Flood Inundation Modeling and Damage Assessment in Lahore Using Remote Sensing

Zunaira Abbas[1], Mehreen Akhtar[1], Saira Akram[2], Sumaira Hafeez[1], Sajid Rasheed Ahmad[1]
[1] College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan.
[2] Center for Remote Sensing and GIS, University of the Punjab, Lahore, Pakistan.
Correspondence: Sumaira Hafeez (sumaira.gis@gmail.com)

Citation | Abbas. Z, Akhtar. M, Akram. S, Hafeez. S, Ahmad. S. R, "Flood Inundation Modeling and Damage Assessment in Lahore using Remote Sensing", IJIST, Vol. 5 Issue. 4 pp, pp. 638-647, Dec 2023.
Received | June 01, 2023**; Revised |** Aug 18, 2023**; Accepted |** Aug 24, 2023; **Published |** Dec 11, 2023.

Introduction:

Ravi River has a great contribution to the glorious history of Lahore City, the second biggest city in Pakistan. But similar to all rivers of Pakistan, River Ravi occasionally experiences extreme floods. During the past 100 years, two extremely high floods created devastation in Lahore City, which caused enormous loss of properties and lives. To save the main metropolitan areas of Lahore in both these floods, the Shahdara Breaching section, on the western bank of the river, was operated. The potential of loss due to floods has increased even more owing to the rise in population, industrialization, and spring of unplanned settlements in the floodplain of the river.

Importance of Study:

This research provides a solution that has the potential for long-term effects in flood management, hygienic improvement of the area, planned urban development around the river, and improvement of sub-surface water quality.

Novelty Statement:

The present study is focused on determining the flood damage assessment using advanced geospatial techniques with HEC-RAS applications.

Materials and Methods:

The reach of the Ravi River is from Shahdara to Balloki. Flood frequency analysis was performed to calculate a flood return period of five and fifty years. Hydraulic modeling of the river on HEC-RAS is used to find river capacity, its Validation, calibration, assessment of hydraulic capacity, flood inundation extent, and depth analysis.

Results:

It is concluded that a flood of 3643.97 cumecs magnitude corresponds to 5 years return period and 7406.699 cumecs magnitude corresponds to 50 years return period. If the same phenomena occur in a repeating manner, then the built-up settlement near Ravi can meet alarming threats. According to the maximum likelihood classification, the damage assessment was mapped wherein the results show that the buildup area was 15657 acres, the water body was 7059.246 acres, the cultivated area was 38395.3 acres, and uncultivated 59464.51 acres were affected.

Conclusion:

The solution can also address the problems arising due to changes in river course and depletion of natural habitat.

Recommendations:

However, along the Lahore City, the required width is not available. In this condition, an engineering solution is mandatory to pass the flood. Channelization can be proposed to create the width of the river. The reclaimed land should be used for high-quality urban development to increase revenues. For the sake of channel stability, a detailed sediment study should be done.

Keywords: Flood, HEC-RAS, Remote sensing and GIS, Inundation, Damage Assessment, Hydrological Modeling.

Introduction:

The existence of a water body has been the foremost significant consideration of human settlement. Thus, practically all authentic urban areas of the planet lie on the bank of a River [1]. Old civilizations all around the world like Asia, Africa, and Europe are settled along the water bodies to facilitate their population, similarly, Lahore (Pakistan) has been with the Ravi River since ancient times even though the river changed its path [2].

The course of the Ravi River gradually changed in the direction of the settlements on both sides of the banks, due to the high sediment concentration. Supplement to these reasons is the development of dams. A country on the upstream has a dam on the river while the countries on the downstream side of a transboundary river will have increased weakness [3].

The risk of floods is particularly notable in evolving countries, with deprived metropolitan planning and bounded resources to hold out river training works. Causes of flood can be usual and unusual [4]. The advanced countries still are not fully safe. Over the past 20 years worldwide frequency of floods has been greater than before up to 40% [5]. Similar intimidations are being tackled by Lahore, the second major city in Pakistan. Normally, Lahore City was constructed along the Ravi River. Ravi River catchment is present in the Monsoon area, which is linked with heavy rainfalls in the summer, resulting in heavy overflow.

