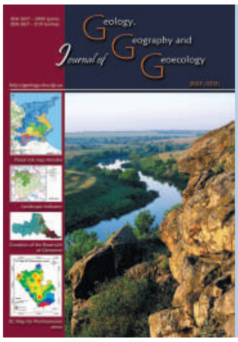

Journal of Geology, Geography and Geoecology

Journal home page: geology-dnu.dp.ua

ISSN 2617-2909 (print)
ISSN 2617-2119 (online)

Journ. Geol. Geograph. Geology, 32(3), 560-568
doi:10.15421/112350

Rainfall Based Dynamic Flood Inundation Simulation for Kelani River Basin of Sri Lanka

Piratheeparajah Nagamuthu

Department of Geography, University of Jaffna, Jaffna, Sri Lanka, npiratheeparajah@gmail.com

Received 10.10.2022;
Received in revised form 24.01.2023;
Accepted 16.03.2023

Abstract. Kelani river basin is inundated annually, primarily by heavy precipitation and rapid unplanned development, causing physical, social, and economic impacts. Two major attributable factors are inefficient rainfall forecasting and flood inundation modeling to facilitate flood management in this region. This study aims to simulate flood inundation in the Kelani River Basin in Sri Lanka using the Hydrological Engineering Center – River Analysis System (HEC-RAS). The model was used to create the scenarios for the elevation of the Kelani River basin, river network, water levels of the five hydrometric stations in the upper stream, land use and the land cover of the river basin were produced to identify the flood inundation and to suggest the possible solutions. A digital terrain model of the river basin was developed from elevation data using GIS techniques. HEC-RAS is the suitable analysis system to identify the flood inundation area by the receiving rainfall on every scale of the rain gauge, and the received rainfall can make the prediction earlier. According to the models of HEC-RAS on terrain, rainfall, river network, and water level of this study, following areas such as Kolonnawa, Hanwella, Homagama, and Kaduwela areas were inundated in the Colombo district after receiving above 85mm rainfall in the catchment areas of Kelani river basin and Wattala, Kelani, Biyagama, Ja-Ela in Gampaha district inundated after receiving 110 mm. It is proposed to build a reservoir in the Glanhouse area, along with a water retention bund in Hanwella, Dompe, Kolonnawa, Biyagama, and Kelani, to protect the vulnerable areas from frequent floods.

Keywords: Kelani River basin, Inundation, Dynamic modeling, rainfall prediction.

Динамічне моделювання повеней з урахуванням кількості дощових опадів для басейну річки Келані Шрі-Ланки

Піратіпараджа Нагамутху

Географічний факультет Університету Джафни, Джафна, Шрі-Ланка, npiratheeparajah@gmail.com

Анотація. Басейн річки Келані щорічно затоплюється, головним чином через сильні опади та швидку незаплановану забудову, що спричиняє фізичні, соціальні та економічні наслідки. Двома основними факторами, що спричиняють це явище, є неефективне прогнозування опадів та моделювання паводків для полегшення управління повенями в цьому регіоні. Метою цього дослідження є моделювання повеней в басейні річки Келані в Шрі-Ланці за участю Гідрологічного інженерного центру – Системи аналізу річок (HEC-RAS). Модель була використана для створення сценаріїв підйому рівня басейну річки Келані, річкової мережі, рівнів води на п'яти гідрометричних станціях у верхній течії, землекористування та рослинного покриву басейну річки, що дозволило ідентифікувати паводкові затоплення та запропонувати можливі рішення. Цифрова модель рельєфу басейну річки була розроблена на основі даних про висоти з використанням ГІС-технологій. HEC-RAS є придатною системою аналізу для визначення зони затоплення паводком за кількістю опадів на кожному масштабі дощоміра, а отримана кількість опадів дозволяє зробити прогноз заздалегідь. Згідно моделей HEC-RAS рельєфу місцевості, кількості опадів, річкової мережі та рівня води в цьому дослідженні, такі райони, як Колоннава, Ханвелла, Хомагама та Кадувелла були затоплені в районі Коломбо після того, як на водозбірних площах басейну річки Келані випало більше 85 мм опадів, а Ваттала, Келані, Біягама, Джа-Ела в районі Гампаха були затоплені після того, як випало більше 110 мм опадів. Для захисту вразливих районів від частих повеней пропонується побудувати водосховище в районі Гланхаус, а також водоутримуючі дамби в Ханвелла, Домпе, Коллонава, Біягама і Келані.

