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Technical Note

Impacts of Land Use and Land Cover Changes on PeakDischarge and Flow Volume in Kakia and Esamburmbur Sub-Catchments of Narok Town, Kenya

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Abstract: Due to population growth and an expanding economy, land use/land cover (LULC) change is continuously intensifying and its effects on floods in Kakia and Esamburmbur sub-catchments in Narok town, Kenya, are increasing. This study was carried out in order to evaluate the influence of LULC changes on peak discharge and flow volume in the aforementioned areas. The Event-Based Approach for Small and Ungauged Basins (EBA4SUB) rainfall–runoff model was used to evaluate the peak discharge and flow volume under different assumed scenarios of LULC that were projected starting from a diachronic analysis of satellite images of 1985 and 2019. EBA4SUB simulation demonstrated how the configuration and composition of LULC affect peak discharge and flow volume in the selected catchments. The results showed that the peak discharge and flow volume are affected by the variation of the Curve Number (CN) value that is dependent on the assumed LULC scenario. The evaluated peak discharge and flow volume for the assumed LULC scenarios can be used by local Municipal bodies to mitigate floods.

Keywords: EBA4SUB; Esamburmbur; Kakia; LULC changes; flow volume; peak discharge

1. Introduction

Due to the growth of society and the economy, various human activities have profoundly influenced the hydrological cycle and water resources management. The phenomenon of land use/land cover (LULC) change is a significant indicator of such impacts [1]. LULC changes have important impacts on hydrological processes, the economy, and the ecology of watersheds. Besides ecosystem vulnerability, LULC changes are major determinants of global environmental changes with potentially severe impacts on human wellbeing and livelihoods [2]. Significant changes between physical and hydraulic soil properties under agricultural areas and natural vegetation cover were observed, reinforcing the hypothesis that agricultural activity may influence the soil water balance [3].

Barasa and Perera [4] investigated the influence of LULC changes on river peak discharge in the Sosiani River basin in Kenya and found that peak discharge was directly increasing with the increase in farmlands and urban areas and with the reduction in forest areas. The same is expected to occur also for Narok town watershed, where from 1985 to 2019, the forest and pastureland declined by 39.7% and 25.7%, respectively, while agriculture and built-up areas increased by 55.4% and 10.6%, respectively [5].

Broadly stated, the effects of LULC changes on soil physical proprieties are known, especially when considering the conversion of forests to pastures or croplands [3,6]. Although the impacts of LULC changes on watershed hydrology are known, variability in local factors and their influence on the hydrograph make it difficult to draw generalizations. Moreover, the spatial distribution of LULC characteristics can also affect the hydrograph shape [6]. The relationship between LULC and hydrograph main characteristics (i.e., peak discharge, flood volume, flood duration) is often investigated considering the Curve Number (CN) approach [7]. CN approach was developed by Soil Conservation Service (SCS) in the 1950s and was subsequently updated by the National Resources Conservation Service (NRCS). Currently, this method is included in widely used rainfall–runoff models (e.g., HEC-HMS, EPA-SWMM, SWAT, GLEAMS) and it is particularly appealing for researchers because, assuming only one parameter (CN) that is well-classified with respect to soil properties and the antecedent moisture condition, they can easily estimate infiltration and surface runoff. In brief, the CN method, described in the following, is a lumped (in space and in time) approach that defines the total surface runoff of a rainfall event. Its popularity is rooted in its convenience, its simplicity, and its authoritative origins, and consequently it is applied in a large number of research papers. A modified SCS-CN method was used for runoff estimation, considering parameters like slope, vegetation cover and watershed area [8]. The underestimation of runoff due to CN composition is most severe for wide CN ranges, low CN values, and low precipitation depths [9]. LULC changes in a watershed generally tend to aggravate floods as they promote the removal of the original vegetation coverage, increase imperviousness, canalize river reaches, and promote the occupation of floodplain [10]. Therefore, understanding how the LULC change process acts on floods is very important for adequate LULC planning and the development of tools for hydraulic risk management.

Various rainfall–runoff models have been widely used as tools to explore the potential impacts of LULC changes on streamflow using both hydrological and statistical modeling [1,8,10–12]. In practical hydrology, estimating the design hydrograph and related peak discharge for small and ungauged basins, i.e., where the observed discharge is not available, is a common problem [13]. In such circumstances, due to the difficulty of calibrating the usually huge number of parameters present in advanced and distributed rainfall–runoff models, the use of parsimonious and opportunely designed rainfall–runoff models is preferred.

Among these, the recently developed Event-Based Approach for Small and Ungauged Basins (EBA4SUB) [14,15] is a rainfall–runoff model characterized by a limited user subjectivity and the employment of advanced hydrological modules. It is noteworthy that EBA4SUB's main aim is to set up a framework that provides very similar results when applied in two analyses at different times for the same case study. In doing so, the user subjectivity can be minimized. Indeed, it is recognized by the literature that the user subjectivity in case of ungauged basins can lead to a huge uncertainty in the modeled results [14]. EBA4SUB has been used in different small watersheds, located in various countries with different geomorphological features and climatic regimes, giving promising results [15].

Comparison between the observed and simulated peak discharge values (obtained using EBA4SUB and other approaches, such as the rational method and empirical formulas) in previous works [14,15] showed relevant differences and this result was expected considering the challenging application. However, the error percentages were in line with common values present in the literature related to similar applications performed with more complex and sophisticated models calibrated on observed data, and this was encouraging considering that EBA4SUB is usually applied without calibration.

