Urban land cover and morphometric analysis for flash flood vulnerability mapping, and riparian landscape conservation in Kebena river watershed, Addis Ababa

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Abstract

The city of Addis Ababa has a degraded stream ecosystem and its watersheds are exposed to redundant flash floods that can destroy the existing urban infrastructures and utilities. This research aimed to map flash flood vulnerability of the watershed inside Addis Ababa, and evaluate the status of the riparian landscape. Methodologically, the study employed the Biophysical Composition Index (BCI) to detect the impervious surface, and the Normalized Difference Vegetation Index (NDVI) to classify the vegetation cover. Arc-hydro tool was used to identify the micro-watersheds and measure the morphometric factors then principal component analysis (PCA) elucidates the most important factors, and the fuzzy overlay analysis combined land cover and morphometric analysis result to produce the final flash flood vulnerability map. Moreover, riparian buffering 15, 30 and 90 m distances were defined to measure the degree of imperviousness, greenness and vulnerability to flash flooding. Accordingly, 969 hectares of land were depicted within the watershed as flash flood vulnerable areas. These are primarily found in the southeastern and southwestern parts where impervious land cover prevailed, and the northwestern portion where extremely rugged terrain covered by reduced vegetation. In all buffering distances the proportion of impervious surface is greater than the vegetation cover. Even within 15m buffering distance, which was set as the national urban planning standard. It is concluded that Kebena watershed is vulnerable to flash floods as the riparian landscape dominated by impervious and depleted vegetation cover. Integrating multiple geospatial techniques is helpful to devise a method for sustainable riparian landscape monitoring.

1. Introduction

The growth of urban areas accompanied by increased parking lots, roadways and rooftops has increased spatially and has resulted in expanded impervious surfaces. This has clear implication on the hydrological characteristics of a watershed by preventing surface flow infiltration (Sahoo and Sreeja, 2012). This increase in impervious surfaces becomes a major cause for flash flooding. Subsequently, it is responsible for damage to urban infrastructures and utilities (Gholami et al., 2010). A more sustainable land cover type regulating the watershed hydrology and the riparian environment is vegetation cover. The watershed ecosystem services endowment is determined by the structure and distribution of the vegetation cover (Engelhardt et al., 2011). Moreover, Rosenmeier et al. (2002) showed the positive influence of vegetation cover on surface runoff reduction and groundwater recharge. Bosch and Hewlett (1982) have studied the water yield change due to the conversion of different vegetation cover types in watersheds.

The traditional way of identification and classification of land cover types is less explanatory and timeconsuming. The current remote sensing technology has made land use and cover classification much easier (Piyoosh and Ghosh, 2017a). The remotely sensed data can give a general picture of a relatively large area within a short period of time through spectral indices. Though most indices represent a single land cover type, they can mix one land cover type with the others (Deng and Wu, 2012). There are different types of indices that can represent the features that are of interest. For instance, Bhatti and Tripathi (2014) listed the Normalized Difference Vegetation Index (NDVI) for vegetation, the normalized difference snow index (NDSI) for snow, the normalized difference water index (NDWI) for water, and the normalized difference built-up index (NDBI) for built-up areas. Similarly, for impervious surface evaluation, Xu (2010) used the normalized difference impervious surface index (NDISI), whereas Piyoosh and Ghosh (2017b) applied the normalized difference soil index (NDSI) for bare soil. To quantify these indices different remote sensing imagery types are available, but require their own adjustment because of the spectral variability. There are a number of previous studies on evaluation of Landsat-8 Operational Land Imager (OLI) data for these different indices (Bhatti and Tripathi, 2017; Piyoosh and Ghosh, 2017a).

Morphometric analysis helps to evaluate the watershed geospatial, hydrological and hydraulic characteristics (Srivastava et al., 2014). Strahler (1964) used morphometric analysis to show the geologic characteristics, landform pattern, soil physical properties, soil erodibility, and the hydrologic response of the watershed. By applying geographic information systems (GIS) and remote sensing technology, automated and semi-automated morphometric analysis becomes fast and easy. As a result, the extent of morphometric analysis application has broadened. Javed (2009) and Patel et al. (2012) used morphometric analysis to detect spaces and their physical barriers for different development and economic benefits. Others have used it to prioritize sub-watersheds for soil erosion control measures (Ahmed et al., 2017; Farhan et al., 2017; Meshram and Sharma, 2015). Morphometric analysis can also be used to identify areas that are affected by flash flood hazards (Farhan et al., 2016, Youssef et al., 2010).

According to Engelhardt et al. (2011), the watershed geomorphology controls the extent and abundance of riparian vegetation, which influence runoff regimes. This shows the need of considering the relationship between geomorphology and the riparian vegetation cover, as this helps to analyze the watershed development and restoration. Besides, Groffman et al. (2003) revealed that riparian zones are hot spots of interactions between plants, soil, water, microorganisms and people, and may be seriously affected by urbanization.

