Analyzing the impacts of urbanization on runoff characteristics in Adama city, Ethiopia

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Abstract

Background It has been increasingly recognized that urbanization is responsible for alterations of land use/land cover globally with substantial environmental impacts on all temporal and spatial scales. Particularly, it significantly affects the hydrologic cycle. Floods are the major threats to several cities worldwide with more effects in developing countries. Likewise, urban water management has become the main focus of sustainable urban development and poses higher demand for information related to the interaction between the urbanization process and hydrological attributes, but little is known in the context of Ethiopian urban centers. For this, Adama city, a fast grown and flood vulnerable urban area is considered to examine the impacts of urbanization on the storm runoff at different spatial scales from 1995 to 2019. Preparing land use/land cover (LULC) maps for different periods, the dynamics of LULC transformations were analyzed. The SCS-CN method was used to compute runoff at respective years from which spatiotemporal changes of the city's hydrology were assessed at the city and watershed levels. Regression analysis was used for exploring the relation between the spatiotemporal changes of imperviousness ratio and runoff.

Results The findings show that the urban built-up area undergone about 22% expansion annually from 1995 to 2019. Besides the runoff is increased by 23% in the City and 31% and 16.6% in the watersheds. Moreover, the significant direct linear relationship is found between the spatiotemporal variations of runoff and imperviousness ratio at both spatial scales.

Conclusions Adama city has experienced significant LULC transformations over the last 24 years with significant effects on hydrological attributes, which pressed an alarm for increasing flood hazards. Hence, in order to realize sustainable growth of the city, future developments should be guided by impervious surface-based land use regulations.

1. Background

Around the world, more people are concentrated in towns and cities. In 2017, the proportion of urban population was 55 percent, it is estimated to reach 68 percent in 2050 (UN 2018). Urbanization is undeniably an ongoing global trend with substantial alterations of land use/land cover (LULC) (Rasul et al. 2018; Deribew & Dalacho 2019). LULC changes are the main causes of global environmental change (Gashaw et al. 2017; Hassen & Assen 2017; Esa et al. 2018; Guzha et al. 2018), and manifest in climatological, biodiversity and hydrological responses.

In particular, urbanization significantly contributes to the occurrence of pluvial floods (Pathirana et al. 2014; Alemu 2015; Parsasyrat & Jamali 2015; Birhanu et al. 2016; Saberifar and Shokri 2016; Emilsson & Ode Sang 2017; Erena & Worku 2018). By modifying land cover around many urban areas, it increases impervious surfaces that reduces infiltration and resistance to flow. Consequently, the volume and flowrate of the runoff rise, thereby exceeding the acceptance of local drainage capacity. Urban floods are the major threats to several cities worldwide, and its frequency and related risks are likely to increase in the future (Rosenzweig et al. 2018; Rasul et al. 2018). In the context of developing countries, unplanned urban growth is the common scenario (Bajracharya et al. 2015), leading to rapid densification, and the construction of buildings is associated with a rapid increase of impervious land areas.

The focus of the recent studies related to the hydrological influences attributable to urbanization is increasingly extending from hydraulic channels towards imperviousness ratio and imperviousness pattern (Su et al. 2014). Apart from the understanding of the direct relationship between the extent of impervious surface and storm runoff, studies (Mejía & Moglen 2009; Sanyal et al. 2014; Su et al. 2014; Zhang et al. 2018) have reported that the impacts can be influenced by the pattern of imperviousness and the scale of the study area. In addition, other LULC changes could counterbalance the effects of increased impervious area (Chen et al. 2015).

