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Assessment of Vulnerable Houses in Populated Areas along a River Valley due to Possible Severe Flooding for Long-term Flood Safety Management

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ABSTRACT

Floods are one of the key natural disasters that have always been problematic for human beings. The extreme flooding can cause severe damage to both the people and property located in an area. This study focusses on the precise assessment of vulnerable houses in both rural and urban populated areas along a river valley in case of high flooding. For this purpose, about 286 km long study reach of Jhelum River downstream of Mangla dam in Pakistan has been chosen for analysis. Based on the available data, unsteady flow modeling on the study reach has been carried out by using the model MIKE-11. The flood routing was performed for the highest past flood event i.e. 1992 flood having maximum outflow of 26,293 m^3/s from Mangla dam. Based on the extension of flooding and existing position of houses, the number of people at risk (PAR) and vulnerable houses along the study reach has been estimated using the 2017-census data. Total estimated PAR is about 1785483. The total number of vulnerable houses has been estimated to be about 278186 out of which 56.5% are rural houses and 43.5% are urban houses. Further as per available data, the assessment of vulnerable houses in rural and urban populated areas has been categorized with respect to the materials used in their roofs and walls. The results of this research would definitely help in improving the existing flood protection measures along the Jhelum River as well as in planning new useful flood resilient measures.

Keywords: Jhelum River Valley; vulnerable houses; people at risk; flood safety; MIKE-11

INTRODUCTION

Floods are consistently regarded as one of the greatest threats that might result in significant catastrophe. High floods might have a big influence on people and infrastructure as well. In flood management projects, the risk of flooding has always been a major concern. Particularly in a river stretch below a dam, the danger of inundation is increasingly noticed as essential for effective floodplain management. Catastrophic floods can occur because of dam break or excessive outflows caused by severe weather fluctuations, even if the dam remains undamaged (Ehsan et al. 2024; Ehsan et al. 2016).The floods in Pakistan affect a large number of individuals each year. The causes of each form of

flooding are distinct (Afzal and Ehsan, 2015; Ehsan et al. 2024; Natarajan and Nisha, 2020; Munoz et al. 2022; Sopery et al. 2022).Depending on the shape of the river valley, the flow patterns change. The degree of inundation also varies in relation to the specific form of the river reach when there is severe flooding in a river valley. The way that a river valley reacts to floodwater will vary greatly across different rivers. The improvement of current

flood resilience measures are crucial in river valleys inorder to reduce the long-term harm caused by floods (Ehsan et al. 2016; Ehsan, 2009).

Pakistan's varied topography makes it prone to floods. During this period, riverine flooding is common in low-lying regions along the river, while flash floods are also occurring in hilly and semi-hilly areas. The snow melt flow from the river's catchment areas combned with heavy precipitation causes the floods in Pakistan (Ehsan et al. 2024; Khan 2013).

Pakistan, as a developing nation, lacks the resources to handle its natural flood catastrophes effectively. Thus, it results in significant losses of resources, agriculture, and most crucially, lives (Ehsan et al. 2024; Khan 2013).

Flood prediction models are essential for risk analysis and extreme event management. Reliable and precise flood predictions aid in water resource management, policy recommendations, and analysis. The importance of advance

systems for both short-term and longterm forecasting of hydrological occurrences, has enhanced in order to reduce the harm. Because of the active type of weather situations, it is inherently challenging to estimate flood occurrence. Consequently, flood modeling relies heavily on data and several presumptions (Solomatine and Ostfeld, 2008; Mosavi et al. 2018).

The study reach of Jhelum River downstream of Mangla dam in Pakistan is the focus of this research. One of the huge earth and rock-fill dams in the world, Mangla dam rises about 125 m above the riverbed. The main dam's crest length is around 2561m. (WAPDA 2004). The Mangla reservoir's water surface area is approximately 253 km^2 under normal operating conditions, and its original catchment area is about 33360 km^2 (WAPDA 2001).

With a variety of hydraulic structures including different bridges and five tributaries; Figure 1 depicts the Jhelum River valley between the Mangla dam and the Trimmu barrage. The main hydraulic structures are Jhelum bridges, Rasul barrage, Malikwal bridge and Khushab bridge. There are five tributaries between Mangla dam and Rasul barrage; Suketar nallah, Bandar kas, Jabba kas, Kahan river and Bunha river. Further, Figure 1 also shows the confluence point of the Jhelum river and Chenab river (Ehsan 2009).

The majority of the people located along the Jhelum River is engaged in agriculture and lives in rural areas. The Mangla dam supplies electric power to downstream areas and also irrigates the downstream fields of agriculture. Some urban populated locations are also included in the project area i.e. Jhelum City, Pind Dadan Khan, Malikwal, Bhera, Khushab, Jouharabad, Sahiwal etc. (Ehsan 2009).

Depending on available data, the study reach of about 286 km has been considered for one-dimensional unsteady flow modeling in MIKE-11. The simulations were run for different flooding scenarios. By analyzing the flood routing results and using the available 2017-census data, a thorough assessment has been carried out for the population and houses/buildings along the study reach, vulnerable to flooding.