Addis Ababa's unprecedented growth has also a clear impact on the land cover dynamics and the urban and sub-urban watershed characteristics. Furthermore, Addis Ababa's roadways are experiencing frequent flooding, which makes traffic difficult. The 2017 Addis Ababa City Fire, Emergency Prevention and Rescue Agency report shows that more than 70 flood incidences were recorded following the 2017 rainy season and caused more than 740,000 USD worth damage to infrastructure and private property. Belete (2011) related the enhanced flash flood hazard to the increase of uncontrolled impervious surface growth. For the riparian buffering, the urban planning guidelines of the Ministry of Urban Development and Construction (MUDC, 2012) recommends fifteen meter buffering distance on either side of the stream. However, these recommendations have not been implemented in most of Addis Ababa. Thus, the riparian zones are in a degraded condition and hardly provide the expected ecosystem services. As Alemayehu (2001) revealed, they are used for household and industrial sewer and waste disposal sites instead.

Overall, while research has been done on the issues, it is hardly possible to find a kind of assessment for this specific watershed, and other research has also failed to integrate the methods of urban land cover and hydro-morphological characteristics for area prioritization and mapping the flash flooding and functioning of riparian landscape. Moreover, not much attention has been put on this area and the current preservation and river side development efforts have focused largely on physical and structural solutions to the problems. The city projects development also have given little concern on the landscape based watershed monitoring and conservation planning. Studies have weakly shown the relationship of the hydro-morphological and land cover dimension to measure the vulnerability of flash floods and the role of the riparian landscape. Thus the main objectives of this study were:

1. Map and evaluate the flash flood vulnerability levels of the area using the quantitative measures of

urban land cover and the hydro-morphological characteristics of the watershed

2. Assess the level of the riparian landscape functioning to identify sustainable solutions to urban watershed and riparian ecosystem management and conservation.

2. Methods and Data

2.1. The Study Area

Kebena watershed is one of the oldest settlement quarters of Addis Ababa, which covers Yeka, Gulele, Arada, Kirkos and Bole sub-cities. It also extends to Sululta District of Oromiya special zone surrounding Addis Ababa. The Kebena watershed is located in the northern part of the city, and covers about 5000 hectares of land. It is a predominantly rugged highland terrain with the elevation ranging from 2317 to 3182 m.a.s.l (fig 1).

2.2. Methods

The watershed was defined based on the 30m shuttle radar topographic mission (SRTM) data of the United State Geological Survey (USGS). To support this the 30m grid elevation data were collected from the Addis Ababa city administration. The topographic data were reprocessed and converted to a digital elevation model (DEM). The Arc- hydro and Arc-swat modeling tools were used to extract the Kebena watershed by taking an outlet at a point before meeting the stream locally known as Banteyiketu. The watershed includes the streams locally known as the main Kebena and Ginfile rivers. The Arc-hydro modeling tools were again used to subdivide the micro-watersheds. For image indices evaluation the ArcGIS raster calculator was used and a Principal Component Analysis (PCA) of the morphometric variables was made using the R-studio programing language.

2.2.1. Land Cover Analysis

The study identified urban and suburban land cover based on a distinction between vegetation cover and impervious surface cover. This study calculated NDVI and BCI to identify the vegetation and impervious surface covers, respectively. The main data used was Landsat-8 Operational Land Imager (OLI) data collected on 23rd of December, 2015 along row 168 and path 54, and then extracted by the target area shape file. Before performing the calculation the atmospheric correction and band rationing was made first by eq. 1 and eq. 2, based on the metadata (USGS, 2015):

$L\lambda = M\rho Qcal + A\rho$ (1)

$P_\lambda = \frac{L_\lambda^{'}}{\sin(\theta_{\mathrm{SE}})}$(2)

Where: Lλ is top of atmosphere spectral radiance (Watts/ (m2 * srad * µm));

Mρ is Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number);

Qcal is the Digital Number of the band being processed;

Aρ is Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number) and

Pλ is top of atmosphere planetary reflectance ($L_\lambda^{'}$), with correction for solar angle (ϑ_{SE})

The NDVI was calculated using eq. 3 to determine the amount of vegetation cover in the watershed:

$\mathrm{NDVI} = \frac{\mathrm{OLIBand\ 5-OLIBand\ 4}}{\mathrm{OLIBand\ 5+OLIBand\ 4}}$(3)

Recently different studies used various indices in impervious surface extraction. For instance, Sun et al. (2017) used a modified NDISI and Bhatti and Tripathi (2014) applied NDBI to maximize their specific advantages. However, BCI appears a more effective index type to represent the urban land cover type. It has a high positive value for impervious surfaces (Deng and Wu, 2012), which differentiates the feature easily. To calculate the BCI (eq. 4; Baig et al., 2014), it is necessary to assess the tasseled cap (TC) transformation of greenness, brightness and wetness (eq. 5 – 7; Deng and Wu, 2012).