The evaluation of future projections on the Narok town watershed in terms of LULC scenarios and related flow is highly necessary for the best mitigation of floods and effective land planning. Therefore, the aim of the present study is to investigate the effects of projected LULC changes on peak flow and total runoff resulting in the two catchments of Narok town, Kenya. The assumed LULC changes are projections based on a diachronic analysis of satellite images showing the LULC changes that occurred in the period 1985–2019. The results can give new insights toward the best management practices needed in order to achieve sustainable development of the area without increasing the flood risk. It should be emphasized that so far there has been no research regarding the possibility of using the EBA4SUB model to determine the design hydrographs in the investigated catchments.

2. Materials and Methods

2.1. General Overview of the Study Area

Narok county is located in the Southern part of Kenya and it covers a total area of 17,933 km^2. The study area, shown in Figure 1, is a small portion of Narok county territory and it is characterized by an extension of 46.2 km^2. In detail, the study area is located in proximity of Narok town, in the North-Eastern part of Narok County, where the seasonal Kakia and Esamburmbur streams meet and drain into Enkare Narok river through Narok town. The two seasonal rivers run through the town center where they act as the town's storm drain channels before emptying into the Narok river [5]. In terms of coordinates, Narok town lies between 01°05′ S and 1°7′ S and between 35°52′ E and 35°56′ E [16]. The average rainfall in the area is 750 mm per year. The precipitations of the area are characterized by an average rainfall of 750 mm per year. The majority of the rainfall occurs in March and May with an average value approximately equal to 1000 mm while the monthly average value is around 500 mm between September and December.

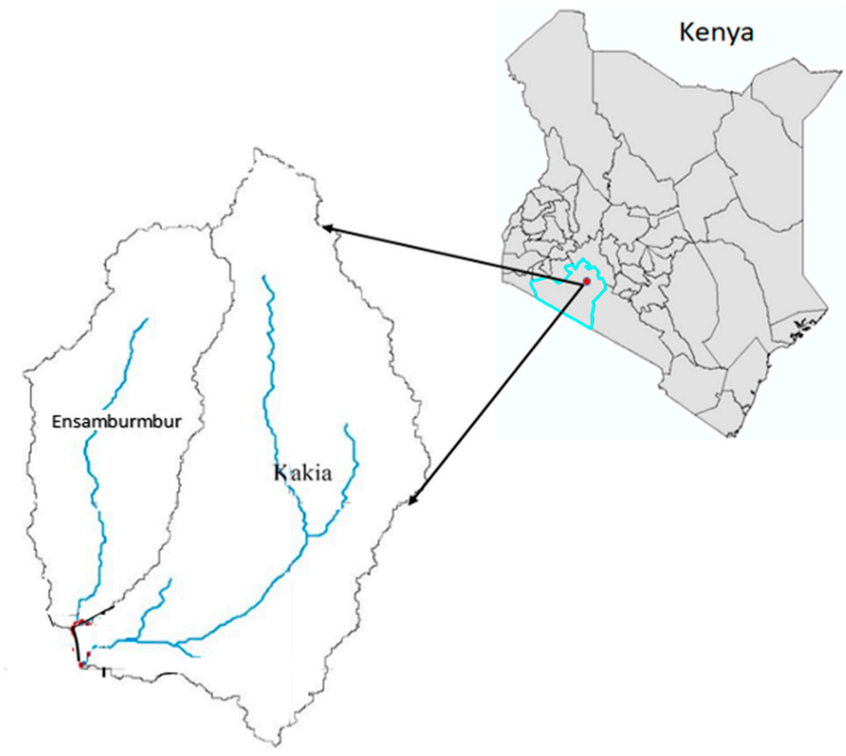

Figure 1. Kakia and Esamburmbur sub-catchments.

The temperature ranges from a minimum of 8 °C to a maximum of 28 °C. Narok town watershed is formed by Kakia and Esamburmbur. The town has a population of around 40,000 people, mostly Massai.

2.2. LULC and Soil Type

LULC was prepared through Landsat 5 and 8 at 30 m resolution obtained from the United States Geological Survey (USGS) and processed according to supervised classification. In detail, the images were processed using Erdas Imagine 2015, then imported in ArcMap, converted into shapefiles, and supervised classification as in Sertel et al. [17] was performed.

The LULC changes that occurred in the period 1985–2019 showed a decrease in forests and pasturelands, which were replaced by agriculture and built-up areas [5]. Indeed, in 1985 the area was mainly pastureland and forest, and the land tenures were predominantly pastoralists. After that, Narok town was urbanized at a rapid rate. Different factors increased the migration toward the area, such as the development of higher learning institutions, and the intensification of opportunities created by the Maasai Mara Game Reserve. In addition, the settlement of high population-running businesses contributed to the intensification of agriculture in the surrounding area to supply the town. This situation led the landowners to start cultivating and clearing forests to expand their farms. Based on the major types of LULC transitions from 1985 to 2019, the land use map of 2019 constituted the base for future projected LULC scenarios.

Therefore, the major observed LULC changes were processed in different future scenarios starting from the Landsat image of November 2019. After the images were processed using Erdas Imagine 2015, the supervised classification methods were used to assign different LULCs under projected scenarios. Focusing on the effects of LULC changes to determine the Curve Number (CN) as an important parameter related to the generation of runoff, as presented here, four projected LULC scenarios were investigated (see Table 1 and Figure 2).

