DOI: 10.31577/ahs-2022-0023.02.0018

ACTA HYDROLOGICA SLOVACA

Volume 23, No. 2, 2022, 163–171

Drainage systems design in urbanized areas under land use changes scenarios: case study of Narok Town (Kenya)

Etienne UMUKIZA, James M. RAUDE, Andrea PETROSELLI, Simon M. WANDERA, John M. GATHENYA, Ciro APOLLONIO*

Land use/land cover (LULC) changes due to urbanization have a strong influence on runoff process. In the case of Narok town, in Kenya, several flash floods have caused human losses and economic damages. Design hydrograph and its peak flow are the key elements to determine hydraulic geometrical properties in designing an adequate drainage system. In consideration of LULC changes and consequent hydrograph variability, in this study existing channel geometric properties were verified, using field measurements through a ground survey employing Real-Time Kinematic equipment at Kakia and Esamburmbur channels of Narok town. To improve the drainage system, the evaluated peak flows under assumed future LULC scenarios were used to design hydraulic properties for a sustainable urban drainage system. Three hydrological/hydraulic models (EBA4SUB, Manning's equation, and Civil 3D) were used under different LULC scenarios for computing channel geometry and correspondent water level. The change in channel geometry was found to obstruct free flow for different scenarios of peak discharge and flow volume. The presented results could be used to support the design of storm water drainage systems by local authorities, in order to mitigate flood hazards and consequently to reduce the hydraulic risk.

KEY WORDS: Peak flow estimation, Rainfall-runoff modeling, LULC changes, Kenya case study, EBA4SUB model, Drainage systems.

Introduction

Land use/land cover (LULC) maps are a key input in environmental evaluations for the sustainable planning and management of socio-ecological systems (Pelorosso et al., 2021). In particular, urbanization is considered the most important driver in LULC changes due to developments of facilities such as roads, houses, schools (Habete and Ferreira, 2016; Han et al., 2009; Ohana-Levi et al., 2018).

Rapid socio-economic development and urbanization are drivers of significant changes in land use and can cause, as a consequence, high potential runoff (Blöschl et al., 2007, Apollonio et al., 2016). Additionally, various human activities have profoundly influenced the hydrological cycle and water resources management due to the growth of society and the economy (Apollonio et al., 2018; Umukiza et al., 2021; Pellicani et al., 2018). Uncontrolled land use is among the main reasons of variations in hydrologic and hydraulic processes (Zope et al., 2016; Apollonio et al., 2016). Moreover, urbanization processes as part of LULC tend to increase runoff rates and peak discharges due to the increased imperviousness and reduced infiltration along the built-up area (Ohana et al., 2013). As a matter of the fact, the process of urbanization is accompanied by vegetation removal as consequence, leading to increased runoff.

Novelli et al. (2016) proposed an efficient Artificial Neural Networks (ANN) classification method based on LANDSAT satellite data to evaluate LULC changes in a river basin area considering a time trend of 28 years. Shaina Beegam and Prince Arulraj (2018) reported urbanization as a direct effect on the environment which in turn affects the variations in runoff, that ultimately turn to flood. Recanatesi and Petroselli (2020), selecting a strategic case study in the periurban environment of the metropolitan area of Rome, determined that the increase in the flood risk is more pronounced in the part of the selected area that has been more extensively interested by the soil loss. In recent decades, urbanization has become an environmental concern in many developing countries (Guo et al., 2011; Fenner et al., 2019). Globally, floods are among the most devastating natural hazards and their frequency is increasing. There are several causes of floods, such as natural factors, and anthropogenic activities such as blocking of drainage channels, uncontrolled land use, and deforestation in headwater regions (Młyński et al., 2018). Each year, floods cause major disruption throughout the world, leading to loss of both human and animal life and damage to properties (Sharif et al., 2016). However, some land-use actions if correctly planned and realized can help to reduce flooding problems. For instance, urbanization in floodplain areas increases the risk of flooding due to the increase of peak discharge (Suriya and Mudgal, 2012).

The problems outlined above are also found in Kenya. In the case of Narok town, Kenya, the increase in floods events was recognized in recent years, resulting from the fact that Narok county areas is urbanizing at a rapid rate like many county areas in developing countries (Mwangi et al., 2019). Furthermore, population growth commonly leads to urbanization and expansion of agricultural land; hence this circumstance adversely affects hydrological processes (Coomes et al., 2001). Also, the lack of an adequate urban drainage network can increase the flooding risk (Alfarajat et al., 2014).

In fact, hydraulic structures for water control are sized to resist a design event, characterized by a hydrograph associated with a probability of occurrence (Erpicum et al., 2021; Piscopia et al., 2015). Usually, hydraulic structures are designed based on design hydrograph and its peak discharge to ensure efficiency and safety during service life. In many parts of the world, hydraulic structures are mostly considered safety-focused, risk-averse, and display hesitancy to use unproven innovation over legacy tools. Indeed, hydraulic structures engineering should involve and respond to the increasing demands for sustainability to reverse the challenges of today and the future (Erpicum et al., 2021). Although obtaining runoff estimation in ungauged catchments is very important when designing hydraulic structures, it is indeed a challenging problem to predict runoff for these basins because of the difficulty in obtaining adequate historical flow observations (Petroselli et al., 2020).