BCI = $\frac{\frac{H+L}{2}-V}{\frac{H+L}{2}+V}$ (4)

$H = \frac{TC1-TC1min}{TC1max-TC1min}$ (5)

$V = \frac{TC2-TC2min}{TC2max-TC2min}$ (6)

$L = \frac{TC3-TC3min}{TC3max-TC3min}$ (7)

Where: H is "high albedo", the normalized TC1;

L is "low albedo", the normalized TC3;

V is "vegetation", the normalized TC2;

TCi (i=1, 2, and 3) are the first three TC components and

TCimin and TCimax are the minimum and maximum values of the i^{th} TC components, respectively.

Although the land cover type of the study area can be classified essentially into impervious, bare and green areas, there is an inherent mixture of land cover types, particularly between impervious versus bare land and bare land versus green spaces. As a result, histogram evaluation was applied to show the threshold value separating the land cover types. The intersection point in the histograms of the two classes was taken as the threshold value (Sun et al., 2017). Then, spectral discrimination index (SDI) was used to measure the degree of dissociation. The use of SDI degree of separability between the two selected land cover classes depends on the two variables between and within group variance. The SDI value greater than one implies that the two land cover classes are distinguished well, while values less than one represents poor separability because of large overlaps (Deng and Wu, 2014). SDI is calculated as follows:

SDI $=\frac{|\mu_i-\mu_s|}{\sigma_i+\sigma_s}$ (8)

Where SDI is separability index value of the selected land covers,μ_ι and μ_ς are average index values of two land cover classes and σ_ι andσ_ς are standard deviations of a certain index for the two classes.

2.2.2 Morphometric analysis

A morphometric analysis of the watershed provides a mathematical measure of the earth's surface structure. It also measures the spatial characteristics of the drainage basin runoff potential, and helps to manage the ground and surface water reserves. There are several features used to evaluate the watershed landform arrangement. Farhan et al. (2016) and Pareta and Pareta (2011) grouped the parameters into network, geometry, area and relief. This study also used these categories and 20 morphometric measures were calculated under these categories. Similar to Farhan et al. (2017) and Meshram and Sharma (2015) the study used PCA to identify the most important morphometric factors, which are described below. These six variables were identified based on the PCA component matrices relationship. In the first factor loading matrix the degree of association shows that some factors are correlated highly, some moderately, and others do not correlate at all. Hence, to optimize correlation the study applied the Varimax rotation to transform the factor loadings (Fabrigar et al., 1999). The six main morphometric factors are described below.

Mean Stream Length Ratio (Lurm): One of the important factors for measuring the watershed surface flow and discharge is the Stream Length Ratio (Lur). It is the ratio of the mean stream length of a given order to the mean stream length of the next lower order, and is computed for each pair of the orders (Horton, 1945). The mean Lur (Lurm) is the average of all orders of the watershed. Lurm is an important variable that can be used to examine the hydrological characteristics of the drainage basin, for example, surface runoff and the hydrological properties of the underlying bedrock permeability (Farhan and Ayed, 2017).

Mean Bifurcation Ratio (Rbm): bifurcation ratio (Rb) is the ratio of the number of stream segments of a given order to the number of segments of the next higher order (Schumn, 1956). The average of the Rb of each level of stream order in the given watershed is called Rbm. Rbm is related to the branching pattern of a drainage network and is defined as the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin, and an index indicating the relief and dissections of the landscape. According to Strahler (1957), the high value of Rb confirms geological and structural disturbances of the area that restrict runoff. Therefore, high value of Rb limit the surface runoff responses of the area.

Circularity Ratio (R) is the ratio of a watershed area to the equivalent circle area having the same perimeter of the watershed (Pareta and Pareta, 2011). The value of *Rc* is ranging between 0, showing a line, and 1 displays a perfect circle. The higher the circular character of the basin is, the greater the rapid response of the watershed after a heavy rainstorm event (Altaf et al., 2013).

Length of overland flow (Lf): is defined as the length of the runoff of rainwater on the surface of the land before it reaches a channel of the main river (Prasad et al., 2008). The variation of*Lf* is related to variation in slope, lithology, land cover, rainfall intensity and infiltration capacity (Al-Saady et al., 2016). A high *Lf* value of a watershed denotes a high vulnerability to flash floods.

Gradient ratio (Rg) is the ratio of basin relief and basin length, and measures the overall slope of the basin. Hence it is defined as the elevation difference between the source and the mouth of the course of the river channel in a drainage basin divided by the length of the longest channel. It computes the channel slope and helps to evaluate the runoff volume (Sreedevi et al., 2004). The higher the value reflects the greater exposure to flash flooding.

Dissection index (Dis): the ratio of relative relief and absolute relief of the basin (Farhan et al., 2016). The value always ranges between zero for complete absence of dissection and the prevalence of plane topography, and one for uncommon instances, such as vertical cliff topography at the seashore, or a vertical escarpment (Pareta and Pareta, 2010). *Dis* of different blocks (upper, middle and lower course) within the basin correlate with flood height and flood stagnation period of the basin. Accordingly, flash flood occurrence should be expected at areas with high dissection index values, that is to say, high potential energy (Vara, 2018).

