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Flood probability analysis for different return periods in District Peshawar, Pakistan

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Abstract

Floods are the most destructive among all hazards across the globe. Research revealed that there is a marked increase in frequency and intensity of floods. Therefore, it is important to assess flood risk and reduce its probability and negative consequences. Assessment of flood probability helps to identify those areas which are very likely to be flooded in future. The current study attempts to assess the probability of floods by studying the causes, nature and intensifying factors in district Peshawar. In order to achieve the desired objectives, primary data regarding flood hazard were collected in a questionnaire survey, field observation and interviews of the relevant community and departments. Whereas secondary data were taken from Satellite images, irrigation department and Pakistan Meteorological Department. Flood hazard probability was determined for different return periods by developing flood scenarios. The Flood-2008 in the study area was considered as a landmark event for these scenarios. For visual interpretation, four different return periods of 5, 10, 50 and 100 years were mapped. Fast expansion in the built-up areas and other developmental works, violation of landuse planning and presence of bottlenecks (flood intensifying conditions) were found as main causative factors for the probability of flood hazard in the area under investigation. On the basis of findings from this study, it is recommended to build check dams or reservoirs in the upstream area, and a proper flood forecasting and warning system must be established. Furthermore, it is also recommended to implement the landuse planning regulations in the flood plain, in order to reduce the probability of flood.

Keywords: Flood risk, Probability, Landuse, Water depth, Return periods.

1. Introduction

Water is a precious resource and a very basic need of all living organisms. Although, in the absence of water, life is impossible, however, sometimes floods may happen when large quantities of water are not properly managed. Flood risks are enhancing and became important all over the world (Munich 2010; Borga et al. 2011). It is reported that 1/3 area of the globe is exposed to floods. It was recorded that 82 percent of the world population is prone to various levels of floods (Ajin et al. 2013; Alexander 1993). The average annual death toll due to floods is about 9,000 people (Munich 2010; Coto 2002; Kebede 2012; Guha et al. 2011). The number of flood disasters in the decades of 1950s, 1960s, 1970s, 1980s and 1990s were 6, 7, 8, 18 and 26, respectively (UNDP 2012). This trend showed that the risk of floods has increased significantly with time. Reasons behind this are heavy rainfall with changing spatio-temporal patterns, snow melting, dam failure, climate change and encroachments in the flood plain. These are the major factors which trigger the probability of flood risk in all developing countries. Similar situation exist in Pakistan and especially in the study area.

Flood probabilityis the chances of such level of flood in a specific area within a particular period of time that has potential to cause negative consequences on the environment and society (Abbott 1996; Georgia et al. 2011; Di Baldassarre, 2013). Therefore, flood probability assessment is the most important need of all communities vulnerable to floods. For visual interpretation of flood probability assessment, modern geo-spatial technology like GIS-based models can help to develop maps showing those areas that may be inundated in a particular level of flood. In flood probability assessment this spatial distribution and frequency of floods are very important (Diakakis 2012). The development of flood hazard maps need historical data of flood events in a specific area (Erich et al. 2007). These maps help the line agencies in interventions as well as guide local people to be prepared physically and mentally. Data revealed that heavy rainfall, intrusion into the flood plain and climate change are the major triggering factors for the probability of floods in Peshawar. This study attempted to assess the probability and chances of floods in the area under investigation, temporally covering four different return periods. For this purpose different scenarios were developed, based on historical devastating flood of the year 2008. After analysis of primary and secondary data, the resultant flood hazard was mapped for 5, 10, 50, and 100 years return periods.

2. Materials and methods

2.1. Study site and data collection

Location of the study area is 34°00′05″ to 34°10′02″north latitude and 71° 23′02″ to 71°38′50″ east longitude (GOP 1998). Mostly floods are caused by the Budhni Nullah in the study area (Fig. 1). Length of Budhni Nullah is 38 kilometers. Whereas total length including all major tributaries is 122 kilometers (GoP, 2015). The climate and weather of the study area are extremely hot and cold in summer and winter, respectively. Among all the summer months, June and July are very hot and humid months. Rainy season called summer monsoon starts from July and prevails until September. Historical discharge data of Budhni Nullah revealed that floods occurred both in winter as well as in summer seasons. On average, amount of rainfall in winter is higher than summer rainfall (GoP, 2017; Rahman, 2003).

Data showed that physiography and landuse of the study area played significant role in triggering of flood probability. The study area is an alluvial plain where slope is the major cause of high velocity of flood water in the upper part which contribute to flood probability in this region. There is a gradual decrease in slope eastward (Fig. 1). Therefore, flow velocity of flood water are greater in upper zone than the middle and lower zone of the study area. Whereas, encroachments onto flood plain are continuous at a very high pace in the lower urban part of the study area. These encroachments were major factors in creating high flood probability in lower parts of the study area.

