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# Risk assessment of Rawal dam outburst flood using integrated hydrological and geo-spatial approaches

**Alishba Touseef [1], Shakeel Mahmood*[1]**

[1]*Government College University, Department of Geography, Lahore, Pakistan*

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**ABSTRACT**

This study is an effort of Rawal Dam outburst flood risk assessment using integrated hydrological and geo-spatial approaches. Satellite data sets including Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Landsat-8 image having 30 m spatial resolution were downloaded from United State Geological Survey (USGS) geo-database. Watershed modeling was applied to delineate the catchment area and drainage geo-visualize network. Spatial hydrological model was utilized to the vertical and horizontal profile of estimated flood in the downstream areas in case of dam breaching. Similarly, Google Earth Pro was used to calculate lake volume. The estimated flood has depth of more than 15 m. Downstream areas are at high risk. The results of the study can assist disaster management authorities and decision-makers in devising location specific effective flood risk reduction strategies in the region.

## 1. Introduction

Globally, flood is one of the destructive hazard causing damages to the properties, economies and lives (Mahmood & Rani, 2022). Around 70% of the human population is living in or in the proximity of flood hazard zones (Aksoy et al. 2016). Flood is the abnormal behaviour of the river with heavy discharge comparatively more than the river's channel capacity leading to inundation of the adjacent dry areas. Similarly, Geo-morphometric characteristics and surface runoff are the main factors of flash flood genesis (Mahmood, 2019). The high intensity rainfall and melting of snow and glaciers add huge volume of water beyond the channel's capacity and cause overtopping (Mahmood & Ullah, 2016; Mahmood et al., 2016). The frequency and magnitude of floods has been increased because of climatic variability and changing trends of economic activities. The increase in investment in flood prone areas has increased flood risk (Mahmood & Rani, 2018; Mahmood & Hamayon, 2021). The frequency and intensity of extreme rainfall events are still on rise. Pakistan is exposed to hydro-meteorological, geological and biological hazards (Mahmood et al., 2019; Gull & Mahmood, 2022). Flood is one of the hydro-meteorological hazards and may lead to dam lake outburst flooding.

Generally, most of the recent studies consider either the probability analysis of dam overtopping or estimation of economic loss estimates caused by dam failure (Mo & Liu, 2010). Some studies are; Aboelata et al. (2003) used GIS model and estimated dam risk failure and life loss. de Béjar (2011) discussed more about risk of barriers in watershed-reservoir-dam systems being overtopped by floods. They converted a haphazard representation of the hourly rain from the storm into effective surface runoff, containing losses from surface retention, interception, and evaporation. They compared the annual maximum series models' overtopping probability to those based on monthly maximum series models. Zhong et al. (2011) suggested a risk-based analysis approach for assessing the risk of hydrological factors, seepage and bank slope failure, respectively, and for evaluating the integrated risk by coupling these factors. Li et al. (2012) developed a LHS-MC method to appraise dam burst risk. A new evaluation model built on the interval analytic hierarchy process (IAHP) and the expansion of methodology for improved outcomes was presented by Zhang et al. (2013). The interval data improves the degree of risk identification confidence for hydropower projects. Yang et al. (2013) proposed a systematic strategy for the assessment of inundation risks brought on by the construction and breach of landslide dams, which included the evaluation of the

* **Corresponding Author**
(anumg977@gmail.com) ORCID ID (Not Available)
*(shakeelmahmoodkhan@gmail.com) ORCID ID 0000-0001-6909-0735

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likelihood of a breach, the risk of inundation upstream and downstream, and the classification of flood hazards. Du et al. (2020) examined the risk of tailings dams using InSAR time series technique. Psomiadis et al. (2021) used the HEC-RAS technique and satellite data to estimate the danger of dam outburst and flood wave. The importance of risk assessment of ageing dams portfolio was emphasized by Concha Larrauri et al. (2023).

Flood overtopping risk contains the probability that the water level exceeds the dam and the associated consequences caused by the dam accidents, in the design reference period. From the view of probability theories, it synthesizes disciplines of reliability math, stochastic hydrology, stochastic hydraulics, engineering economics, and social statistics and so on, to make the best of the balance between flood control and flood utilization benefits (Zhang & Tan, 2014). The risk of dam lake outburst flooding is also increasing because of increasing intensities of rainfall leading to unprecedented discharge in the river channel. The high-level discharge can overtop the dam or may lead to dam burst. Therefore, the aim of this study is to assess the risk of Rawal Dam outburst flooding in downstream areas using integrated hydrological and geo-spatial approaches.

