Improving Drainage Systems in Urbanised Areas under Projections of Land-Use Changes: Case Study of Kakia and Esamburmbur Channels of Narok Town, Kenya

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ABSTRACT

The changes in land use/land cover (LULC) during the process of urbanization have a profound influence on runoff increases and flooding incidents. Narok town, in Kenya, experienced numerous disasters associated with cyclic flash floods that produced 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. Due to the continuous occurrence in LULC changes resulting in variability of design hydrograph, this study was carried out to evaluate existing channels geometric properties (conveyance capacity), with field measurements through a ground survey using Real-Time Kinematic equipment at Kakia and Esamburmbur channels of Narok town.

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ABSTRACT

The changes in land use/land cover (LULC) during the process of urbanization have a profound influence on runoff increases and flooding incidents. Narok town, in Kenya, experienced numerous disasters associated with cyclic flash floods that produced 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. Due to the continuous occurrence in LULC changes resulting in variability of design hydrograph, this study was carried out to evaluate existing channels geometric properties (conveyance capacity), with field measurements through a ground survey using Real-Time Kinematic equipment at Kakia and Esamburmbur channels of Narok town. To further improve the drainage system in the main channels, the evaluated peak flows under assumed future LULC scenarios were used to design hydraulic geometrical properties (width, depth) for a sustainable urban drainage system.

Three geomorphic-based hydrological and hydraulic models (EBA4SUB, Manning's equation, and Civil 3D) were used under different LULC scenarios for computing channel geometry and correspondent water level. Results show that infrastructures such as highway bridges and commercial buildings contributed to narrow the channel downstream. The change in channel geometries was found to obstruct free flow for different scenarios of peak discharge and flow volume. The design conveyance capacity for the two channels considering the evaluated peak discharge from the assumed LULC scenarios can be used in improving the drainage system by local Municipal bodies to mitigate flood hazards.

Keywords: esamburmbur, kakia, hydraulic design structures, lulc changes, peak flow.

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I. INTRODUCTION

Land use/land cover (LULC) can be defined as how the land is used by humans regarding the functional role of land for economic activities (Vojtek & Vojteková, 2019). Urbanization is probably the most important driver in LULC changes due to developments of facilities such as roads, houses, schools (Habete & Ferreira, 2016; Han et al., 2009), and has been the most intense form of LULC changes in many developed areas (Ohana-Levi et al., 2018; Vojtek et al., 2019).

Rapid socio-economic and urbanization are drivers of significant changes in land use and can cause, as consequence, high potential runoff (Han et al., 2009). Moreover, various human activities

have profoundly influenced the hydrological cycle and water resources management due to the growth of society and the economy (Umukiza et al., 2021). Uncontrolled land use is among the main cause of changes in hydrologic and hydraulic processes (Zope et al., 2016). Furthermore, urbanization processes as part of LULC tend to increase runoff rates and peak discharges due to the increased imperviousness and reduced 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.

For instance, Shaina Beegam & Prince Arulraj (2018) reported urbanization as a direct effect on the environment which in turn affects the variations in runoff, which ultimately turn to flood. Recanatesi and Petroselli (2020) concentrated on the relationship between LULC change and flood risk, selecting a strategic case study in the peri-urban environment of the metropolitan area of Rome, Italy, and 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. LULC changes are indeed an important factor in causing variability of rainfall-runoff properties. In recent decades, urbanization has become an environmental concern in many developing countries (Guo et al., 2011). Moreover, urban development planning should be considered as an integrated tool, taking into account drainage systems as the peri-urban area can potentially be converted into a built-up area.

Globally, floods are among the most devastating natural hazards and their frequency is increasing. There are several causes of floods, such as natural factors (e.g. climate change, heavy rainfall, high tides), and anthropogenic activities such as blocking of drainage channels, uncontrolled land use, and deforestation in headwater regions (Tingsanchali, 2012; 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 measures if correctly planned and implemented can help in reducing the flooding problems through the

developed mitigation measures. For instance, urbanization in floodplain areas increases the risk of flooding due to the increase of peak discharge (Suriya & Mudgal, 2012).