Ключові слова: басейн річки Келані, затоплення, динамічне моделювання, прогноз опадів

Introduction

Natural hazards can be classified into five significant divisions: climatic, geological, geomorphological, and environmental (Fung et al., 2020). There is no boundary or limitation to climatic hazards, and it can be in any part whether it is tropic or sub tropic polar or subpolar. (Piratheeparajah & Rajendram, 2015). However, climatic hazards are the worst hazards and they can occur everywhere worldwide (Lacombe et al., 2019). Flood is one of destructive hazards in Sri Lanka occurring every year in more than 14 districts, and it is responsible for the loss of more than 120 lives, 1.2 trillion US$ worth economic impact, and severe environmental impacts (Nagamuthu & Rajendram, 2015). Entire Sri Lanka is affected every year due to the annual flood. There are 103 major river basins in Sri Lanka; 77 of these 103 face flood vulnerability every year, especially during the South West Monsoon Season. Intense rainfall is the primary factor for flood impact all over Sri Lanka (Wanninayake & Rajapakshe, 2018). There are three primary processes for rainfall in Sri Lanka, namely monsoon, convection, and frontal or cyclonic processes and, therefore, primary seasons prevailing in the country are the first Inter-Monsoon Season, South West Monsoon Seasons, Second Inter-Monsoon Season, and North-East Monsoon Season (Iresh, 2019). However, floods are always associated with the southwest and northeast monsoon seasons. However, Ratnapura, Gampaha, and Colombo areas in the Southern and Western parts of Sri Lanka face problems with floods frequently, especially in the Kelani river basin, Gin Ganga river basin, and Nilwala Ganga river basins face many threats of flood in the southwestern monsoon season (Kottagoda & Abeysingha, 2017).

Flood hazards in the city of Colombo affect the smooth and fast dynamics of the city. Flood hazards in the Colombo district have been increasing yearly in the recent decades due to climate change, wet zone location, and high intensity of rainfall during the southwest monsoon season (Dilhani & Jayaweera, 2016). Kelani River is an invaluable asset to the City of Colombo, simultaneously it is a problem for the city due to the occurrences of flood (Manawadu & Wijeratne, 2021).

Flood hazards in the Colombo district have been increasing in the recent decades due to climate change, location in the wet zone area, and the high density of rainfall area (flood hazards are a significant threat to the dynamic and effective process of Colombo city) (Sangasumana et al., 2017). However, the Kelani River is the primary and dominant factor, which is the cause of the flood impacts in Western province. Colombo simultaneously functions as the administrative and commercial capital of Sri Lanka. Hence, any hazards or threats to Colombo will intimately affect not only Colombo city but the whole country (Dammalage & Jayasinghe, 2019). In this context, this paper discusses the flood modeling and mitigation measures of the Kelani river basins of Colombo, Sri Lanka (Iresh, 2019; Manawadu & Wijeratne, 2021).

Kelani River flood is a severe issue in Sri Lanka, and the governing authorities of the particular area are facing difficulties in managing the riverine flood of Kelani. Every year, especially during the southwest monsoon season, most of the river basin areas face flood vulnerability. The intensity and the amount of rainfall in the upper part of the Kelani river basin is the primary reason for the flood in the lower part of the Kelani river (Surasinghe et al., 2020). However, there is no study about the Kelani River flood in relation to the rainfall in the upper basin and the water level in the different parts of the Kelani river basin. There is an urgent need for a model that can predict the flood impacts in the Kelani river basin based on the received rainfall in the catchment areas of the Kelani river basin, and it would help to mitigate or prevent the severe flood damage caused by the Kelani River in the Western province. Similarly, there are very few studies about the riverine flood in Sri Lanka, especially on the models to forecast the flood impact (Surasinghe et al., 2020; Kottagoda & Abeysingha, 2017). In this context, this study describes an appropriate model to predict the flood inundation of the Kelani River. The first objective of this study is to formulate and calibrate a Hydrological Engineering Center – River Analysis System (HEC-RAS) model to understand the flood inundation patterns of areas of Kelani River Basin based on the received rainfall in the upper part (Catchment) of the river basin. The second objective of this study is to assess the flood impact around the Kelani river basin due to the Kelani river flood. The third objective of this study is to suggest mitigation measures for the flood impact in the study area.

Material and Methods

Department of Survey, Sri Lanka acted as a crucial information place; and contour map of Kelani river basin, natural drainage system map of Kelani river basin, land use map, transportation network, and location map of hydrological centers and administrative maps were obtained from the above source. Daily rainfall data, for eleven (11) stations

(Figure 1), which are located around the Kelani river basin of Colombo from 1999 to 2019, were obtained from the Department of Meteorology, Colombo. The Department of Irrigation provided the hydrological data for 07 water level observation centers of Kelani River, and the remaining hydrological data were obtained from the Disaster management Center. The District Secretary of Colombo provided historical data regarding the flood impact, flood mitigation activities, and disaster related reconstruction and rehabilitation activities. The following data have been obtained for this study.

