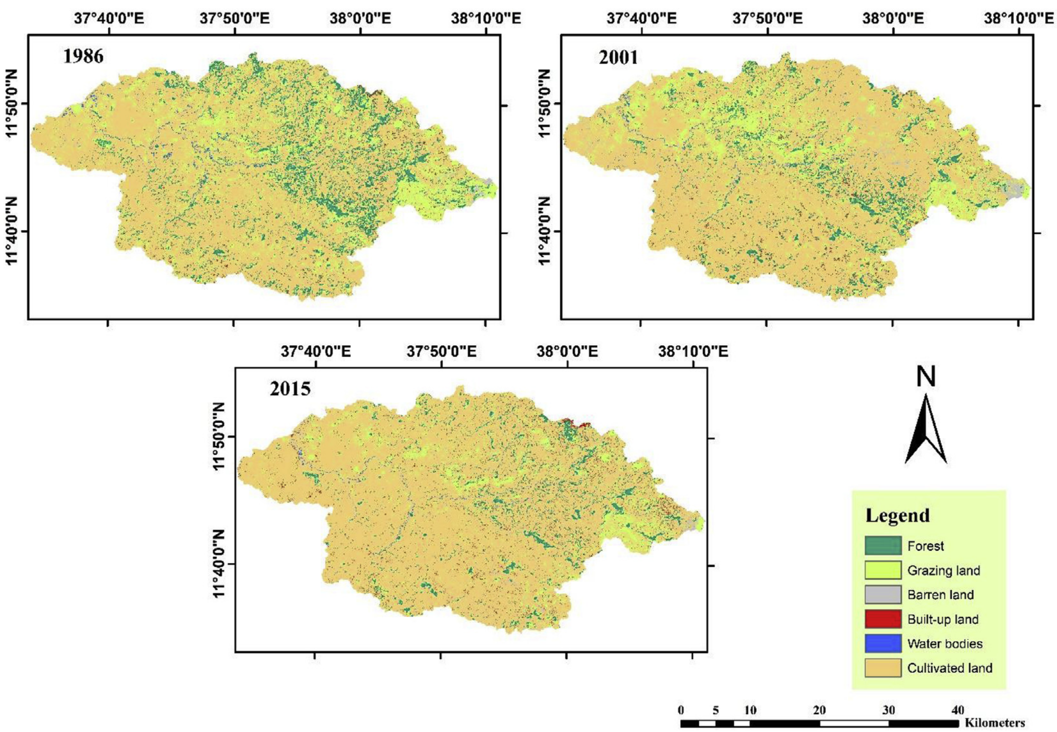

Fig. 5. The LULC maps of the Gumara catchment for the year 1986, 2001 and 2015.

Table 3
LULC change matrices between 1986 and 2015 (percentage of the total catchment).

		LULC of 2015										
		FL	GL	BaL	BL	WA	CL	P_{j+}	L_{ij}	C_j	S_j	D_j
LULC of 1986	FL	**3.50**	0.62	0.05	0.18	0.03	6.36	10.75	7.25	−5.26	3.96	−1.30
	GL	0.47	**5.63**	5.63	0.27	0.01	10.97	17.72	12.09	−7.92	8.33	0.41
	BaL	0.05	0.10	**0.11**	0.02	0.01	0.49	0.77	0.66	0.47	1.32	1.80
	BL	0.07	0.05	0.01	**0.05**	0.00	0.54	0.72	0.67	0.74	1.33	2.07
	WA	0.01	0.01	0.01	0.00	**0.08**	0.36	0.47	0.39	−0.12	0.54	0.42
	CL	1.39	3.39	0.70	0.94	0.22	**62.94**	69.57	6.63	12.09	13.26	25.35
	P_{+j}	5.49	9.80	1.25	1.46	0.35	81.67	100	27.68		28.76	28.76
	G_{ij}	1.98	4.17	1.14	1.41	0.27	18.72	27.68				

Note: Bold diagonals are persistence FL = forest, GL = grazing, BaL = Barren, BL = built-up, WA = water, CL = cultivated, P_{i+} = earliest time (1) total, P_{+j} = recent time (2), G_{ij} = gain, L_{ij} = loss, C_j = net change, S_j = swap and D_j = total change.