Locally, there has been an increase in floods in Narok town, Kenya, in recent years, resulting from the fact that Narok county is urbanizing at a rapid rate like many towns 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 risk of flooding (Alfarajat, 2014).

To further improve the drainage conveyance capacity due to the effects of LULC changes such as continuous urban expansion and intensification of agricultural activities towards the upstream area, the drainage system should take into account the transitions in land-use changes to appropriately design hydraulic structures such as channel, culverts, bridges, etc.

The design hydraulic structures for water control are sized to resist a design event, characterized by a hydrograph associated with a fixed probability of occurrence (Erpicum et al., 2021). Moreover, engineers and hydrologists deal with periodic peak flows when designing water management and drainage systems (Oluwatobi & Oluwole, 2017). Generally, 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 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

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of the difficulty in obtaining adequate historical flow observations (Petroselli et al., 2020a). Thus, accurate estimation of flood discharge remains one of the major challenges to many engineers and planners who are involved in drainage project design (Heritage & Entwistle, 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 (Piscopia et al., 2015; Petroselli & Grimaldi, 2018; Petroselli et al., 2020b) 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. After the quantification of peak discharges under different scenarios, the management structures are designed to convey the stream flow. Such knowledge will help in managing structure measures necessary for controlling the potential overflow hazard risks. In brief, this study attempts to propose channel geometries considering the expected peak flow estimated under different LULC change scenarios, for improving the urban drainage system to achieve sustainable development with good control of flood risk.

II.   DATA USED, MATERIALS AND METHODS

2.1   General Overview 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 km². The study area, shown in Figure 1, is a small portion of Narok county territory, being characterized by a total extension of 46.2 km² (Umukiza et al., 2021) and it pertains to the hydrographic catchments of two seasonal streams, Kakia and Esamburmbur.

The precipitations of the area are characterized by an average rainfall of 750 mm per year, with the majority of the rainfall occurring in March and May. 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.
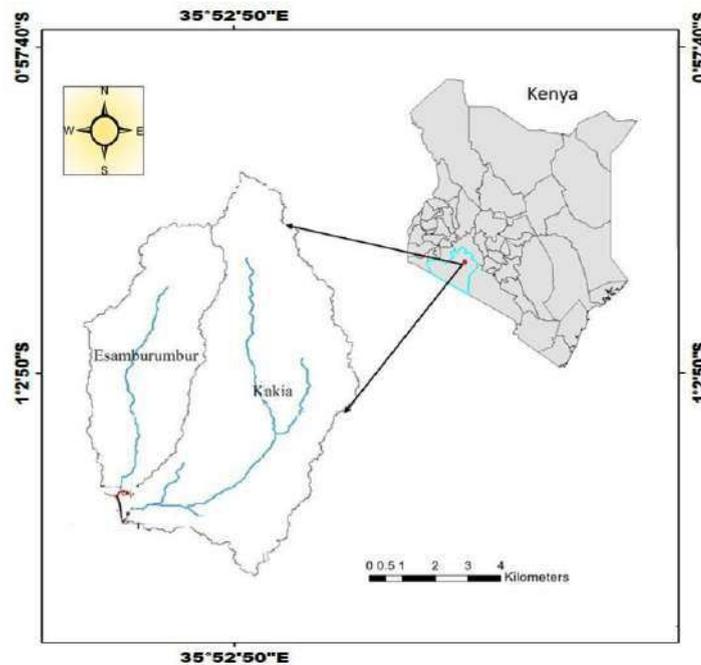
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Figure 1: Kakia and Esamburmbur sub-catchments. Source: Umukiza et al. (2021)

2.2. 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, we hypothesized in Umukiza et al. (2021) four projected future scenarios, based on major types of LULC identified in 2019 (scenario "0").

Therefore, due to LULC changes previously mentioned, we considered in Scenario one (1) 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, we assumed an intense increase in urbanization and agricultural activities 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, we assumed a small increase in built-up area and reforestation, 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, we assume a considerable increase in a built-up area, we maintain the same extent of the agricultural area as Scenario 2, and we reduce 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, we assumed 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. A summary describing the current and the assumed future scenarios is presented in Table 1.