In the context of Ethiopia, the effects of LULC change on watershed hydrology have become the focus of environmental research for a recent decade (Shewangizaw & Michael 2010; Getachew & Melesse 2012; Getahun & Van Lanen 2015; Demeke & Andualem 2018; Mekonnen et al. 2018; Yohannes et al. 2018; Dinka & Chaka 2019); however, these studies focused on a natural basin. Few attempts (e.g., Billi et al. 2015; Birhanu et al. 2016) to highlight the impacts of LULC change on hydrology of urban areas are far from Adama city, one of the rapidly grown and flood vulnerable urban areas in the country. Besides, there is little understanding in relation to spatial variability of the impact of urbanization in different sub-catchments. On the other hand, Sinha et al. (2016) attempted to examine the decadal expansion of built-up land in Adama city, but the environmental impacts, particularly on the hydrology of the city remained unclear. In response to existing flooding problems of Adama city and the thoughtfulness of a potential increase in the future, proper storm water management demands spatiotemporal information related to interaction between urbanization process and hydrological characteristics of the City.

The central aim of this study is to analyze the impacts of urbanization on surface runoff attributes in Adama City. More specifically, it is conducted (i) to analyze the spatiotemporal changes of LULC from 1995 to 2019; (ii) analyze the changes of runoff due to the LULC changes and (iii) to explore the relationship between the spatiotemporal changes of imperviousness and the runoff.

2. Materials And Methods

2.1 The study area

Adama City is one of the fast-growing and flood vulnerable urban areas in the country (Bulti et al. 2017). It stretches between 8°26'15"N to 8°37'00"N latitude and 39°12'15"E to 39°19'45"E longitude. The population of the city has grown at the rate of 9% from 2004 to 2016 (Bulti & Asefa 2019). The latest approved land use plan of the city is prepared in 2004 (Bulti & Sori 2017). The administrative boundary set by this plan is selected to limit the spatial extent of the analysis. The City falls in two main watersheds: Awash and Mermersa (Fig. 1), with spatial coverage of 7,329.7 ha and 6,036.8 ha, respectively.

2.2 Data used and image pre-processing

Data used in this study were collected from different sources, including websites, organizations and stakeholders. Landsat 7 TM/ ETM+ (Enhanced Thematic Mapper Plus) (L1TP product of path 168, row 54) was used for mapping LULC of the study area. LandSAT image is widely used for urban LULC mapping, despite its medium spatial resolution and mixed pixel problem (Lu & Weng 2005; Chen et al. 2016). It is freely accessible for multiple dates. One image from each year with cloud contamination less than 10% were accessed from the United State Geological Survey (USGS) (<https://espa.cr.usgs.gov/>). All images are within the dry season, as the accuracy of LandSAT image classification during the dry season is found to be higher than during the wet season (Liu et al. 2015).

Geometric accuracy of land use maps is important in urban studies (Sertel & Akay 2015). Landsat Level 1 (L1T) images are geometrically corrected and orthorectified by the National Aeronautics and Space Administration (NASA) (Gutman et al. 2013). The atmospheric effects were reduced through conversion of raw digital number (DN) values to the surface reflectance, which was undertaken in radiometric calibration module in ENVI software.

2.3 Land use/land cover mapping

Considering the importance of short-term changes in urban areas due to rapid urbanization and climate changes (Zhang et al. 2018), LULC maps of the study area were prepared at about 5 years' interval (1995, 2000, 2005, 2010, 2015 and 2019) using LandSAT images through supervised classification method. It involves defining classification scheme, selecting training samples, running an algorithm to assign each pixel into a class and accuracy assessment.

Defining classification scheme

The analysis focused on spectral resolution because the spectral dimension is the most important source of cover type information in coarse resolution images. The success of LULC usually measured by the ability to match the spectral classes in the data to the information classes of interest (Weng 2010). Information classes are those categories of interest that the analyst is actually trying to identify in the imagery, whereas spectral classes are groups of pixels that are uniform (or near-similar) with respect to their brightness values in the different spectral channels of the data.

In a complex urban landscape, a particular land use class may have diverse spectral characteristics (e.g., roof cover of old and new buildings). By contrast, different classes (objects) can have the same spectral characteristics (e.g., rock and concrete or bright building roofs). Hence, it is rare that there is a simple one-to-one match between these two types of classes. Many times it is found that 2 to 3 spectral classes merge to form one informational class.

Given the importance of the appropriate classification scheme, in this study, initially, by visually analyzing the color composite LandSAT images with different band combinations, different classes were identified, and aggregated into four: urban, bare land, agriculture and vegetation (Table 1).