Hence, Lahore had been vulnerable to hazardous flooding in previous times thanks to high-level releases in the Ravi River during the rainy season. The on-record second-highest flood for the Ravi River is the flood of 1955, with peak flows of 14,932 cumecs at Shahdara. It broke flood mounds of the school canal that is artificial. Irrigation Department Punjab assessed that flood releases of more than 7000 cumecs went through the breaches at Ravi Siphon and about 8000 cumecs through the infringements at Shahdara Bridge. The flood occurred in the second last decades of twenty century with a scale of about 17000 cumecs at Shahdara, was the foremost exceedingly terrible flood of the twelfth decade to smash Lahore City. The flood demanded 731 lives and evacuated 1,250,000 individuals. The Shahdara Flow waterfront was ruptured, which caused the overwhelming inundation of the area between Shahdara and Kala Shah Kaku. Lower Reaches, the Balloki and Sidhnai headworks were exposed to releases far away over their layout positions, and walls were broken to rescue the structures. According to the Indus Basin treaty in 1960, for Irrigation systems and power production India utilizes the water of the Ravi River. Before entering the river into Pakistan, Madhopur Headwork is present in India, with a channel volume of 17,750 cumecs, further 24 km upriver is the Thein Dam, having a shaft ability of 20,678 cumecs. The operational time of Thein Dam was 2011. This huge storage capacity, if discharged at the speed of most waste weir capability, will produce a large flood to securely pass any flood, it's obligatory to depart most breadth for the streamflow that is currently absent for Ravi stream on Lahore.[6]

Due to amendments in the temporal flow pattern, the geographic stream route, urban planning [7], rise in stream pollution [8], [9], and regular floods (World Bank 2010), the connection between the proposed urban space of city town and Ravi flow have lost. Ever Since the nineteenth century, engineers have come up with the collaborative answer of stream centralization to lessen flood further by utilizing constant water to reinforce the superiority of metropolitan areas, raise customary of life, and enhance the aesthetic of the town [10]. River channels create dangers to the immediate surroundings by forcing a negative impact on the surroundings, the marine environment, and the usual function of flooded areas. Rarely, the damage to the environment is to such a large extent, that is reversed by channelization.

In 1996, in 36 hours during the monsoon, Lahore received 496 mm of rain destroying all records in recent memory that flooded Lahore and ruined its socio-economy to the basic lower level. The present study is focused on determining the flood damage assessment using advanced geospatial techniques with HEC-RAS applications[11]–[13].

Lahore currently faces the following threats from Ravi.

- Unhygienic conditions in low flows
- Floods in high flows
- Increase in inundation threat if the river course is changed

Objectives:

The intention of the study is to map the inundated and flooded area around the River Ravi, which was not included in the planning of Lahore. Objectives of the study are:

- Hydraulic modeling and computing the water surface profile for 5 and 50 years design flood using HEC-RAS
- To determine the flood inundation maps and depths for 5 and 50-year design flood in a GIS environment
- Identification of flood damage for inundated areas.

Materials and Methods:

Study Area:

Lahore city is the densely populated district of the country and river Ravi separates it from shadara. Flood inundation calculation software i.e. ArcMap, HEC-GEORAS, and HECRAS were used to prepare maps and to conduct the study. River Reach understudy is, from Shahdra to Balloki Reach. This study concludes the estimated loss of property, lives, and biodiversity during the time of flood.

Solutions to hydraulic engineering problems are sensitive in the sense that a solution with a higher factor of safety can negatively affect upstream or downstream reach. The selected reach of the Ravi River is from Shahdra to Balloki reach.

For a good engineering solution to the problem of the Ravi River, the following scheme is adopted in the given order.

- Flood frequency analysis
- Hydraulic modeling of the river on HEC-RAS. Validation, calibration, and assessment of hydraulic capacity
- Flood inundation extent and depth.
- Flood damages for inundated areas.

Development Environment:

Basic data for flood modeling and map generation was collected from different resources are given in Table 1.

Table 1: Data collection sources

Data Type	Specification	Source
Landsat Data	30m resolution imagery	https://earthexplorer.usgs.gov/
Topographic Data	Cross-Sectional data	NESPAK
Hydro-Metrological Data	Peak Annual Discharge data	H&WM department of WAPDA
SRTM Data	Use a low filter path to decrease noise	https://earthexplorer.usgs.gov/

All the data was dumped into HEC-RAS to calculate flood and create inundation of flood.

Landsat Data:

30 m resolution imagery was downloaded from http://earthexplorer.usgs.gov/ for the study area. Landsat 8 level 1 data was used [14]. A color composite of the required bands was created. The project area was extracted from the color composite.

Topographic Data:

Cross-sectional data of the river understudy was accessed from NESPAK. The data was in a conical coordinate system which was then projected into a projected coordinate system i.e., UTM WGS 1984 43N.