A recent study (Umukiza et al., 2021) evaluated future projections on the Narok town watershed in terms of LULC scenarios and related design flows for the best mitigation of floods and effective land planning. The study investigated the effects of projected LULC changes on peak flow and total runoff for the two catchments (Kakia and Esamburmbur) of Narok town, Kenya using the Event-Based Approach for Small and Ungauged Basins (EBA4SUB) rainfall-runoff model (Petroselli and Grimaldi, 2018) to determine the design hydrographs and peak discharge in the investigated catchments. As consequence of the aforementioned study, the present work aims to 1) carry out the hydraulic and geometric properties design of Kakia and Esamburmbur channels based on the peak flow determined under forecasted LULC change scenarios on watersheds, and 2) propose adequate conveyance capacity of the channels based on predicted effects of LULC changes as future likely scenarios to occur on rainfall-runoff regime within the watershed.

Material and methods

Description of the study area

The County Government of Narok lies between latitudes 0°50′ and 1°50′ South and latitude 35°28′ and 36°25′ East. It borders the Republic of Tanzania to the South, Kisii, Migori, Nyamira, and Bomet counties to the West, Nakuru County to the North, and Kajiado County to the East. It covers a total area of 17,933 km^2. The study area, shown in Fig. 1, is a small portion of Narok county territory, being characterized by a total area of 46.2 km^2 and it pertains to the hydrographic catchments of two seasonal streams, Kakia and Esamburmbur.

An average rainfall of 750 mm per year characterizes the precipitations of the area, with the majority of

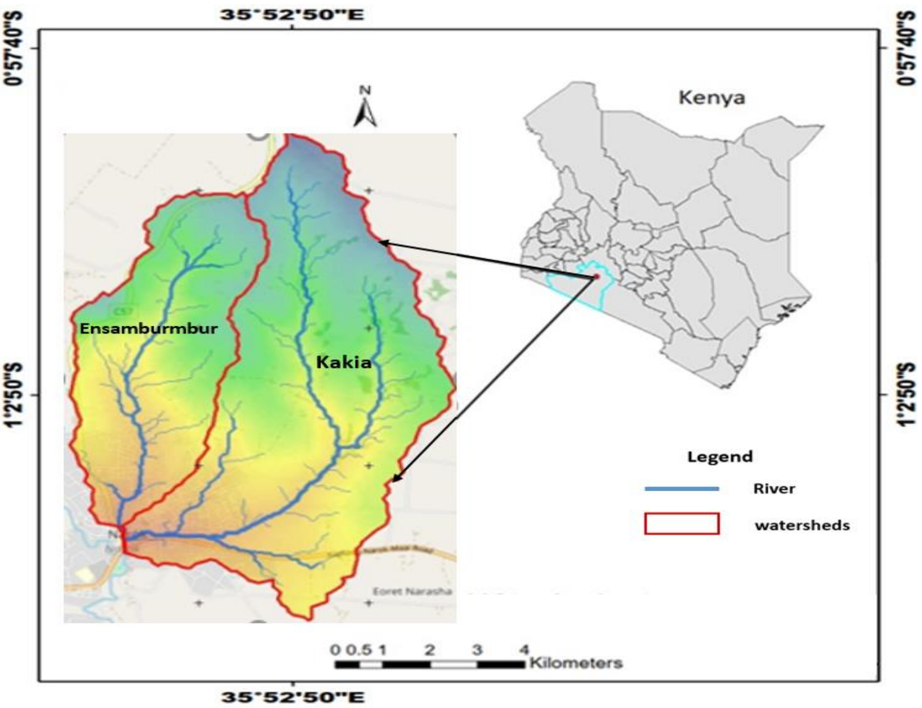

Fig. 1. Kakia and Esamburmbur sub-catchments.

the rainfall occurring in the March to May season. The temperature ranges from a minimum of 8°C to a maximum of 28°C.

The elevation of the investigated area lies between 1,844 m to 2,138 m above sea level and the water flow length is estimated to cover a maximum distance of 10,000 m to the outlet, for Kakia stream. The main economic activities are commercial farming (wheat, maize, and potatoes), livestock farming, and tourism in the famous Maasai Mara area.

LULC Changes in Narok Town Sub-catchment

The study by Marie Mireille et al. (2019) reported that LULC change that occurred in the investigated area in the period 1985–2019 showed a decrease in forest and pasturelands which were replaced by agriculture and built-up areas. Therefore, the major observed LULC changes were processed using supervised classification methods to assign different future scenarios starting from the Landsat image of November 2019, using Erdas Imagine 2015 (Umukiza et al., 2021).

To further understand the future likely impacts of various activities in the catchment, Umukiza et al. (2021) hypothesized four projected future scenarios (Table 1), based on major types of LULC identified in 2019 (scenario “0”). Therefore, due to LULC changes previously mentioned, Scenario one (1) considered that the built-up area is 20% of the total area, the agricultural area is 75%, and the pastureland is assumed to be in poor condition with a rate of 5% of the total area. In this scenario, intense increase in urbanization and agricultural activities were assumed, leading to a drastic decrease in forest areas and rangelands.

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

Scenario 3 assumes 50%, 40%, and 10% for the built-up area, agricultural area, and rangelands, respectively, of the entire catchment. In this scenario, a considerable increase in a built-up area was assumed, maintaining the same extent of the agricultural area as Scenario 2, and reducing the forest with a small part of rangeland.