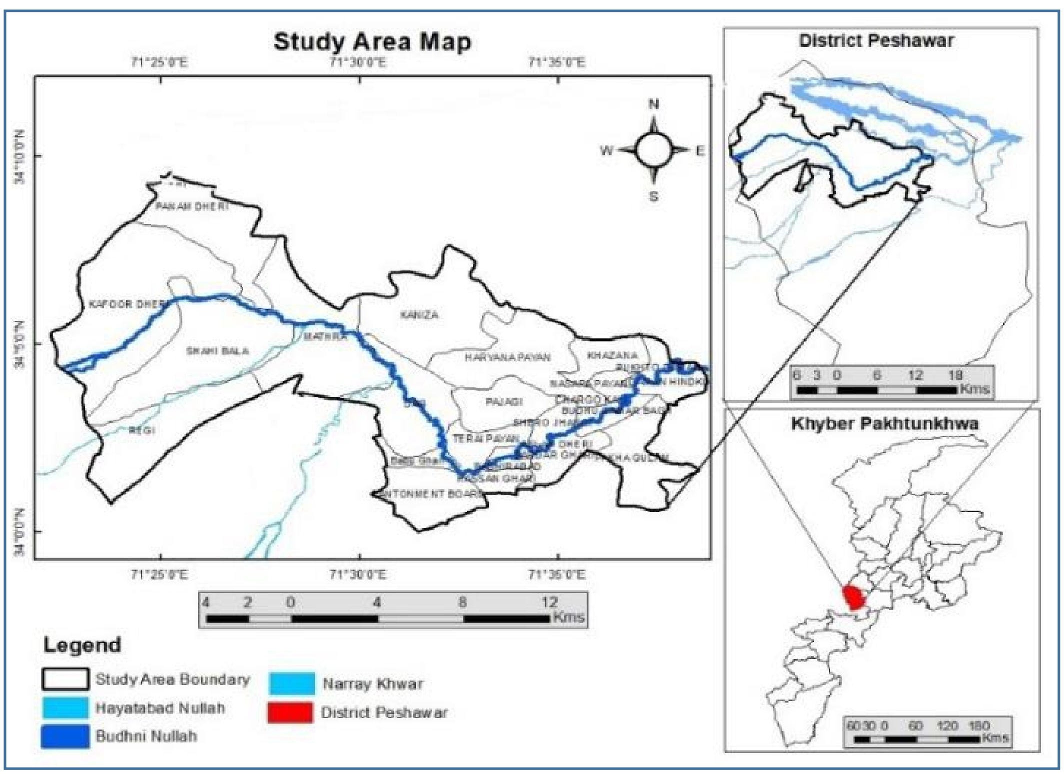

Fig. 1. Location of the Study Area

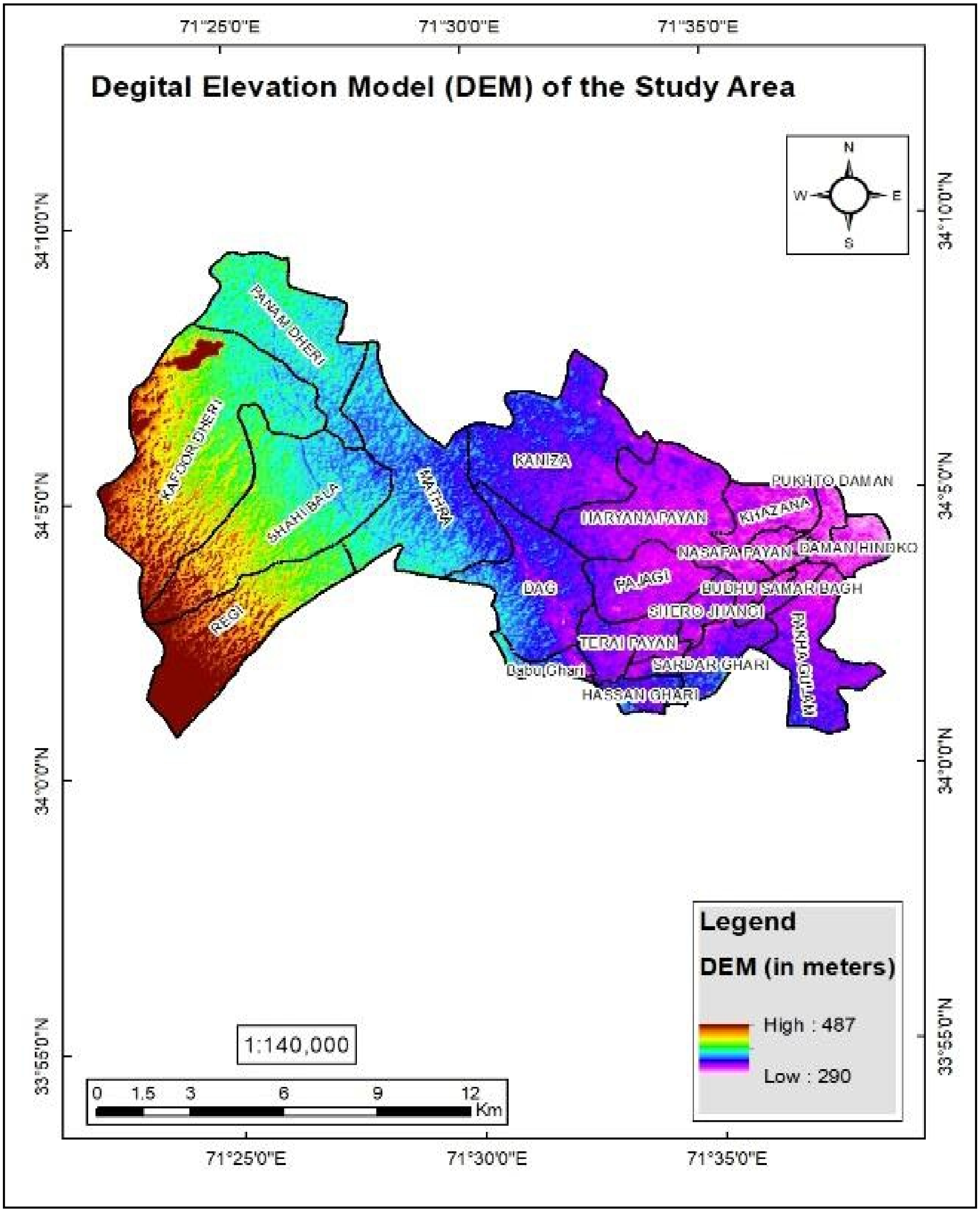

Fig. 2. DEM of the study area.

2.2. *Data collection*

Active participation of local people and stakeholders was involved in this research. In addition to indigenous knowledge, advanced geo-spatial techniques and date base Geographical Information System (GIS) and satellite-based remote sensing (RS) methods were also used for maximum accuracy in results. Computer generated results were cross checked by using standard validation techniques, such as ground truthing during field visits. The collected data included; land-use, stream (Nullah) discharge data of the past 40 years, Isohyet (rainfall) data, elevation/slope and other factors that intensify flood in the selected area. Landuse data was extracted from newly available Satellite image (Sentinel). Stream discharge and flow data of Budhni Nullah were provided by the Provincial Irrigation Department, Peshawar. Elevation (altitude) and terrain (slope) data of the area were extracted from satellite-based digital elevation model (DEM). Primary data for this research was mostly collected through interviews, questionnaires and Focus Group Discussion (FGDs) with local people, stakeholders and officials of relevant departments. Gaps in the data, selection of alternative sources and verification of data were completed during several field visits and surveys.

Keeping in view the depth and velocity of flood-2008, the study area was divided into 3 parts. The western area (Nasir Bagh road and Warsak road areas) is considered as upper part. The eastern zone (from Charsadda road to Shah Alma river) is lower part, whereas, area inbetween these two parts (Warsak road to Charsadda road) is middle part (Fig. 1). There are 84 villages located in the proximity of one kilometer along both sides of the Budhni Nullah. Historical record showed that 38 villages (localities) at different locations were regularly affected by different magnitudes of floods in the Budhni Nullah. Out of the aforementioned 38 villages, 15 were chosen on the basis of severe damages with five (5) villages from each part of the study area.

Total 200 questionnaires and 50 interviews were conducted for this study. During field surveys, 15 severely affected houses were selected in each sample village. Stratified random method of sampling was selected in order to conduct questionnaire survey and interviews. This sample was divided into 2 strata. In strata one, respondents of questionnaires and interviews were from business community, labors, shopekeeprs and farmers. Whereas, officials of the relevant departments were visited in the second strata. 150 questionnaires and 25 interviews were used in strata one, while the number of questionnaires and interviews in strata two were 50 and 25, respectively. Visited line agencies included; Provincial Disaster Management Authority (PDMA), Irrigation department, Meteorological department, Agriculture, Housing department and officials of Local government. Beside questionnaires and interviews, six (6) Focus Group Discussion (FGD), 2 in each part of the study area, were carried out with local people during field visits.

3. Results and discussion

In this study, analysis were carried out in different steps. Data incorporated in this study included; landuse, discharge data of Budhni Nullah, Satallite images, field data and historical flood events data. For in-depth study, different parameters such as water depth, seasonality, critical points and flood intensifying factors were also used. Based on the flood of 2008 and other historical data, four flood scenarios were developed in this study. Finally, different categories based on velocities and depths of flood water were generated and tabulated for 5, 10, 50, 100 years return periods.