Table 1. LULC, assigned CN, and LULC percentages in different years and projected scenarios.

LULC	CN	1985	2019	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	(-)	(%)	(%)	(%)	(%)	(%)	(%)
Forest	70	46.0	6.3	0	15	0	5
Pastureland	74	51.6	25.9	5	30	10	20
Agricultural area	82	0.0	55.4	75	40	40	40
Open space	79	0.5	0.0	0	0	0	5
Built-up area	90	1.9	12.5	20	15	50	30

Scenario 1 consists of considering three types of land use for the study area where the current built-up area (12.5%) is increased to 20%. Therefore, scenario 1 assumes that due to LULC changes the built-up area is 20% of the total area, the agricultural area is 75%, and pastureland is assumed to be in poor condition as 5% of the total area. In this scenario, we assume an intense increase in urbanization and agricultural activities leading to a drastic decrease in forest areas and rangelands.

Scenario 2 consists of 15% of the entire catchment for built up area, 40% for agricultural area, 30% for pastureland, and 15% for forest. In this scenario, we assume a small increase in built-up area and reforestation, while agriculture is assumed to reduce and give an increase in rangeland.

Scenario 3 assumes 50%, 40%, and 10% for built-up area, agricultural area, and rangeland, respectively, of the entire catchment. In this scenario, we assume a considerable increase in a built-up area, we maintain the same extent of agricultural area as in Scenario 2, and we clear down the forest with a small part of rangeland.

Scenario 4 assumes 20%, 5%, 30%, 40% and 5% for pastureland, forest, built-up area, agricultural area and open space, respectively. In this scenario, we assume a regular step of 10% of proportion from pastureland, built-up area and agricultural area and a small rate for forest and open space.

Regarding soil data, they were retrieved from the soil map of Kenya. Narok county has different soil types, mainly clay, loam and sand, but the study area was found to be predominantly clay loam, as shown in Figure 3.

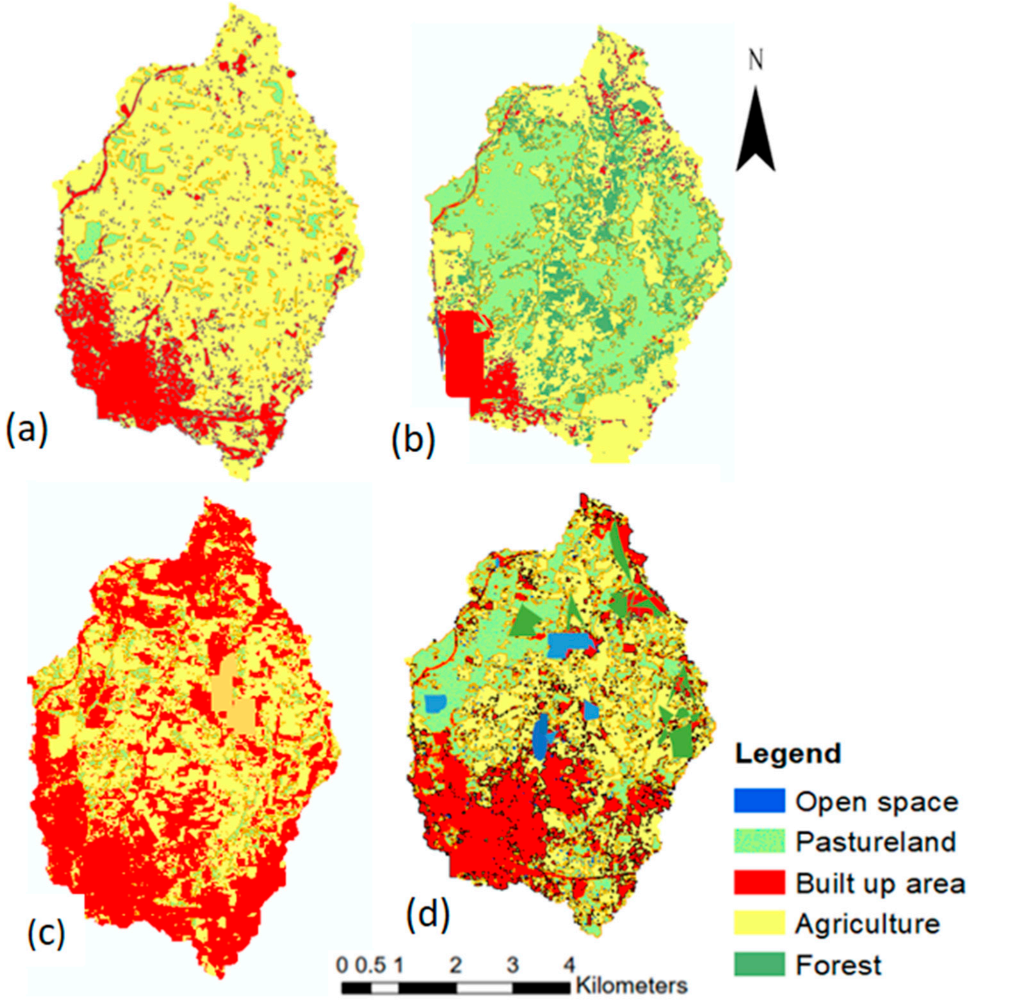

Figure 2. Projected LULC scenarios of Kakia and Esamburmbur sub-catchments: (**a**) scenario 1; (**b**) scenario 2; (**c**) scenario 3; (**d**) scenario 4.