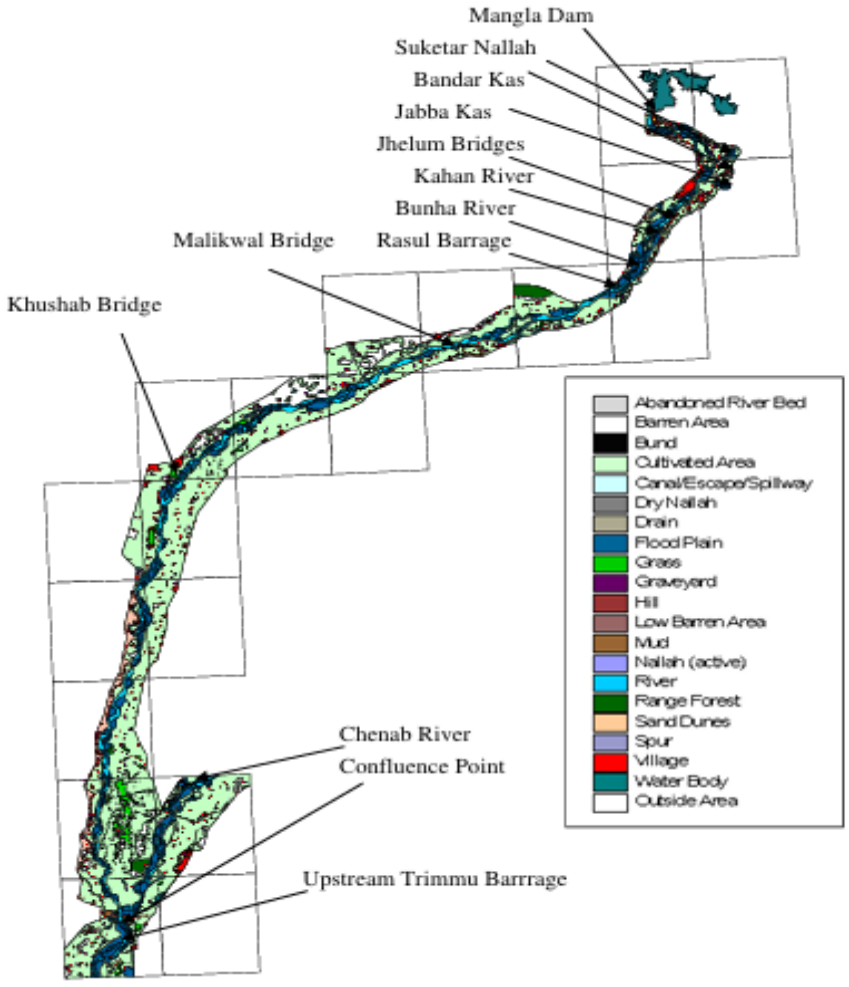


FIGURE 1. Study Reach of Jhelum River

LITERATURE REVIEW

Some of the recent flood studies based on modelling in MIKE Software as mentioned in Table 1.

TABLE 1. Summary of Literature Review

Author(s)/Year	Models Utilized
Liu et al. (2020)	MIKE Flood
Tansar et al. (2020)	MIKE Flood
Chen et al. (2021)	MIKE-11
Mir et al. (2022)	MIKE-11
Ghosh et al. (2022)	MIKE-11/MIKE-21
Farooq et al. (2023)	MIKE-11/ MIKE-21
Tuan et al. (2024)	MIKE-11/MIKE-21
Yang et al. (2024)	MIKE-11

The MIKE Flood was used by Liu et al. (2020) to do urban flood modeling. This modeling was based on the integration of the hydrodynamic models MIKE-11 and MIKE-21 to study the flood submergence caused by a burst levee or proactive flood diversion in the City of Qiqihar.

Flood inundation modeling and hazard assessment in Lower Ping River Basin, Thailand was conducted by Tansar et al. (2020) using MIKE Flood. The coupled 1D-2D hydrodynamic (HD) modeling package was applied for different return periods to investigate and classify flood hazards. Chen et al. (2021) used MIKE-11 to analyze the flood evolution of Yihe river channel by NAM hydrological model and 1-D hydrodynamic model (HD). The calculated results of hydrological model were used as the lateral inflow conditions of HD model.

At the lake site and downstream site of the Dalung Proglacial Lake, which is situated in the Suru catchment of the Zanskar River, Indus River Basin, Western Himalayas, Mir et al. (2022) used MIKE-11 for one-dimensional hydrodynamic modeling of Glacial Lake Outburst Floods (GLOFs).

To create a comprehensive hydrodynamic flood modeling framework for Mumbai, India's Mithi catchment, Ghosh et al. (2022) employed MIKE11 (1D) for river discharge and stormwater drainage

discharge in conjunction with a two-dimensional

flood model (MIKE-21) to simulate the overland flow in the MIKE FLOOD platform along with the major flood influencers such as rainfall and tidal elevation.