2.2.3. Multi-criteria fuzzy overlay analysis

To prioritize areas by flash flood vulnerability level, the research employed a multi-criteria decision-making process. The model considers both the land cover and morphometric factors. As it is shown in fig 2, eight different factor maps of the watershed area were used to map the flash flood vulnerability. Two of these maps are the land cover maps that highlight the impervious and vegetation cover areas. The other six factor maps were produced using the micro watershed morphometric characteristics computed by Lurm, Rbm, Rg, Dis, Lf and Rc. Although different methods were applied to standardize the multi-criteria evaluation, this study used fuzzy logic, which provides a broader range of membership functions than other methods of standardization (Myint and Wang, 2006). Ahmed et al. (2017) applied fuzzy logics to prioritize sub-watersheds by their morphometric characteristics. In a traditional overlay analysis, the results are transformed into 0 and 1 binomial functions, but the fuzzy membership function transforms the input raster into a 0 to 1 scale. This transformation indicates the strength of a membership in a set, based on a specified fuzzification algorithm. Thus 1 represents full membership and 0 infers the complete exclusion from the membership of the fuzzy set (Esri, 2015). However, the varying set of membership ranges between 0 and 1 (Jiang and Eastman, 2000). The Arc-GIS fuzzy environment specifies the algorithm used in fuzzification of the input to set the membership the environment has about seven types of membership function (Gaussian, Small, Large, Near calculates, Ms-large, Ms-small, Leaner).

This study also applied fuzzy overlay analysis for flash flood vulnerability mapping using the land cover and morphometric values of the area. Figure 2 illustrates the method and organization of the model. Based on related literature, experts consultation and researchers personal knowledge of the area, the membership functions of the land cover and morphometric factors were determined. After the factors were selected and the fuzzy membership functions were assigned, the model indicated how these factors interact by choosing fuzzy-logic operators. These operators are mainly known as AND / OR operators that show the minimum and maximum possible suitability of the factors, respectively (Jiang and Eastman, 2000; Mohammed et al., 2017)

First, the BCI and NDVI based land cover maps were classified. Then, for impervious surfaces the MS-large membership function was used in the model, which helps to incorporate large values in high membership. For the vegetation cover the MS-small membership function was used in the model that allows to consider reversal membership. This means that flash flood is getting higher in areas of higher impervious surfaces and lower vegetation cover. Besides, the fuzzy overlay of the morphometric factors was executed step by step, and the broader categories of these factors (network, relief, area and geometry) were overlaid independently, before the model executed the overlay of the whole categories of the morphometric parameters together. Consequently, the final flash flood vulnerability map was produced by making an overlay analysis using the morphometric and the land cover based vulnerability map (see figure 2).

2.2.4. Riparian buffer zone evaluation

The effect of land cover and the flash flood vulnerability was evaluated in each strip of buffering distance. This study considered the MUDC's (2012) 15m buffer distance on either side of the river, and other countries' experiences which have more detailed riparian buffering tools. In this regard, the Montgomery County Planning Commission (2012) considered 7.5m as a shorter distance, 23m as a medium and 91m as a longer buffering distance. Therefore in this study the buffer strip widths of 15m, 30 m and 90m were evaluated. Thus, the degree of imperviousness, vegetation cover and flash flood vulnerability was quantified for each buffer strip width. This helps to measure the watershed and riparian landscape status, and to propose different intervention mechanisms.

3. Results

3.1. Land cover extraction

Flash flood vulnerability mapping of the Kebena watershed used the land cover and the micro-watershed morphometric feature evaluation. The land cover assessment classified the impervious surface from the calculated BCI values (fig 3a and c), and the vegetation cover using the NDVI values (fig 3b and d). It is, however, difficult to separate impervious surface, bare land and vegetated land due to spectral mixing. But, the histograms (fig 4) show a reasonably good separability between bare and impervious cover, based on the value of BCI, while the NDVI histogram shows a high separation capability between bare and vegetated surfaces. As shown in figure 4a, in the BCI histogram, impervious surface has its highest point around 0.35 whereas the bare land has a peak around the index value of 0.0, with a crossing point at 0.12. On the other hand, in the NDVI histogram, vegetation has the highest point at about 0.4 and bare land has a peak around 0.09 with the crossing point at 0.17 (fig 4b). Based on these separation points, the impervious and vegetation cover of the watershed was extracted with a good precision as shown in figures 3c and 3d. The separability of the land cover classes was at a best level in both cases as it is confirmed by the SDI value. The BCI separability of impervious versus bare land estimated about 1.6. Similarly, the NDVI based vegetation cover versus bare land dissociation level appears as high as 2.1.

3.2. Morphometric analysis

The morphometric analysis of the Kebena watershed was conducted by subdividing the watershed into 29 micro-watersheds. Each micro-watershed was identified by continuous ID number. There are several morphometric parameters that may broadly be categorized into four classes: 'network', 'areal', 'geometry' and 'relief'. As it is shown in table 1, of these, micro-watershed numbered 9 has the largest area and the highest number of stream segments. The longest perimeter was recorded for micro-watershed 18 followed by 9. Micro-watershed 15 has a relatively longest stream length next to the micro-watershed 9 and 16. On the other hand, the micro-watershed 17 has the shortest perimeter, smallest area and number of stream segment. fig 5 illustrates the micro-watershed area and the streams with their orders.