Hydro-Meteorological Data:

Discharge data of the Ravi River at Shahdara was attained from the H&WM department of the WAPDA. The data was comprised of peak annual discharge from 1986-2017. These data were used to regulate and confirm the HEC-RAS model for the study area. Flood values of 5 and 50-year return period for the Ravi River basin was calculated using the Gumbel Extreme Value Distribution Formulae

SRTM Data:

SRTM data was obtained from https://earthexplorer.usgs.gov/. The project area was under two different tiles. The mosaic tool was used to combine tiles of the area under study. The use of a low path filter was made to decrease any noise in the SRTM data. The SRTM data was first projected to UTM WGS 1984 43 N and then the required reach was extracted from the overall area. Prepared the updated digitized maps and error-free SRTM data, then a DEM is generated by these. Digital Elevation Models (DEM) are used for different purposes like preparation of orthorectified, flood planning, destruction control, land, and farm management, 3-Dimensional view, and many others [15]. Land use features are added as a barrier and assigned their elevation values. A minimum 30m resolution containing SRTM should be used to model 1D and 2D flood applications for those rivers, having rates more than ten thousand square kilometers [16]–[18].

Flood Frequency Analysis:

Flood Frequency analysis was conducted on annual maximum discharge using the Gumbel Extreme method. The Gumbel probability distribution method is used for the analysis of hydrological and weather data like floods, maximum rainfalls, and such types of other occurrences [19].

Flood frequency analysis was performed using the formula:

$$x_T = \bar{x} + K\ \sigma$$

Where,

X_T = XT is the magnitude of the flood and T is the return period of an event.

x = mean value of the variant

σ = standard deviation of the variant

$$\sigma_{n-1} = \sqrt{\frac{\sum (x-\bar{x})^2}{N-1}}$$

K = frequency factor [f(T, assumed frequency distribution)]

$$K = \left[\frac{y_T - \bar{y}_n}{S_n}\right]$$

$$y_T = -\left[\ln \ln\left(\frac{T}{T-1}\right)\right]$$

In study 5 and the 50-year return period, flood values were computed attached as Table (1) below. Annual Peak discharge values from 1986 to 2017 were used.

Hydraulic Analysis: Hydraulic analysis of the current river is very important to evaluate the hydraulic power of the river and possible threats against various floods [20], [21]. This will help to evaluate the danger of a flood of contiguous areas of the Ravi River.

The following parameters are required to judge the hydraulic capacity of the river:

(i) Geometry of river
(ii) Manning's n-value
(iii) Boundary condition(s)
(iv) Modeling of the river in HEC-RAS

Geometry of River:

Initially, geographical data and DEM were prepared with the help of ArcGIS to generate the river geometry. TIN was created from DEM for the area under study, using GIS tools. Then HEC-GEO-RAS modeling of the river was carried out. River geometry was created by digitizing the different layers of the river area under study. Empty layers are created for the digitization.

- River centerline
- Banks of river
- Ineffective flow area
- Flow paths of the river
- Bunds of river
- Cross-section cut lines

Manning's N-Value:

To assign Manning's "n" value, land use of the river was digitized. This land use is divided into two categories.

1) The river channel was allocated to the n value of 0.033
2) The floodplain was assigned to the n value 0.04.

Boundary Conditions:

A river flows from upstream to downstream in the area under observation. The boundary condition is chosen as the downstream slope, and the value of the downstream slope is = 0.0002 according to the digital elevation model [22].

Modeling of River in HEC-RAS:

In the drop-down of the geometric data editor, the button of the tab imports the files in the format that is acceptable for the software. Calculations were made in SI units here is the metric required. HEC-RAS was then used for steady flow flood simulation of the flood calculated by Gumbel's distribution [23]–[25]. Two profiles were first used to define the boundary condition of flows defining the Reach boundary condition tab. In this study, standard deepness was selected to describe the margin conditions of flows and add the downstream slope of the river i.e. 0.00021. When the simulation of flow was completed, the height of the flood water level of each profile could be verified by checking the L-Section of the water surface profile and the height of the ground surface.

Flood Damage of Inundated Areas:

Land-use maps are essential to flood estimate modeling. Satellite imageries were overlapped on marked-out SRTM data; key features were retraced and digitized again, thus generating an efficient digitized map. A geodatabase involves thematic map layers. For each land-use map, according to data requirements, a number of thematic layers were created. By using the maximum likelihood classification (supervised classification) technique the land use map was developed. Landsat image was divided into 4 different categories to calculate the damaged area.

- Built-up Area
- Water Bodies
- Cultivated Areas
- Uncultivated Areas

The land use map of the study site is in Figure 1.