Table 1
Land use/land cover classification scheme used in the study

LULC class	Description
Urban	Comprises areas with all types of artificial surfaces, including buildings and transportation infrastructure (asphalt, gravel, railway). Areas under construction are also included
Barren land	Includes a surface with no or little vegetation, open land, exposed soil, rocks and sand (eroded gullies)
Agricultural	Includes areas used for cultivation (both annuals and perennials) and grazing
Vegetation	Comprises areas with vegetation cover, such as areas covered with both indigenous and exotic tree and shrub land. It also includes green spaces in built-up areas: an area of grass, trees, or other vegetation set apart for recreational or aesthetic purposes inside urban built environment

Training sample section

Training samples for each class were collected from each image. In order to reduce the sampling biases, consistency in sample selection was kept by selecting pixels that remained unchanged at different times to train the classifier. First, samples were selected from LandSAT image of 1995 (first image). Subsequently, these samples were treated as training samples for the first image and used as a base for the adjacent image (2000). Second, the base samples were overlaid with the second image to check if change in class occurred. If changes were observed, new sample with more confidence was substituted from the surrounding area. Similarly, the same procedures were followed by selection of training samples for the rest of the images.

Classification algorithm

Each image was classified into a set of spectral classes using Support Vector Machine (SVM) algorithm in ENVI software. SVM is non-parametric classifier. Unlike parametric classifiers such as maximum likelihood which assumes that the data is normally distributed, non-parametric classifiers do not base classification on a normality assumption or statistical parameters (Phiri & Morgenroth 2017). Because of highly heterogeneous land covers data (e.g., urban areas) are unlikely normally distributed, the distribution of land cover surfaces is associated with various uncertainties which prevents their description based on data distribution (Lu & Weng 2007). In this respect, non-parametric classifiers provide better results as compared to parametric classifiers in complex landscapes.

Accuracy assessment

LULC classification accuracy was assessed quantitatively using error matrix which is the commonly used method in LULC classification accuracy assessment (Weng 2010). In this regard, sample pixels were selected from each of classified images through a stratified random sampling scheme in ENVI software. The samples were overlaid with the existing map (for 1995), google earth (for 2000, 2005 and 2010) and digital orthophoto (for 2015 and 2019) to visually

interpret and determine their respective classes. Based on the error matrix generated for each classified map, overall accuracy, user's accuracy and producer's accuracy were calculated, in addition to kappa variance. The accuracy requirements for change detection analysis were determined based on the suggestion of Congalton and Green (2009). In this case, the value of the Kappa statistics, greater than 0.8, indicates strong agreement between classified classes and ground truth.

2.4 Methods

Analysis of LULC dynamics

The spatiotemporal changes of LULC were identified using areal data generated from classified maps in GIS environment. Quantitative areal data from the overall LULC changes, as well as gains and losses in each class were compiled to analyze the nature and rate of the changes. The percentages of changes were computed using Eq. 1 similar to other studies (Butt et al. 2015; Gashu and Gebre-Egziabher 2018). In this case, the positive and negative values suggest a gain and loss in spatial extent, respectively.

[Due to technical limitations, the formula could not be displayed here. Please see the supplementary files to access the formula.]

Analysis of imperviousness change

Impervious surfaces are generally anthropogenic features (buildings, parking lots, roads, etc.) which rainfall water cannot permeate (Tabbutt & Ambrogi 2013; Zhang et al. 2018). They are usually related to urban growth and expansion can be delineated using different methods. Extracting urban impervious surfaces from LandsAT imagery using standard classification techniques can provide adequate results (Parece & Campbell 2013). Percent impervious area (PIA) refers to the areal proportion of impervious surfaces within the defined boundary (e.g., watershed, administrative boundary). Likewise, in this study, it was computed by using the ratio of areal data of urban class at different years to the extent of the respective analysis boundaries. The changes of imperviousness were computed with respect to the first year (Eq. 2). This helped to assess the impact of urbanization in increasing the impervious surface in the study area.

[See supplementary files for formula.]