The spatial information system has been used to design flood modeling for the Kelani river basin. This model is formulated based on the flow in the Kelani river according to the structure, and the geomorphological features which decide how much of the area along the Kelani river basin are affected in the Western Province of Sri Lanka. Based on this model, we can forecast flood-affected areas according to the rainfall in the Kelani river basin. It is a dynamic model that will help predict the Kelani River's water level, flood-affected areas, and flood levels.

Hydrological Engineering Center – River Analysis System (HEC-RAS) 5.0.3 software was used to design this dynamic model for the modeling purpose; data in the shapefile format were converted to data preparation, which was obtained from the Department of Survey.

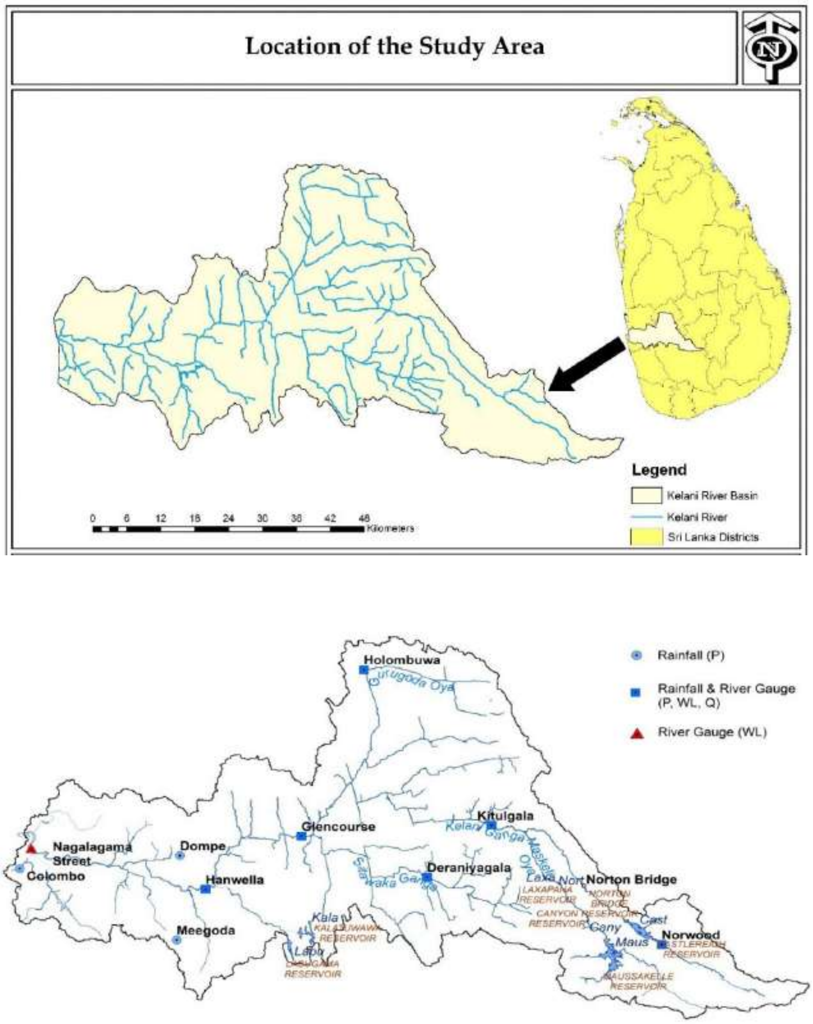

Fig. 1. Geographical location and the rain gauge stations of the Kelani river basin area

All vector data were converted to raster data. First, the triangular irregular network (TIN) data was formulated based on the elevation data, then converted into the digital elevation model (DEM) format. Arc map 10.4 software was used for the above-all data format activities.

Usage of HEC-RAS software: DEM was used to create a dynamic model in the HEC-RAS. DEM was used as input and changed in the HEC-RAS data format. The model has been opened using a geometric data tool.

Two Dimension (2D) Flow Area: A two-dimensional flow area was drafted to create the flood model; then, a grid was formulated in the drafted area. Flood water flow has been created as a model based on this grid using computing software of the computer.