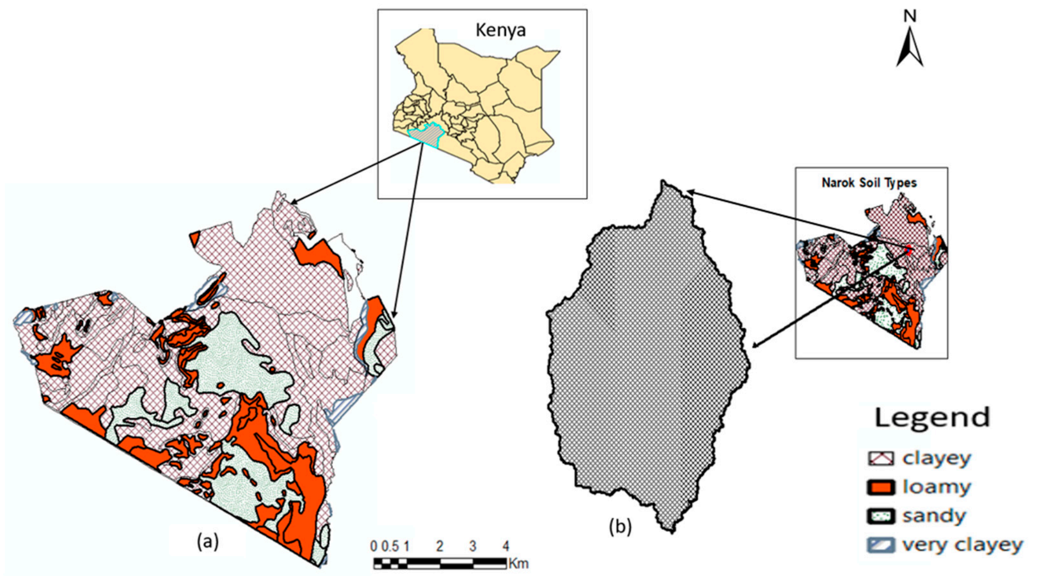

Figure 3. Soil type map of Narok County (**a**) and selected study area (**b**).

2.3. Determination of Curve Number and Concentration Time

The Curve Number (CN) is a dimensionless parameter indicating the runoff response characteristics of the drainage basin [18]. According to the original formulation, the CN value ranges theoretically between 0 and 100 [19] where 0 means that all the precipitation infiltrates and does not form surface runoff, while 100 means that infiltration is not occurring, due to extreme soil impermeabilization, and all the precipitation is transformed into runoff. This parameter is related to land use treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition (AMC) at the moment of precipitation in the drainage basin.

The Curve Number (CN) was calculated here with the combination of spatial LULC data, soil type, and assuming an AMC condition equal to II (soil in average wetness condition at the moment of the precipitation). The CN was, in detail, first assigned for each type of LULC considering the official look up tables, and weighed for each of the two sub-catchments considering the percentages of the specific LULC.

Different types of spatial and current LULC were identified in the study area from 1985 to 2019 [5]. As aforementioned, the values of CN were assigned based on the tables provided in the NEH-4 [20,21]. Based on the soil map of the study area, the hydrological soil group was found to be group C, where the dominating soil texture is clay loam.

The NRCS CN tables were consulted for current and hypothetical scenarios of LULC changes. The evaluation of CN to different and spatial LULC changes scenarios developed in this study serves to evaluate how the LULC changes affect runoff at the catchment outlet. The average values of CN have been established at catchment scale for composite land use areas and types. An average CN value of the catchment within each assumed scenario was calculated according to the following equation [22]:

$$CN = \frac{\sum CN_i A_i}{A}. \tag{1}$$

where CN_i and A_i are the CN value (-) and area value (km^2), respectively, of the generic LULC, CN (-) is the weighted CN considering the specific areas as weights, and A (km^2) is the total area of the investigated case study.

While the CN mainly affects the relationship between gross rainfall, excess rainfall, and infiltration, the concentration time (T_c) is one of the main characteristics influencing the shape and the peak of the runoff hydrograph, with smaller (larger) T_c values leading to shorter (longer) hydrographs characterized by higher (lower) peak discharges [23]. Therefore, T_c is one of the basic parameters used in many modern hydrological models; however, its usage is still controversial [20,21]. In the absence of observed rainfall and runoff-synchronized data, as usual for ungauged basins, T_c is usually estimated employing empirical formulas. Nevertheless, T_c was found to have a strong variability that can be up to 500% if different formulas are employed [24].

In this study, T_c was then calculated using the following Kirpich equation, as it was used in many studies and confirmed good prediction [25,26]:

$$T_c = \left[\frac{0.948L^3}{H}\right]^{0.385} \tag{2}$$

where T_c is the concentration time (h), L is the length of the longest waterway from the point in question to the basin divide (km), and H is the difference in elevation between the point in question and the basin divide (m).

2.4. The Inputs of the EBA4SUB Model, Data Processing, and the Performed Analyses

The input data needed by the EBA4SUB model are the Digital Elevation Model (DEM) of the investigated catchments, the LULC data and the rainfall data. The main parameters of the model are CN and T_c [14,15]. The DEM was gathered from earth explorer 2020 of the United States Geological Survey's Earth Explorer (USGS) site (http://earthexplorer.usgs.gov/) (accessed on 15 January 2021).