0.08% of barren, built-up and water bodies remained unchanged. In light of the above, it could be concluded that the largest transition was observed from grazing to cultivation and from forest to cultivation.

Estimates of annual rates of change of LULC are presented in Fig. 6. The rates of change varied from −3 to 6% per year among different LULC types and with different time periods. For instance, the results revealed about 2% per year decrease in forest and grazing lands during 1986–2015. While, barren and built-up lands increased by about 2.2% over the same period.

The observed LULC changes in the Gumara catchment are similar to the studies conducted for few other catchments in Ethiopia. For instance, the Dembecha (Zeleke and Hurni, 2001) and Tigray (Aynekulu, 2006) catchments also witnessed a major decline in forest land that was converted to agriculture. However, other studies reported not only a

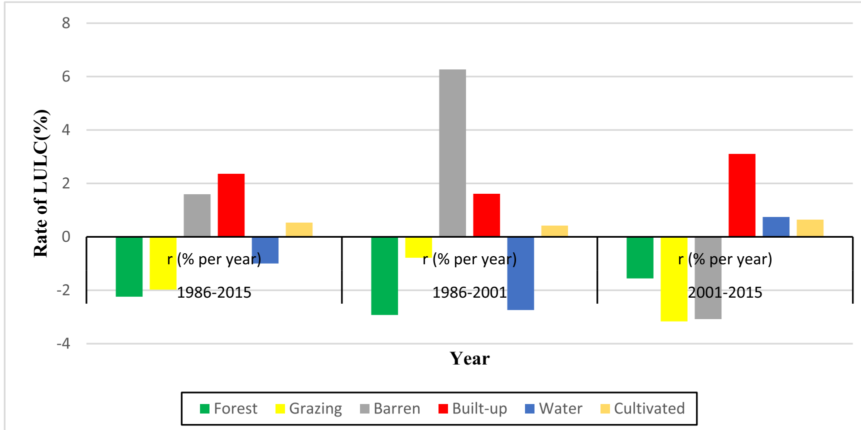

Fig. 6. Annual rate of LULC change between 1986 and 2015.

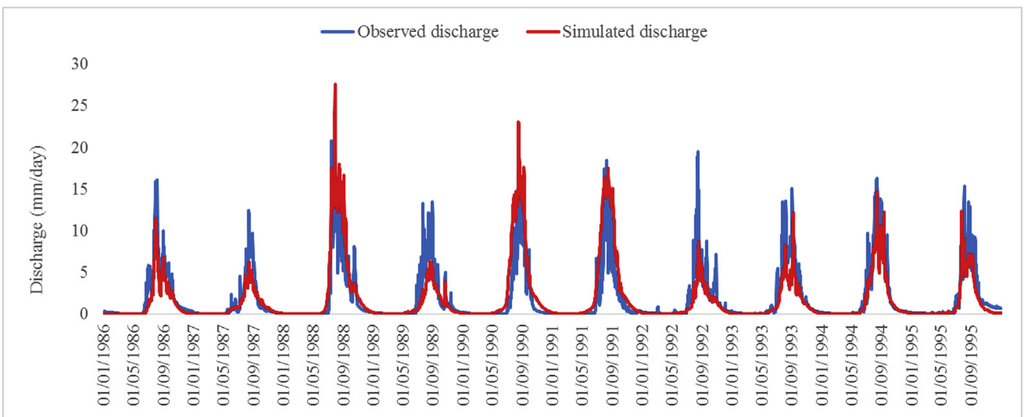

Fig. 7. A comparative view of observed and simulated discharge during calibration (1986–1990) and validation (1991–1995).

Table 4
The HBV model performance and simulated water balance for the Gumara catchment during calibration (1986–1990) and validation (1991–1995).