The risk of dam lake breach and the related effects brought on by dam accidents are included in the flood overtopping risk during the design reference period. Making the most of the balance between flood control and flood utilisation benefits requires taking into account probability theories, stochastic hydrology and hydraulics, engineering economics, sociological statistics, and other factors (Zhang & Tan, 2014). Because of the intensifying rainfall that is causing an exceptional discharge in the river channel, the probability of dam lake outburst floods is also rising. The high-level discharge may cause the dam to burst or cause it to topple. The purpose of this study is to evaluate the potential for flooding caused by an outburst at Rawal Dam using integrated hydrological and geospatial methodologies.

## 2. Study Area

Relatively, Rawal dam is located in Margalla Hills and covering an area of 8.8 km$^2$ (Samad et al., 2016). The government of Pakistan constructed it in 1962 on the Korang River along with some other small streams originating from Margalla Hills (Ahmed et al., 2021). It is the partly arched gravity dam with crest level 534 m and crest length 210 m (Figure 1). Water may be discharged at a rate of 80,000 cusecs (cubic feet per second) via eight Ogee gated spillways. It is able to command an agricultural area of 500 acres (2 km$^2$). The live storage capacity of Rawal dam is 37,500-acre feet (ft) and the dead storage capacity is 45,00-acre ft with a gross capacity being 42000-acre ft. Its saddle length is 6,991 ft (2,131 m) and its height of 24 ft (7.3 m). Whenever there is an increase in water level of more than its capacity its spillways get open (Mateen & Garstang, 2008). The left bank canal of Rawal dam is Shahana Disty with a capacity of 40 ft$^3$/s used for irrigation purposes and the right bank canal of it is Ojri Disty with a capacity of 70ft$^3$/s supplying 100-acre ft of drinking water to Rawalpindi. Four main and 43 tributary streams from the Margalla Hills feed Rawal Lake in a typical rainfall year. The flash and riverine floods are generated by heavy rains in catchment regions of major and other tributary streams.