Evaluation of spatiotemporal changes of runoff

Evaluation of the temporal variations of the runoff due to the impacts of LULC changes involves computation of runoff and percentage change with respect to a baseline/reference year.

Rainfall-runoff was calculated using soil conservation service curve number (SCS-CN) technique. It is largely accepted method to examine the relationship between different land uses and runoff, and widely used for water resources management and planning (Abas & Hashim 2014; Bhaskar & Suribabu 2014; Ongsomwang & Pimjai 2015; Viji et al. 2015; Tailor & Shrimali 2016; Hameed 2017; Prakash & Sreedevi, 2017; Rao et al. 2017; Satheeshkumar et al. 2017; Zhang et al. 2018). SCS-CN method provides an adequate result with a minimum information (Bhuyan et al. 2003) that makes it more useful for ungauged watershed (Pandey & Stuti, 2017; Satheeshkumar et al. 2017). The value of CN reflects the impact of land cover on the runoff yield ranging from 0 (100% infiltration) to 100 (0% infiltration). Evapotranspiration losses are considered to be insignificant in the storm event (Chen et al. 2015).

Runoff can be easily obtained using three important properties of the watershed: soil permeability, land use and antecedent soil water conditions (Bansode et al. 2014; Chen et al. 2015). In this regard, soil types in the study area were converted into respective hydrologic similar units. The study area was spatially intersected with LULC and soil maps to calculate the area under the different hydrological similar units (HSU) and to assign CN values. Since the study area comprises different characteristics (soil type and land cover), the weighted curve number was considered and computed using Eq. 3. Moreover, Equations 4 and 5 were applied for converting the average antecedent moisture condition into wet condition and for computing the potential maximum soil retention, respectively. Using hourly average rainfall, the accumulated runoff depth for respective areas was computed using Equations 6.

[See supplementary files.]

Using the computed runoff for respective years, the temporal variations of the runoff due to the impacts of LULC changes were assessed through runoff depth change ratio. Following the method applied by Li & Wang (2009), by taking the runoff depth of the first year (1995) as a baseline, the percentage changes in runoff for 2000, 2005, 2010, 2015 and 2019 were computed using Eq. 7. This helped to determine the temporal variations in storm runoff attributable to the changes in LULC of the study area with respect to the baseline.

[See supplementary files.]

Regression analysis

Regression analysis was carried out to explore the relationship between the spatiotemporal changes of PIA and runoff. It is the common method to investigate the relationship between a quantitative outcome and a quantitative explanatory variable (Seltman 2018).

The validity of the model assumptions was determined by examining the structure of the residuals and the data pattern through graphs. Examination of residual plots is a simple and effective method for validation of standard assumptions in regression analysis (Chattefuee and Hadi 2006). In this context, the normality assumption was validated using a normal probability plot of standardized residuals which is a plot of the ordered standardized residuals against the normal scores. Under normality assumptions, this plot should resemble a (nearly) straight line with an intercept of zero and a slope of one, and they are equal to mean and standard deviation of the standardized residuals, respectively. In addition, scatter plots of the standardized residual against PIA and fitted

values were used to validate the linearity assumption. Under the standard assumptions, the standardized residuals are uncorrelated with the explanatory variable and with fitted values. The random scatter of points of these plots explains the validity of linearity assumption.

The strength of the linear relationship between the runoff variations and the PIA was determined using the value of Pearson's correlation coefficient (r). It is a dimensionless quantity that commonly used to compare the linear relationships between pairs of variables in different units. Accordingly, the non-zero value of the correlation coefficient indicates the variables are correlated. Further, the positive and negative values indicate direct and indirect relationship, respectively. Moreover, similar to Bulti & Assefa (2019) the strength of the correlation was described using the absolute value of correlation coefficient: very weak ($|r| < 0.19$), weak ($|r| < 0.39$), moderate ($|r| < 0.59$), strong ($|r| < 0.79$), very strong ($|r| < 1$).