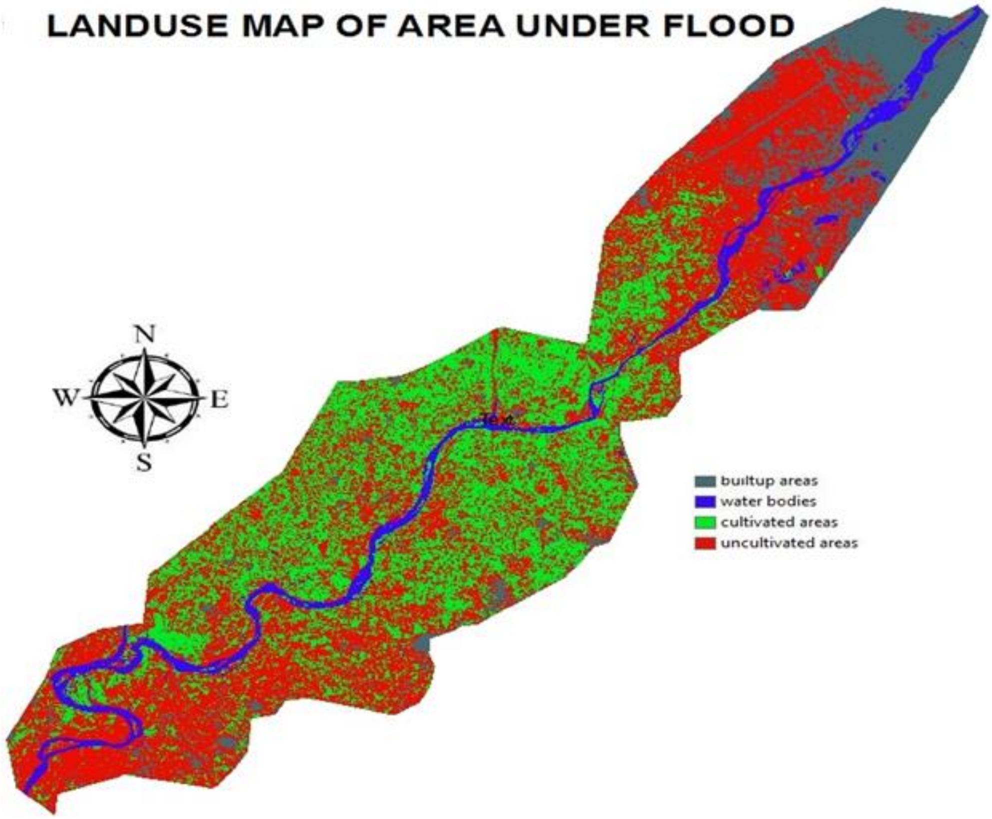

Figure1: Modeling of Ravi River in HEC-RAS

Figure 2 is shown in Figure 2.

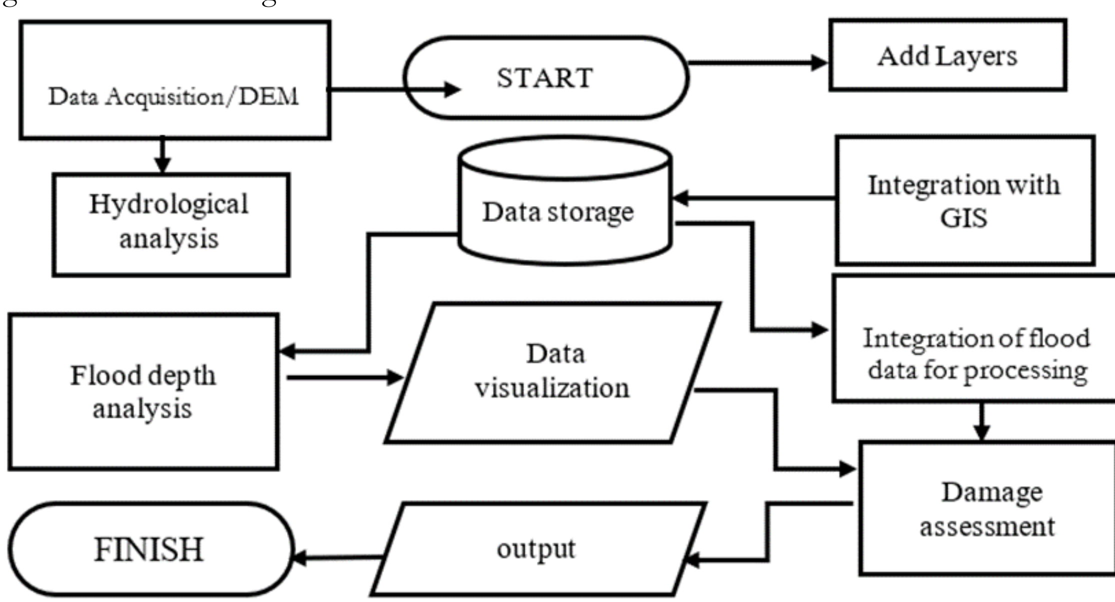

Figure: Flow diagram

Results and Discussions:

Table 2: Flood damage

Classes	Area in m^2	Area in Acre
Built-up Area	63361800	15657.02
Water bodies	28567800	7059.246
Cultivated area	1.55E+08	38395.3
Uncultivated area	2.41E+08	59464.51

STEP 3:CALCULATION OF FREQUENCY FACTOR KT				XT $X_T = \bar{X} + K.\sigma$
RETURN PERIOD	In(InT/T-1)	0.5772+In(InT/T-1)	FREQUENCY FACTOR KT	FLOOD MAGNITUDE AGAINST RETURN PERIOD
2	-0.366512921	0.210687079	-0.164335922	65994
5	-1.499939987	-0.922739987	0.71973719	128704
10	-2.250367327	-1.673167327	1.305070515	170224
15	-2.673752092	-2.096552092	1.635310631	193650
25	-3.198534261	-2.621334261	2.044640724	222685
50	-3.901938658	-3.324738658	2.593296153	261603

The computed values are in Cusecs however, in HEC RAS Model equivalent values i.e. 3643.97 cumecs and 7406.699 cumecs were for 5 and 50-year return periods respectively as in Figure 3 and 4.

Flood Inundation Extent for 5 and 50 Years Return Period:

Figure 3: Flood extent for 5 years return period

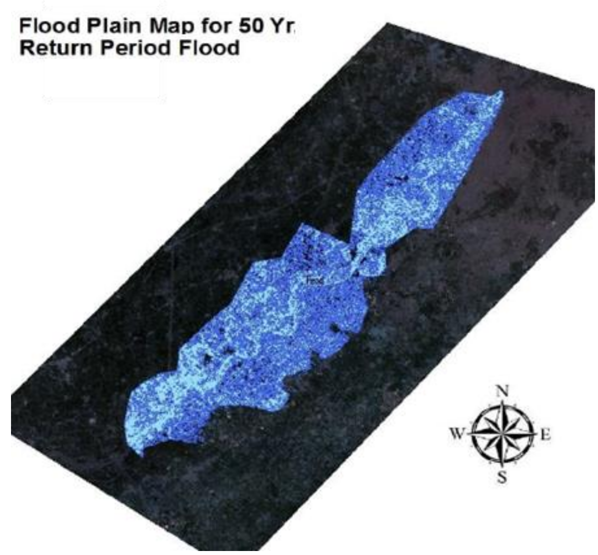

Figure 4: Flood extent for 50 years return period

Flood levels were calculated at different cross sections for a 5 and 50-year return period as follows as the water surface profile PF2 and water surface profile PF1 [26]. Geometric data was transferred to Arc GIS using HEC-GEO-RAS, and RAS mapping was done. An inundation mapping tool was used for water surface generation and then flood plain delineation was performed, before that the velocity and stress were calculated for pf1 and pf2 for 5 and 50-year return periods.

Discussion:

The flood frequency analysis was performed using the Gumbel method. Hydraulic modeling and computation of water surface profile for 5 and 50 years return period, was performed in software. Using the HEC-RAS results inundation of the flooded area was calculated in software and damage assessment was also performed.

Conclusions:

- It is concluded that a flood of 3643.97 cumecs magnitude corresponds to 5 years return period and 7406.699 cumecs magnitude corresponds to 50 years return period. If the same phenomena occur in a repeating manner, then the built-up settlement near Ravi can meet alarming threats.

- According to the maximum likelihood classification, the damaged buildup area was 15657 acres, the water body was 7059.246 acres, the cultivated area was 38395.3 acres and the uncultivated 59464.51 acres were affected as in Figure 5, 6.