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

In the present work, we focus on design of channel geometry based on the peak discharges evaluated in Umukiza et al. (2021), under different scenarios of LULC. The effect of LULC changes have been expressed using the Natural Resources Conservation Services (NRCS) – Curve Number (CN). CN value was calculated with the combination of spatial LULC data, soil type, and assuming an Antecedent Moisture Condition (AMC) equal to II following what was done in Umukiza et al. (2021). The average CN value for the two investigated catchments from the projected LULC scenarios was determined according to Equation 1 (Gajbhiye et al., 2014):

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

where

CN_i, and A_i – are CN value [-] and area value [km^2], respectively, of the generic LULC parcel,

CN_i – is the weighted CN considering the specific areas as weights [-]

A – is the total area of the investigated catchment [km^2].

Evaluation of design peak discharge

Engineering designs of hydraulic structures require estimated design peak flow and flow volume for flood management. For small and ungauged catchments, like in our study area, usually enough observed flow data are not available, so calibration of the advanced hydrological and hydraulic model is difficult. Therefore, the Event-Based Approach for the Small and Ungauged Basins (EBA4SUB) rainfall-runoff model was used in Umukiza et al. (2021), since it is particularly suited to estimate design hydrograph, peak discharge, and flow volume in ungauged basins (Młyński et al., 2020). In detail, the inputs data needed by the model are the Digital Elevation Model (DEM) of the investigated catchments, the LULC data, and the rainfall data while the main parameters of the model are CN and time of concentration Tc (Petroselli and Grimaldi, 2018).

Based on this, the estimated values related to peak discharges for 50 and 100 years return periods for the different projected scenarios are summarized in Table 2.

Channel parameters

Channel dimensions at each cross-section were obtained using the RTK instrument. The main parameters like depth, width, and bottom slope for both streams for their complete length were determined. The inspections allowed to estimate Manning’s roughness coefficients. The measurements of dimensions in terms of width, depth, and slope along the existing channels were carried out at an interval of 10 to 20 m (see Fig. 2).

The peak discharge estimated in Umukiza et al. (2021) under different LULC scenarios and assuming return periods equal to 50 and 100 years was used as a design discharge. Therefore, the following design considerations have been adopted in this study:

1. The flow is one-dimensional; depth and velocity vary only in the longitudinal direction of the channel. This implies that the velocity is constant and the water surface is horizontal across any section perpendicular to the longitudinal axis.
2. Flow is assumed to vary gradually along the channel so that hydrostatic pressure prevails and vertical accelerations can be neglected (Chow, 1959).

3. The longitudinal axis of the channel is approximated as a straight line.
4. The bottom slope of the channel is small and the channel bed is fixed; that is, the effects of scouring and deposition are negligible.
5. Resistance coefficients for steady uniform turbulent flow are applicable so that relationships such as Manning's equation can be used to describe resistance effects.

It is noteworthy that the assumption of the steady flow, used here, has some limits, related to neglecting the lateral inflow due to increase of catchment area of the basin, and to the existence of water structures in channel network locally effecting hydraulic characteristics and hence changing the supposed course of water depth along the channel. However, in our case, we did consider the whole catchment area for both Kakia and Esamburmbur. The uppermost contributing

Table 1. **Details of Projected Scenarios Based on Major Types of LULC Transition Found for LULC in 2019. Source: Umukiza et al., 2021**

	Different rates LULC [%] of the entire catchment				
LULC	**2019**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Forest	6.3	0	15	0	5
Pastureland	25.9	5	30	10	20
Agricultural	55.4	75	40	40	40
Open Space	0	0	0	0	5
Built-up area	12.5	20	15	50	30

Table 2. **Peak discharge [$m^3 s^{-1}$] for different return periods (*Tr*, years) under various LULC Scenarios (Kakia and sub-catchment). Source: Umukiza et al., 2021**

	Kakia		Ensamburmbur	
LULC Scenarios	**Tr50**	**Tr100**	**Tr50**	**Tr100**
2019	130.3	164.1	75.1	94.2
Scenario 1	154.2	191.1	88.9	110.1
Scenario 2	121.4	154.0	70.8	89.0
Scenario 3	172.2	210.4	100.6	121.8
Scenario 4	145.3	181.0	83.4	104.2