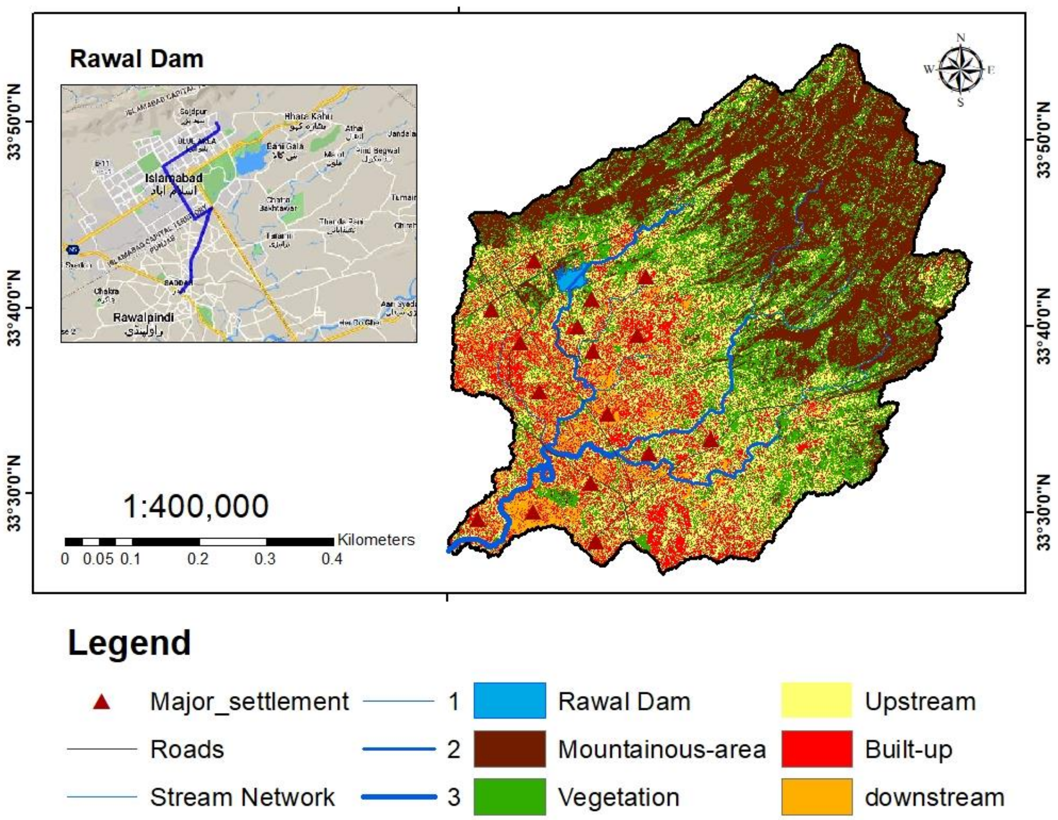


**Figure 1.** Location of the study area

## 3. Research Methodology

Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Landsat-8 image having twelve distinct bands covering having 30m spatial resolution is downloaded from the USGS Earth explorer open source geo-database. Watershed modeling was applied to delineate the catchment area and drainage geo-visualize network. Spatial hydrological model was utilized to the vertical and horizontal profile of estimated flood in the downstream areas in case of dam breaching after (Mahmood, 2019; Mahmood & Rahman, 2019a, b). Similarly, Google Earth Pro was used to calculate lake volume.

Watershed of the study region is delineated by utilizing GDEM as input spatial data in Geographical Information System (GIS) environment. The ASTER GDEM was selected as input data for this study because of its accuracy and better output. Hydrology tool of Spatial Analyst of ArcGIS is used in to simulate elevation data. By applying Fill, Flow Accumulation and Flow Direction operations, the drainage network and watershed boundary was extracted (Figure 2).

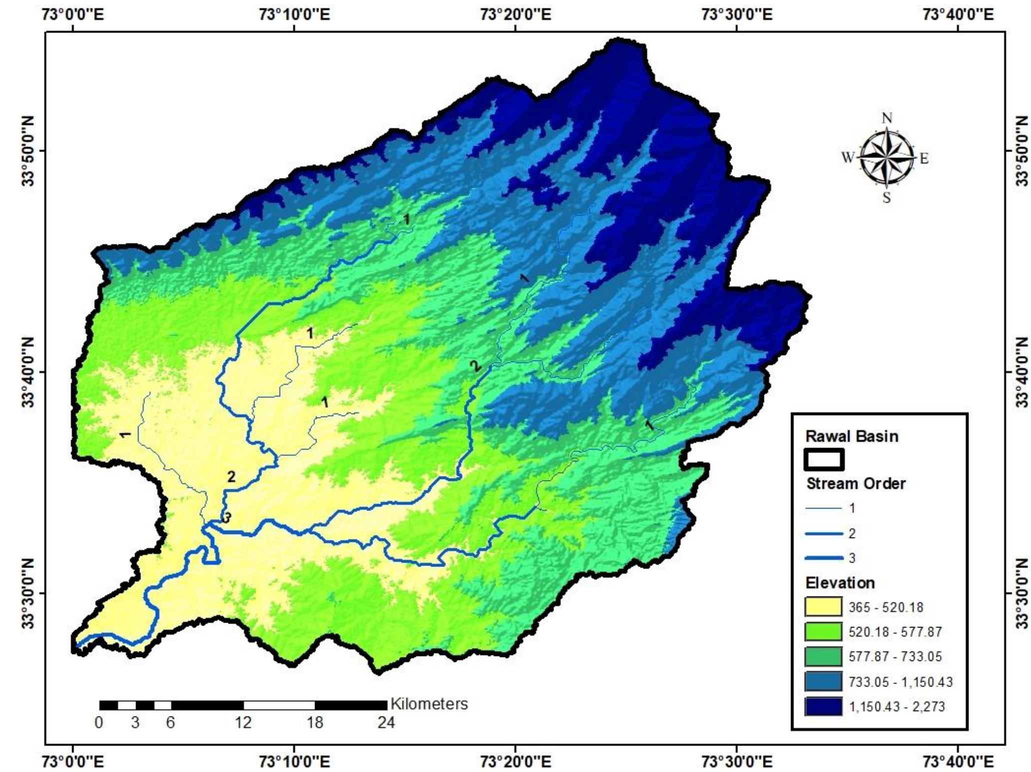


**Figure 2.** Rawal watershed and upstream and downstream region of Rawal

### 3.1. Lake volume calculation

First, Rawal Dam was digitized using Google Earth Pro and saved the polygon in Keyhole Markup Language (KML) format. GPS Visualizer is used to converting KML data into elevation data and then imported it into ArcGIS. By using GPX to feature tool data was converted into feature. After that, Triangular Irregular Network (TIN) was created by converting GDEM to TIN. In the last step, the surface volume 3D-Analyst tool was selected and TIN was used as input data and the lake volume gets calculated.