To analyze the flood dynamics in the Huaihe River, Farooq et al. (2023) employed the Saint-Venant equation along with a one-dimensional MIKE-11 model were used to understand the flood dynamics in the Huaihe River and a two-dimensional MIKE-21 model was used to evaluate the risk in the Cinan Feizuo flood protection zone.

To assess floods in the lower Ba River Basin, Vietnam, Tuan et al. (2024) employed MIKE Flood, a combined model of MIKE-11(1D) and MIKE-21(2D) to determine the degree of flooding for the downstream Ba River, Phu Yen province. Yang et al. (2024) used the MIKE-11 by integrating the rainfall-runoff module and hydraulic module to simulate various water flow scenarios considering different rainfall and operating conditions in order to examine the flood control features of a study region in the Guo River Basin, which is located in the Northern Anhui Plain.

MODELLING CONCEPT IN MIKE-11

The calculations for simulations of unsteady flow are based on hydrodynamic flow circumstances. The implicit finite Difference scheme created by (Abbott and Ionescu 1967) serves as the foundation for one- dimensional flood modelling. MIKE-11 being a hydrodynamic tool, uses the 'de Saint Venant' equations, which are based on the conservation of mass and conservation of momentum (DHI 2017).

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left[\alpha \frac{Q^2}{A}\right]}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \tag{2}$$

Where,
Q = discharge (m^3/s)
A = flow area (m^2)
q = lateral inflow (m^3/s)
h = stage above datum (m)
C = chezy resistance coefficient ($m^{1/2}/s$)
R = hydraulic or resistance radius (m)
α = momentum distribution coefficient

The de Saint Venant equations are converted into a set of implicit finite difference equations using a computational grid of alternating 'Q' points and 'h' points; points where the discharge (Q) and water level (h) are calculated at every time step as indicated in Figure 2 (DHI 2017). According to the user's specifications, the model automatically creates the computational grid. The Q-points are always positioned midway between adjacent h-points, whereas the separation between h-points might vary. The discharge is generally considered to be positive in the positive horizontal direction (distance is increasing).

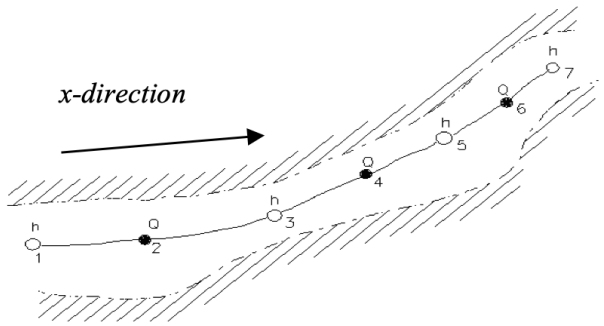


FIGURE 2. Computational grid of a Channel Section

MODELLING IN MIKE-11

Due to strong ability of accurately modeling complex river systems in comparison to other tools, MIKE-11 has been chosen for modelling the study reach. According to the available cross-sectional data and other related information, the model was set up in MIKE 11 for one-dimensional unsteady flow modeling. The river valley is exceptionally wide and shallow, with a mild longitudinal average slope of approximately 0.0004. Due to unavailability of reliable roughness data, an average value of 0.05 (Manning's 'n') has been adjusted for calibration and further used for all considered scenarios.

Based on available data several hydraulic structures have beenidentified at the corresponding downstream sites. For all modeling scenarios, the upstream and downstream boundary conditions are an outflow hydrograph at Mangla dam and respective water levels upstream of Trimmu barrage. Additionally, the contribution of five tributaries between Mangla dam and Rasul barrage (Figure 1) has also been introduced as inflow boundaries.

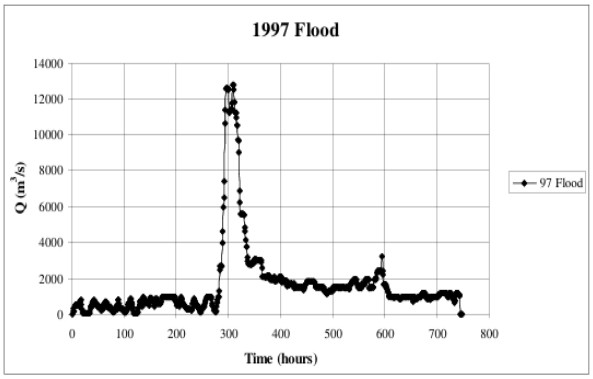


FIGURE 3. Peak Outflow Hydrograph at Mangla-97 Flood

The model has been calibrated for the 1997 flood with the maximum discharge of 12,798 m^3/s as shown in Figure 3. The available outflow hydrograph (97-flood) downstream of Mangla dam (Figure 3) has been taken as upstream boundary condition for calibration and the available time varying water level upstream of Trimmu barrage has been defined as downstream boundary condition. Further, as per data availability, the contribution of tributaries was added, and different hydraulic structures were also defined at the respective locations.

Depending on the available data, the calibration was done mainly at Rasul barrage by comparing the measured peak discharge with the simulated value as shown in Figure 4.