	Calibration (1986–1990)	Validation (1991–1995)
Water Balance [mm/year]:		
Simulated discharge	710	638
Observed discharge	687	738
Precipitation	1573	1467
Simulated actual evapotranspiration	856	835
Goodness of fit:		
Coefficient of determination	0.75	0.69
Nash-Sutcliffe efficiency (−)	0.70	0.68
Kling-Gupta efficiency (−)	0.83	0.77
Nash-Sutcliffe efficiency for log(Q) (−)	0.70	0.67
Mean difference (mm/year)	23	−101
Percent BIAS (%)	3	−14

decline but also a subsequent recovery of forested lands in other regions like northern Ethiopia (Nyssen et al., 2009) and the Chemoga catchment in northwest Ethiopia (Bewket, 2002). Contrary to these variable trends, the Gumara catchment only indicated a continuous decline without recovery of forest and grazing lands. Any efforts to restore these lands should address the underlying causes in Ethiopia such as increase in population (Yalew et al., 2016) and livestock (Jacob et al., 2015), land tenure system (Gebrelibanos and Assen, 2015), farming system (Mengistu et al., 2012), scarcity of energy sources (Tegene, 2002) and poverty at large (Gebrelibanos and Assen, 2015).

3.2. Rainfall-runoff modelling for LULC change impact analysis

The HBV model was successfully calibrated and validated for the Gumara catchment. This is substantiated by visual inspection of the observed and simulated hydrographs (Fig. 7), as well as the good to very good scores of their various goodness of fit statistics (Table 4). For instance, daily NSE was quite good during calibration (0.70) and validation (0.68). The water balance was also simulated fairly well, with the annual percent BIAS in the range of −14 to 3%. The goodness of fit statistics, indicated reliable model performance, following the recommended thresholds given in literature (Moriasi et al., 2007). In general, the selected top 30 parameter sets, used to investigate LULC change impacts on hydrology, had good to very good values of goodness of fit measures-comparable with those noted in Table 4. Therefore, the simulated rainfall-runoff process was considered good, and, therefore, the model was used for studying the LULC change impacts on the hydrology of the Gumara catchment.

The simulated water balance components using the top 30 parameter sets in case of all three LULC scenarios (1986, 2001 and 2015) indicated small differences among the water balance components, which were in the range of only ± 5%. In general, discharge showed a slight (but negligible) increase under 2015 LULC compared with 2001 and 1986 situation, whereas actual evapotranspiration indicated a small decrease. Similar to the simulated discharge, soil moisture and groundwater recharge indicated small increase. The monthly values of the water balance components are presented in Fig. 8. These results are based on the simulation carried out with a parameter set with average value of each parameter, which was derived from values of the top 30 parameter sets. In general, the modelling results indicated no