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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 (In Percentage) of the Entire Catchment					
LULC	2019	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Forest	06.30	00.00	15.00	00.00	05.00
Pastureland	25.90	05.00	30.00	10.00	20.00
Agricultural	55.40	75.00	40.00	40.00	40.00
Open Space	00.00	00.00	00.00	00.00	05.00
Built-up area	12.50	20.00	15.00	50.00	30.00

In the present work, we focus on design 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), an important parameter related to the generation of runoff as presented in the study by Umukiza et al. (2021). CN value ranges between 0 (no runoff, all rainfall becomes infiltration) and 100 (no infiltration, all rainfall becomes runoff) and was calculated with the combination of spatial LULC data, soil type, and assuming an Antecedent Moisture Condition (AMC) equal to II (average soil humidity) 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):

$$CN = \frac{\sum CN_i A_i}{A} \qquad (1)$$

Where CN_i, and A_i are CN value (-) and area value (Km²), respectively, of the generic LULC parcel, CN_i (-) is the weighted CN considering the specific areas as weights and A (km²) is the total area of the investigated catchment.

2.3 Evaluation of Design Peak Discharge

Engineering designs of hydraulic structures such as bridges, culverts, spillways, urban drainage systems, etc., require estimated design peak flow and flow volume for flood management (Heritage & Entwistle, 2020). For small and ungauged catchments, as is the case in our study area, usually enough observed flow data are not available (Heritage & Entwistle, 2020), 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 concentration-time T_c (Petroselli & Grimaldi, 2018; Petroselli et al., 2020; Piscopia et al., 2015).

For the complete application and detailed inputs used for the EBA4SUB model to estimate flood hydrograph, flow rate, and flow volume with regards to the investigated catchments, refer can be made to the aforementioned work. Based on this, the evaluated values related to peak discharges for 50 and 100 years return periods for the different projected scenarios are summarized in Table 2.

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Table 2: Peak discharge for different return periods under various LULC Scenarios (Kakia and sub-catchment). Source: Umukiza et al. (2021)

LULC	Discharge /Tr	Kakia		Ensamburmbur	
		Tr50	Tr100	Tr50	Tr100
2019	Peak Discharge (m³/s)	130.3	164.1	75.1	94.2
Scenario 1	Peak Discharge (m³/s)	154.2	191.1	88.9	110.1
Scenario 2	Peak Discharge (m³/s)	121.4	154	70.8	89
Scenario 3	Peak Discharge (m³/s)	172.2	210.4	100.6	121.8
Scenario 4	Peak Discharge (m³/s)	145.3	181	83.4	104.2

2.4. Engineering Works and Flood Channel Dynamics

2.4.1. Evaluating Engineering Works

In the present work, a detailed engineering survey using the RTK instrument was carried out to obtain channel dimensions at each cross-section and the items that may affect channel efficiency were noted. The key dimensions like depth, width, and bottom slope for both streams for their complete length were determined. Parameters such as the flow channel length and width at each level of bifurcation as well as the curvature of the turning area of flow channels were particularly investigated. The real dimensions of the channels and identification of materials with which the banks and bottoms of the channels are constructed were noted 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 m to 20 m focusing on the position of constructions across the lined channel like footbridges and bridges (see Figure 2).

Figure 2: Surveyed Channels and Identified Cross-Sections and Infrastructures

2.4.2. Computation of Channel Geometric Properties

The highest peak discharge estimated from each of the different forecasted LULC scenarios was the fundamental feature to convey into the channel. Also, the determination of flow rates in the stream channels is a central task of surface water drainage. Hence, the present work considered the determined flow corresponding to the important water that can be overflowing the channel embankment from different scenarios. The peak discharge estimated in Umukiza et al. (2021) under different LULC scenarios and assuming

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return periods equal to 50 and 100 years was used as a design discharge. A hydraulic structure may be defined as any structure that is designed to handle water in any way, such as the retention, conveyance, control regulation, and dissipation of the energy of the water (Gitleman, 2014).

However, the hydraulic design consists of the calculation and application of the most suitable geometry like width, shape, elevation, and orientation of the structure. The design procedure took into consideration the following considerations:

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·

Therefore, the estimated peak discharges were conveyed into the channel by using Manning's and continuity equations. The parameters of the canal geometry (width and depth) were computed and the freeboard was reserved. 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.