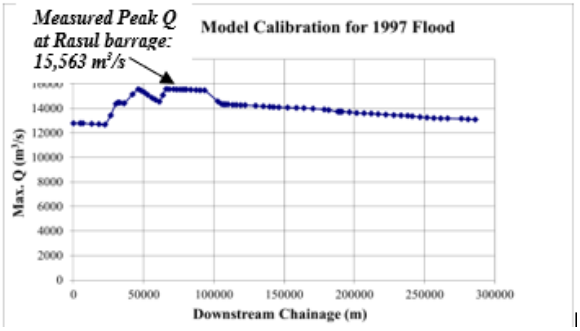


FIGURE 4. Model Calibration for 1997 Flood

FLOOD ROUTING FOR PAST HIGHEST FLOOD

The biggest flood occurred in 1992, having maximum outflow of 26,293 m^3/s from Mangla dam, has been selected for flood routing in the model. Figure 5 shows the hydrograph for 92-flood (Ehsan, 2009). Further, the contributions of tributaries have been added accordingly at different locations as per data availability

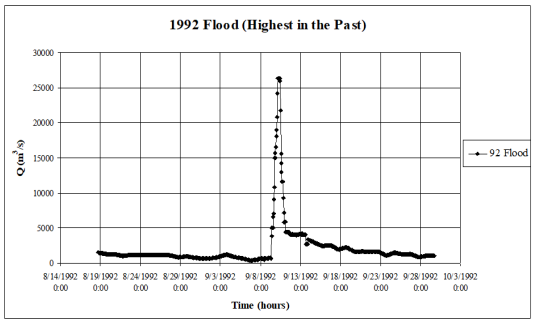


FIGURE 5. Past Highest Flood downstream of Mangla dam

The flood routing results for 1992 flood are shown in Figure 6. The highest peak discharge is 28,520 m^3/s at Chainage 42118 m. Due to contribution of tributaries; maximum discharge values are increasing at the respective river locations.

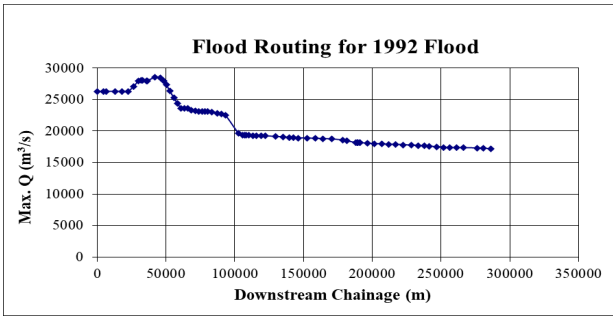


FIGURE 6. Flood Routing Results for 1992 Flood

ANALYSIS OF RESULTS

The simulated results of flood routing for 1992 flood scenario were further analyzed for the estimation of number of people at risk (PAR) and vulnerable houses in populated areas located along the study reach.

ESTIMATION OF PAR

Based on the extent of flooding as per simulated results, the available location of houses on maps and 2017- Census data, the vulnerable population in terms of people at risk (PAR) has been estimated along the study reach for 1992 flood scenario. The PAR along the study reach is both rural and urban as shown in Figure 7. Total estimated PAR is 1785483. Overall, the rural PAR is higher than the urban PAR as displayed in Figure 7. The maximum total PAR has been estimated at Chainage 31904 m along the study reach downstream of Mangla dam.