Statistical significance test was also conducted to offer an objective measure in the decision about the validity of the generalization, and it was determined using p-value statistics. In this case, the null hypothesis states that there is no significant relationship between the changes in PIA and runoff. In theory, the p-value is a continuous measure of evidence (Gelman 2012), yet in this study, the term "significant" refers to the 95% confidence level ($p < 0.05$); it is standard in statistical practice in most of the Engineering researches (Bulti & Assefa 2019).

3. Results

3.1 Dynamics of land use/land cover

Figure 2a – f demonstrates the LULC maps of Adama city for 1995, 2000, 2005, 2010, 2015 and 2019. Overall classification accuracies are 89%, 91%, 93%, 91%, 92% and 90% for the year 1995, 2000, 2005, 2010, 2015 and 2019, respectively. The values of Kappa statistics for classified images are greater than 0.8, indicating strong agreement between the classified LULC classes and ground truth, hence the maps satisfied accuracy criteria for LULC change detection analysis.

The information summarized in Table 2 shows the spatial extents, percentage changes over time as well as the annual average growth of the four LULC classes (agriculture, barren land, urban and vegetation) in Adama city between 1995 and 2019. Besides Fig. 3 demonstrates the spatiotemporal variations of the proportions of each class occurred over the span of 24 years.

Overall, the results show the extensive LULC changes in Adama city over the study period. Agricultural land was dominant class at the beginning of the study period, but declined with the continuous increase of urban land area. It can be seen that the rate of annual urban expansion greater by far, from the rest land use classes.

The coverage of agricultural land was slightly less than 50% of the total area at the beginning of the study timeframe. In the following 10 years, it moderately decreased to about 44% before it dramatically dropped to nearly 10% in the final year. By contrast, the proportion of urban class was 5% in 1995, this figure rose to just over 30% in 2019, showing an increase of more than five folds of its initial spatial share. It showed nearly 22% of average annual expansion across the study period. Temporally, the rate of urban land expansion was comparatively low in the first fifteen years between 1995 and 2010, which showed nearly 8% increase, then it peaked about 32% of the total area in the last year.

On the other hand, vegetation class showed a remarkable increase in spatial cover between 2010–2015 has also contributed to the increase of its share of the study area from 11–18% in the first and last years of the study period, respectively. With nearly equal proportion, the areal share of the barren land increased during the study timeframe.

Table 2
Areal extents and percentage change over time of land use/land cover classes in Adama city from 1995 to 2019

LULC class	Area (ha)						Percentage change (					Annual average change (%)
	1995	2000	2005	2010	2015	2019	1995–2000	2000–2005	2005–2010	2010–2015	2015–2019	1995–2019
Agriculture	6482.7	6044.0	5886.7	4608.4	2333.5	1362.8	-6.8	-2.6	-21.7	-49.4	-41.6	-3.3
Barren land	4724.6	5117.8	4910.6	5572.7	5475.4	5337.3	8.3	-4.0	13.5	-1.7	-2.5	0.5
Urban	683.3	1047.7	1381.7	1850.7	3236.1	4251.0	53.3	31.9	33.9	74.9	31.4	21.8
Vegetation	1475.9	1156.9	1187.5	1334.7	2321.5	2415.4	-21.6	2.6	12.4	73.9	4.0	2.7

3.2 Spatiotemporal changes of runoff

In order to examine the impact of LULC change on hydrology of Adama city, the runoff depth of each watershed at different times is computed. The average hourly rainfall ($P = 39.7$ mm), reported by Adama City Master Plan Revision Project (2004) was used for computing the surface runoff. The results summarized in Table 3 and depicted in Fig. 4 demonstrate the hourly accumulated runoff depth in the city and its watersheds from 1995 to 2019, with a more detailed look at the trend of change in runoff depth.

Overall, the results indicate the continued increase in runoff depth for the three watersheds during the 24-year timeframe. This rising trend is occurring across all of the selected years for the analysis. In all the cases, the accumulated hourly runoff depth of the Awash watershed is greater. In addition, during study timeframe, the runoff depth is increased in all areas, except for that of Awash watershed slightly decreased in 2005.