Flood Inundation Extent and Depth:

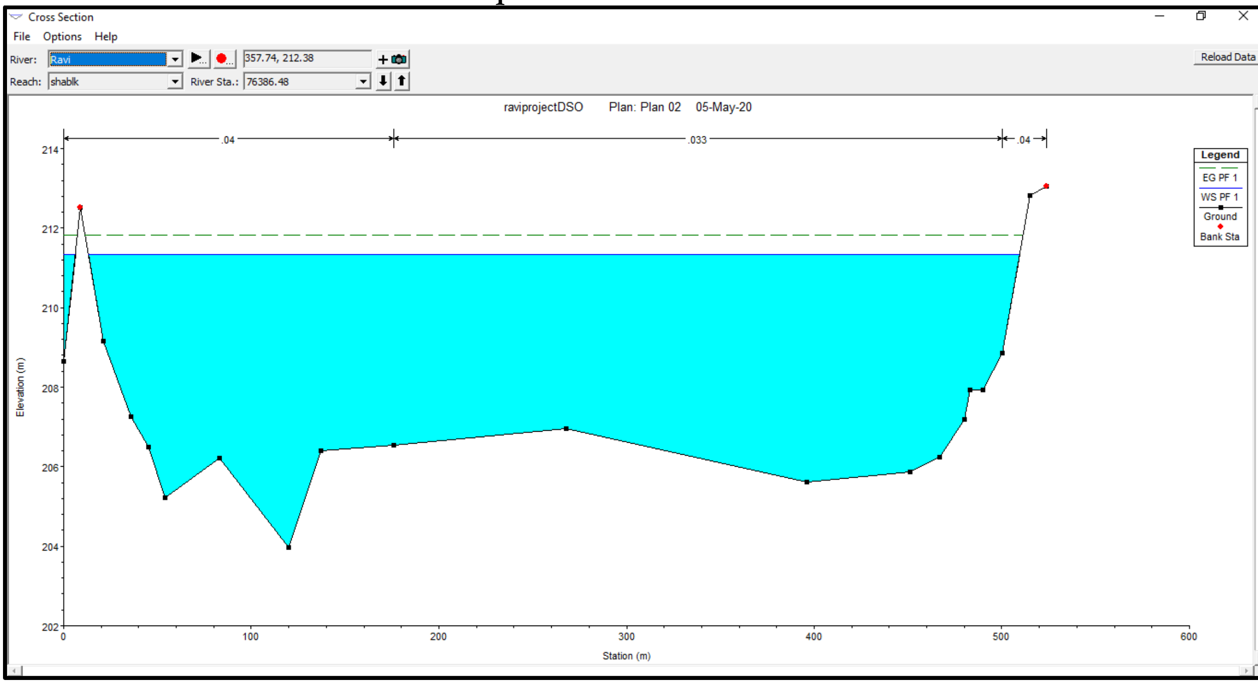

Figure 5: Cross section for 50 years return period

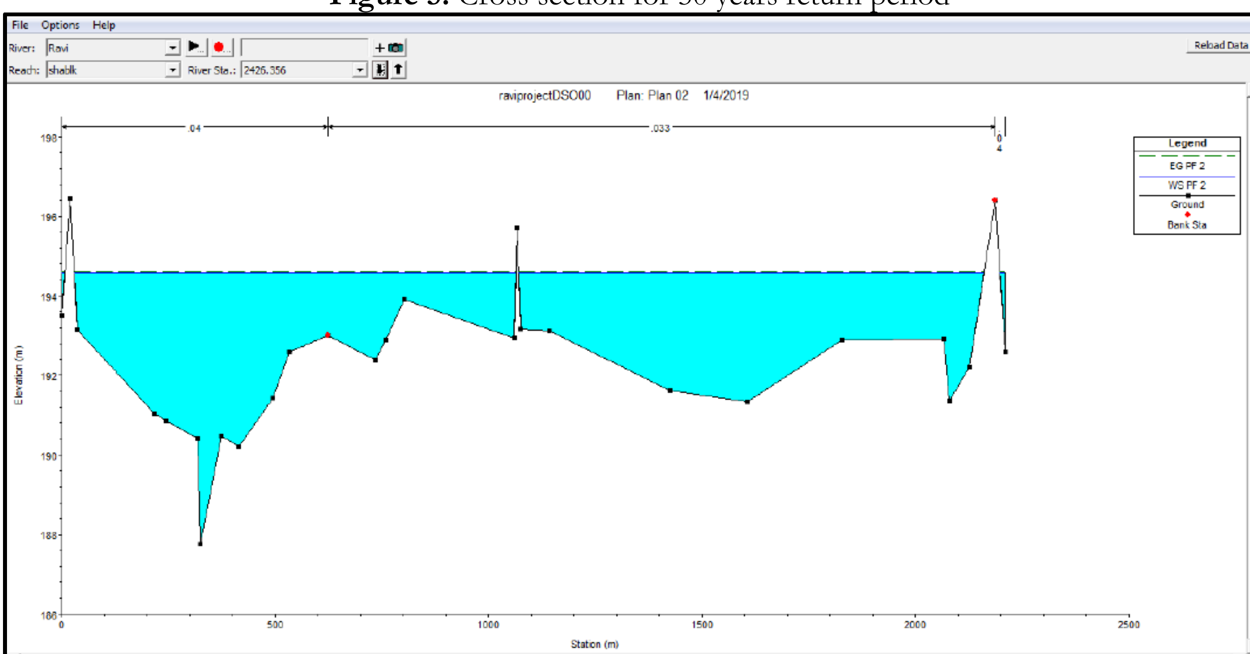

Figure 6: Cross section for 5 years return period

Figure 7 shows the flood inundation map that may finally hit various areas in the study site, where the red dots show the most prone area that may come under the flood. In Figure 7, the SW of the study site may be the most dangerous and may face severe damage.