3.1. *Analysis of landuse patterns*

Land-cover and landuse data are usually used to derive surface roughness map. If these are not available, interpretation and classification of remotely sensed imagery can be utilized. Values of roughness coefficients (Manning's coefficient) were assigned as a function of the land-cover classes (Fig. 2), which can be linked to the land cover and landuse maps as attribute data, in order to generate a spatial representation of the roughness and runoff (Kebede, 2012; Ajin et al., 2013). In the study area, landuse trend revealed that there is a gradual decrease in agricultural land. Change in landuse from agriculture practices to residential and commercial activities is one of the major factor which is responsible for high probability of flood events and associated damages. This situation was found particularly in the middle and lower parts of the study area. Reasons behind this factor were increase in population growth and urban sprawl. Another factor enhancing probability of floods was narrowness of the Budhni Nullah by encroachments into flood plain. Officials said that actual width of the Nullah in documents is 110 feet, while currently it remained only 62 feet.

Runoff Coefficient "C"
1. Vegetation Cover= CVC= 0.5826
2. Built Up= CBU= 0.7967
3. Barren Land= CBL= 0.38
Average Rainfall426 mm/year

Formula $Q = C i A$

Where

$Q_{VC} = C_{VC} i A_{VC}$

$Q_{BU} = C_{BU} i A_{BU}$

$Q_{BL} = C_{BL} i A_{BL}$

Runoff Coefficient estimated= $Q = Q_{VC} + Q_{BU} + Q_{BL}$

Different landuse have different runoff values (Arcement et al., 1990). It was observed in the study area that build-up areas have greater runoff than vegetation covered. Table 1 showed that in the localities of Daman Hindko, Mathra and Sardar Ghari probability of flood are very likely due to less vegetation as compared to total area of the village. Furthermore, probability of floods in the built-up areas located near to Budhni Nullah was also very likely.

Table 1. Estimated runoff for different landuse.

Villages	Vegetation		Built-up		Barren land		Estimated Runoff Coefficient (Q) m^3/year
	Area covered (m^2)	$Q_{VC} = C_{VC} i A_{VC}$ (m^3/year)	Area covered (m^2)	$Q_{BU} = C_{BU} i A_{BU}$	Area covered (m^2)	$Q_{BL} = C_{BL} i A_{BL}$	$Q = Q_{VC} + Q_{BU} + Q_{BL}$
DAMAN HINDKO	6273	1556880.815	9485	3219153.987	745	120600.6	4896635.40
DAG	2021	501587.1396	2847	966255.2874	1292	209148.96	1676991.39
SHAHI BALA	7361	1826908.924	5472	1857165.062	930	150548.4	3834622.39
PANAM DHERI	7369	1828894.424	5356	1817795.335	880	142454.4	3789144.16
MATHRA	8628	2141362.613	6215	2109334.953	1028	166412.64	4417110.21
KAFOOR DHERI	9348	2320057.685	3726	1264582.789	1044	169002.72	3753643.19
REGI	3024	750519.3024	8930	3030790.206	2190	354517.2	4135826.71
SARDAR GHARI	3448	855750.8448	10410	3533093.622	360	58276.8	4447121.27
TERAI PAYAN	2405	596891.178	1426	483976.1292	980	158642.4	1239509.71
HASSAN GHARI	2983	740343.6108	7280	2470789.776	580	93890.4	3305023.79
BABU GHARI	720	178695.072	6424	2180268.341	590	95509.2	2454472.61
CHARGO KALI	657	163059.2532	1474	500267.0508	574	92919.12	756245.42
BUDHU SAMAR BAGH	8468	2101652.597	3155	1070788.701	472	76407.36	3248848.66
PUKHTO DAMAN	6258	1553158.001	2516	853915.8072	391	63295.08	2470368.89