At city scale, the runoff depth is started at slightly over 17 mm in 1995, this figure is increased to reach over 21 mm in the final year, indicating about 23% increase in the span of 24-years. Further analysis indicates that the runoff depth of the city is identified at a nearly equal amount from that of its watersheds across the entire period. For each year, the difference between the depth of Awash watershed and the city is less by 0.2 mm than that of the city and Mermersa watershed. The runoff depth in Awash watershed is started at about 18.9 mm and steadily increased to 20.1 mm before it fell to 19.22 mm (about 4.1%) in 2005. Then it goes up to reach 20.01 mm at the final year.

Table 3
Hourly accumulated runoff depth in the city and its watersheds from 1995 to 2019 (units are in millimeter)

Spatial boundary	1995	2000	2005	2010	2015	2019
Awash watershed	18.87	20.05	19.22	21.22	21.16	22.01
City boundary	17.09	18.36	18.50	19.65	19.99	21.02
Mermersa watershed	15.05	16.42	17.65	17.83	18.61	19.86

3.3 Relation between the changes of PIA and runoff

In this study, the degree to which the temporal variations in runoff depth can be explained by the changes of PIA is examined through the regression analysis using the computed results (Table 4) of both variables computed using equations 2 and 7. All percent changes at respective years are calculated with respect 1995. In all of the cases, a dataset of 6 observations is used. The scatter plots overlaid with the best-fit line depicted in Fig. 5 illustrate the relationship between the percentage changes of runoff depth and that of PIA from 1995 to 2019.

The results reveal that the observed percent change of runoff depth is directly related to the changes of PIA in both scales. Further, Pearson correlation coefficient appears a very strong correlation between the two variables. Moreover, the significance test of the relationship between the two variables resulted in the p-value smaller than 0.05, suggests rejecting the null hypothesis. Based on this evidence it can be underlined that the observed linear relation between the percentage variation of runoff depth and the PIA is highly significant. Further, the value of the coefficient of determination indicates that 87.88%, 75.65% and 87.10% variation in the data are accounted by the models for the City, Awash watershed and Mermersa watershed, respectively. With this variability, from the estimated model equations, the slope of regression lines shows that the unit percentage change of PIA in the City, Awash and Mermersa watersheds results the percent changes of runoff depth equal to 0.0377, 0.0249 and 0.0568, respectively.

Table 4
Percentage change of PIA and runoff in Adama city and its watersheds from 2000 to 2019 with respect to the baseline year (1995)

Spatial boundary	2000		2005		2010		2015		2019	
	Δ_{PIA}	Δ_Q	Δ_{PIA}	Δ_Q	Δ_{PIA}	Δ_Q	Δ_{PIA}	Δ_Q	Δ_{PIA}	Δ_Q
City boundary	153.3	107.4	202.2	108.3	270.8	115.0	473.6	117.0	622.1	123.0
Awash watershed	151.5	109.1	200.9	117.2	262.4	118.4	438.1	123.6	575.3	131.9
Mermersa watershed	151.5	109.1	200.9	117.2	262.4	118.4	438.1	123.6	575.3	131.9

4. Discussion

This study aimed at analyzing the impacts of urbanization on hydrology of Adama city at different spatial scales. By taking the importance of short-term changes into account, LULC maps were prepared at the interval of 5 years using LandsAT images, and the spatiotemporal transformations of LULC were assessed. Surface runoff at respective years was computed using the SCS-CN method, and the impacts of LULC changes on hydrologic attributes of the city were examined. The relation between urbanization and change in the runoff was explored through regression analysis using the datasets of temporal changes of IAR and runoff depth.

The study reveals extensive LULC changes during the study timeframe, particularly, urban built-up land area has expanded more than five times, indicating averagely the city undergone 22% urban expansion annually from 1995 to 2019. A built-up expansion rate of 7.9% during the study period, which is slightly less than the growth rate of the city's population reported by Built & Assefa (2019). On the other hand, the result is greater than the findings of Sinha et al. (2016). The disparity could be due to incorporation of transportation (gravel roads and railway) in urban classes in the case of the present study.