The LULC information was derived from the different projected scenarios. The DEM file was clipped for Kakia and Esamburmbur according to the catchment shape, with no pits and no flat areas [27] using ArcMap 10 and QGIS 3.10 software. Other than geomorphological input, i.e., the DEM, EBA4SUB needs (1) the CN parameter estimation (determined thanks to LULC), affecting the transformation of gross rainfall in excess rainfall; (2) the Tc parameter estimation, affecting the transformation of excess rainfall in runoff; (3) the assumed rainfall data to achieve the rainfall–runoff modeling.

The used rainfall data were provided considering the depth–duration–frequency (DDF) curves, which were calculated from the official intensity–duration–frequency (IDF) curves [28] of Narok, available from Atlas Kenya (Kenya Ministry of Water Development, 1978). Regarding the temporal distribution of the rainfall pattern, EBA4SUB allows for the selection of patterns like Chicago, triangular or rectangular. As recommended in Piscopia et al. [15], we selected the Chicago hyetograph assuming a peak position at the center of the rainfall pattern. Indeed the Chicago hyetograph was used because it represents an upper threshold condition for peak discharge determination, circumstance that favors safety [14].

After having determined the input data, the EBA4SUB model estimates the design hydrograph as in the following. The first module of the software calculates the design hyetograph. In detail, the DDF parameters (a and n), reported in Table 2, are used assuming the desired rainfall duration to calculate the cumulative rainfall depth for different return periods Tr (here we assumed Tr equal to 5, 10, 25, 50 and 100 years). The DDF functional shape is expressed using the following equation [11,13]:

$$\mathrm{Hp} = \mathrm{a} * \mathrm{tp}^{\mathrm{n}} \tag{3}$$

where Hp is the cumulative rainfall depth (mm), tp the rainfall duration (h), a (mm/h) and n (-) the DDF parameters based on the assumed return period. Regarding the rainfall duration, it is assumed equal to the catchment concentration time. After having estimated Hp, as aforementioned, the Chicago hyetograph is selected and the design rainfall temporal distribution is determined.

Table 2. DDF parameters of the study area for different return periods.

	Return Period (Years)				
DDF parameter	5	10	25	50	100
a (mm/h)	40.31	47.02	57.23	62.14	70.27
n (-)	0.206	0.21	0.188	0.196	0.195

The second module of the software calculates the excess rainfall, using the CN4GA (Curve Number for Green Ampt) procedure. CN4GA is a mixed and automatic approach combining the empirical equation of NRCS CN and the Green Ampt equation to estimate the excess rainfall temporal distribution starting from design rainfall, based on CN and AMC specification. The AMC used here was condition II (AMC-II). Therefore, the soil was assumed to be in average wetness conditions at the moment of the design rainfall.

The third and last module of the software is the excess rainfall–runoff propagation, which allows for the estimation of the design hydrograph and that is performed applying the Width Function-Based Instantaneous Unit Hydrograph [14,15]. WFIUH is automatically calculated from DEM flow paths and the Tc estimation, leading to the basin travel time distribution. In detail, surface flow velocities are calculated based on case study slopes and LULC employing empirical formulas for hillslope cells and calibrating channel cells ensuring that the projection of the WFIUH center of mass on the temporal axis is equal to the basin lag time, expressed as 60% of Tc [14,15].

3. Results and Discussion

Table 3 presents the main identified characteristics of the study area as obtained from the geomorphological analysis of DEM and LULC. Different values of CN in consideration of LULC were assigned and are shown in Table 1. The assignment was performed employing the original CN look up tables and following what done in Recanatesi and Petroselli [18], i.e., assuming the soil as being in average wetness condition (AMC II). The results, reported in Table 4, show that the CN for both the investigated areas was 72.5 in 1985 whereas in 2019 its value increased to 80.2 due to LULC changes, with an increase of 9.6%. It is noteworthy that flood risk evolution in a watershed located in urban or peri-urban environments is frequently studied in terms of LULC changes [18], so we followed a similar approach here.

Table 3. Identified characteristics of the study areas.

Characteristics	Kakia	Esamburmbur
Catchment area (km^2)	30.5	15.7
Catchment average slope	2.8%	3.1%
Altitude range (m)	1828–2123	1827–2082
Average altitude (m)	1975.5	1954.5
Length of the watercourse (km)	10.7	8.2

Table 4. CN values for Kakia and Esamburmbur sub-catchments in 1985, 2019 and in the assumed scenarios. The table reports also the differences with respect to the 2019 condition.

	1985	2019	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CN (-)	72.5	80.2	83.2	79.0	85.2	82.1
Difference Respect to 2019 (%)	−9.6	-	+3.8	−1.5	+6.3	+2.4

In addition to the current situation, the projected LULC scenarios were developed, and the average values of CN were found to be 83.2, 79.0, 85.2, and 82.1 under scenarios 1, 2, 3, and 4, respectively. The assumed scenarios, with respect to the 2019 condition, determine an increase in CN value equal to 3.8% for scenario 1, 6.3% for scenario 3, and 2.4% for scenario 4, while for scenario 2 we can observe a decrease in the CN value equal to 1.5%. From such values, we can expect an increase in peak flows and flood volumes for scenarios 1, 3 and 4, and a decrease in peak flows and flood volumes for scenario 4.

The determination of Tc considered the length from the confluence with Narok river to the headwaters, equal to 10.7 km for Kakia and 8.2 km for Esamburmbur, and the catchment average slope, equal to 2.8% for Kakia and 3.1% for Esamburmbur. Thus, Tc was determined in the two catchments according to Equation (2) and the resulting values are approximately 100 min for Kakia and 80 min for Esamburmbur.