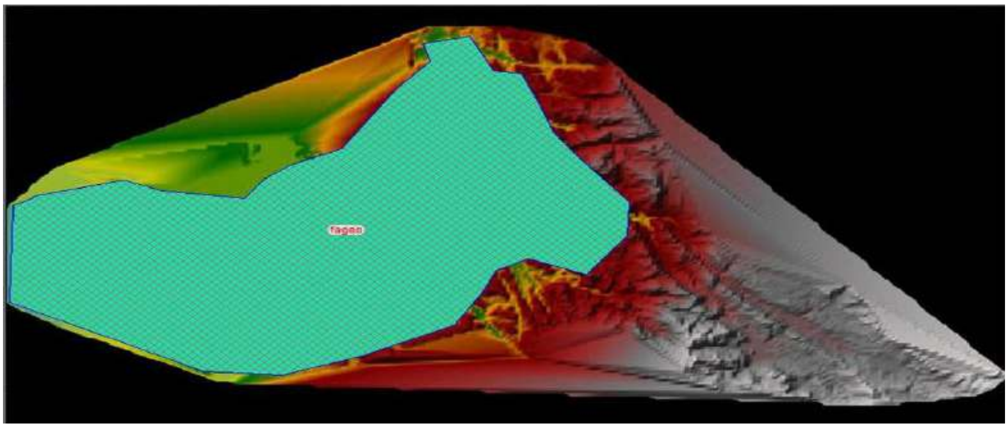

Fig. 2. Two Dimensional (2D) Flow area of Kelani River Basin

Define the River Water Level Centers: Low-level and high-level river basins helped define the trend of a river. High-level river basins of the Kelani River were identified in Holombuwa, Kitulgala, and Deraniyagala, and low-level river basins were identified in the Kelani delta areas. Then hydrological data, especially water discharge values of the selected places for the high-level river basin, were input into the system. Then the flood inundation area was identified, then the simulation model was obtained based on the water discharge in the quiet time interval according to the hydrological values of the selected high-level river basin of the Kelani River.

Results and discussion

Flood Inundation Areas Based On Rainfall: The primary objective of this study is to identify the flood inundation areas according to the received rainfall of the upper part of the river basin. According to the analysis used by HEC-RAS, the following ten stages (indicated in figure 3) indicate how flood inundation areas expand according to the increased rainfall within 24 hours. There is a 25mm rainfall that varies in each stage; stage 1 indicates that only 25 mm rainfall was received within 24 hours in the catchment area, and stage 10 indicates it received 250 mm rainfall within 24 hours in the catchment area. In stage 1, there is no flood in any part of the Kelani river basin because it gets only 25 mm of rainfall within 24 hours in the catchment area. However, in stage 10, many areas such as Colombo, Hanwella, Kolannawa, Kaduwela, Homagama, Wattale, Dombe, Biyagama, and Kelani are facing flood inundation problems because the catchment area is receiving 250 mm rainfall within 24 hours period (Figure 3 and Table 1).

According to the model based on received rainfall, flood inundation areas were validated through the field survey.

Table 1. Total received rainfall of the catchment area and the affected area, %

Stages (Indicated in the Maps)	Total received rainfall within 24 hours, mm (Catchment area)	Percentage of the areas facing flood inundation (in %)
1	25	Nil
2	50	13
3	75	19
4	100	24
5	125	31
6	150	36
7	175	39
8	200	51
9	225	58
10	250	63

Flood Inundation Administrative Divisions: The Kelani River flood has impacted Colombo and Gampaha districts in the Western Province of Sri Lanka. Following areas such as Homagama, Ganwela, Kaduwela, Kollannawa, and Colombo, City of Colombo district. Figure 4 illustrates the flood impacted administrative divisions in the Colombo and Gampaha districts.

Flood Impacting Land Uses: Several types of land use are affected by the Kelani river basin flood.