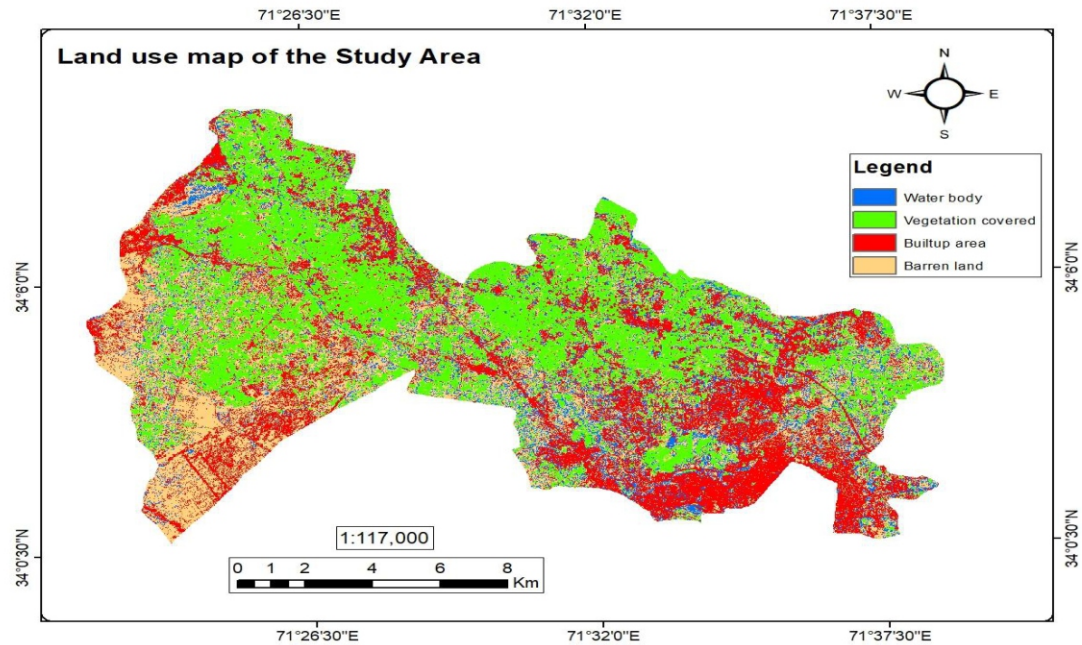

Fig. 3. Landuse of the study area.

3.2. Analysis of flood-2008

From water depth data of flood-2008, inundation level of different areas in the study area was identified in Flood-2008. For this purpose, water depth contours were digitized for visual interpolation and maximum water depth was considered for flood probability at different locations. These locations were then verified during the field surveys. The contours considered for maximum water depth during flood-2008 were: 30, 60,120, 150, 180 and 210 centimeters. After analysis of Flood-2008 data, locations of maximum depth were identified (Fig. 3). This Figure was used for further analysis. It is worth mentioning that after comparing Flood-2008 contours data with field surveys, it was identified that all critical points coincide each other.

3.3. Analysis of field data/Observations

Data gathered from the local people, experts and field observations were very important for this research. Some important points were identified as following:

3.3.1.Bottlenecks and flood intensifying factors

Geomorphological setting of any area particularly slope, drainage pattern, and permeability play pivotal role in triggering of flood hazard (Coto, 2002). During field visits, several intensifying factors and Bottlenecks were observed and identified after discussion with the local people. Bottlenecks are the narrowness of Budhni Nullah at some locations, which reduces the water flow. Factors responsible for triggering the probability of flood are called intensifying factors (Coto, 2002; ISDR, 2010). In the study area, these factors included tight curves, bridges, encroachments and confluence points of the Budhni Nullah.

Confluence points of Budhni Nullah with its tributaries: Based on field observations and discussion with locals, it was observed that there were four places where normally flood starts and reaches upto peak. When these information were checked with the Satellite data and water depth of Flood-2008, it was noticed that these were locations where tributaries meet the main Budhni Nullah with 90 o (right angle) connectivity (Fig. 4a). During rainy season, these branches carry huge quantity of rainy water from vast hilly areas of the District Khyber (catchment area). At these points, flood water started backward flow and consequently water overflows the banks leading to floods. Hence, these confluence were the points where flood hazard probability is very likely.

Low bridges: Flood hazard probability was found very likely at place where bridges have been constructed very low. These bridges create an obstruction to the normal flow of flood water in Budhni Nullah. For instance, one old and lengthy bridge located in the village Daag is composed of 22 pipes (Fig. 4b,c). These pipes were mostly filled with sediments which retard the flood velocity. Therefore, at these places, there are high probability of overflow of flood water.

Soild waste dumping points: Due to high fertility rate and urban expansion, solid waste is generated continuously at high pace in the study area. Figure 4d reflects the problem, which retard the flow of flood water, causing overflow and increasing the flood hazard probability.

Tight Curves in the Budhni Nullah: Budhni Nullah continuously changing its way throughout the study area. Visual interpretation of the satellite image revealed that there are locations where Budhni Nullah has taken U-turns, making very tight curves of 90 o and 180o degrees (Fig. 4e,f). These were the points, where overflow of flood water during floods are very likely. The existence of tight natural curves, irregular elevation of Nullah banks and borrowing of levees material by the people were some of the factors that increase the probability of flood in study area.