The study also indicates that the observed alterations of LULC in the study area resulted in an increase in runoff depth in the city by 23% over the study timeframe. This figure is slightly less than the result of the study (Birhanu et al. 2016) reported for the impacts of LULC change in Addis Ababa city over the period of 10 years, and it is greater than that of Billi et al. (2015) for Dire Dawa city over 21 years. This disparity could be underpinned by local conditions, which can be associated with socio-economic, level of urbanization, level of spatial planning and environmental variability. At the watershed level, while an

increase of 31.9% in Mermersa, a 16.6% increase in Awash is found. Along with other (e.g., Chen et al. 2015), the findings of this study indicate that the impacts of LULC changes on runoff can be influenced by spatial scale of the analysis. In addition, while urban land continuously increased across the study period, the runoff in Awash watershed decreased from 2000 to 2005. The opposite effect shows that the alterations in other LULC classes appears to counterbalance the impacts of urbanization in storm runoff.

The significant linear relationship between the spatiotemporal variations of runoff and imperviousness ratio is another important finding of this study. The result is slightly different from other studies Sanyal et al. (2014) and Chen et al. (2015) in which the deviation from a linear relationship between urban expansion and runoff variation is reported for some of the analyzed watersheds pertaining to northern China. The result of this study is referred to Adama city and its watersheds.

This study would increase understanding of the cumulative impact of urbanization in the hydrologic regime of the city, and can be viewed as a springboard for all stakeholders. By limiting the extents of future impervious surfaces that can be converted from the remaining available land through new expansion, urban renewal and infill developments, the impacts of urbanization can be arguably managed to show sustainability of the city's development. It spotlights the potential of imperviousness ratio to be used as an alternate pragmatic planning tool for controlling the hydrologic influences attributable to urbanization, and could be integrated to storm water management regulations.

5. Conclusions

The quantitative evidence obtained in this study revealed that Adama city has undergone an excessive LULC change over the last twenty-four years (1995–2019). During the study period, the urban built-up land area has been expanded by 22% annually. The overall impacts of these changes on hydrologic regime were increased runoff depth significantly. In particular, the magnitude of runoff in the city was increased by 23%, while 31% and 16.6% increase is found in the case of Awash and Mermersa watersheds. Opposite effect of LULC changes on runoff is also obtained in the Awash watershed from 2000 to 2005. Moreover, the increases magnitude of runoff is linearly related to the spatiotemporal changes of imperviousness ratio.

The findings in the study would provide valuable information related to the impacts of urbanization on runoff characteristics and can be helpful for decision makers and planners to scientifically develop sustainable land use plan in the study catchment. However, the results should be viewed as an initial step for understanding of the hydrologic influences attributable to urbanization and further studies are required in several fronts. The impacts of urbanization are assessed using the variations of accumulated runoff depth corresponding to variations in the volume of water yield. However, the impacts on other factors (e.g., flowrate) and their combined effect on flooding needs further investigations. On the other, urbanization is undeniably an ongoing global trend, and decreasing the extent of imperviousness may not be always realistic. Hence, it is essential to investigate the possible ways to use the impervious surface in flood hazard management.

Abbreviations

LULC
Land use/land cover
PIA
Percent Impervious Area
SCS-CN
Soil Conservation Service Curve Number

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

We have agreed to submit for Environmental Systems Research journal and approved the manuscript for submission.

Availability of data and material

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

DTB has conceived of the study and made contributions in design, data collection and analysis, interpretation of the results and draft the manuscript. BGA supervised the study and reviewed the whole content. Both authors read and approved the manuscript.

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Figures

Figure 1
Location map of the study area

Figure 2
Land use/land cover maps of the study area from 1995 to 2019

Figure 3

The proportions of land use/land cover classes in the study area from 1995 to 2019

Figure 4

Hourly runoff depth in Adama city and its watersheds from 1995 to 2019

Figure 5

Relationship between spatiotemporal changes of runoff depth and imperviousness ratio in the study area from 1995 to 2019

Supplementary Files

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- [Methodsformulas.docx](#)