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

Where: n is Manning's roughness value, R is Hydraulic radius (m), Q is peak flow (m³/s), A is the wetted area (m²); S is the bottom slope (m/m). The minimum velocity was checked to ensure that there is no scouring of the channel bed and no siltation as the water flows.

III.   RESULTS AND DISCUSSION

3.1. Engineering Constructions across the Channels

Concerning Kakia channel, from the upstream to the downstream direction, the channel was found to be no uniform with regard to 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 situation can obstruct the flow leading to overflowing. Hence, the changes in channel geometry affect the free flow and may cause overflow in the narrower section of the channel. Table 3 presents the characteristics of the cross-sections engineering constructions.

Table 3: Geometrical Parameters and Constructions on cross-sections of Kakia and Esamburmbur Channels

Distance from upstream to downstream (m)	Height of the banks (m)	Width (m)	Construction
Kankia Chanel			
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

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Esamburmbur Channel			
120	2.55	7.10	footbridge
170	2.00	6.95	footbridge
295	2.50	4.00	Bridge at highway

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 & Blanka (2012) argued that stream flow derived from surface runoff is responsible for the determination of channel cross-section capacity.

Hence, 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 flow conditions. For better flood control, the construction of embankments should consider straightening the channel and maintain a uniform and efficient width. Figure 3 represents the surveyed profiles of Kakia and Esamburmbur channels.
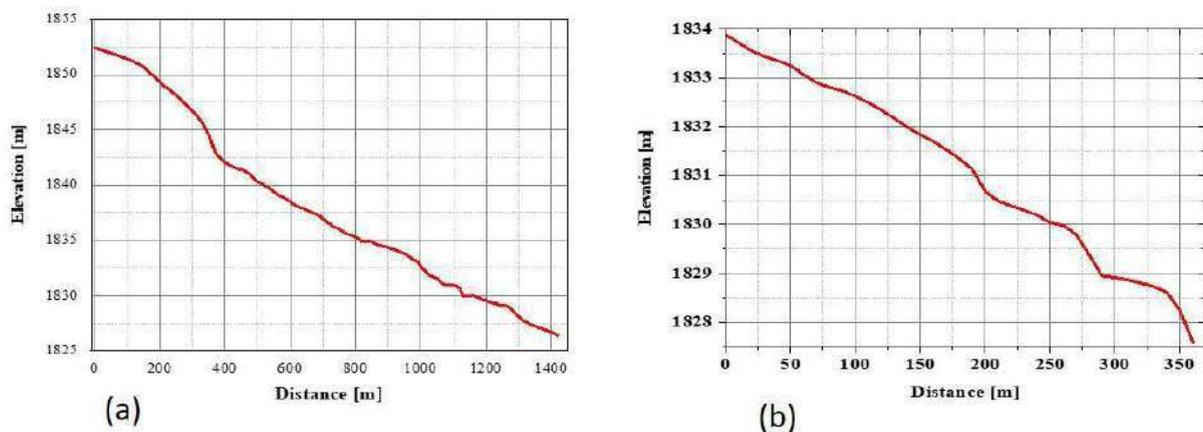

Figure 3: (a) Bottom Profile of Kakia Channel, (b) Profile of Esamburmbur Channel

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 and 1833.87 m for the Esamburmbur channel and from 1826.42 m to 1852.43 m for Kakia. The slopes were found to be 1.8% and 1.7% for Kakia and Esamburmbur channels respectively.

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. Therefore, Figure 4 represents the water level and the variation of discharge for rectangular and trapezoidal shapes respectively.