The results related to flood volumes and design peak discharges for the assumed return periods and for the different projected scenarios are shown in Figures 4 and 5 for Kakia and in Figures 6 and 7 for Esamburmbur. For sake of brevity, referring to Kakia subcatchment, in scenario 3, characterized by the greater CN value, estimated as 85.5, the peak discharges are 78.3 m^3/s and 210.4 m^3/s and volumes are 390,904 m^3 and 1,090,813 m^3, respectively, for 5- and 100-year return periods. While in scenario 2, characterized by the lower CN value, estimated as 79.0, the discharges are 46.2 m^3/s and 154 m^3/s and the volumes are 232,350 m^3 and 790,788 m^3, respectively, for 5- and 100-year return periods.

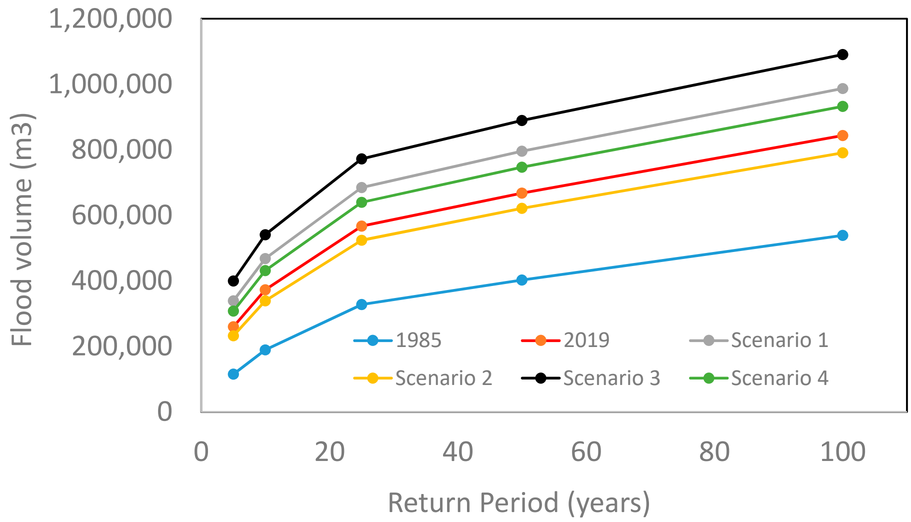

Figure 4. Design flood volume from Kakia for different LULC scenarios.

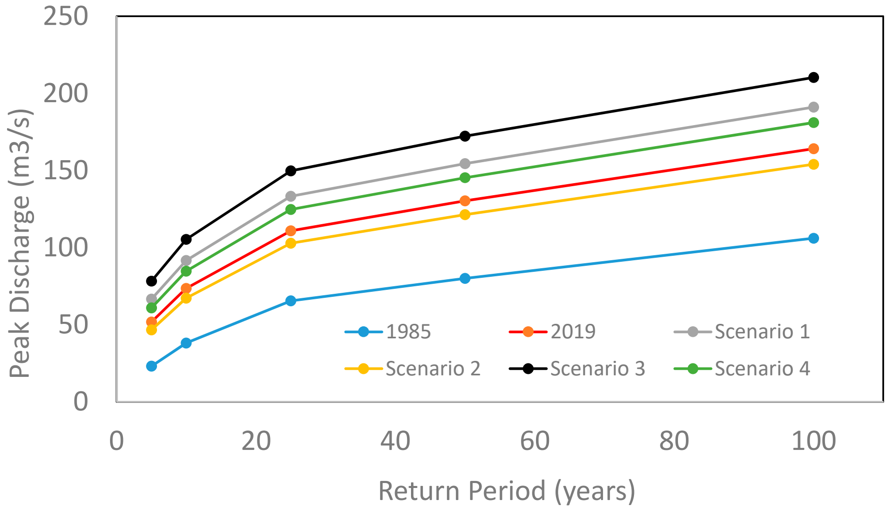

Figure 5. Design peak discharge for Kakia under different LULC scenarios.

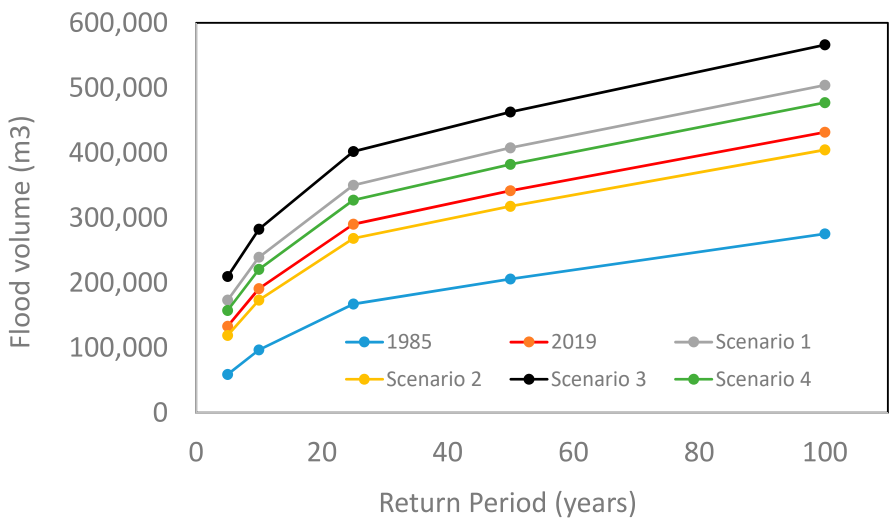

Figure 6. Design flood volume from Esamburmbur for different LULC scenarios.