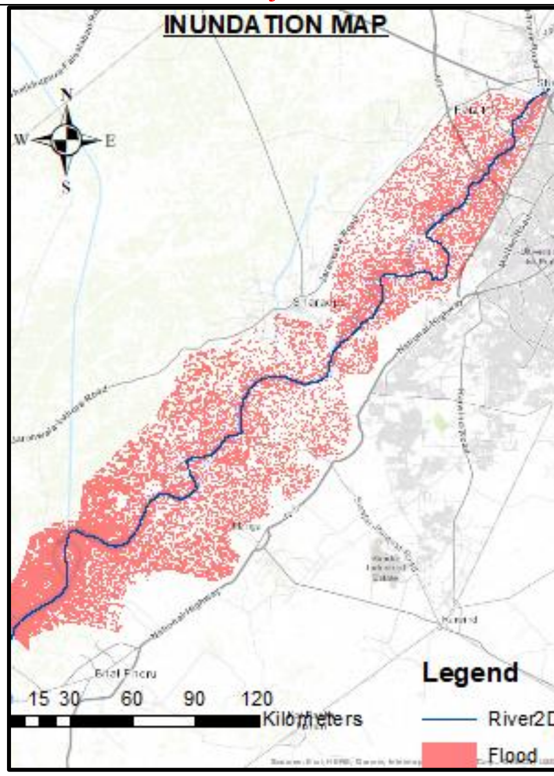

Figure 7: Final inundation map

Conflict of Interest Statement:

The authors have no conflict of interest in publishing this research with IJIST.

Project Details: NIL

References:

[1] J. M. Buttle et al., "Flood processes in Canada: Regional and special aspects," Can. Water Resour. J., vol. 41, no. 1–2, pp. 7–30, 2016, doi 10.1080/07011784.2015.1131629.

[2] B. M. Popkin, K. E. D'Anci, and I. H. Rosenberg, "Water, hydration, and health," Nutr. Rev., vol. 68, no. 8, pp. 439–458, 2010, doi: 10.1111/j.1753-4887.2010.00304.x.

[3] M. Mohsin Atiq, A. S. Shakir, and H. N. Hashmi, "Safe Passage of Riverine Flood from Highly Urbanized City: A Case Study of Lahore City in Pakistan," J. Civ. Environ. Eng., vol. 08, no. 04, 2018, doi: 10.4172/2165-784x.1000320.

[4] H. S. Chang and T. L. Chen, "Spatial heterogeneity of local flood vulnerability indicators within flood-prone areas in Taiwan," Environ. Earth Sci., vol. 75, no. 23, 2016, doi: 10.1007/s12665-016-6294-x.

[5] Y. Hirabayashi et al., "Global flood risk under climate change," Nat. Clim. Chang., vol. 3, no. 9, pp. 816–821, 2013, doi: 10.1038/nclimate1911.

[6] A. Ali, Mechanisms , Impacts , and Management. 2013.

[7] K. Ahmad and W. Al, "Variation in the ravi river water quality," Sanit. Water All Proc. 24th WEDC Conf., pp. 153–156, 1998.

[8] H. A. Shakir and J. I. Qazi, "'Impact of industrial and municipal discharges on growth coefficient and condition factor of major carps from lahore stretch of river Ravi,'" J. Anim. Plant Sci., vol. 23, no. 1, pp. 167–173, 2013.

[9] M. Akhtar, S. Mahboob, S. Sultana, T. Sultana, K. A. Alghanim, and Z. Ahmed, "Assessment of pesticide residues in flesh of Catla catla from Ravi River, Pakistan," Sci. World J., vol. 2014, 2014, doi: 10.1155/2014/708532.

[10] R. G. Death, I. C. Fuller, and M. G. Macklin, "Resetting the river template: The potential for climate-related extreme floods to transform river geomorphology and ecology," Freshw. Biol., vol. 60, no. 12, pp. 2477–2496, 2015, doi: 10.1111/fwb.12639.