Initially 20 morphometric factors were calculated, but only six were used for the morphometric analysis. Fourteen factors were discarded after conducting the PCA analysis. The remaining six factors are Lurm, Rbm, Lg, Rc, Diss and Rg.

3.3. Flash flood vulnerability mapping of Kebena Watershed

The final flash flood vulnerability map (fig 6) was developed by the fuzzy overlay modeling technique. In fact, the extracted morphometric factors represented the broader classes of 'network', 'geometry', 'area' and 'relief'. When the value of the extracted morphometric factors (Lurm, Rbm, Lg, Rc, Diss and Rg) is high, the model sets a high priority to flash flood vulnerability. This means that the flash flood is getting higher as the value of the selected morphometric factor is greater. The land cover factor considered both the NDVI and BCI indices to identify the land cover classes. The model again sets high vulnerability with increasing impervious and decreasing vegetation covers. Figure 6 reveals that 969.8 ha (about 19%) of the watershed area is highly vulnerable to flash flood, 2092.1 ha (about 41.5%) of the area is moderately vulnerable to flash flood, and 1980.5 ha (about 39.3%) has a low vulnerability.

Historical records of the flood incidences in micro watersheds during the last ten years were collected by the Addis Ababa fire and emergency preparedness office till 2017. The GPS locations of the locations with recurrent flash floods indicate that four of them are located in our study area (indicated by yellow triangles in fig 6). Comparison of the modeled flash flood risk and the observed flood incidences shows a good relation. Out of the four spots three of them are lying on the very high vulnerable area, while the fourth location was classified as having a high flash flood risk.

The Addis Ababa fire and emergency preparedness office have collected the flood data across the city when incidents damage human life or property. Although the extent of the flash flood varies from time to time, it creates a problem in any rainy seasons of the country. According to the office expert the flash flooding in this study area, which is caused by the seasonal heavy rain, disrupts pedestrians and vehicle movement. Since the area constitutes high built-up and rugged sloped terrain the city administration has not paid much attention to this problem.

3.4. Riparian buffering and the status of its landscape functioning

The riparian buffer assessment considered 15m, 30m and 90m buffering distances. The study measured the extent of imperviousness, vegetation abundance and the flash flood vulnerability, in the stripes of buffer distances. The pattern of impervious and vegetation cover in each buffering distance shows the extent of the riparian landscape functioning.

Having this in mind the extents of the given land covers were measured. With a 15m buffering width, 21.0 ha (about 32%) of the area was covered by vegetation, and 29.0 ha (44%) of the area was impervious. With the 30m buffering distance vegetation cover and impervious surface occupy about 20.7 hectare (32%) and 28.3 hectare (44%), respectively. Finally, when the 90 m buffer widths are considered, 82.0 hectare (32%) of the land is covered by vegetation and 106.1 hectare (42%) of it was covered by impervious surface. In all levels of buffering, the percentage share of impervious surface cover is higher than the vegetation cover (see table 2). This shows that the riparian buffering area is dominated by built-up zones, which potentially increases the flash flood risk.

Concerning flash flood vulnerability, within a 15m buffered distance 7 hectares (about 10.7%) of an area was highly vulnerable. 7.6 hectares (about 11.9%) of land of the 30m buffering was under highly vulnerable and 40 hectares (16%) of land of the 90m buffering distance is also under highly vulnerable zone (see table. 3).

4. Discussion

4.1. Flash flood vulnerability mapping

Researches have been made Flash flood hazard assessment using the different aspects of the morphometric parameters (Elkhrachy, 2015; and Angilieri, 2010). This research integrated the land cover assessment, morphometric analysis and the final flash flood vulnerability map which depicted 969.8ha of land as highly vulnerable area. It is significant on the southeastern and southwestern part where the land cover is dominated by impervious and northeast part where high, rugged terrain and depleted vegetation cover area of the watershed.

The fuzzy overlay method proves to be an effective technique in the area where sufficient flash flood records were not available. This method is helpful to identify flash flood prone zones of the watershed. Historical flash flood records partly match with our analysis results, which indicates that the applied methods are effective and can be used to prioritize areas for intervention measures.

4.2. The status of the riparian environment

The integrated aspect of the watershed land cover and morphometry controls the watershed and riparian landscape status. The stream ecosystem of the study area was highly degraded and hardly provides the expected services. In all buffering distances the area covered by impervious surface is greater than the cover of vegetated surface. The urban planning guideline of 15m buffering distance is also seriously violated and continuously occupied by built-up, covering about 31.7 hectares of land, which may represent about 1585 housing plots. Riparian vegetated zones have different advantages like controlling surface hydraulic retention and the stream nutrient up-taking time (Weigelhofer et al., 2012), to monitor urban nonpoint source pollution (Allison et al., 2006) and to keep up species richness (Spackman and Hughes, 1994). It also helps in maximizing cultural services for local low income urbanites (Vollmer et al., 2015). So different levels of riparian buffering should be one of the important conservation planning and management strategies (Marczak et al., 2010). However, further studies have to be made in the riparian buffering zones less than 15m to support specific stream level analysis and design recommendation.