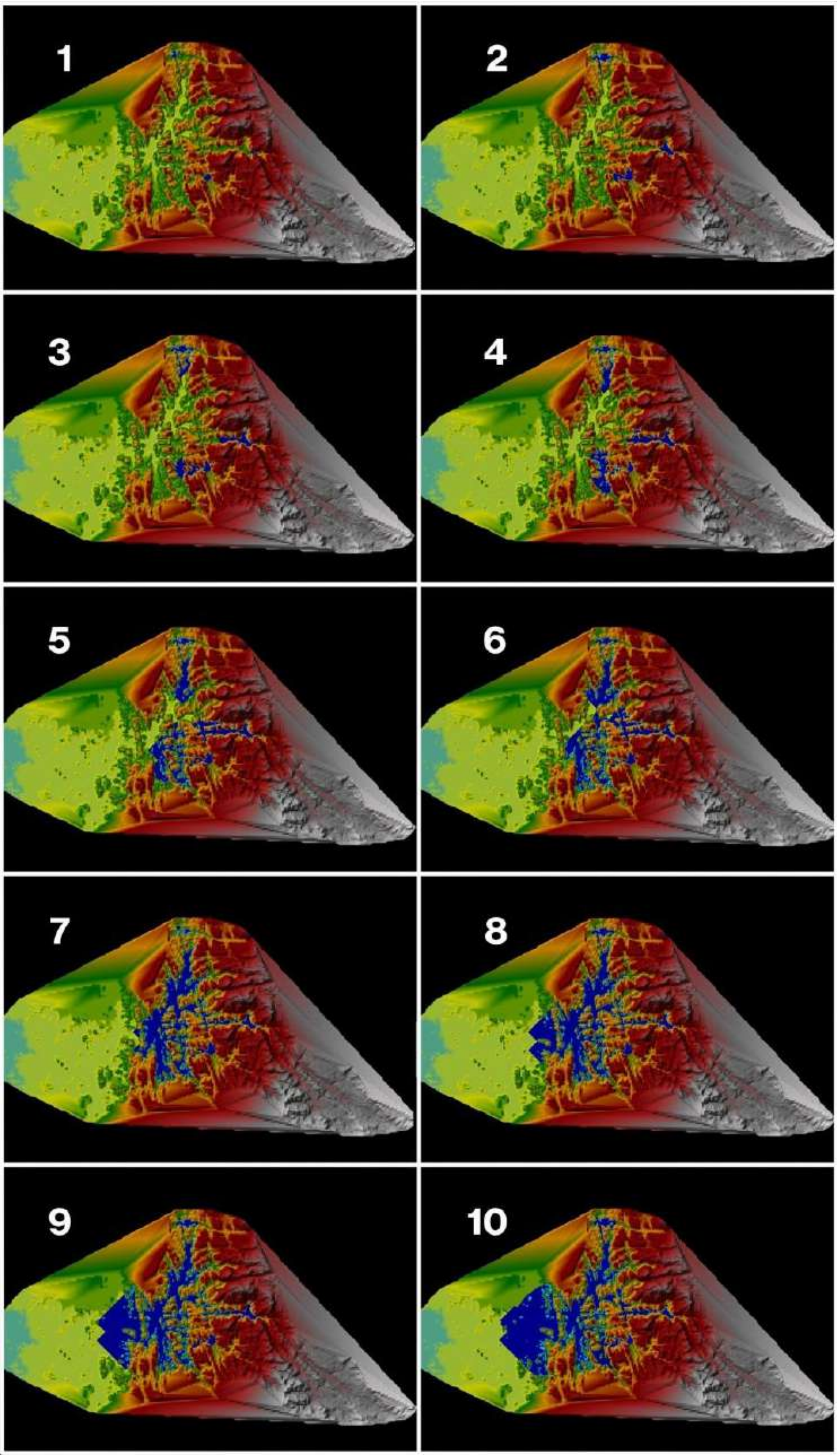

Fig. 3. Rainfall-based Flood Inundation Area in ascending orde

Agriculture, home gardening, coconut and rubber are affected by floods to a large extent. Similarly, many roads, bridges, and other transportation networks are also affected by the Kelani river basin flood. Kelani river basin floods affect the buildup areas along with the river in the Western Province. The following fig-

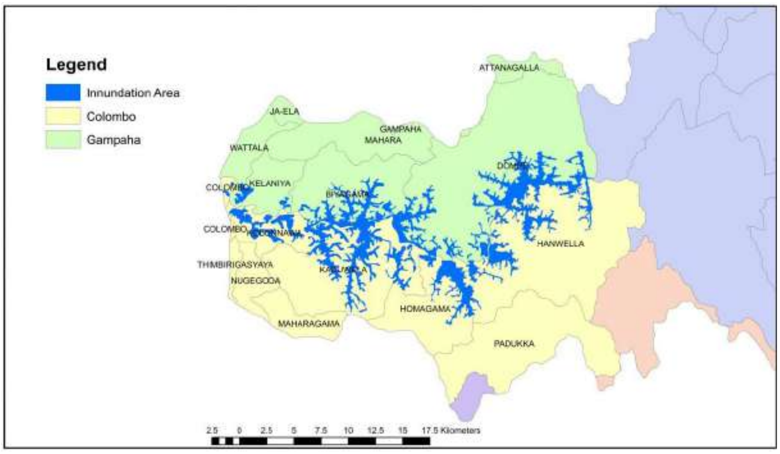

Fig. 4. Flood Affected Secretariat Divisions of Kelani River Basin

Table 2. Flood affecting Secretariat Divisions and Extents

District	Divisional Secretariat Divisions	Area in Hectare
Colombo	Colombo	26.27
	Hanwella	1888.25
	Kolonnawa	833.43
	Kaduwela	1975.01
	Homagama	649.77
Gampaha	Wattala	10.67
	Dompe	2494.72
	Biyagama	1175.72
	Kelani	191.46

ure indicates the different land uses in the Kelani river basin (Figure 5).

Assessment of Flood Impacts: Several kinds of human impacts have been identified in the Kelani river basin. Deaths, injuries, damage of the entire house, and partial damage of the house were identified in the study area from 2000-2016 (Figure 6 and table 3).

The following table indicates the impacts of the flood on humans in the Colombo district; Ganwela, Homagama, Kaduwela, Kollannawa, Maharagama, Pathukka, Thimbirigasayaya, and Sri Jayewardenepura are the affected divisional secretariat divisions. Biyagama, Kelani, Wattala, Modara, and Ja-Ela are affected divisional secretariat divisions in Gampaha District.