3.2. Channel Dynamic and Geometric Properties

The calculation of geometric properties of the channel was performed with Civil 3D hydro flow extension, based on the Manning and continuity

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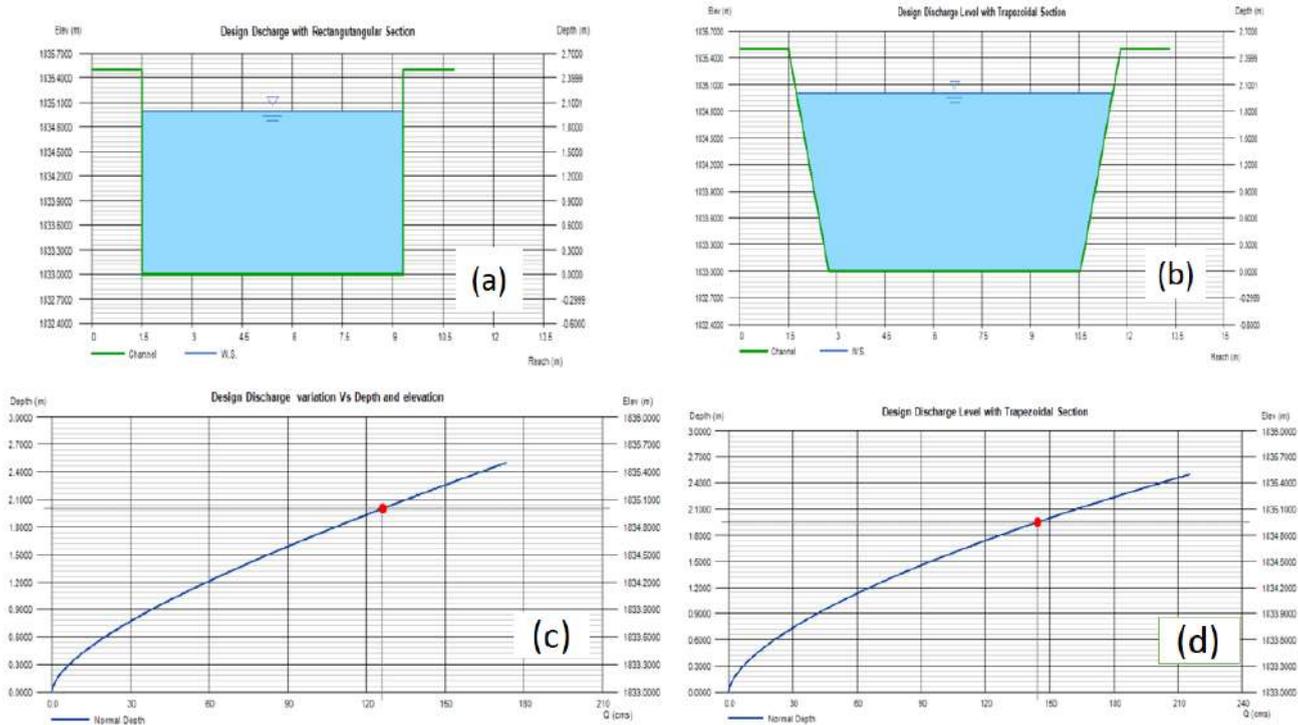56 Volume 22 | Issue 7 | Compilation 1.0 © 2022 London Journals Press

Figure 4: (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

The cross-section was taken at the level of bridges constructed across 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 situation of the flood occurring according to the inhabitants that were interviewed during the surveys. It should be pointed out that inadequate water passage structures to accommodate peak flow can result in flood and construction failures.

Regardless of the channel cross-sectional shapes (rectangular and trapezoidal), they should be all confirm to proper design standards with regards 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 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 opted 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. Changes in a conveyance from cross-section to cross- section are important to determine the adequacy of stream drainage. For instance, within a cross-section, the conveyance was used to compare overbank flow and channel carrying capacity. Hence, the designed peak discharge and corresponding channel properties, in consideration of their conveyance capacity for Kakia and Ensamburmbur channel, are presented in Table 5.