Measures to control flash flooding and maintain the watershed and riparian landscape

The analyses results presented in the previous sections, show the flood prone areas of the watershed and the status of the riparian environment. Other studies also indicated that the present and future conditions of the flood hazard are more exacerbated in Addis Ababa and Ethiopia as a whole. For instance, the Intergovernmental Panel on Climate Change (IPCC, 2013) scenario and the current climate variability report of the National Adaptation Program of Action (NAPA, 2007) predict an increasing trend of rainfall and more flooding in the country. It is, therefore necessary to alleviate vulnerability to flash flooding by implementing measures that enhance infiltration of rain and reduce surface runoff.

Maintaining the watershed green spaces and controlling the impervious surface growth is an important flash flood mitigation mechanism. In fact, it is part of the natural flood management approach that works with natural hydrological and morphological processes, features and characteristics as compared to traditional engineering and structural approach (Saiff, 2011). This would be a more effective and cost-efficient mechanism in most developing countries for urban and suburban watersheds conservation management. Cruijsen (2015), for instance, suggested public spaces, parks, water squares and green squares for water retention, open water and urban farming as a best fit design to confront the flash flood problem. However, it is hardly possible in most African cities since these the competition for space is huge, especially from commercial business and residential land construction, and because of several other reasons (Burak et al., 2017; Kimengsi and Fogwe, 2017). This is also true in Ethiopia urban centers, particularly in Addis Ababa. If it would be somehow possible to maintain the green spaces at least along the riverine landscape it could help to reduce the flash flood problem. Nevertheless, as urbanization gets strong, some marginalized areas and this riparian vegetation cover also becomes occupied by impervious surface. According to our analysis, the share of vegetation cover is already lower than the proportion of impervious surface in the Kebena watershed. Therefore, maintaining the remaining riparian vegetation is an important way to control the flash flood damage, which is more sustainable and cost effective methods to conserve the watershed.

The riparian buffering is also helpful to take multistep intervention to confront the existing and upcoming challenges. Accordingly, stripes of buffering distances help to take a choice of intervention measures at different part of the stream block. For example, removal or relocation of people who were inhabited on flash flood vulnerable area (969.8ha) is difficult. It is also hardly possible to remove impervious surface even in a15m buffering distance, which is taken as the national standard since it is challenging to relocate this large number of inhabitants. However, the impervious surfaces that lie in a flash flood vulnerable areas requires the city administration's special consideration because of the following two reasons. Firstly, peoples who are living in this area highly exposed to heavy rainfall and flash flooding event that damage their house itself and take human life too. Secondly, it occupies 2.8 hectares of land, which may represent nearly 141 housing units, which may somehow be modest to relocate from this hazardous area. In fact, the present and upcoming intensity of urbanization and built-up growth continued to occupy the remaining green spaces and bare land, thus, it is necessary to control and maintain the existing green spaces up to the maximum buffering distance (90m). This helps to gain the benefits of green spaces like flood slowing function and other stream ecosystem services, and it enables to compensate the existing impervious area impact. Inspire of the fact that afforestation approach has some argumentative issues (Calder and Aylward, 2009), it is possible to rehabilitate the remaining bare lands up to the maximum buffering distances to minimize flooding and control the consequent damage. Therefore, stripes of buffering distances are useful planning instruments to take multistep intervention measures to conserve urban and suburban watershed. Though there is strong competition and land use tradeoff over space in the urban landscape, it is possible to maintain riparian green spaces as it is helpful not only to upgrade the riverine landscape but also alleviate flash flood vulnerability over the watershed. Furthermore, as it is an urban landscape it is impossible to prohibit the impervious growth. However, all the urban planning and design works and the grey infrastructure development have to enhance pervious structures and encompasses green infrastructures.

Conclusion

This research evaluates the urban and suburban watershed land cover and morphometry as the main factors of the watershed hydrology, and its riparian environment functioning. The study identified 29 micro-watershed and analyzed 20 morphometric parameters, then the PCA measure reduced the variables in to six. These are Lurm, Rbm, Lg, Rc, Diss and Rg. The fuzzy multi-criteria overlay analysis depicted 969 hectares of flash flood vulnerable area. The 15, 30 and 90m riparian buffering distances were delineated and the cover of the impervious was greater than the vegetation cover and large proportion of the riparian buffering area are also vulnerable to flash flood. Within the national urban planning minimum buffering standard about three hectares of impervious was found on flash flood vulnerable areas.