Colombo and Gampaha are the highest population-dense areas in Sri Lanka, for example, Kelani (6867), Ja-Ela (3358), Wattala (3250), and Biyagama (3162). More number of houses were affected in the Gampaha district than Colombo district by the Kelani river flood inundation (Table 4).

Discussion

Kelani river flood is becoming a grave threat to the western province of Sri Lanka (Surasinghe et al., 2020). Annually administrative authorities of the western province face challenges in mitigating the flood impact in the Kelani river bank areas, especially during the southwest monsoon season (De Silva & SB, 2015). The intensity of rainfall in the upper catchment area is the leading cause of the flood in the Kelani river areas (Perera, 2021). Very few studies consider the rainfall intensity and the Kelani River flood (Samarasinghe et al., 2022). Several studies focused on the various

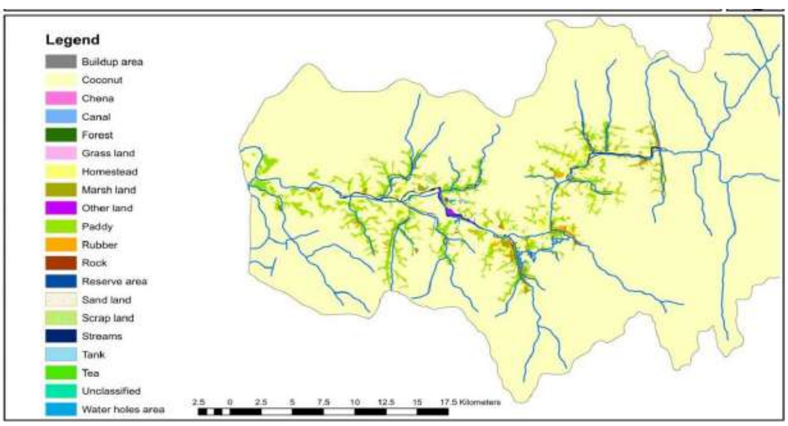

Fig. 5. Affected Land use Types in Kelani River Basin

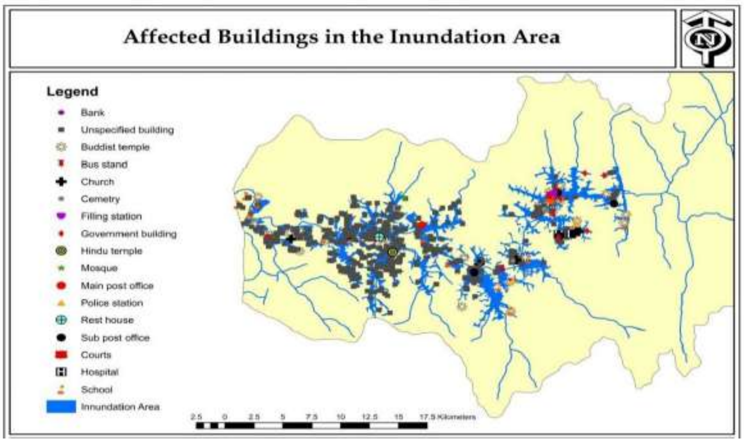

Fig. 6. Affected Buildings in the Flood Inundation area of Kelani River Basin

Table 3. Human Impacts of Flood in Colombo District during the last 20 years

Divisional Secretariat Division	Deaths	Affected People	Partially Damaged Houses	Fully Damaged Houses
Colombo	1	289263	36	1
Henwella	1	18208	334	37
Homagama	3	9894	32	25
Kaduwela	6	47512	92	11
Kolonnawa	1	363694	268	2
Maharagama	-	11875	86	6
Padukka	-	1443	4	-
Thimpirigasaya	1	109324	100	1
Sri Jeyawart-hanapura	-	52583	17	3
Total	13	903796	969	86

Table 4. Flood Impacts in Gampaha District during the last 20 years

Divisional Secretariat Division	Deaths	Affected People	Partially Damaged Houses	Fully Damaged Houses
Biyagama	4	79167	153	7
Dompe	3	7138	128	10
Kelani	3	173687	187	19
Wattala	5	324739	376	24
Mahara	2	16970	153	22
Ja-Ela	6	79599	397	11
Total	23	681300	1394	93

aspects of the Kelani river flood, mainly focusing on the impact of the river flood (Manawadu & Wijeratne, 2021). The current study attempts to study the relationship between the received rainfall and the flood inundation areas along with the Kelani river flood (Fowze et al., 2008). The present study emphasizes the extent of the area affected by the Kelani river flood based on the received rainfall. According to that, if the catchment area receives more than 250 mm of rainfall, 63% of the area will be affected by the rising water level in the Kelani river basin, especially near the delta area. A few studies revealed that unauthorized development is the leading cause of the increased flood inundation along the Kelani river basin (Fowze et al., 2008). There are some contradictions between the studies related to the area of flood inundation in the Kelani river basin (Surasinghe et al., 2020). However, several studies agreed that there is an increase in the flood inundation area in the river basin (Samarasinghe et al., 2022; Makubura et al., 2022; Iresh, 2019). But few studies indicate that climate change is the leading cause of the increasing flood inundation in the study area (Kottagoda & Abeysingha, 2017).