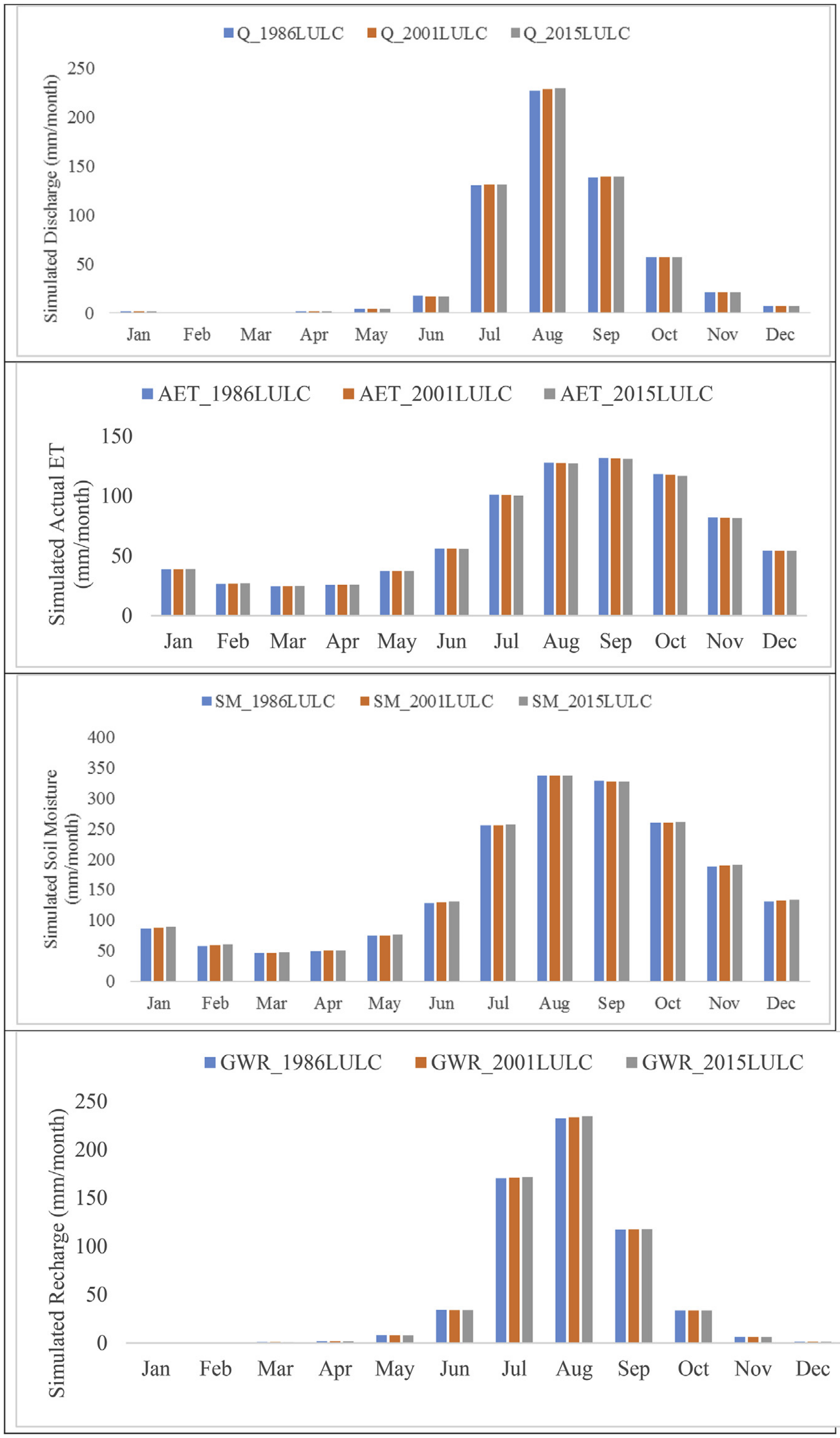

Fig. 8. Simulated water balance components under studied LULC scenarios.

substantial impact on hydrology of the Gumara catchment due to LULC changes. However, seemingly stable discharge and other water balance components, in view of considerable LULC change, were contrary to our expectations and a study conducted in Gilgel Abay (W. Gumindoga et al., 2014a,b). Uncertainties in the modelling process might have masked the LULC change impacts. Parameter uncertainty was therefore examined in detail. For example, several parameter optimization options, such different parameter search methods (Monte Carlo, Genetic Algorithm), were tested using random or constrained searches. In the end, the results were more or less similar. Thus, parameter uncertainty did not appear to be a major concern in this case. But, the land use representation in the HBV model was still simple, as only three categories could be represented, which means lumping of several LULC types (e.g. grazing with forest; water and barren with urban; and lumping all types of agricultural lands into one category). Moreover, distributed representation of LULC was not possible, nor were crop growth processes simulated using a physically based approach. Therefore, the suitability of using simple conceptual-rainfall runoff models, like HBV, for LULC change impact could be questioned, although some published studies have attempted to relate HBV model parameters to