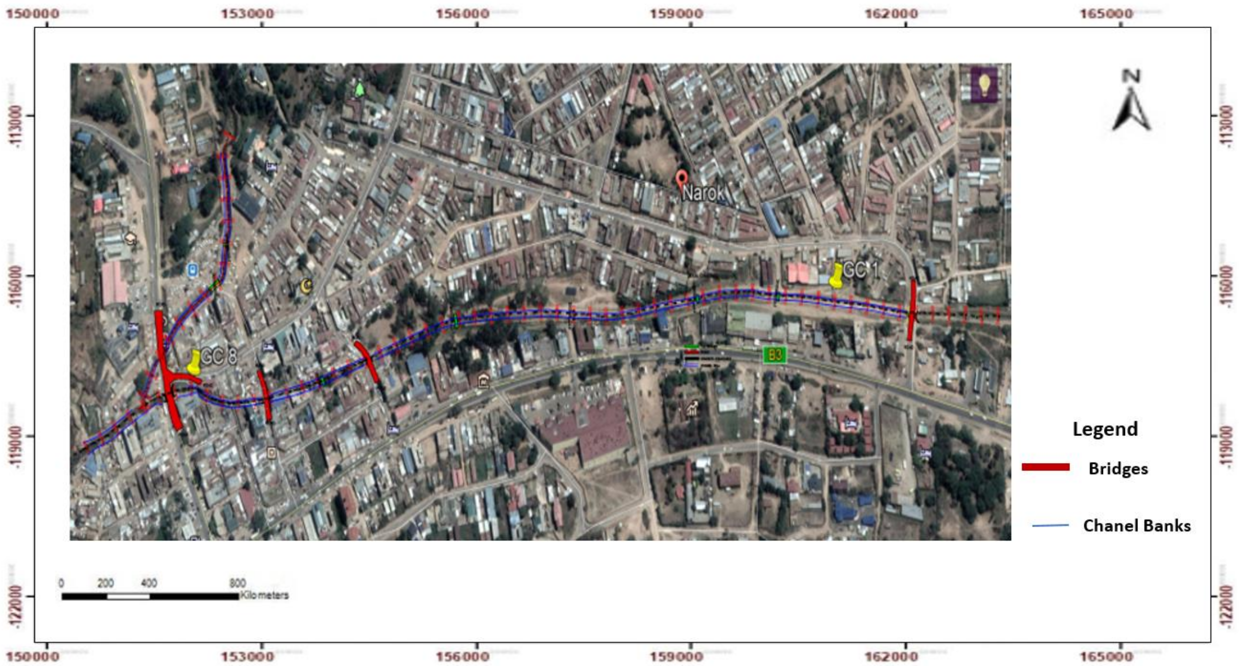

Fig. 2. Surveyed Channels and Identified Cross-Sections and Infrastructures.

inflow channel was considered in the downstream flow accumulation. Therefore, there will not be an additional drainage network with time due to the increase in the watershed basin.

In addition the assumption of steady uniform flow can be considered be valid, because the cross-section structures are at height of the channel banks and the flow is at the lower level of the height of the channel banks. For the channel design, the case of overflow due to overtopping of cross-sectioning structures has been avoided. Therefore, as there are no water structures that can disturb the flow, we can justify the steady uniform flow hypothesis.

Then, the estimated peak discharges were conveyed into the channel by using Manning's and continuity equations. For improving the existing lined channel (rectangular cross-section), the morphology of the channel is considered to be a rectangular cross-section for the first step, and trapezoidal in the second step for determining the suitable case to convey a given flow at the corresponding scenario of predicted runoff due to LULC. Under such hypothesis, Manning's Equation is expressed as follows.

$$Q = \frac{A*R^{\frac{2}{3}}\ S_f^{\frac{1}{2}}}{n} \qquad (2)$$

where:

n – is Manning's roughness value,
R – is Hydraulic radius [m],
Q – is peak flow [$m^3\ s^{-1}$],
A – is the wetted area [m^2];
S_f – is the slope of hydraulic grade line [$m\ m^{-1}$].

The minimum velocity was checked to ensure that there is no scouring of the channel bed and no siltation as the water flows.

Results and discussion

Concerning Kakia channel, from the upstream to the downstream direction, the channel has varing height and width due to features constructed across the channel. For the Esamburmbur channel, it was observed that the channel narrowed downstream and that the banks decreased in height due to the bridge positioning. This state can obstruct the flow leading to overflowing. Therefore, the alterations in channel geometry affect the flow and may cause overflow in the narrower section of the channel. Table 3 presents the characteristics of analyzed the cross-sections.

The narrowed channel section of the active channel on the lowest 295 m of Esamburmbur channel may contribute to the overflow. The channel widths near the bridges were relatively narrow which can influence more overtopping discharge. The upstream and downstream of aligned channel with regard to the height and width were found to decrease due to features constructed across the channel. Moreover, Kiss and Blanka (2012) argued that streamflow derived from surface runoff is responsible for the determination of channel cross-section capacity. Thus, poor design of the channel especially narrowing of the channel towards the bridge is likely contributing to flooding. Therefore, the morphology of the channels and their conveyance capacity should be adjusted to prevent overflow conditions. It is evident that for better flood control, the construction of embankments should consider straightening the channel and maintaining a constant width.

From the survey data analysis, the real dimensions in terms of length, width, slope, and banks height of the channels were identified. The total lengths were found to be 1420 m and 360 m for Kakia and Esamburmbur respectively. While the elevation of the channel varies from 1827.59 m a.s.l and 1833.87 m a.s.l for the Esamburmbur channel and from 1826.42 m a.s.l to 1852.43 m a.s.l for Kakia. The slopes were found to be 0.018 [$m\ m^{-1}$] and 0.017 [$m\ m^{-1}$] for Kakia and Esamburmbur channels respectively. The calculation of geometric properties of the channel was performed with Civil 3D Hydraflow extension, based on the Manning

Table 3. **Geometrical Parameters and Bridges on cross-sections of Kakia and Esamburmbur Channels**

Distance from upstream to downstream [m]	Height of the banks [m]	Width [m]	Bridge type
Kakia Channel			
460	2.30	7.65	footbridge
650	3.45	7.27	footbridge
820	3.02	8.80	footbridge
1120	2.67	5.85	Bridge
1300	2.50	8.70	Bridge
Esamburmbur Channel			
120	2.55	7.10	footbridge
170	2.00	6.95	footbridge
295	2.50	4.00	Highway bridge

and continuity equations to obtain an accurate geometry of the channel, to convey designed peak discharge for all scenarios in different return periods. As the walls of the channel are formed with unfished concrete, the Manning's "*n*" coefficient for the concrete channel. It was hence selected here as equal to 0.017 (s $m^{-1/3}$). Consequently, Fig. 3 represents the water level and the variation of discharge for rectangular and trapezoidal shapes respectively.