In this context, this dynamic model helps to predict further severe flood warning areas that can be affected based on the received rainfall. Also, this model helps clearly define the Kelani River's flood-affected area due to every centimeter of rainfall. Also, this model helps to implement the planned development project in the Colombo and Gampaha districts.

The construction of multipurpose reservoirs should help to reduce the flood impact and fulfill the water needs in the Colombo and Gampaha districts. Valley with a gentle slope helps to construct the reservoir in the Kegalle, Gampaha, and Colombo. Glencorse area has enormous potential to build up a new reservoir located on the border of Kelaniya and Colombo. This reservoir would be able to help agriculture and hydropower production. As a result, this new reservoir could help to develop the economy and mitigate the flood impacts in the Kelani river basin area (Figure 7).

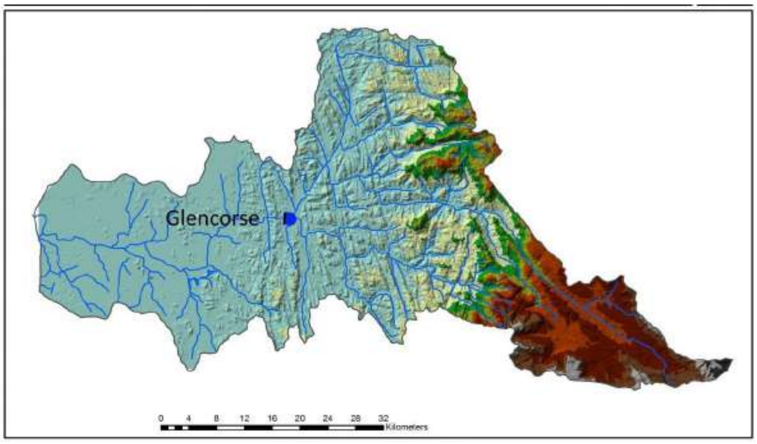

Fig. 7. Proposed Construction of the Reservoir at Glencorse

Kelani river basin flood affects the heart of the city of Colombo. Hence, building up flood prevention bunds would help to prevent stormwater from entering the settlement area during the flood in the Kelani river basin. These bunds can be situated in the Ganwella, Dompe, Kolonnawa, Biyagama and Kelani areas (Figure 8).

Damage to the canals and narrow channels induces flood impacts in the Kelani river basin area. For example, there is no suitable way to evacuate the flood

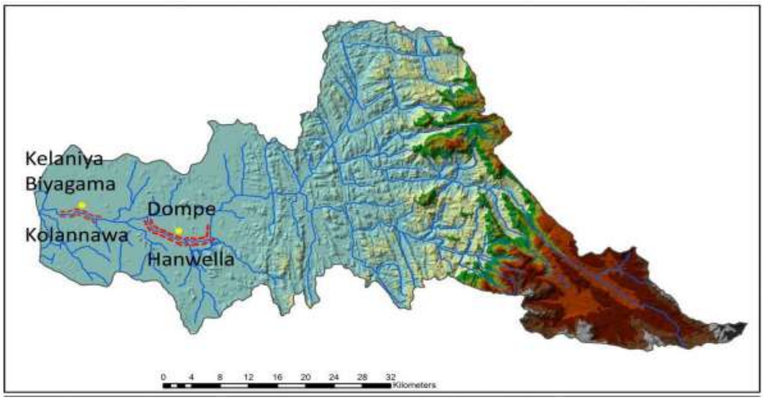

Fig. 8. Proposed Flood prevention bunds

water in the Peliyagoda area due to the lower elevation. Hence, this type of canal can help evacuate the floodwater during a flood emergency.

Presume that the buildings have an open space on their ground floor to help the flood water flow without damaging the building. So, the Urban Development Authority (UDA) and Disaster Management Center (DMC) have to implement a new rule for the building to have the open space for flood flow for the construction of new buildings around the Kelani River basin. In this context, received rainfall is the primary and significant factor determining the flood inundation area due to the overflow in the Kelani river basin. The impact of Kelani river flood is determined by the rapid and continuous unauthorized developments in the Kelani river basin.

Conclusions

Kelani river basin plays a very vital role in the lives of people residing in Colombo and Gampaha, and the function of the entire country. In case of occurrence of floods in the Kelani River, it affects more than 1.3 million people along the Kelani River due to the high density of the population. Therefore, this study emphasized a dynamic model for forecasting using GIS software with the input of several geographical parameters, mainly considering the rainfall to predict the Kelani River flood for saving more than 1.8 million people. However, avoiding human activities near the Kelani River would be the most feasible solution to avoid the flood impacts in the Kelani river basin.