### 3.2. Horizontal and vertical profile of flood

Hydrologic and hydraulic characteristics of the downstream areas were modelled by employing HEC-RAS and HEC-GeoRAS spatial hydrological model (Demir & Kisi, 2016; Mahmood et al. 2019). Then simulated data was imported into ArcMap for processing, and the horizontal and vertical profile of the estimated flood in downstream areas was geo-visualized. HEC-GeoRAS is used to create river geometry by using GDEM as input data. The river geometry includes river centreline, riverbanks (left and right), flow route lines and channel cross sections (XS-Cut lines) with intervals of 1000m and breadth of 1500m (Figure 3). A total of 50 cross-sections were generated. The geometric data tool of HECRAS generated the vertical profile of the flood with the help of cross sections. Then from the steady flow data, spatial extent and flood depth were geo-visualized. Manning's roughness coefficient "n" value of the river channel is resolute by applying Chow (1959) method. The "n" for the riverine zone of Rawal Dam is 0.02 presenting the confrontation to flood flow in the channel and flood plain. The "n" is also used as input data in the geometric data tool.

Weighted overlay analysis technique is implemented and cumulative flood risk is geo-visualized in ArcGIS environment.

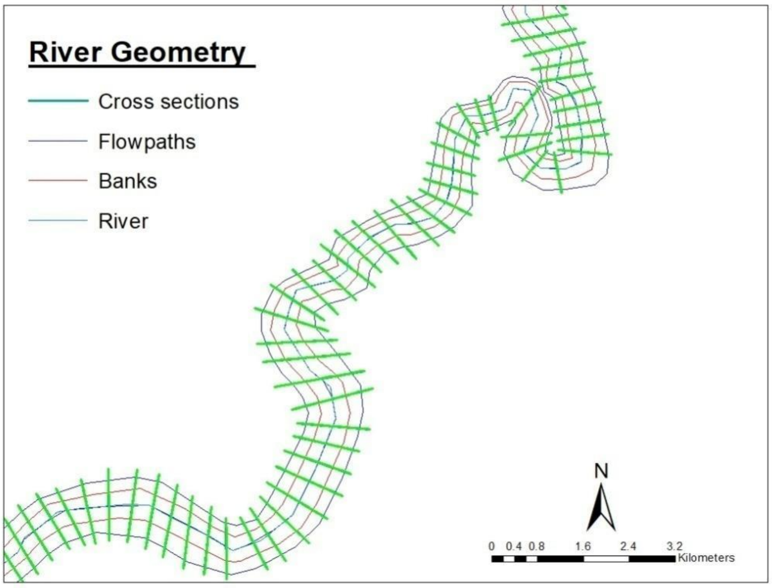


**Figure 3.** Geometry of the selected reach developed in HEC-Geo-RAS

## 4. Results and Discussion

The area exposed to dam lake outburst floods in downstream of Rawal Dam has diversity in topography, human activities and population density. The drainage pattern, gradient and nature of the river channel also variation. These factors further intensify flood risk. The detail of the estimated flood spatial extent and vertical profile is given in the following section.

### 4.1. Spatial extent and vertical profile of predicted flood

The vertical profile means depth of the predicted flood is ranging from 3 to 15 m. The depth depends on the nature of valley and huge discharge from upstream. The estimated depth in main channel is more than10 m from dam to downstream areas whereas the variation in depth is geo-visualized on both side of the channel (Figure 4). The spatial extent of flood also varies along the channel. The extent is maximum in the downstream areas (Figure 5). The study area has diverse topography. The elevation is ranging from 300m to 2200m above mean sea level. Elevation is decreasing from northeast to southwest direction. The higher-level stream order is third.