The cross-section was taken at bridges surveyed along the channel. Channel crossings were found to require adequate and careful design. They must functionally allow for the passage of the maximum amount of water that can reasonably be expected to occur within the lifetime of the structure. For the case of Kakia and Ensamburmbur channels, many constructions across the channel were found downstream and the channel width changes from one point to the other in these locations. Also, the area is potentially an affected zone in the event of the flood occurring according to the inhabitants that were interviewed during the surveys. Regardless of the channel cross-sectional shapes (rectangular and trapezoidal), they should all conform to proper design standards with regard to alignment with the channel conveyance capacity. Therefore, the conveyance capacity was evaluated to cause no direct or indirect property damage and designed to accommodate increased runoff which could be occasioned by upstream land cover change and development. For rectangular cross-sections, the depth is the same considering a given section across an entire channel, while in a trapezoidal cross-section, the depth decreases with a bankside slope. The channel is gradually varied from cross-section to cross-section, hence the depth changes also. However, with the same bottom width, rectangular section was preferred compared to a trapezoidal section due to its necessity to increase the top width where space is critical, to efficiently allow the estimated peak flow. Hence, the designed peak discharge and corresponding channel properties, in consideration of their conveyance capacity for Kakia and Ensamburmbur channel, are presented in Table 4.

The results show a big difference between the current channel geometric properties of the two channels when compared to the required dimensions for both channels to convey the estimated peak flow in the different LULC scenarios and return periods. Thus the dimensions as per the current peak flow can be addressed either by adjusting the channel height or width to accommodate the extra flow water. For an appropriate design to convey the assumed peak discharge, the design should be based on a 50 years return period (SWMM, 2007). Also, it was noticed that for the same depth and peak flow, the shape of the rectangular sections is preferable since it presents the same dimensions at the bottom and top while for a trapezoidal section, the top width needs to be wider which could be difficult to realize. Therefore, knowing the peak flow that is more likely to happen, can give the idea of corresponding channel geometries that are adequate to carry the designed peak discharge.

The study by Jaeger et al. (2019) investigated different approaches to optimize flows in misaligned structures and concluded that aligned construction according to flow direction tailored reinforcement and redesigned stream embankment can contribute to containing overflow.

From the findings, we can suggest that the rate of urbanization assumed in Scenario 3 is not recommended

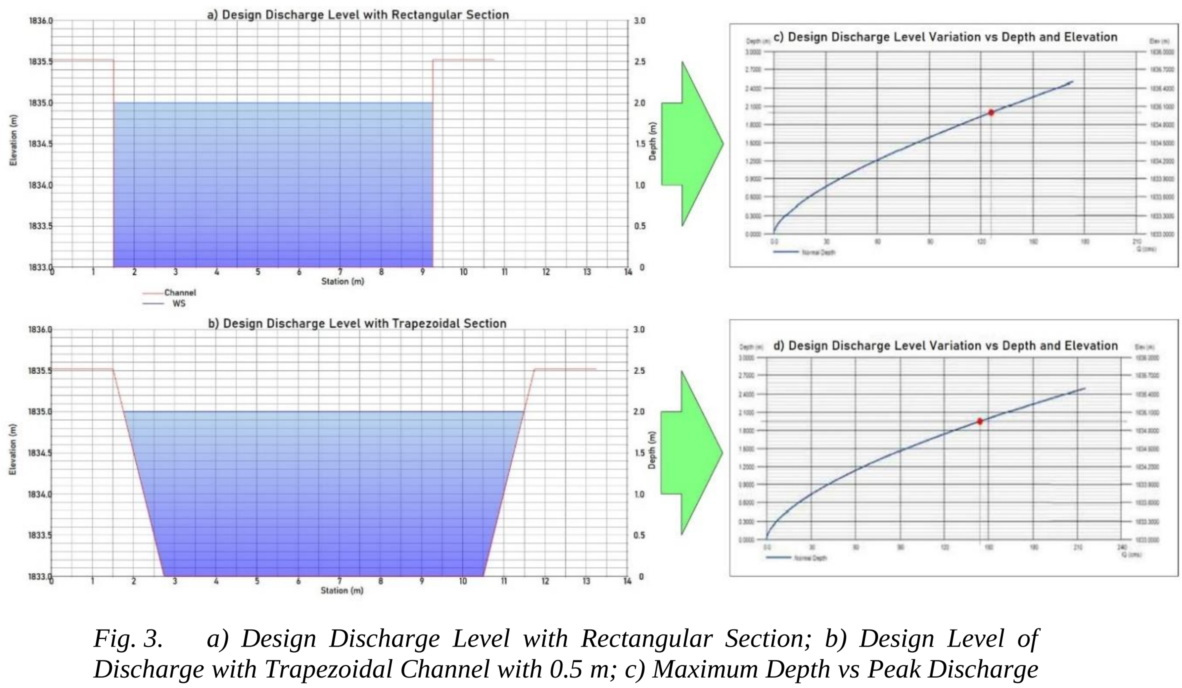

Fig. 3. a) Design Discharge Level with Rectangular Section; b) Design Level of Discharge with Trapezoidal Channel with 0.5 m; c) Maximum Depth vs Peak Discharge Variation for Trapezoidal; d) Maximum Design Depth vs Peak Discharge for Rectangular Section.