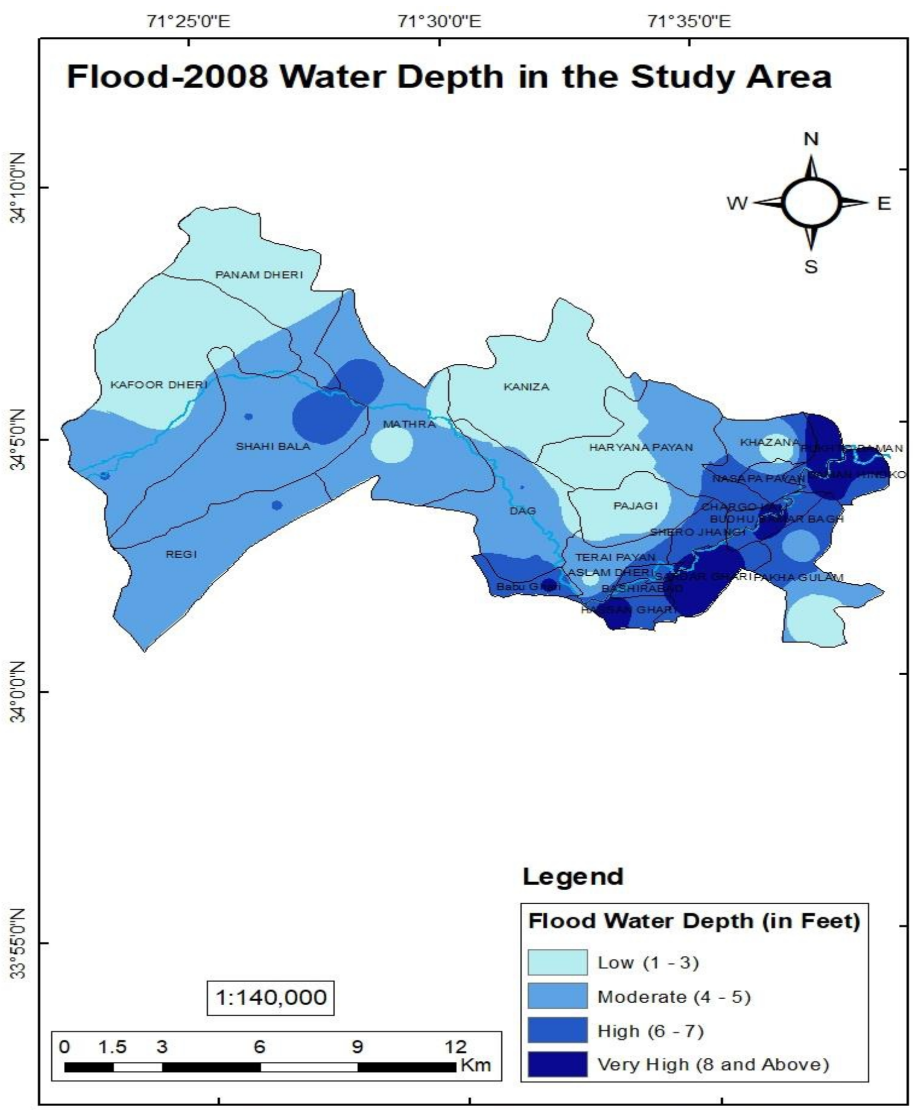

Fig. 4. Flood water depths during Food-2008.

Fig. 5. Critical points and flood intensifying factors
(a) Confluence point (b) & (c) Low bridge (d) Solid waste disposal point (e) & (f) Tight curves

3.3.2.Analysis of Nullah discharge data (Hydrographs)

Analysis of the rivers/streams discharge rate over time is carried out through making hydrographs (Coto, 2002; Rojas, 2000). Peak discharge uncertainty was accounted for generating an ensemble hydrograph of Budhni Nullah based on Flood-2008 data.

40 years stream discharge data was utilized to construct hydrograph for Budhni Nullah. The peak discharge data was calculated for 5, 10, 50 and 100 years return periods (Table 2 & Fig. 5). Peak discharge data and the return periods are summarized in table 2. (for more details see Appendix A). These hydrographs were incorporated to generate the final flood hazard probability maps.

4. Flood hazard probability

Flood hazard probability maps display information, such as, intensity of the flood corresponding to an exceedance probability level (Apel et al., 2009). Flood hazard maps can be broadly categorized according to the likelihood, intensity and spatial distribution of flood risk (Kebede, 2012; Brandimarte et al., 2009; Khan et al., 2013; Kok et al., 2002).

Spatial distribution of flood hazard probability is an important part of this study. For this purpose, maps were the most suitable way to show the areas prone to floods. Based on different parameters, like elevation, slope, landuse, depth (inundation levels) of Flood-2008, presence of bottlenecks, intensifying factors and hydrographs, these flood probability maps were generated for the study area (Fig. 6). The study area has been divided into five regions (Fig. 6 & Table 3) ranging from high likely to unlikely probability of floods for four different scenarios of 5 (Fig. 6a), 10 (Fig. 6b), 50 (Fig. 6c) and 100 (Fig. 6d) years return periods (YRP).