Generally, Kebena watershed environment is significantly degraded and highly exposed to a flash flood that is mainly caused by the rapid expansion of urban built-up, degraded vegetation cover and the upland rugged terrain of the area. Besides, this rapid growth of the impervious surface and the continuous degradation of the vegetation cover distressed the status of the watershed and the riparian environment making the intended landscape function weak. The study, therefore concludes that geospatial modeling technique has a vital role to generate integrated, well developed urban flash flood data and hazard controlling approach in areas where continues data recording of events were not accustomed, like in Ethiopia. Such a research result, thus, is important to prioritize areas for immediate intervention like drawing early warning and controlling system. At the same time stripes of buffering distances are taken as an important planning tool, to monitor riparian green spaces, control flash flood vulnerability and maintain the riverine ecosystem services. As a recommendations, the grey infrastructure including roadways and city drainage system planning and design should integrate the green infrastructure and other perviousness enhancing structures. By using stripes of the riparian buffering distances, it is possible to devise measures to maintain the stream ecosystem based on the watershed geomorphic, hydraulic and environmental characteristics. It is also helpful to take an important decisions on relocating vulnerable built-up, preserving the existing green space and rehabilitating some degraded spaces.

Replicating these methods of quantifying and mapping other watersheds of the city of Addis Ababa and the surrounding urban region is one of the major areas of concern for future research. The Work can strengthen again by using a very high-resolution grid information to integrate hydro-metrological analysis.. Moreover, the research shall quantify and measure the level of ecosystem services that can produced in the riparian landscape.