[11] K. Chapi et al., "Spatial-Temporal Dynamics of Runoff Generation Areas in a Small Agricultural Watershed in Southern Ontario," J. Water Resour. Prot., vol. 07, no. 01, pp. 14–40, 2015, doi: 10.4236/jwarp.2015.71002.
[12] K. Komi, J. Neal, M. A. Trigg, and B. Diekkrüger, "Modelling of flood hazard extent in data sparse areas: a case study of the Oti River basin, West Africa," J. Hydrol. Reg. Stud., vol. 10, pp. 122–132, 2017, doi: 10.1016/j.ejrh.2017.03.001.
[13] K. Khosravi et al., "A comparative assessment of flood susceptibility modeling using Multi-Criteria Decision-Making Analysis and Machine Learning Methods," J. Hydrol., vol. 573, pp. 311–323, Jun. 2019, doi: 10.1016/J.JHYDROL.2019.03.073.
[14] Z. Zhu et al., "Benefits of the free and open Landsat data policy," Remote Sens. Environ., vol. 224, no. February, pp. 382–385, 2019, doi: 10.1016/j.rse.2019.02.016.
[15] M. K. Shah, M. E. Student, A. T. Motiani, and I. Prakash, "Assessment of Coastal and Adjacent Area Flooding of Jamnagar District Using Remote," vol. 1, no. 11, pp. 68–75, 2015.
[16] G. Ettritch, A. Hardy, L. Bojang, D. Cross, P. Bunting, and P. Brewer, "Enhancing digital elevation models for hydraulic modelling using flood frequency detection," Remote Sens. Environ., vol. 217, no. August, pp. 506–522, 2018, doi: 10.1016/j.rse.2018.08.029.
[17] A. R. da Paz, W. Collischonn, C. E. M. Tucci, and C. R. Padovani, "Large-scale modelling of channel flow and floodplain inundation dynamics and its application to the Pantanal (Brazil)," Hydrol. Process., vol. 25, no. 9, pp. 1498–1516, 2011, doi: 10.1002/hyp.7926.
[18] J. Neal, G. Schumann, and P. Bates, "A subgrid channel model for simulating river hydraulics and floodplain inundation over large and data sparse areas," Water Resour. Res., vol. 48, no. 11, pp. 1–16, 2012, doi: 10.1029/2012WR012514.
[19] M. A. Butt et al., "Flood Frequency Analysis of Chenab River for Predicting Peak Flows during Late Monsoon Period," Adv. Remote Sens., vol. 08, no. 01, pp. 1–29, 2019, doi: 10.4236/ars.2019.81001.
[20] H. Aksoy, V. S. Ozgur Kirca, H. I. Burgan, and D. Kellecioglu, "Hydrological and hydraulic models for determination of flood-prone and flood inundation areas," IAHS-AISH Proc. Reports, vol. 373, pp. 137–141, 2016, doi: 10.5194/piahs-373-137-2016.
[21] P. Dimitriadis et al., "Comparative evaluation of 1D and quasi-2D hydraulic models based on benchmark and real-world applications for uncertainty assessment in flood mapping," J. Hydrol., vol. 534, pp. 478–492, 2016, doi: 10.1016/j.jhydrol.2016.01.020.
[22] F. Zhang, S. Ahmad, H. Zhang, X. Zhao, X. Feng, and L. Li, "Simulating low and high streamflow driven by snowmelt in an insufficiently gauged alpine basin," Stoch. Environ. Res. Risk Assess., vol. 30, no. 1, pp. 59–75, 2016, doi: 10.1007/s00477-015-1028-2.
[23] F. Onen and T. Bagatur, "Prediction of Flood Frequency Factor for Gumbel Distribution Using Regression and GEP Model," Arab. J. Sci. Eng., vol. 42, no. 9, pp. 3895–3906, 2017, doi: 10.1007/s13369-017-2507-1.
[24] M. G. and M. G. Jaya Gupta, "The Lomax-Gumbel Distribution," Palest. J. Math., vol. 5, no. 1, pp. 35–42, 2016.
[25] Y. M. Gómez, H. Bolfarine, and H. W. Gómez, "Gumbel distribution with heavy tails and applications to environmental data," Math. Comput. Simul., vol. 157, pp. 115–129, 2019, doi: 10.1016/j.matcom.2018.10.003.
[26] S. Ahmed and I. Tsanis, "Climate Change Impact on Design Storm and Performance of Urban Storm-Water Management System - A Case Study on West Central Mountain Drainage Area in Canada," J. Waste Water Treat. Anal., vol. 07, no. 01, pp. 1–11, 2015, doi: 10.4172/2157-7587.1000229.