The spatial extent of apparent flood peak is variable along the selected reach of Rawal Dam. The extent of flood increases towards downstream. The maximum spatial extent of predicted floods in the downstream is because of increasing width of the river. The downstream area has high population density with major human settlements.

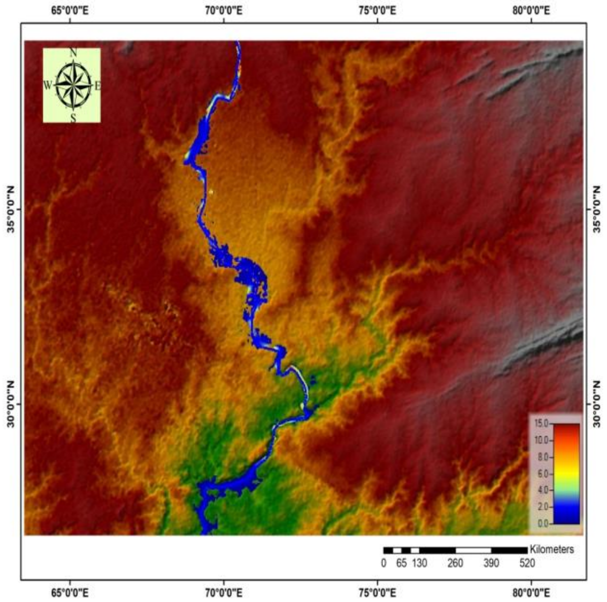


**Figure 4.** Vertical profile of Rawal basin

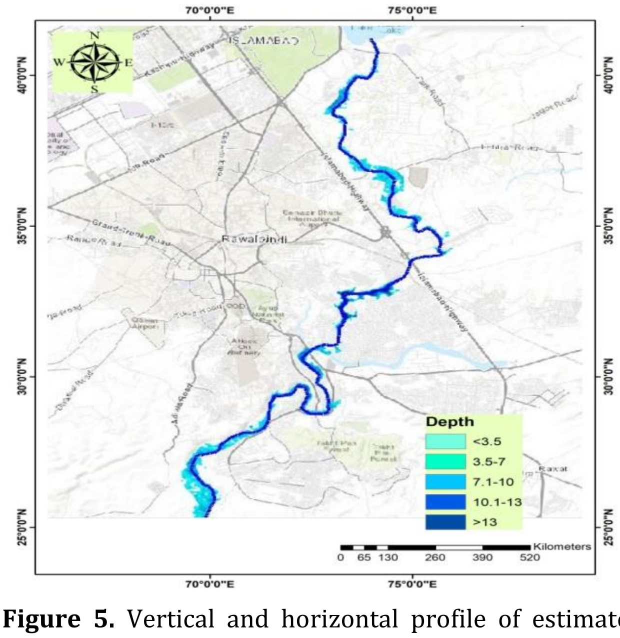


**Figure 5.** Vertical and horizontal profile of estimated flood developed in HEC-RAS

### 4.2. Flood risk zones

The risk of flood and potential socio-economic and physical damages in the downstream areas is prevailing. In the study region, human settlements, agricultural land, road and bridges are exposed to flood. Based on the flood risk, the areas downstream of the dam are categorized into three zones the upper zone, the middle zone and the lower zone. The risk is very high in the upper and lower zone whereas in the middle zone flood risk is lower comparatively whereas in some sections of the reach moderate and low risk also prevail. The spatial extent of the flood is maximum in the lower zone because the river channel is wide and built-up land is more with high population density. The major human settlements exposed to flood include Rawal Town, Rawal Dam Colony, Chak Shehzad, Morian, Margala Town, Phase-I & II of Margala Town, NARC colony, Burma Town, National Agriculture Research Institute, Koral Town, Ghauri Town, Hussain Abad, The human settlements located in the high-risk zone are Gulberg Marque, Koral Town and NARC colony (Figure 6).