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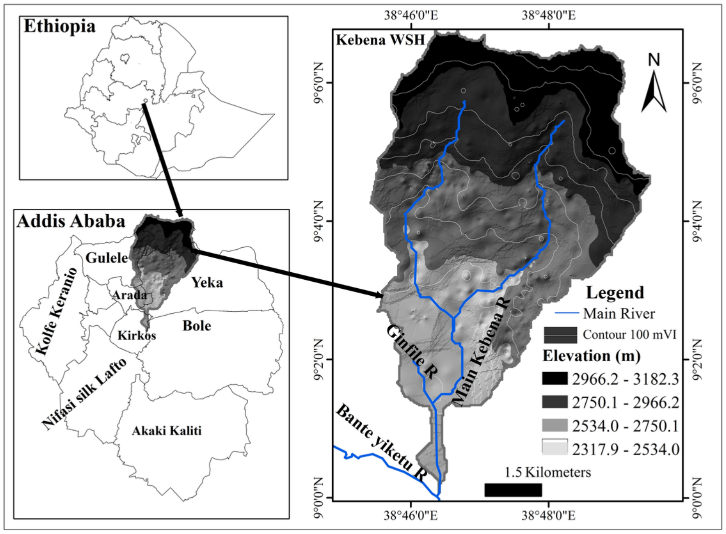
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Addis Ababa
Gulele
Arada
Yeka
Kolfe Keranio
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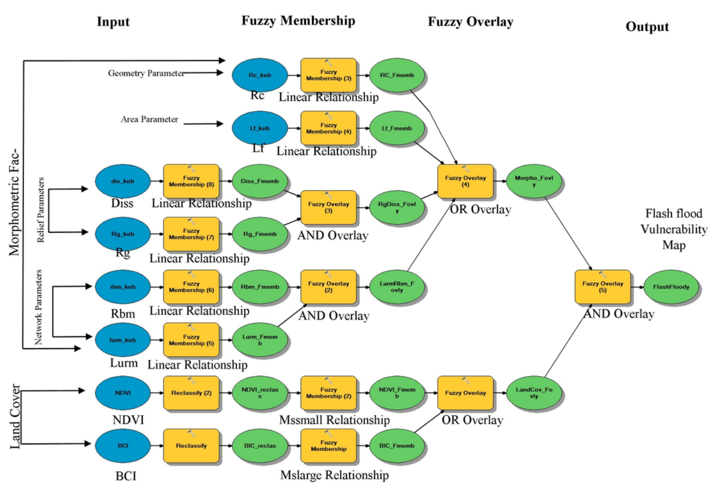
Akaki Kaliti
Kebena WSH
38°46'0"E
38°48'0"E
9°6'0"N
9°4'0"N
9°2'0"N
9°0'0"N
N
Legend
Main River
Contour 100 mVI
Elevation (m)
2966.2 - 3182.3
2750.1 - 2966.2
2534.0 - 2750.1
2317.9 - 2534.0
Ginfile R
Main Kebena R
Bante yiketu R
1.5 Kilometers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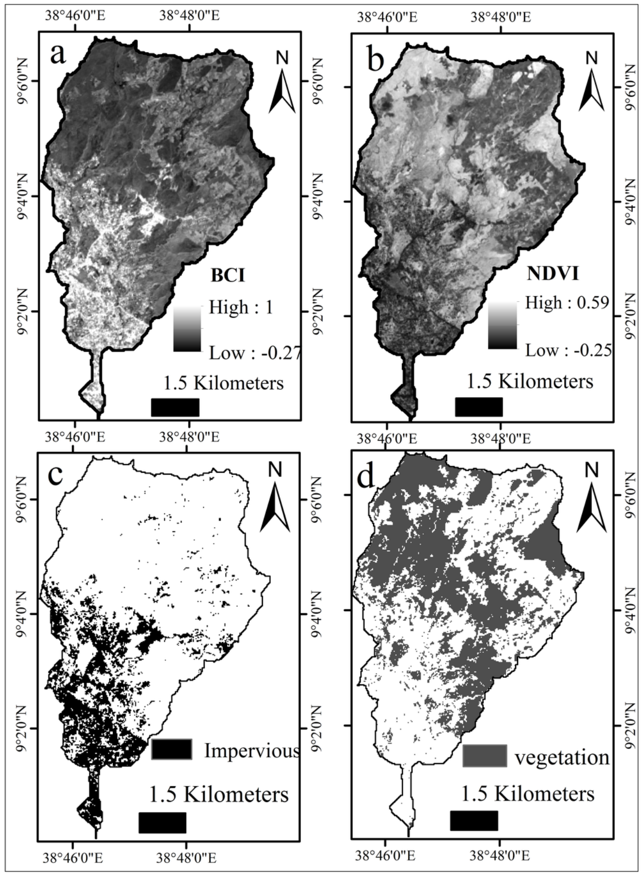
Fuzzy Membership
Fuzzy Overlay
Output
Geometry Parameter
Area Parameter
Morphometric Fac-
Relief Parameters
Network Parameters
Land Cover
Rc
Lf
Diss
Rg
Rbm
Lurm
NDVI
BCI
Linear Relationship
AND Overlay
OR Overlay
Mssmall Relationship
Mslarge Relationship
Flash flood
Vulnerability
Map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a
b
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BCI
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Low : -0.25
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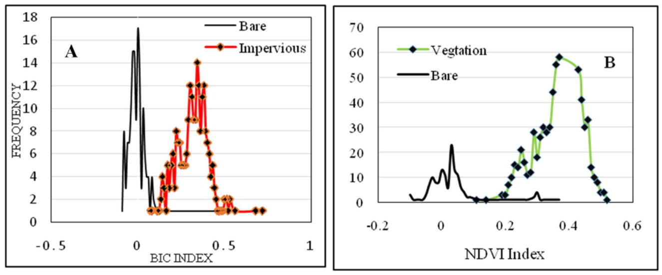
vegetation
1.5 Kilometers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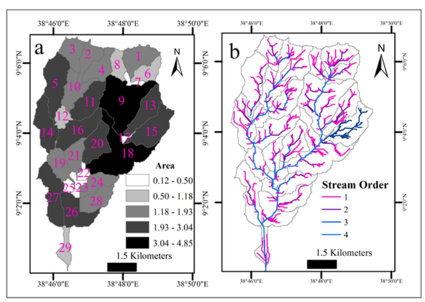
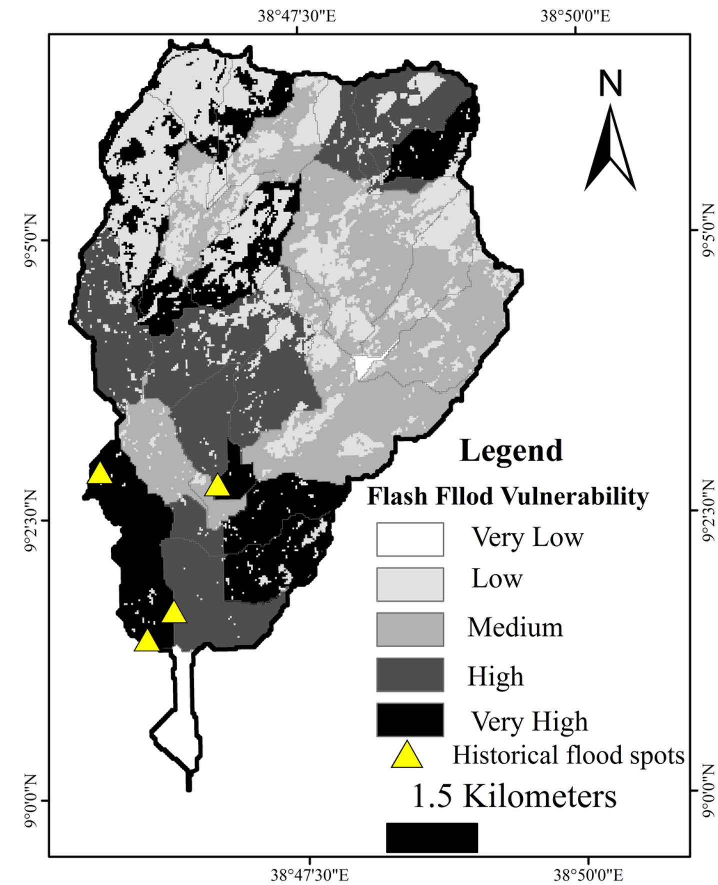
Bare
Impervious
FREQUENCY
BIC INDEX
B
Vegtation
Bare
NDVI Index


a
Area
0.12 - 0.50
0.50 - 1.18
1.18 - 1.93
1.93 - 3.04
3.04 - 4.85
1.5 Kilometers
b
Stream Order
1.5 Kilometers



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