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Total Depth (m)	Depth of water	Area (m²)	Velocity (m/s)	Wetted Perimeter (m)	Width (m)		Discharge (m³/s)	Comments (Tr = return period)
					Bottom m	Top		Kakiachannel
2.50	2	17.11	8.4283	12.1603	7.8	9.75	144.2	The design channel geometry presented here can convey peak flow estimated in scenarios 2 and 2019 at 50 years return periods.
2.50	2	20	8.5138	14	10	10	170.3	Can apply for 2019 and scenario 2 with Tr100
2.6	2.16	21.64	8.8258	14.32	10	10	191	Fit for peak flows estimated in all scenarios except scenario 3 with Tr 100
2.78	2.28	17.15	8.4746	12.0721	7.5	7.5	145.5	Designed for peak flow estimated in scenarios 4 with 50 years return periods.
3	2.39	20.34	8.8995	13.2854	8.5	8.5	181	Designed channel geometry with peak flow estimated in Scenario 4 at 100 years returns period and can be adequate in case of scenario 3 with a design return period of 50 years
2.50	2	8.010	6.5221	8	4	4	52.18	The current geometric properties represented at the position at the main bridge can be adequate to convey, the peak discharge estimated in scenario 4 with 10 years return period.
2.80	2.35	9.425	6.8650	8.7123	4	4	64.7	The designed channel properties can fit to convey peak discharges regarding 2019 at 25 years return period
2.75	2.21	9.985	7.0102	8.9379	4.5	4.5	70.08	The designed geometric properties can fit for the peak discharge estimated in scenario 2 with 50 years return periods
2.85	2.27	11.38	7.3258	9.5538	5	5	83.40	Channel geometric properties are designed for scenario 4 with 50 years return period
2.85	2.34	14.06	7.8287	10.6879	6	6	110.1	Can be designed for peak flow in specific scenario 1 with Tr 50 over design for the rest except scenario 3

Esamburmbur channel

From the channel dynamics, the design peak discharge was evaluated under different cases depending on the assumed LULC transition. 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 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 (Storm Water Drainage System Design Manual, 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. Moreover, the larger the channel width, the maximum discharge, the maximum flow velocity, and the maximum water level will be (Natasha et al., 2019). 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 (Flow et al., 2019). The study by Jaeger et al. (2019) investigated different approaches to optimize flows in misaligned

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structures and concluded that aligned construction according to flow direction tailored reinforcement and redesigned stream embankment can contribute to containing overflowing. The option of increasing the height of the embankments is determined by design peak flow (determined with a return period of flood) and the freeboard above the flood level (Ankum, 2002).

From the findings, we can suggest that the rate of urbanization assumed in Scenario 3 is not recommended 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 in urbanization and agricultural activities is preferred with respect to the increase of pastureland, open space, and allowing space for vegetation as demonstrated that deep-rooted plants impact runoff generation (Apollonio et al., 2021a). For instance, nonstructural measures can be encouraged such as open space preservation can be encouraged in the context of ecological, recreational, and aesthetic values, and regulation of agricultural areas not in sense of declining economy but practice land-use policies for sustainable and protective environment measures.

IV. CONCLUSIONS

The study investigated the channel dynamics due to different scenarios of LULC for Kakia and Ensamburmbur sub-cathments. As between the years 1985 and 2019 some changes in land-cover occurred in Narok town's watershed, 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, range land and open space, hence the necessity to evaluate the channel's capacity in function of the peak flow resulted from the future likely LULC transition.

The engineering constructions (highway bridges and other infrastructures) were found to contribute to channel narrowing down that may obstruct channel dynamics at different scenarios of peak discharge and flow volume. The current channel design was found also to require improvement to accommodate the estimated peak flow for both channels (Kakia and Esamburmbur) by increasing their cross-sections. Moreover, the results from this study indicate that peak discharge is a key-based element to design channel geometry for improving the existing drainage system for the two investigated channels.

Earlier studies highlighted that impervious area's growth due to uncontrolled LULC has a considerable effect on the increase of runoff volume (Apollonio et al., 2016; Dionizio & Costa, 2019; Vojtek & Vojteková, 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, economic processes, planning policies, etc. (Ohana et al., 2013). With regard to channel geometric properties under different scenarios, the engineering constructions (highway bridges and other infrastructures) 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. Structural mitigation was here used to improve the geometric properties of the channel by increasing the height of embankments and enlarging the cross-sectional area. Future research will concentrate on: 1) expanding the surveys in other parts of the river network in the investigated case studied, 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; and 3) employ Biosystems engineering techniques, like natural lamination basins, in the upslope area of the investigated catchments (e.g. Apollonio et al., 2021b) in order to mitigate the urban flood risk.

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