Table 4. Design discharges and hydraulic data for Kakia and Esamburmbur channel

Total Depth [m]	Flow depth [m]	Area [m²]	Velocity [m s⁻¹]	Wetted Perimeter [m]	Width [m] Bottom	Width [m] Top	Discharge [m³ s⁻¹]	LULC Scenarios and Return Periods verified
Kakia channel								
2.5	2.0	17.1	8.4	12.1	7.8	9.75	**144.2**	Scenarios n.2 and 2019 with Tr50
2.5	2.0	20.0	8.5	14.0	10	10	**170.3**	Scenarios n.2 and 2019 with Tr100
2.6	2.1	21.6	8.8	14.3	10	10	**191.0**	All scenarios except n.3 with Tr100
2.8	2.3	17.1	8.4	12.1	7.5	7.5	**145.5**	Scenario n.4 with Tr50
3.0	2.4	20.3	8.8	13.2	8.5	8.5	**181.0**	Scenario n.4 with Tr100 Scenario n.3 with with Tr50
Esamburmbur channel								
2.5	2	8.0	6.5	8.0	4.0	4.0	**52.1**	Scenario n.4 with Tr10
2.8	2.3	9.4	6.8	8.7	4.0	4.0	**64.7**	Scenario 2019 with Tr25
2.7	2.2	9.9	7.0	8.9	4.5	4.5	**70.0**	Scenario n.2 with Tr50
2.8	2.2	11.3	7.3	9.5	5.0	5.0	**83.4**	Scenario n.4 with Tr50
2.8	2.3	14.0	7.8	10.6	6.0	6.0	**110.1**	Scenario n.1 with Tr50 and over design for others except scenario 3

as it can increase the flood risk. However, the application and implementation of some regulations related to LULC practices as in Scenario 2 show little increase in runoff response. From this, we conclude that an increase of green-areas as can influence positively runoff generation (Apollonio et al., 2021). These results are in line with previous studies. In fact, earlier studies highlighted that impervious area's growth due to uncontrolled LULC has a considerable effect on the increase of runoff volume (Dionizio and Costa, 2019). The land-cover trend is toward residential cover and urbanization, mostly occurring along the rural-urban fringe. This might be due to processes including immigration, natural growth and economic processes (Ohana et al., 2013).

Conclusion

In this work, the channel dynamics due to different scenarios of LULC for Kakia and Ensamburmbur sub-cathments have been investigated. Between the years 1985 and 2019 some changes in land-cover occurred in Narok town's watershed, and the same process is expected to continue occurring in future. This trend was a result of an alternation between agricultural and urbanized landscapes growth against forest, rangeland and open space; hence, the necessity to evaluate the channel's capacity in conveying the peak flow resulting from the future likely LULC transition.

The hydrological and hydraulic modelling results show that the current channel design requires improvement to accommodate the estimated peak flow. Additionally, the results from this study indicate that peak discharge is a key element to the design of channel geometry for improving the existing drainage system for the two investigated channels.

With regard to channel geometric properties under different scenarios, bridges contributed to channel narrowing down that may obstruct channel dynamics at different scenarios of peak discharge and flow volume. The channel geometric properties were designed as an improvement to convey the estimated peak flow for both the investigated channels by increasing their cross-sections.

In order to overcome some of the limitations highlighted by the present study, future research should concentrate on: 1) improving the surveys of the river network, using also UAV devices that proved to be effective in flood risk management (Annis et al., 2020); 2) using bidimensional hydraulic models to map eventual flood prone areas; 3) introducing and testing blue-green infrastructure in urban drainage to mitigate natural capital losses and contribute to other forms of capital crucial for human well-being (Cristiano et al., 2022).

Acknowledgement

This project was jointly funded by Pan African University Institute of Science, Technology & Innovation and Kenya National Research fund.

References

Alfarajat, et al. (2014): Mitigation Environmental Risk Of Floods In Jorthhwestern Parts Of Jordan. 300.

Annis, A.; Nardi, F.; Petroselli, A.; Apollonio, C.; Arcangeletti, E.; Tauro, F.; Belli, C.; Bianconi, R.; Grimaldi, S. UAV-DEMs for Small-Scale Flood Hazard Mapping. Water 2020, 12, 1717. https://doi.org/ 10.3390/w12061717

Apollonio, C., Balacco, G., Novelli, A., Tarantino, E., Piccinni, A. F. (2016): Land use change impact on flooding areas: The case study of Cervaro Basin (Italy). Sustainability (Switzerland), 8(10). https://doi.org/10.3390/su8100996

Apollonio, C., Rose, M. D., Fidelibus, C., Orlanducci, L., Spasiano, D. (2018): Water management problems in a karst flood-prone endorheic basin. Environ. Earth Sci. 2018, 77, 676.