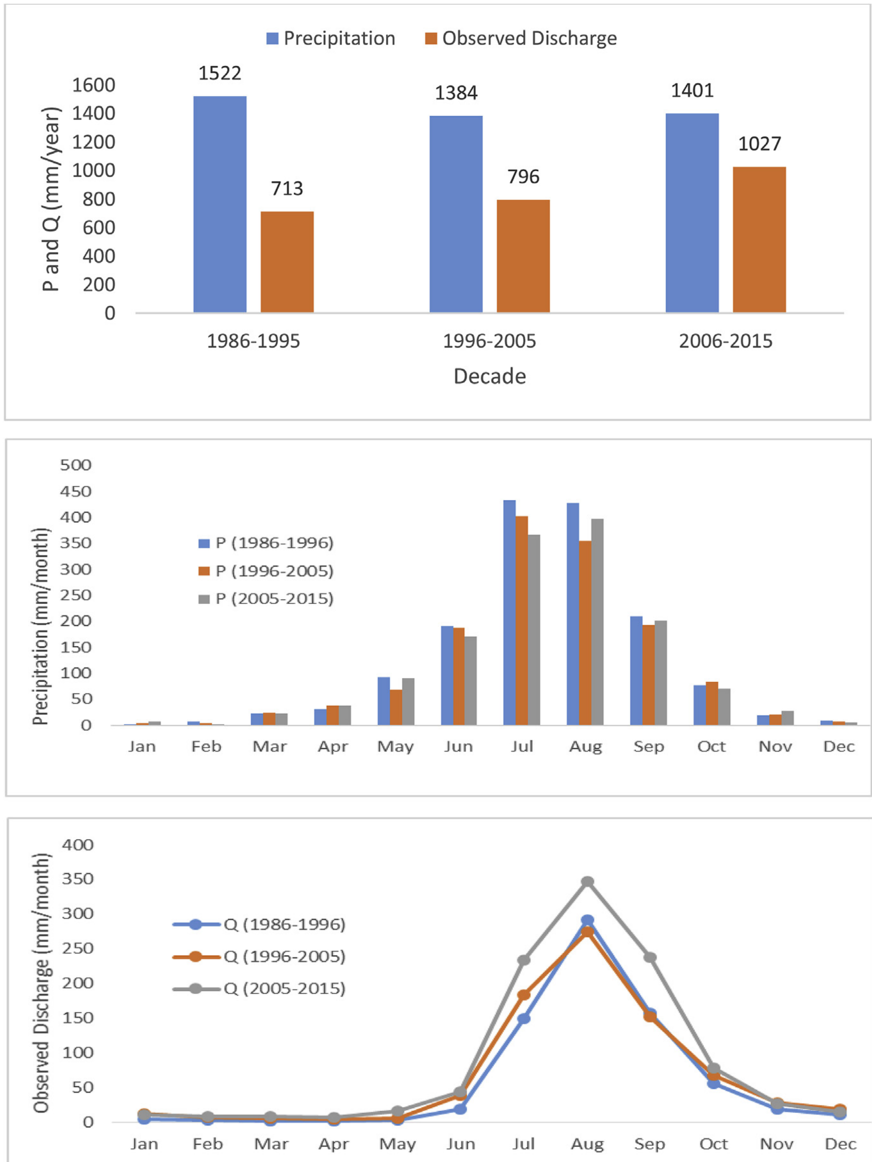

Fig. 9. Statistical analyses indicating decadal means of precipitation and observed discharge.

Table 5
The results of trend analysis in case of the precipitation data of 1985–2015.

Month/annual	Trend analysis summary			
	Kendall's tau	S	P-value	Trend
January	0.054	0.024	0.592	No trend
February	−0.004	0.000	0.975	No trend
March	0.041	0.081	0.310	No trend
April	−0.019	−0.066	0.787	No trend
May	−0.084	−0.622	0.053	No trend
June	−0.084	−0.715	0.060	No trend
July	0.006	0.236	0.940	No trend
August	0.058	0.865	0.339	No trend
September	0.118	0.748	0.002	increasing trend
October	0.045	0.393	0.391	No trend
November	0.277	0.519	< 0.0001	Increasing trend
December	−0.058	−0.021	0.175	Decreasing trend
Annual	0.067	31	0.176	No trend

Table 6
The results of trend analysis in case of the river discharge data of 1985–2015.

Month/annual	Trend analysis summary			
	Kendall's tau	S	P-value	Trend
January	0.475	0.230	< 0.0001	Increasing trend
February	0.561	0.208	< 0.0001	Increasing trend
March	0.518	0.198	< 0.0001	Increasing trend
April	0.557	0.200	< 0.0001	Increasing trend
May	0.553	0.300	< 0.0001	Increasing trend
June	0.265	0.881	< 0.0001	Increasing trend
July	0.290	3.041	< 0.0001	Increasing trend
August	0.282	2.500	< 0.0001	Increasing trend
September	0.346	3.596	< 0.0001	Increasing trend
October	0.140	0.569	0.067	No trend
November	0.157	0.280	0.014	Increasing trend
December	0.211	0.192	0.008	Increasing trend
Annual	0.419	13.723	< 0.0001	Increasing trend

LULC types (Kim and Kaluarachchi, 2008; Seibert, 1999) and have conducted LULC change impact analysis (Akhtar et al., 2008; Gumindoga et al., 2018).