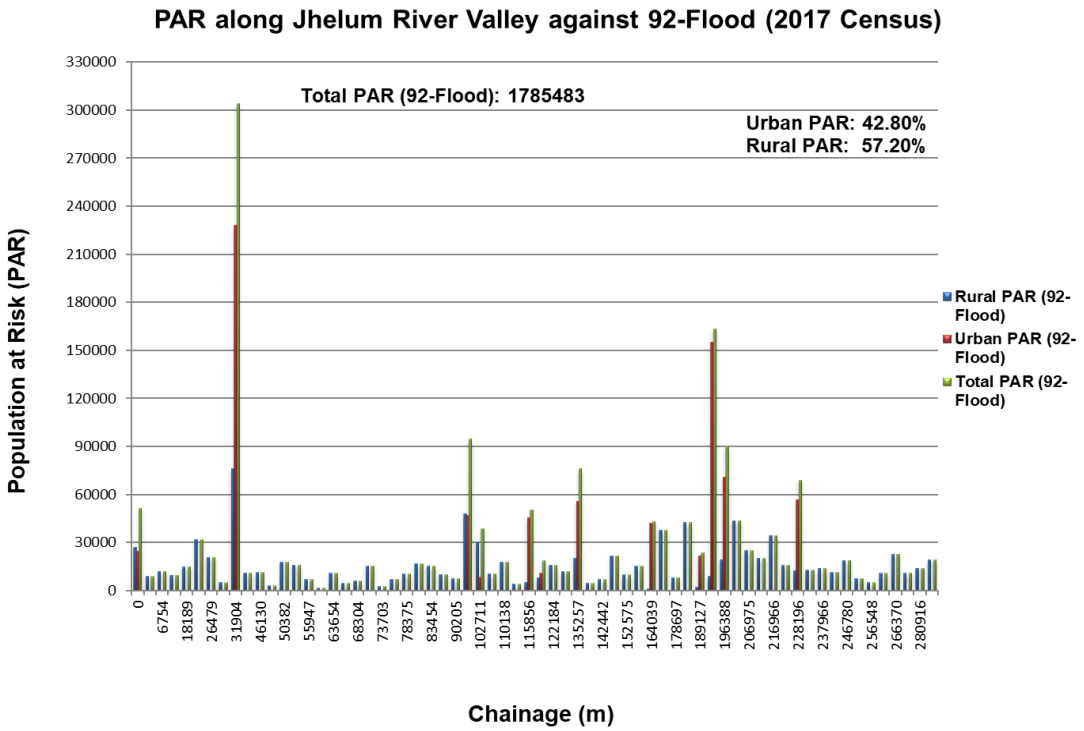


FIGURE 7. Estimated PAR along Jhelum River Valley against 92-Flood (2017 Census)

ASSESSMENT OF VULNERABLE HOUSES

Analyzing the expansion of flooding along the riverbanks of the study reach as per simulation of 1992 flood scenario, the available location of houses in populated areas and housing data of 2017 Census, the number of vulnerable houses along the study reach has been assessed as shown in Figure 8.

The number of vulnerable houses against the 1992 flood varying along the Jhelum River valley as per location of the populated areas. The total number of vulnerable houses has been estimated to be about 278186 out of which 56.5% are rural houses and 43.5% are urban houses. The maximum number of possible vulnerable houses in both urban and rural populated areas along the study reach has been evaluated at the Chainage 31904m downstream of Mangla dam.

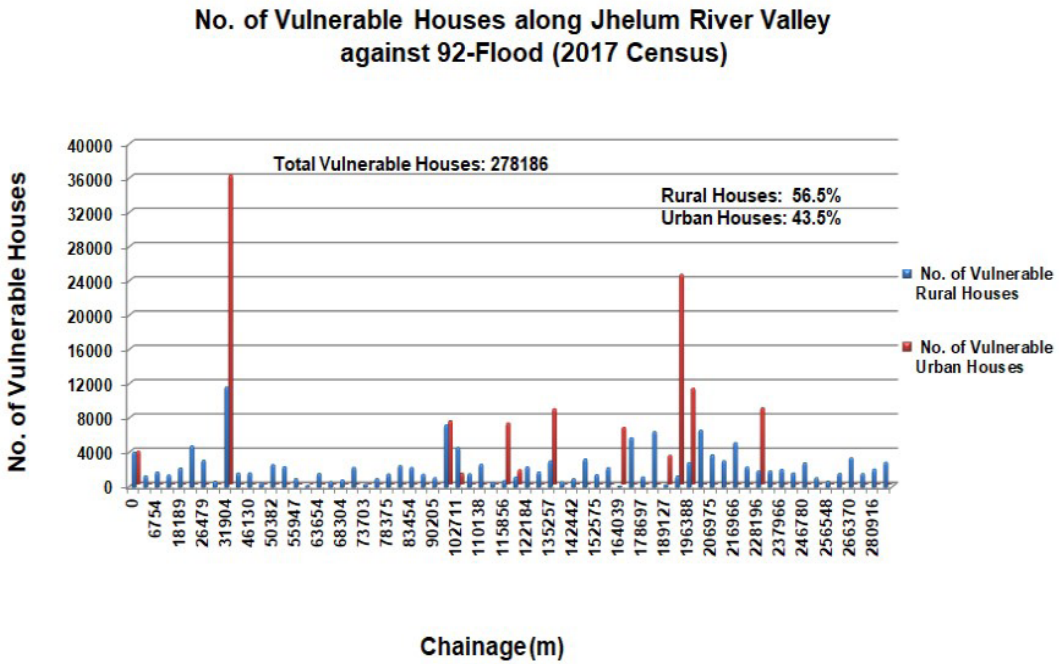


FIGURE 8. Vulnerable Houses along Jhelum River Valley against 92-Flood (2017 Census)

CATEGORIZATION OF VULNERABLE HOUSES

Based on the available data of housing units for rural and urban areas from 2017 Census, the estimated vulnerable houses for 1992 flood scenario have been further categorized with respect to the material used in their roofs and walls.