Apollonio, C., Petroselli, A., Tauro, F., Cecconi, M., Biscarini, C., Zarotti, C., Grimaldi, S. (2021): Hillslope Erosion Mitigation : An Experimental Proof of a Nature-Based Solution.

Blöschl, G., Ardoin-Bardin, S., Bonell, M., Dorninger, M., Goodrich, D., Gutknecht, D., Matamoros, D., Merz, B., Shand, P., Szolgay, J. (2007): At what scales do climate variability and land cover change impact on flooding and low flows? Hydrol. Process. 2007, 21, 1241–1247.

Chow, V. T. (1959) Open Channel Hydraulics. McGraw-Hill, New York.

Coomes, O. T., Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Folke, C., Bruce, J. W., Coomes, O. T., Dirzo, R., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., … Xu, J. (2001): The causes of land-use and land-cover change: Moving beyond the myths The causes of land-use and land-cover change: moving beyond the myths Helle Sk a. May 2014.

Cristiano, E., Annis, A., Apollonio, C., Pumo, D., Urru, S., Viola, F., Deidda, R., Pelorosso, R., Petroselli, A., Tauro, F., Grimaldi, S., Francipane, A., Alongi, F., Noto, L.V., Hoes, O., Klapwijk, F., Schmitt, B., Nardi, F.; Multilayer blue-green roofs as nature-based solutions for water and thermal insulation management. Hydrology Research 2022; nh2022201. doi: https://doi.org/10.2166/nh.2022.201

Dionizio, E. A., Costa, M. H. (2019): Influence of land use and land cover on hydraulic and physical soil properties at the cerrado agricultural frontier. Agriculture (Switzerland), 9(1), 1–14. https://doi.org/10.3390/agriculture9010024

Erpicum, S., Crookston, B. M., Bombardelli, F., Bung, D. B., Felder, S., Mulligan, S., Oertel, M., Palermo, M. (2021): Hydraulic structures engineering: An evolving science in a changing world. Wiley Interdisciplinary Reviews: Water, 8(2), 1–11. https://doi.org/10.1002/wat2.1505

Fenner, R., O'Donnell, E., Ahilan, S., Dawson, D., Kapetas, L., Krivtsov, V., Ncube, S., Vercruysse, K. (2019): Achieving Urban Flood Resilience in an Uncertain Future. Water 2019, 11, 1082. https://doi.org/10.3390/w11051082

Gajbhiye, S., Mishra, S. K., Pandey, A. (2014): Relationship between SCS-CN and Sediment Yield. Applied Water Science, 4(4), 363–370. https://doi.org/10.1007/s13201-013-0152-8

Guo, H., Li, X., Huang, Q., Zhang, D. (2011): Effect of lulc change on surface runoff inurbanization area Zhongchang SUN.

Habete, D., Ferreira, C. M. (2016): Impact of Forecasted Land Use Change on Design Peak Discharge at Watershed and Catchment Scales: Simple Equation to Predict Changes. Journal of Hydrologic Engineering, 21(7), 04016019. https://doi.org/10.1061/(asce)he.1943-5584.0001384

Han, J., Hayashi, Y., Cao, X., Imura, H. (2009): Evaluating Land-Use Change in Rapidly Urbanizing China: Case Study of Shanghai. Journal of Urban Planning and Development, 135(4), 166–171. https://doi.org/10.1061/(asce)0733-9488(2009)135:4(166)

Jaeger, R., Jacobs, C., Tondera, K., Tindale, N. (2019): Improving flows in misaligned culverts. Water (Switzerland), 11(9), 1–15. https://doi.org/10.3390/w11091932

Kiss, T., Blanka, V. (2012): River channel response to climate- and human-induced hydrological changes: Case study on the meandering Hernád River, Hungary. Geomorphology, 175–176, 115–125. https://doi.org/10.1016/j.geomorph.2012.07.003

Marie Mireille, N., Mwangi, H. M., Mwangi, J. K., Mwangi Gathenya, J. (2019): Analysis of Land Use Change and Its Impact on the Hydrology of Kakia and Esamburmbur Sub-Watersheds of Narok County, Kenya. Hydrology, 6(4), 86. https://doi.org/10.3390/hydrology6040086

Młyński, D., Petroselli, A., Walega, A. (2018): Flood frequency analysis by an event-based rainfall-runoff model in selected catchments of southern Poland. Soil & Water Res., 13: 170–176.

Młyński, D., Wałęga, A., Ozga-Zielinski, B., Ciupak, M., Petroselli, A. (2020): New approach for determining the quantiles of maximum annual flows in ungauged catchments using the EBA4SUB model, Journal of Hydrology, Volume 589, 125198, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2020.125198.

Mwangi et al. (2019): Understanding urban environment problems in the newly urbanizing areas of kenya, a case of narok town. International Journal of Scientific and Technology Research, 8(6), 236–241.