Table 2. Summary of Budhni Nullah Discharge data

return periods (years)	Discharge (m^3/S)
5	4929.469
10	7530.01
50	13568.28
100	16168.82

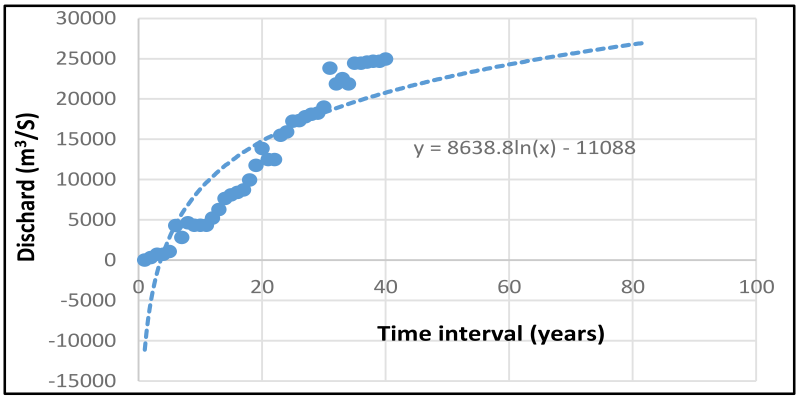

Fig. 6. Hydrograph for Bdhni Nullah

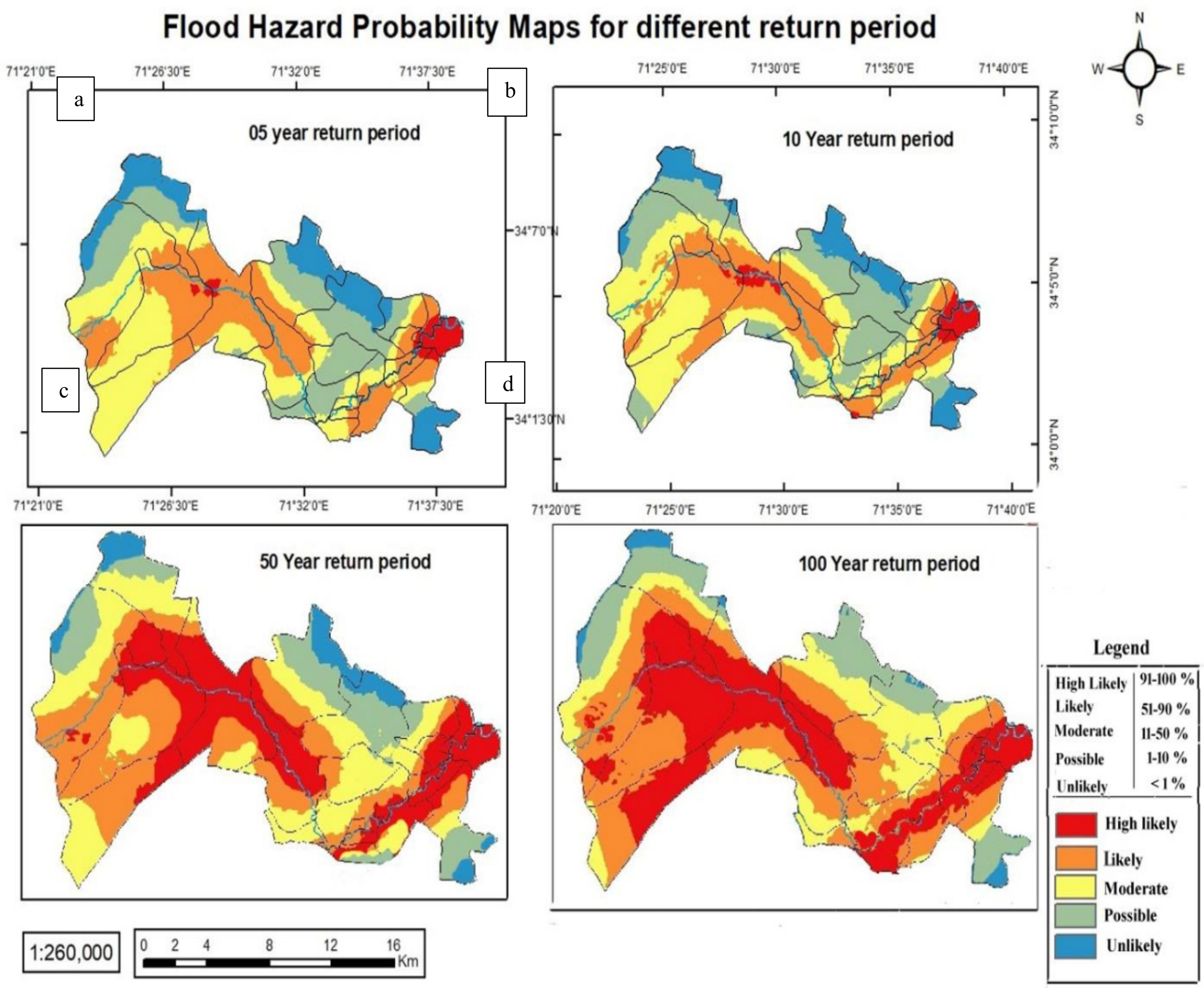

Fig. 6. Flood hazard probability: a) 05 years return period (YRP) b) 10 YRP c) 50 YRP d) 100 YRP.

