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Estimation of Direct Runoff in the Data Scarce Catchments surrounding Nasirabad in Baluchistan by SCS – CN Method

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Abstract. Baluchistan, a largest province of Pakistan, has faced multiple instances of flash flooding in recent past. The study focuses on the Nasirabad Division that is sandwiched between the several catchments including Catchments of Bolan and Mulah rivers. There, among other surrounding rivers have given excessive peak discharge volumes in year-20222.Despite frequent flood occurrences, it is not feasible to prevent the floods completely by constructing large storages. Rather, their adverse impacts could be minimized by flood risk management. Although, many institutions are available to reduce the harmful impacts of floods however there is inadequate focus on pre-flood planning measures that includes ascertaining the potential flood magnitudes. Where, in data scarce catchments of Baluchistan, long term record of discharge is not available; therefore, data of rainfall is used to compute discharge volumes in the catchments surrounding Nasirabad by using SCS-CN method with the help soil type and land cover data. These estimated peak discharge volumes could be used in planning and design of hydraulic structures and communicating flood risk warning in time. It is found that the Peak storm precipitation in the catchments surrounding Nasirabad: Bolan River, Mullah river, Chattar River, Tank Pusht River, Gorri river, Sorri River and Talli Tangi river catchment are 125mm, 127.2mm, 91mm ,91mm, 91mm, 91mm and 108mm respectively in a period between 1914 to 2022. Where, data of same precipitation gage is used to approximate the rainfall of Chattar, Tank Pusht, Gorri and Sorri River. The peak discharge by SCS-CN method in same period. The maximum estimated peak discharge varies from 0.68 BCM against the peak precipitation of 155 mm in the 1889.7 Sq. mile catchment of Bolan River to 0.01 BCM against the precipitation of 91 mm in the 41 Sq. mile catchment of Gorri River.

Keywords: Keywords: Floods, Baluchistan, Peak storm, Peak discharge estimation.

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1. Introduction

There are a number of natural threats that are plaguing mankind around the globe. Among them flood has proved to be very frequent occurring phenomenon in the past century with intensity and frequency changing quickly owing to climate and anthropogenic changes(Tripathi, 2015). The effect of natural disasters like flood and Tsunami varies and largely depends on the level of preparedness to avoid or reduce their harmful impacts. Underdeveloped country like Pakistan, has been facing flood hazards from last 76 years. Since inception, Pakistan has faced 29 flood and still the state has not yet developed a system to protect lives and properties from devastative demolition. The first ever flood hit the country in 1950, followed by 1955, 1956, 1957, 1959, 1973, 1975, 1976, 1977, 1978, 1981, 1983, 1984, 1988, 1992, 1994, 1995 – and from 2010 onward, Pakistan has experienced it almost every year (Momna Tahir, 2017).

In Pakistan, the most common natural disaster is the flooding in which there occurred a large scaled disaster leading to deaths, destruction of property, infrastructure and loss of food crops & land (Tariq & Van De Giesen, 2012). The flood generates in two ways one is riverine and the other is flash flooding due to intense rainfall storms. The former is comparatively predictable as it generates from melting of glaciers however the latter is difficult to predict as they originates from extreme weather events with short duration and severe impacts. The latter type is experienced in monsoon from July to September (Memon et al., 2015). According to official stats, around 90 percent of the people were affected by 2012 flood which caused an economic loss of about 10 billion US dollars and around 8000 persons were perished. The flash floods usually occur in the steep, and the steep and barren territory of Baluchistan and Dera Ghazi Khan Watershed (Tariq & Van De Giesen, 2012). There are 18 major River Basins and 73 Sub-Basins which on average generate about 10 MAF of Flood flow, out of which only 2.5 to 3.0 MAF could be utilized through rivers, reservoirs, flood dispersal structures and weirs whereas the rest of the flow wastes in the sea. According to the previous history, Balochistan has experienced flood events many times. Nasirabad division, which is located on the border of Sindh province, remains always under the threat of flash floods, the recent flood years are 2010, 2012, 2020 and 2022. These events mainly affected Jafrabad division (PDMA Balochistan, 2022).

According to Balochistan irrigation department, in August 2022 when the flood situation occured, initially Uch Canal & Sem Drain in Sohbatpur Sub Tehsil overflowed and overwhelmed the Sohbatpur Town along with the main Dera Allah Yar – Sohbatpur road and several other link roads. A breach occurred at Thora Band of the Indus River on 12th August which caused overflow in Shahi and Begari canal coming from Indus River and overwhelmed the surrounded area of Jaffarabad district. After that on 15th, 16th August it turned southwest and entered Rojhan Jamali. The flood moved on to Usta Mohammad but by-passed towards Gandakha Sub-Tehsil. On 19th August it turned towards Beroon area. By 20th August, both Beroon area and its surroundings in Khirthar Canal and Gandakha Town, were inundated by flood water. More than 80% area of Jaffarabad District, majorly Sohbatpur, Dera Allah Yar, Rojhan Jamali, Khanpur, Faizabad and Gandakha and about 35% area of district Naseerabad was overwhelmed by the flood water. Province Balochistan normally face rainfall of 250 - 300 mm per annum, however, flood situation is generated when its value exceed 400mm because of heavy showers. Massive damages in the Canal Irrigation System at Nasirabad, Jaffarabad and JhalMagsi Districts during the floods of monsoon 2022, resulting in huge loss to the irrigation infrastructure, standing crops etc. and causing several breaches of the Pat Feeder and Rabi canals. After the flood recession, it raised another serious problem of reduced capacity of water channels due to huge mud & silt deposition in channels, carried by the high flows of flood (Balochistan Irrigation Dept., 2022).