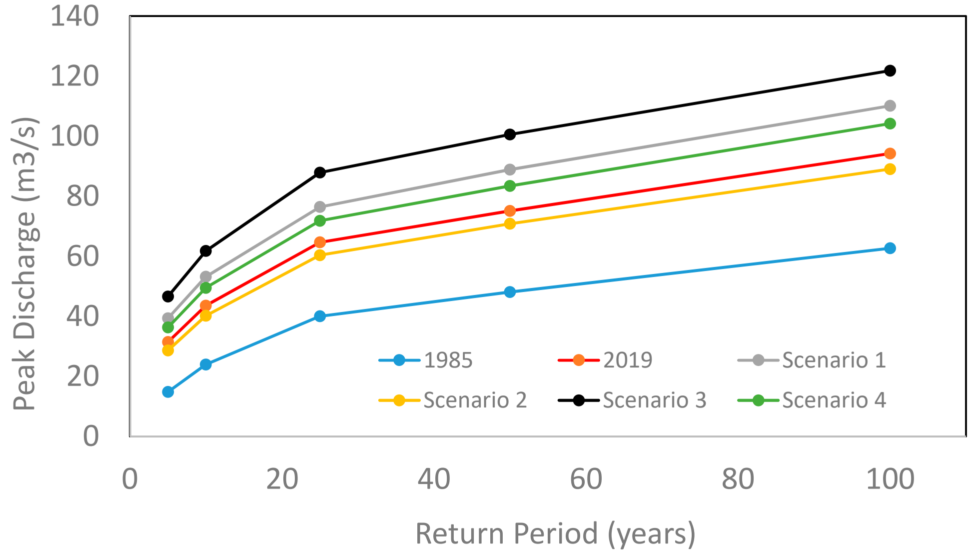

Figure 7. Design peak discharge for Esamburmbur under different LULC scenarios.

As it can be seen from Figures 4–7, and as expected, the design peak discharges and flow volumes increase with the return period and with the weighted CN value of the specific projected LULC scenario. Figures 4–7 allow the following considerations.

A first comment to be made is related to the magnitudes of the flood volumes and peak discharges in Kakia and Esamburmbur, which are very different to each other, with the values of Kakia being approximately the double those of Esamburmbur, although the CN in the specific scenario is the same. The difference is due to the size of catchment area that affects the runoff propagation. Indeed the same CN for the two catchments means that the same rainfall is transformed into the same excess rainfall, but a greater catchment area means that a specific excess rainfall is conveyed and becomes a greater peak discharge and flood volume.

A second comment is related to the similarity of the shapes among scenarios 1 and 4, which are similar although the LULC for the two scenarios is quite different. This circumstance is due to the fact that the CN approach is lumped in space, so different spatial configurations of LULC leading to similar CN values (83.2 for scenario 1 and 82.1 for scenario 4) are characterized by a similar excess rainfall and hence a similar peak discharge and flood volume. A more accurate representation of the reality could be achieved if a distributed model, instead of a lumped one, was employed. Anyway, such a choice would imply the need for observed data useful for calibrating the usually great number of input parameters involved in such models.

A third comment is related to the comparison between the LULC condition of 1985, the condition of 2019, and the projected scenarios. Concerning Kakia, the time interval from 1985 to 2019 has been characterized by a sensible increase in peak discharge, ranging from 54% (return period 100 years) to 124% (return period 5 years). Similar increases can be observed for flood volumes. The same can be stated for Esamburmbur, where the time interval from 1985 to 2019 has been characterized by a sensible increase in peak discharge, ranging from 50% (return period—100 years) to 112% (return period—5 years). Additionally, here, similar increases can be observed for flood volumes. An increase of 9.6% in CN from 1985 to 2019, due to an uncontrolled urbanization and increase in agricultural areas, produced a much bigger increase in surface runoff, with average values (considering all the return periods) equal to +80% for peak discharge and +83% for flood volumes for Kakia, and to +72% for peak discharge and +83% for flood volumes for Esamburmbur. The situation reflects what happens when uncontrolled urban planning occurs.

Concerning the four future scenarios, scenario 3 is characterized by the higher increase in CN with respect to the 2019 condition. The strong assumed increase in built-up areas and agricultural areas on the entire catchment leads to a +37% for peak discharge and s +39% for flood volumes for Kakia, and a +38% for peak discharge and a +42% for flood volumes for Esamburmbur (averaging all the return periods). We can state that this urban planning is not recommended because it increases the flood risk.

Scenarios 1 and 4 are also characterized by an increase in flood volumes and peak discharges, although less impacting than in scenario 3. In terms of urban planning, scenario 4, characterized by a moderate increase in pastureland, built-up area and agricultural area, is to be preferred with respect to scenario 1, where the increase in urbanization and agricultural activities is preferred with respect to the increase in pastureland. In any case, both scenarios 1 and 4 are characterized by a higher surface runoff condition with respect the 2019 condition.

Finally, scenario 2 is the only one characterized by a decrease in surface runoff. The assumed increase in pastures and the decrease in urban and agricultural areas leads to a −8% for peak discharge and −9% for flood volumes for Kakia, and a −7% for peak discharge and −8% for flood volumes for Esamburmbur (averaging all the return periods). We can state that in terms of urban planning this scenario is the best among the investigated ones and could help in mitigating the flood risk.