Novelli, A.,Tarantino, E., Caradonna, G., Apollonio, C., Balacco, G., Piccinni, F. (2016): Improving the ANN Classification Accuracy of Landsat Data Through Spectral Indices and Linear Transformations (PCA and TCT) Aimed at LU/LC Monitoring of a River Basin. In Proceedings of the 16th International Conference on Computational Science and Its Applications, Beijing, China, 4–7 July 2016; Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Torre, C.M., Taniar, D., Apduhan, B.O., Stankova, E., Wang, S., Eds.; Springer: Beijing, China, 2016; pp. 420–432.

Ohana, N., Karnieli, A., Egozi, R., Peeters, A. (2013): Effects of land-cover change on rainfall-runoff relationships: a case study of the Yarkon-Ayalon watershed, Israel. First International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2013), 8795, 87951G. https://doi.org/10.1117/12.2027190

Ohana-Levi, N., Givati, A., Alfasi, N., Peeters, A., Karnieli, A. (2018): Predicting the effects of urbanization on runoff after frequent rainfall events. Journal of Land Use Science, 13(1–2), 81–101. https://doi.org/10.1080/1747423X.2017.1385653

Pellicani, R., Parisi, A., Iemmolo, G., Apollonio, C. (2018): Economic Risk Evaluation in Urban Flooding and Instability-Prone Areas: The Case Study of San Giovanni Rotondo (Southern Italy). Geosciences 2018, 8, 112. https://doi.org/10.3390/geosciences8040112

Pelorosso, R., Apollonio, C., Rocchini, D., Petroselli, A. (2021): Effects of Land Use-Land Cover Thematic Resolution on Environmental Evaluations. Remote Sens. 2021, 13, 1232. https://doi.org/10.3390/rs13071232

Petroselli, A., Grimaldi, S. (2018): Design hydrograph estimation in small and fully ungauged basins: a preliminary assessment of the EBA4SUB framework. Journal of Flood Risk Management, 11, S197–S210. https://doi.org/10.1111/jfr3.12193

Petroselli, A., Asgharinia, S., Sabzevari, T., Saghafian, B. (2020): Comparison of design peak flow estimation methods for ungauged basins in Iran. Hydrological Sciences Journal, 65 (1), 127–137. https://doi.org/10.1080/02626667.2019.1686506

Piscopia, R., Petroselli, A., Grimaldi, S. (2015): A software package for predicting design-flood hydrographs in small and ungauged basins. Journal of Agricultural Engineering, 46(2), 74–84. https://doi.org/10.4081/jae.2015.432

Recanatesi, F., Petroselli, A. (2020): Land Cover Change and Flood Risk in a Peri-Urban Environment of the Metropolitan Area of Rome (Italy). Water Resour Manage 34, 4399–4413 (2020). https://doi.org/10.1007/s11269-020-02567-8

Shaina Beegam, N., Prince Arulraj, G. (2018): A review article on impact of urbanization on hydrological parameters. International Journal of Civil Engineering and Technology, 9(199–208), 199–208.

Sharif, H. O., Al-Juaidi, F. H., Al-Othman, A., Al-Dousary, I., Fadda, E., Jamal-Uddeen, S., Elhassan, A. (2016): Flood hazards in an urbanizing watershed in Riyadh, Saudi Arabia. Geomatics, Natural Hazards and Risk, 7(2), 702–720. https://doi.org/10.1080/19475705.2014.945101

Storm Water Drainage System Design Manual. (2007). August.

Suriya, S., Mudgal, B. V. (2012): Impact of urbanization on flooding: The Thirusoolam sub watershed – A case study. Journal of Hydrology, 412–413, 210–219. https://doi.org/10.1016/j.jhydrol.2011.05.008

Umukiza, E., Raude, J. M., Wandera, S. M., Petroselli, A., Gathenya, J. M. (2021): Impacts of Land Use and Land Cover Changes on Peak Discharge and Flow Volume in Kakia and Esamburmbur Sub-Catchments of Narok Town, Kenya. Hydrology, 8(2), 82. https://doi.org/10.3390/hydrology8020082

Zope, P. E., Eldho, T. I., Jothiprakash, V. (2016): Impacts of land use-land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. Catena, 145, 142–154. https://doi.org/10.1016/j.catena.2016.06.009

Etienne Umukiza, MSc
Pan African University
Institute of Science, Technology and Innovation, Civil Engineering and Environmental,
Jomo Kenyatta University of Agriculture and Technology
P. O. Box 62000 – 00200 Nairobi
Kenya

James M. Raude Associate Professor, PhD
Soil, water, and Environmental Engineering Department,
Jomo Kenyatta University of Agriculture and Technology
P. O. Box 62000 – 00200 Nairobi
Kenya

John M. Gathenya Full Professor, PhD
Soil, water, and Environmental Engineering Department,
Jomo Kenyatta University of Agriculture and Technology
P. O. Box 62000 – 00200 Nairobi
Kenya

Andrea Petroselli Associate Professor, PhD
Department of Economics, Engineering, Society and Business
Tuscia University
01100 Viterbo
Italy

Simon M. Wandera, PhD
Department of Civil, Construction and Environmental Engineering
Jomo Kenyatta University of Agriculture and Technology
00200 Nairobi
Kenya

Ciro Apollonio Associate Professor, PhD (*corresponding author, e-mail: ciro.apollonio@unitus.it)
Department of Agriculture and Forest Sciences
Tuscia University
01100 Viterbo
Italy