References

Dammalage, T. L., & Jayasinghe, N. T. (2019). Land-Use Change and Its Impact on Urban Flooding: A Case Study on Colombo District Flood on May 2016. Engineering, Technology & Applied Science Research, 9(2), 3887–3891. https://doi.org/10.48084/etasr.2578

De Silva, G., & SB, W. (2015). Event Based Flood Inundation Mapping Under the Impact of Climate Change: A Case Study in Lower Kelani River Basin, Sri Lanka. Journal of Waste Water Treatment & Analysis, 07(01), 7–10. https://doi.org/10.4172/2157-7587.1000228

Dilhani, K. A. C., & Jayaweera, N. (2016). A study of flood risk mitigation strategies in vernacular dwellings of Rathnapura, Sri Lanka. Built-Environment Sri Lanka, 12(1), 1. https://doi.org/10.4038/besl.v12i1.7611

Fowze, J. S. M., Gunasekara, I. P. A., Liyanage, P. P., Hazarika, M. K., & Samarakoon, L. (2008). Flood hazard mapping in lower reach of Kelani River, Sri Lanka. 29th Asian Conference on Remote Sensing 2008, ACRS 2008, 2(05), 731–736.

Fung, K. F., Huang, Y. F., & Koo, C. H. (2020). Assessing drought conditions through temporal pattern, spatial characteristic and operational accuracy indicated by SPI and SPEI: case analysis for Peninsular Malaysia. In Natural Hazards (Vol. 103, Issue 2). Springer Netherlands. https://doi.org/10.1007/s11069-020-04072-y

Iresh, A. D. S. (2019). Flood Frequency Analysis for Kelani River Basin: Case Study in Sri Lanka. Annual Sessions of IESL, 571–578.

Kottagoda, S. D., & Abeysingha, N. S. (2017). Morphometric analysis of watersheds in Kelani river basin for soil and water conservation. Journal of the National Science Foundation of Sri Lanka, 45(3), 273–285. https://doi.org/10.4038/jnsfsr.v45i3.8192

Lacombe, G., Chinnasamy, P., & Nicol, A. (2019). Review of climate change science, knowledge and impacts on water resources in South Asia. Background Paper 1. In International Water Management Institute. https://doi.org/10.5337/2019.202

Makubura, R., Meddage, D. P. P., Azamathulla, H. M., Pandey, M., & Rathnayake, U. (2022). A Simplified Mathematical Formulation for Water Quality Index (WQI): A Case Study in the Kelani River Basin, Sri Lanka. Fluids, 7(5). https://doi.org/10.3390/fluids7050147

Manawadu, L., & Wijeratne, V. P. I. S. (2021). Anthropogenic drivers and impacts of urban flooding- A case study in Lower Kelani River Basin, Colombo Sri Lanka. International Journal of Disaster Risk Reduction, 57(April 2020), 102076. https://doi.org/10.1016/j.ijdrr.2021.102076

Nagamuthu, P., & Rajendram, K. (2015). Occurrences of Flood Hazards in the Northern Region of Sri Lanka. J. S. Asian Stud, 03(03), 363–376. http://www.escijournals.net/JSAS

Perera, K. K. E. (2021). Flood Hazard Assessment Using Gis-Based Multi-Criteria Analysis: a Case Study From Downstream of Kelani River Basin, Sri Lanka. KDU Journal of Multidisciplinary Studies (KJMS), 3(1), 50–68.

Samarasinghe, J. T., Basnayaka, V., Gunathilake, M. B., Azamathulla, H. M., & Rathnayake, U. (2022). Comparing Combined 1D/2D and 2D Hydraulic Simulations Using High-Resolution Topographic Data: Examples from Sri Lanka–Lower Kelani River Basin. Hydrology, 9(2), 1–19. https://doi.org/10.3390/hydrology9020039

Sangasumana, V. P., Dissanayaka, M. L. S., & Sangasumana, R. P. (2017). Issues and Challenges of Urban Flood Hazard Management in North Colombo Region (A case study of 2016 Flood Affected Kolonnawa Urban Council). International Journal of Scientific and Research Publications, 7(10), 310. www.ijsrp.org

Surasinghe, T., Kariyawasam, R., Sudasinghe, H., & Karunarathna, S. (2020). Challenges in biodiversity conservation in a highly modified tropical river basin in Sri Lanka. Water (Switzerland), 12(1). https://doi.org/10.3390/w12010026

Wanninayake, S. B., & Rajapakshe, P. S. (2018). Increasing trend of flood and landslide disasters in Sri Lanka : Socio-Economic perspective. 6th International Conference of Sri Lanka Forum of University Economists, 2017, August, 107–110.