3.3. Statistical analyses to detect changes in hydro-climatic variables

The decadal means of the precipitation and observed river discharge are show in Fig. 9. The Mann-Kendall test was applied on precipitation and discharge data of 30 years (1985–2015), and results are shown in Tables 5 and 6. Discharge at annual scale changed significantly, having a 300 mm/year increase, while there was no significant change in precipitation. Similarly, monthly discharge indicated a significant increase, except during November (which is a dry month). Thus, the LULC changes could have major impacts on the observed hydrological response of the Gumara catchment. Similar to our study, there were no significant changes in precipitation observed in the Upper Tekeze-Atbara basin (located further northwest to the Gumara catchment in the Nile Basin) (Gebremicael et al., 2017).

4. Conclusions and recommendations

This study examined LULC changes and consequent impacts on hydrology of the Gumara catchment of Lake Tana Basin in northwest Ethiopia. The study was based on LULC mapping by applying supervised classification on remotely sensed Landsat data. Then, a LULC change impact analysis was conducted using a conceptual rainfall-runoff model (HBV). Additionally, a statistical analysis by computing decadal means and Mann-Kendall trend statistics on observed precipitation and river discharge was carried out to examine changes in these variables, and also compare these results with the modelling outcomes.

The study successfully generated LULC maps for the years 1986, 2001 and 2015, with reasonably good accuracy of about 90%. These maps indicated that substantial changes in LULC had occurred during 1986–2015. A remarkable increase in cultivated lands could be witnessed owing to a corresponding decline in forest and grazing lands. A small but notable increase in urban and barren lands was also found. The annual rates of these changes were estimated in the range of −3 to 6% during the study period. Consistently, a major LULC transition was observed from grazing land to agriculture (11%), and from forest to agriculture (6%) happened during 1986 and 2015. As a whole, the total catchment area under cultivation was estimated as 70% in 1986, which increased to 82% in 2015, indicating a net increase of about 12%. The forest and grass lands used to cover 11 and 18% of the catchment area in 1986 but declined to 5 and 10%, respectively, in 2015. Overall, 73% of the catchment remained unchanged between 1986 and 2015.

While these changes appear to be substantial, the successfully calibrated and validated HBV model only indicated small but negligible changes (± 5%) in the simulated water balance components (discharge, evapotranspiration, soil moisture and groundwater recharge). On the contrary, statistical analysis of the observed discharge data indicated significantly increasing trends over the study period. For instance, decadal means for the observed discharge were 1027 mm/year in 2006–2015 when compared to 713 mm/year in 1986–1995, indicating an increase of (44%). As there were no significant changes noted in the precipitation regime, there should be other factors responsible for this substantial and significant increase in discharge. The observed LULC change could be a major driver of the observed changes in hydrology, although the HBV model could not simulate this impact. This clearly indicates the limitations of simple rainfall-runoff models, such as HBV, where LULC is often represented in a simplified and lumped manner. Therefore, this study recommends the combined application of statistical and physically based modelling approaches, with good spatial and process based representation of LULC, to rigorously evaluate and synthesize the LULC impacts on catchment hydrology.

The observed decline in forest and grazing lands appears to be a continuous phenomenon in the Gumara catchment, which is contrary to several other catchments in Ethiopia where forest lands had witnessed a declined at one point in time but a significant recovery later due to restoration efforts. The unidirectional trends of declining forests and grazing lands in the Gumara catchment are alarming; if they continue unchecked they are likely to cause complete deforestation and vanishing of grasslands in the near future. Therefore, restoration efforts could be urgently initiated in the area, which should also address the major causes of LULC change such as increasing population, lack of energy sources, farming systems and tenure related issues and poverty. The efforts towards restoring natural LULC (as much as possible) could contribute in mitigating impacts on hydrology, environment, socio-economic and, thus, promote sustainable development in the study region.

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