The results obtained in this study are in line with recent literature findings. For instance, Recanatesi and Petroselli [18] found that the increase in flood risk due to urbanization occurred in the study area from 1954 to 2018. The results from this study indicate that peak discharge is sensitive to LULC changes. As found in Apollonio et al. [29], to evaluate LULC changes and their effects on peak discharge, the CN method was recommended to accurately take into account the contribution due to LULC changes over time. The results from Petroselli et al. [30] showed a good correlation between flooding and LULC changes, as the results from this study show the increase in runoff due to urbanization growth. The variation of CN values due to LULC changes strongly affects the variation of peak discharge and flow volume. This confirms that rainfall–runoff transformation and all the consequent phenomena such as flood occurring are related to the LULC changes [31].

Moreover, Nagarajan and Basil [32] found that an increment of 3.5% in CN caused an equivalent increment in direct runoff, highlighting a linear proportion between urbanization and increment in flood risk for a small catchment in India. Moghadasi et al. [33] stated that in small basins of Golestan province, Iran, subject to great deforestation and urbanization a 5% increase in CN could strongly enhance the surface runoff. Dang and Kumar [34] determined a similar relationship between the increase in CN and the variation of surface runoff in urbanized districts of Ho Chi Minh city, Vietnam, and their results were confirmed by Hu et al. [35] for a urbanized district of Beijing city, China. Kandissounon et al. [36] quantified the contribution of extensive LULC change to urban flooding in Nigeria, describing an urban area where the changes in land cover led to a strong increase in average surface runoff. Costache et al. [37] explored the correlation between LULC changes and the flash-flood potential changes in Zabala catchment in Romania between 1989 and 2019 using Landsat image processing and determined that the LULC changes were highly correlated with the changes that occurred in flash-flood potential. Finally, Vojtek and Vojteková [38], in order to estimate the surface runoff for a small watershed in Slovakia, used the SCS-CN method, identifying the land use based on aerial imagery from 1949 and 2017. In their investigated period, they observed quite significant changes, with arable land that decreased the most by more than half (by 15.62%) while the share of forests increased by 4.55%. In these circumstances, the runoff volume values on the basin area decreased during the years between 1949 and 2017 by 1.95%.

The previous contributions highlighted that impervious areas' growth due to uncontrolled urbanization has considerable effect on the increasing of the runoff volume, and in our opinion the results obtained here confirm that an uncontrolled urban development can have a sensible effect on the increase in surface runoff and flood area generation.

A final consideration is related to the application of EBA4SUB performed here. As aforementioned, the two main model parameters are CN and Tc. In case of the availability of observed rainfall and discharge data, CN and Tc can be directly estimated and the model can be calibrated. Concerning CN, its value could be determined balancing the total excess rainfall volume and the total direct runoff volume. Concerning Tc, its value could be determined observing the time difference between the moment of the maximum rainfall intensity and the moment of the peak discharge, or from the visual analysis of the hydrograph recession limb and its slope changes. However, if observed data are not available, as in the present case study, the model cannot be calibrated and its parameters must be estimated following other approaches. Regarding CN, the original look up tables based on land cover and soil type can be used. Regarding Tc, empirical formulas can be used. This is indeed the fully ungauged basin perspective, and it is noteworthy that EBA4SUB in this kind of application can help in reducing the subjectivity of the user, since its parameters can be automatically estimated based on DEM and LULC data.

4. Conclusions

In this study, two sub-catchments were investigated in terms of the future scenarios of land use/land cover (LULC), assumed based on a diachronic analysis of satellite images showing the LULC changes that occurred in the period 1985–2019. The future LULC scenarios were found to influence the CN. The EBA4SUB conceptual rainfall–runoff model was used to determine peak flow and flow volume. Results showed and confirmed that LULC strongly changes the design peak discharge and flow volumes.

The rapid LULC change that has occurred in the period 1985–2019 was projected in the future in the selected area assuming four scenarios. The results contribute to a clearer understanding of how LULC changes affect peak flows and volumes. The evaluated design peak flow and volumes can be taken into account in sustainable urban planning and drainage system design for Narok town. In particular, we demonstrated that the uncontrolled increase in built-up areas and agriculture (scenario 3) increases the flood risk, while the increase in or at least the conservation of pasturelands and forest (scenario 2) can help in mitigating the surface runoff formation.

In conclusion, the following considerations emerge: the urban development should be coupled with sustainable practices of land conservation at catchment scale. If an increase in built-up areas is pursued, there is the need to adopt strategic countermeasures that do not increase the area vulnerability.

As examples, we can cite the recent contributions by Aryal et al. [39] and by Bhatti et al. [40]. In the first work, agroforestry practices were implemented in urban areas, integrating various aspects of land and water management. Such practices have been recognized as a potential solution to maintain ecological balance. In the second work, the construction of small urban reservoirs has been addressed, recognizing its direct and indirect positive impact on the LULC changes.

Regarding Narok town, the city has been experiencing problems related to lack of an appropriate drainage system. Indeed, the existing drainage system is not capable of containing the volume of water during the floods characterized by high return periods, a circumstance that is leading to the development of many studies searching for solutions for flood mitigation.

For instance, there is a plan for improving the drainage system, especially the two channels Kakia and Esamburmbur, increasing their cross sections. One contribution could be provided by nonstructural interventions, such as choosing a sustainable urban planning, characterized by an LULC change that decreases the CN value, or at least that does not increase its value.

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