Table 2. Summary of Budhni Nullah Discharge data

Probability		Description	
Category	Rating		
High Likely	A	nearly 100% probability in next year	known to occur often – 2 times a year
Likely	B	between 11 and 100% probability in next year	may occurred – every 1-2 years
Possible	C	between 1 and 10% probability in next year	could possibly occur – once every 5-10 years
Unlikely	D	less than 1% probability in next 100 years	unexpected to occur – perhaps once every 100 years

4.1. High likely probability (A)

Results of this study revealed that flood is a serious threat in the study area. East of the study area exhibits high likely flood probability (Fig. 6). Daman Hindko, Pukhto Daman and Budhu Sumerbagh are the villages included in this zone. Encroachment to the Nullah, tight curves in the Nullah and accumulation of all flood water are reasons for high probability in these villages. Other places that mark the probability of flood hazard as high are the points, where Budhni Nullah receives the tributary streams. These points are located in the middle part of the study area (Shahi Bala, Mathra and Patwar). Sardar Colony is also included in this category due to construction in the active flood plain. Upper parts of the study area are marked as likely probability of flood hazard in 5 years. Northern parts of Haryana payan, Kaniza, Panam Dheri and south-east parts of village Pakha Ghulam were identified for unlikely of flood probability and considered as safe places.

4.2. Likely probability (B)

Flood history of the study area reveals a direct relationship of flood intensity with time interval. The flood of 10 years return period, was severed than 5 years flood and flood which comes once in 50 years was more catastrophic than 10 years and so on. Therefore, in 10 years return period a gradual increase in the area prone to high probability was observed (Fig. 6b).

4.3. Possible probability ©

All areas in the proximity of the Budhni Nullah has probably inundated in flood of 50 years return period. This area starts from village Shahi Bala, to Pushto Daman except villages Babu Garhi and Terai Payan. Elevation of the area and construction of embankments to the Budhni Nullah are the possible reasons for this exception.

4.4. Unlikely probability (D)

The flood which occurrs after a century or once in a century is reflected as a catastrophic flood. If such a flood event occurs in the study area, there is probability that more than half of the area will be inundated. Elevation and slope of the areas to the north and north-east play significant role in reducing flood probability. These areas include; northern parts of Kaniza, Panam Dheri, Haryarna Payan and areas in the South-East of Pakha Ghulam. These village were identified for unlikely of flood probability and considered as safe places (Fig. 6).

5. Conclusions

This research was an attempt for the assessment of flood probability for four return periods for the communities located along Budhni Nullah within one kilometer. Historical data revealed that floods are the recurring phenomena in the study area. These floods are mainly caused by Budhni Nullah and all of its tributaries originated in the upstream areas of District KhyberField observations revealed that stream confluence points, encroachment in the flood plain, low lying bridges and tight curves of the Budhni Nullah are the responsible critical points for high flood probability. The study area has been divided into five different zones (from high to Unlikely probability) on the basis of flood probability. Flood scenarios were developed for different return periods of 5, 10, 50 and 100 years. There is a strong link between flood events and the torrential rainfall particularly in the summer monsoon in the study area. July and August are the most hazardous months of the year with respect to floods as revealed by the analysis of floods and stream discharge data from Budhni Nullah. Also, the month of February was observed for peak discharges with some probability of floods in this month. It was concluded that most of the lower parts in the Budhni Nullah were very likely to be inundated in future floods. Reasons behind this were; topography of the area, encroachments and tight curves of the Budhni Nullah, and accumulation of flood water in these low lying areas. Villages Daman Hindko, Pukhto Daman, Budhu Sumerbagh and Mathra were prone to A, B, C and D type of probability. It is recommended to build check dams and reservoirs in the upstream areas along the Budhni Nullah at district Khyber and should install a proper flood forecasting and warning system. Furthermore, it is also recommended to implement the landuse planning and bylaws in the flood plain of Budhni Nullah to minimize human and properties losses due to high probability of flood events.

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Authors' Contribution

Shah Nawaz Khan conceived the idea, carried out the analysis and prepared 1st draft of the manuscript. Amir Nawaz Khan supervised the research and equally contributed in the preparation of the manuscript. Muhammad Ali did the data gathering and helped in writing the manuscript. Anees Bangash Ahmad critically reviewed the manuscript.

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