Frequent Flooding is the most catastrophic natural threat to Pakistan. Floods in the Indus Basin emanate from the monsoon rainfalls and the economic impacts of theses floods have been catastrophic. Since 1947, relief and works operations have cost billions to the government of Pakistan. The national flood policy is embodied in several provincial and federal acts, ordinances, agreements, and treaties. Over time, institutional setup for flood hazard and crisis management has also been established but still the data showed no significance reduction in damage due to floods. It is important to analyse the physical inter-linkage of catchment characteristics to the generated water flows for active flood management (Tariq & Van

De Giesen, 2012). Baluchistan has a history of worst flood hitting by the heavy rainfall and melted ice & snow. In recent past there occurred number of floods which cause catastrophic destruction of infrastructures, agricultural lands and even human lives (Nandy, 2005). The affected population and the breaches & riverages due to flood of 2022 in this province are given in the figure.1 and table.1. Due to such alarming situation in this region, it needs to develop some sustainable flood management strategies to cop up with this worst flooding risk. However, unlike the availability of long term record of rainfall and discharges in the catchments major rivers, i.e. Indus, Jhelum and Chenab, the hydro-meteorological data is scarcely available in catchments of torrents that cause flash flooding in Southern Punjab and Baluchistan. Very few rainfall gages are maintained with discharge gaging even fewer. Therefore, in the absence of discharge gaging, it became difficult to quantify the flood magnitude, which is essential for effective flood risk management.

The main aim of this study is to estimate the peak flood magnitude, with various return periods by adopting Soil Conservation Service Curve Number (SCS-CN) technique, of seven rivers i.e. Mullah river, Bolan river, Sorri river, Gorri river, Tank Pusht river, Chhatar river and Talli Tangi river, which are hitting the Naseerabad division and its surrounding areas in Balochistan, Pakistan.

2. Literature Review

The study area is located in Balochistan which is the largest province of Pakistan which lies in the south-west region 220 to 320 N & 660 to 700 E and it covers about 44% of the area out of total area of Pakistan with around 8 million human inhabitants. Inter-mountainous territory covers about 80% of the total area whereas the coastal plains and flood plains comprise the remaining 20% of this land. The mountain ranges like as Koh-e-Sulaiman, Toba-Kakar, Central Brahui, Kithara, Chagai, and Raskoh, along with the central-East portions of Makran, are the prominent mountain ranges present in Balochistan. The province possess a interior half Mediterranean Sea climate with annual yearly rainfall ranging between the 200 and up to 350 mm mostly in the form of moisture as snow during a year (Ainuddin & Kakar, 2015). Majorly the pastoral structures are made up of mud however some urban colonies are built up with concrete, mud and temporary sheeting. The province has approximately 9,000 pastoral clearances which are blowout. Growth rate in the urban area is approximately 4.5% per annum. The rural migration is negatively affecting rural economy by straining the urban infrastructure and services. Gas, electricity and water are piped to the main towns but these hardly meet the growing demand (PDMA Balochistan, 2022). Floods in the Indus Basin emanate from the monsoon rainfalls while that of Kharan catchment and the Makrane Beach Range is brought about by the Mediterranean Waves and cyclones which are generated over the Arabian Sea. Economic impacts of fluvial floods from the Indus Basin have been catastrophic. Relief and works operations since 1947 when the country was formed have cost the government of Pakistan billions. The national flood policy is embodied in several provincial and federal acts, ordinances, agreements, and treaties. Over time, institutional setup for flood hazard and crisis management has been established. However, data do not show significant reduction due to flood river ages. It is important to analyze the inter-linkage of physical and non-physical actions and the optimization of their mutual productivity for effective flood management. (Tariq, 2012).

Where, the traditional deterministic forecasts have been surpassed by recent probabilistic flood forecasts. Probabilistic forecasting proves to be the most appropriate tool especially when combined with Bayesian decision-making approaches, is the most appropriate tool for rational decision-making in flood warning and flood management (Todini, 2017).

According to data given in figure.1, about 30 to 50 percent population of Balochistan province was affected by the flood in 2022.

The selected region is situated in the Central East province of Baluchistan, comprising approximately 5% of the area, with four districts (Bolan, Jaffarabad, Jhal Magsi, and Nasirabad) and seven tehsils. It is bordered in the south-east by Larkana and Jacobabad districts, in the north & north-east by Dera Bugti and Kohlu districts and in the north-west by Mastung district (USF, 2023).