RURAL HOUSES WITH DIFFERENT ROOF MATERIALS

Figure 9 classifies the possible vulnerable houses in rural populated areas located along the study reach according to the materials used in their roofs. The roof materials used in rural houses include the following (2017 Census):

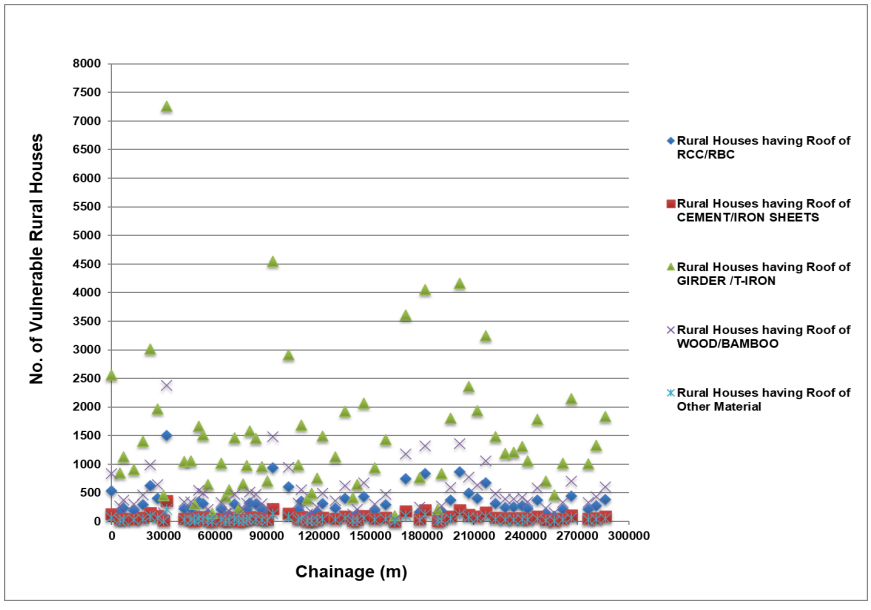


FIGURE 9. Vulnerable Houses in Rural Areas with different Roof Materials (2017 Census)

1. RCC/RBC
2. Cement/Iron Sheets
3. Girder/T-Iron
4. Wood/Bamboo
5. Other materials

Most of the roofs of vulnerable rural houses along the study reach are made of Girder/T-Iron as indicated in Figure 9.

Further, the partial utilization of Wood/Bamboo in roofs of vulnerable houses has been seen along the Jhelum River valley.

However, limited use of RCC/RBC in roofs of vulnerable rural houses has also been noticed along the study reach as shown in Figure 9.

RURAL HOUSES WITH DIFFERENT WALL MATERIALS

Figure 10 displays various categories of vulnerable rural houses with different wall materials including Baked bricks/Blocks/Stones, Unbaked Bricks/Mud, Wood/Bamboo and other materials (2017 Census).

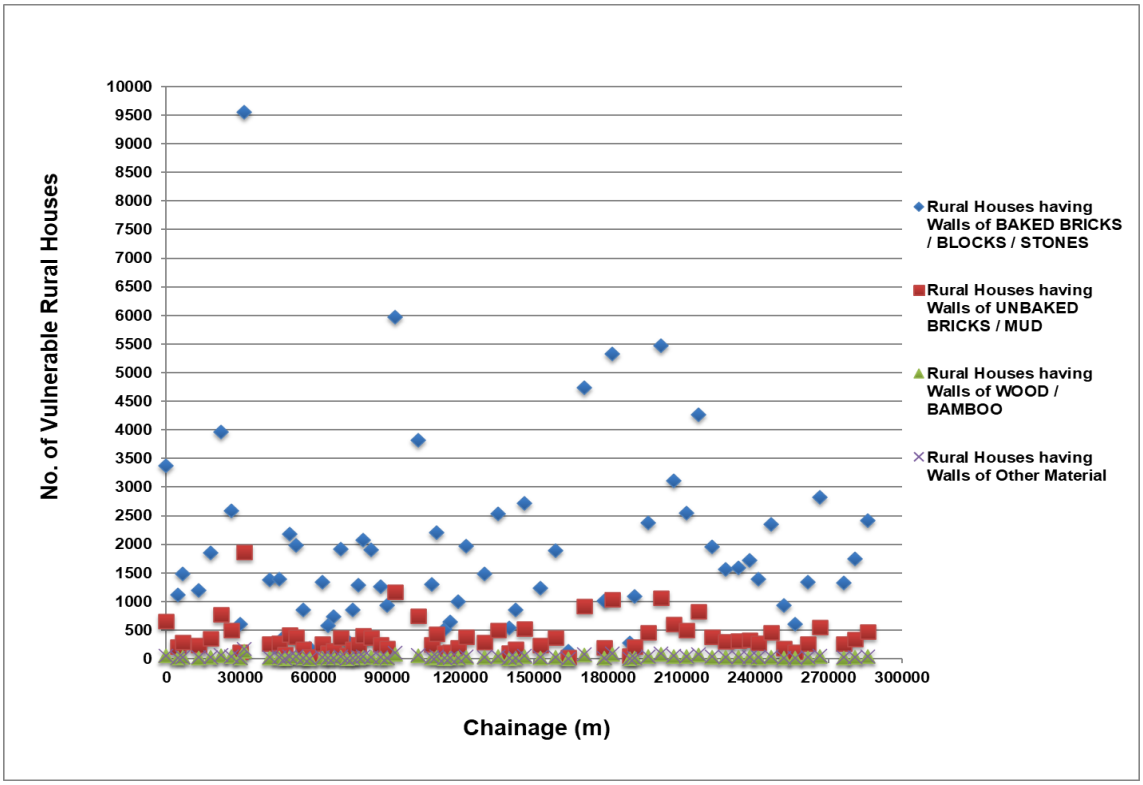


FIGURE 10. Vulnerable Houses in Rural Areas with different Wall Materials (2017 Census)

Majority of vulnerable rural houses along the study reach have walls of Baked bricks/Blocks/Stones. Secondly, the partial use of Unbaked bricks/Mud in walls of vulnerable rural houses has been seen along the Jhelum River valley as depicted in Figure 10.