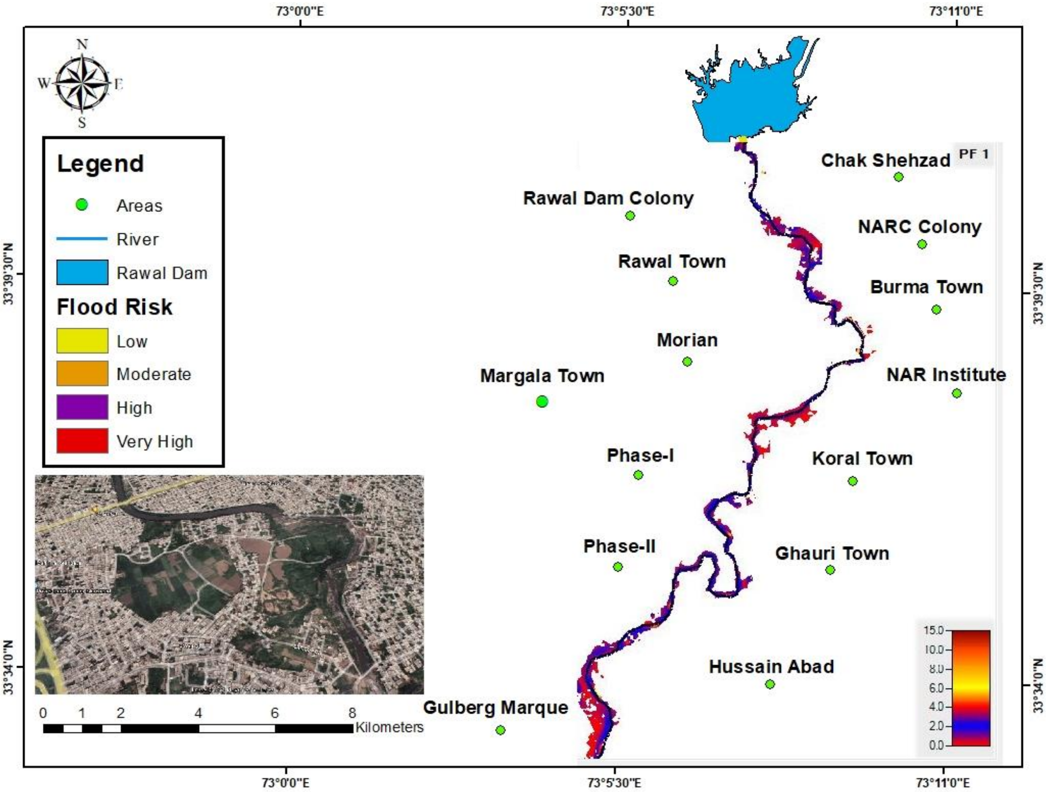


**Figure 6.** Flood Risk Zones

Analysis revealed that the risk of flood is increased with increasing high magnitude rainstorm event generating flash floods in the upstream areas posing risk dam lake outburst floods. Saeed et al. (2011) also narrated that that sedimentation has decreased the storage capacity of Rawal Lake by 34%. Effective soil erosion risk reduction measures in the higher catchment areas can lessen siltation in river channels and dams (Mahmood & Atiq, 2022). In a similar vein, dams may be overtopped by high discharge flash floods. Even the opening of spell ways can lead to flood in the downstream areas. Shaktawat & Vadhera (2021) concluded that risk management of hydropower projects is the need of time. Similarly, Concha Larrauri et al. (2023) stressed that risk assessment of aging dams is highly important. It is recommended that risk assessment of all dams need to be carried out and dam-specific flood risk reduction plan should be reinforced. This will reduce the risk of dam lake outburst floods and potential damages. In this aspect, flood risk reduction (FRR) is essential to minimising the damaging effects of floods.

High-resolution satellite imageries and field measurements can further enhance the results of the study. Similarly, determining vulnerability of the community will assist the disaster management authorities in policy and decision-making. Further studies on vulnerability and exposure to floods are recommended.

## 5. Conclusion

The study concludes that risk of dam lake outburst floods is prevailing in the downstream areas. The downstream areas are characterized by high population density and economic activities. Alongside, physical infrastructure and properties are exposed to floods. The high intensity rainfall events and decreasing capacity of the lake are the main risk factors.

Plantation in the upper catchment areas is recommended to decrease the intensity of rainfall, surface runoff and soil erosion. Removal of silt, clay and sand from the reservoir is also recommended to increase the capacity of the dam. In the entire Rawal Basin, installation of Sensor based hydro-gauging stations and automatic weather stations are also highly recommended to provide real-time data. This may help to reduce the risk of floods. Further studies on vulnerability and exposure to floods are recommended.

## Author Contributions

The contributions of the authors of this article is equal.

## Statement of Conflicts of Interest

There is no conflict of interest between the authors.

## Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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