URBAN HOUSES WITH DIFFERENT ROOF MATERIALS

The estimated vulnerable houses in urban areas have been categorized with respect to the same roof materials as already mentioned in the case of rural houses as displayed in Figure 9. However, the use of roof materials is quite different in vulnerable urban houses. Most of the vulnerable urban houses have roofs of RCC/RBC as shown in Figure 11. Further, significant number of urban houses are made of Girder/T-Iron. Limited number of vulnerable urban houses have been seen with roof materials of Cement/Iron Sheets and Wood/Bamboo at different locations along the study reach as depicted in Figure 11.

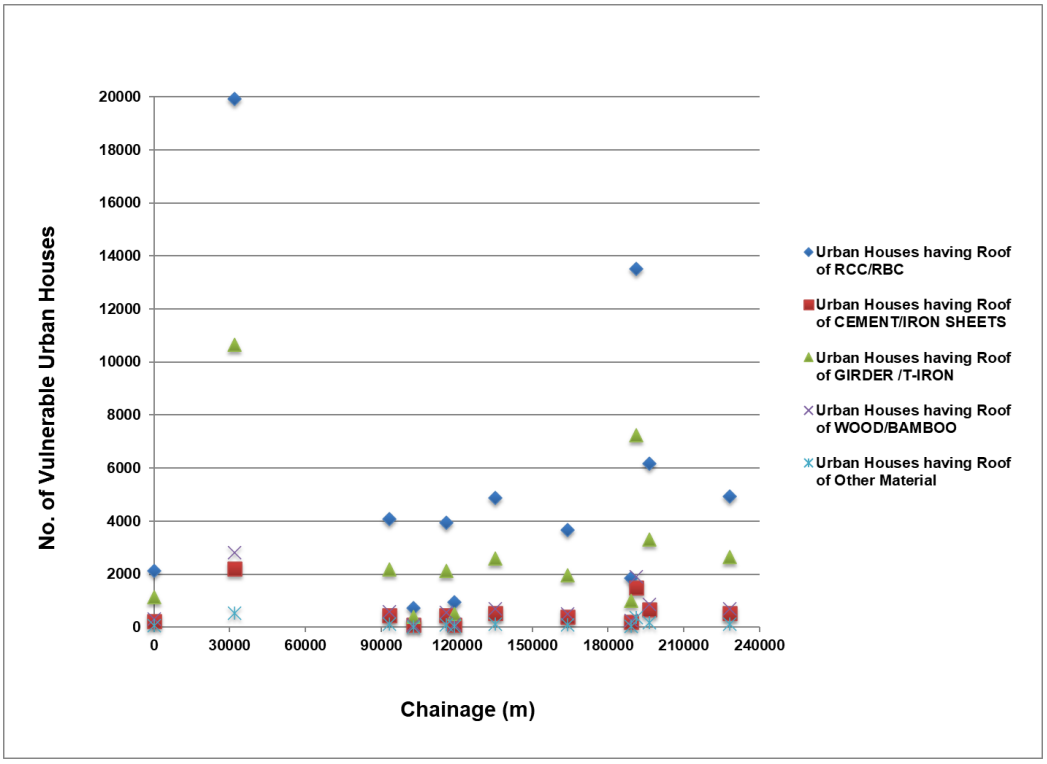


FIGURE 11. Vulnerable Houses in Urban Areas with different Roof Materials (2017 Census)

URBAN HOUSES WITH DIFFERENT WALL MATERIALS

Figure 12 shows the multiple types of vulnerable urban houses with different wall materials. Almost all vulnerable houses in urban populated areas along the study reach have walls of Baked bricks/Blocks/Stones.However, very small number of urban houses with other wall materials have also been noticed along the Jhelum River valley.

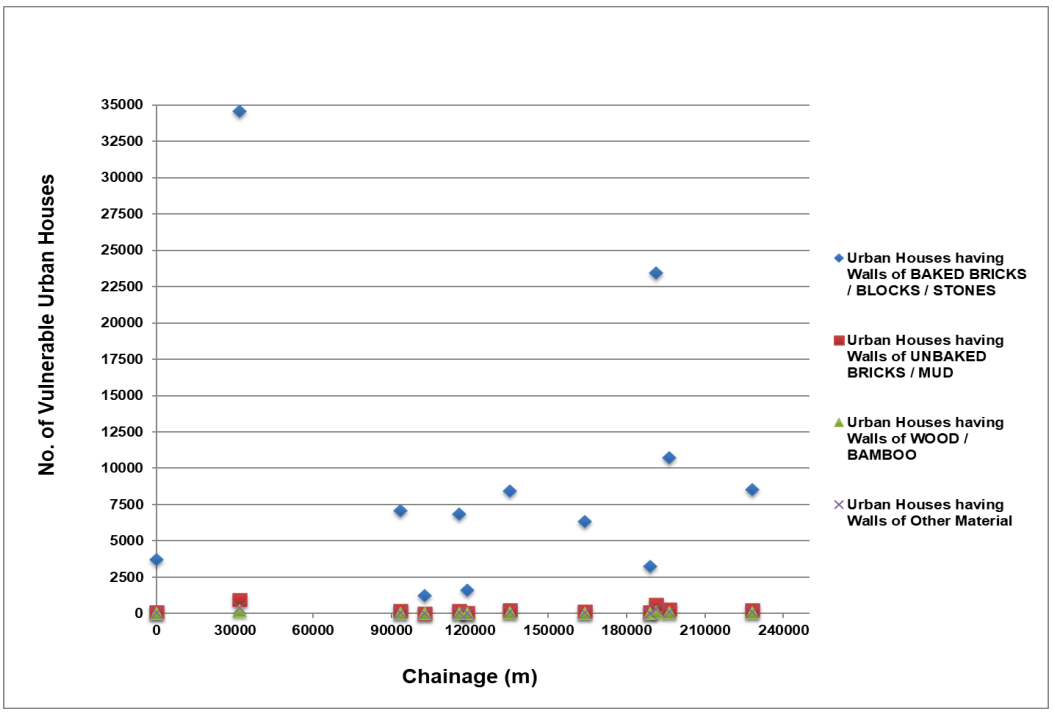


FIGURE 12. Vulnerable Houses in Urban Areas with different Wall Materials (2017 Census)

CONCLUSIONS AND SUGGESTIONS

The evaluation of probable damage to the people and property in case of extreme flooding always plays a key role in planning flood resilience strategies for long-term flood safety management. This study provides detailed estimation of possible vulnerable population and houses in the populated areas located along the Jhelum River valley for the flooding scenario of the biggest flood event occurred in 1992 having maximum discharge of 26,293 m^3/s.

Based on the flood routing results of 1992 flood and 2017-census data, the total vulnerable population in terms of people at risk (PAR) has been estimated to be about 1785483 out of which the rural PAR is 57.20% and urban PAR is 42.80%. Further, based on the available location of houses in vulnerable populated areas and housing data of 2017 Census, the number of vulnerable houses along the study reach has been assessed.

The total number of vulnerable houses has been estimated to be about 278186 out of which 56.5% are rural houses and 43.5% are urban houses. At Chainage 31904 m along the study reach, the maximum possible vulnerable population as well as the vulnerable houses have been estimated. Moreover, depending on the available data of housing units for rural and urban areas from 2017 Census, the estimated vulnerable houses for 1992 flood scenario have been further categorized with respect to the material used in their roofs and walls. Mostly, the roofs of vulnerable rural houses along the study reach are made of Girder/T-Iron. Further, the Wood /Bamboo have been partially utilized in roofs of vulnerable rural houses. However, the limited use of RCC/RBC in roofs of rural houses has also been noticed along the study reach.

A very large number of vulnerable rural houses along the study reach have walls of Baked bricks/Blocks/Stones. Further, the partial use of Unbaked bricks/Mud in vulnerable rural houses has also been seen along the Jhelum River valley. Most of vulnerable urban houses have roofs of RCC/RBC. Further, considerable number of urban houses are made of Girder/T-Iron.

Limited number of vulnerable urban houses have been seen with roof materials of Cement/Iron Sheets and Wood/ Bamboo at different locations along the study reach. A very large number of vulnerable houses in urban populated areas along the study reach have walls of Baked bricks/Blocks/ Stones. However, a slight number of vulnerable urban houses with walls of other materials has also been found.

This study shows the precise estimation of the people and property along the Jhelum River valley vulnerable to high flooding in case of 1992 flood scenario. The results of this research would be quite useful for planning the enhancement in existing flood protection measures both structural and non-structural, as well as introducing new safety measures along the Jhelum River downstream of Mangla dam.

Therefore, the concerned authorities are urged to consider this precise assessment of vulnerable population and houses in both rural and urban areas located along the Jhelum River valley due to a possible extreme flood event like 1992 flood, for strengthening the existing flood embankments/bunds along the Jhelum River and improving the flood warning/ emergency evacuation techniques. Further this study would also help in planning the strategies for sustainable flood resilience management.

Further, this study provides valuable guidelines for the realistic estimation of population and property vulnerable to flooding, located along the river valleys in Pakistan as well as in other parts of the world to ensure proper flood risk management. It is suggested to compare the results of this research with the reliable available data of population and houses in the study area, which get affected by a similar flood event in future, in order to identify the gaps in assessment of the current research. Further it is recommended to carry out detailed assessments of possible risks of flooding in the study area using the results of this study for long-term flood safety management.

ACKNOWLEDGEMENT

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DECLARATION OF COMPETING INTEREST

None.

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