Our main focused region is Nasirabad which is located almost at the middle of Balochistan province, bordered by Dera Bugtid district in east, Jhal Magsi in west, Jaffarabad in south and Bolan in north. Its head office is at Dera Murad Jamali and apart from Quetta District at 270 km. The salient features of this district are given in the table.1 (Ahmed et al., 2020).

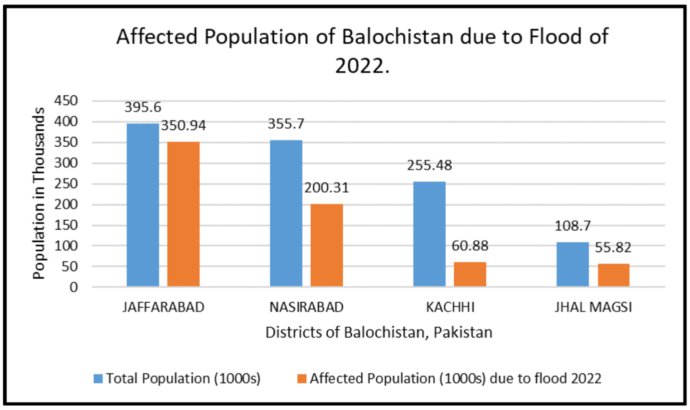

Figure.1: Affected Population due to flood in 2022. (NDMA Pakistan, 2022)

Table.1: Overview of Nasirabad Division

District Name	Nasirabad Division
Head office	Dara Murad Jamali
Population	490,538 publics
Area	3,387 km^2
Population Density	151.9 persons/ km^2
Metropolitan Populace	19.7%
Tehsils	04 Tehsils: 1. Tamboo 2. Chattar 3. DeraMuradJamali 4. Baba Kot
Black Topped Roads	996.0 km
Shingle Roads	252.0 km
Industrial Zones	1 Industrial Estate at Dera Murad Jamali, with 05 working Industrial Units (Rice Husking Mills) and 48 No Objection Certificates (NOC) issued.

Other features such as topographical aspects, forestry, soil type, climate, seismic activities and canal network are described in the table.2.

Table.2: Other Features of Nasirabad

Parameter	Description
Topography	It is located in plane zone with no hilly area. The soil of this region is alluvial type.
Forests	The district's vegetation is typical of Steamy Point Plantations of the Sector. The chief tree species are shakkar kanddi, peelu & bair. There is a good coverage of trees but agriculture has led to the destruction of natural forests. These communal plantation categories comprise of babul, shisham, ber, farash, karir, peelu, black siris, white siris, neem, jhand, and sufaida. Shrubs includes mesquite, prickly sesban, aak, salt tree and camel thorn. The ground cover consists largely of grasses for animals (Forestry Dept. Balochistan, 2023).
Soil Type	The soil of Naserbad division is to be silt loam, silt, clay and also sandy loam. The soil of canal command area of Dera Murad Jamali tehsil is mainly sandy with a few areas having a denser agricultural field loam. The soil in chattar district is sandy

	loam clay (Balochistan Irrigation Dept., 2022).
Climate Conditions	The temperature remains high in summer and very low in winter season. The moisture level increases in summer near Pat Feeder Canal region and dust storms blow from north & west side becoming less strong due to forest vegetation. The rainy season May to October has highest rainfall in June. The maximum and minimum temperature in this zone lies in between 29-43 Celsius degrees. Mean annual rainfall of the region is about 420mm (Balochistan Irrigation Dept., 2022).
Canal Network	The district of Nasirabad receives water from river indus. Pat feeder is the biggest canal system in Nasirabad which was constructed during Guddu Barrage project in 1969 and has a designed discharge of 3200 Cusec with a cultivable command area of 458.425 acres. In addition to the Head Regulators, 5 Cross Regulators are built on the main canal. Farmers on the left side of canal are supplied with water from distributaries through minor and pipe outlets. There are 12 distributary canals being utilized to irrigate the fields with total length of 250 km & culture able command area of 423250 acres (Balochistan Irrigation Dept., 2022).

The SCS curve number method is utilized in hydrology to assess direct runoff resulting from rainfall events. Originally developed by the Soil Conservation Service, this approach remains a fundamental criterion in hydrologic modelling, widely applied in civil engineering for watershed and storm water management system design. By considering variables such as soil type, land use, and hydrologic conditions, the curve number method estimates potential runoff from rainfall. This method is crucial in estimation of peak floods, where the discharge gaging is not available, for developing strategies at the catchment scale for storm water management and evaluating how changes in land use affect runoff dynamics, rainfall patterns, construction of hydrological structures, and the topology of drainage systems (Bansode & Patil, 2014).

Runoff estimation using current techniques can be solved by use of GIS and remote sensing technology. The revised Soil Conservation System (SCS) CN method is also used to predict runoff, while taking into consideration factors like slope, vegetation cover, and watershed size (Bansode, 2014).

3. Methodology

To estimate the flood magnitudes, SCS Curve number method is utilized as discussed before. To obtain the precipitation data, four nearby rain gauge stations are chosen for which rainfall data is obtained from Balochistan irrigation department and PDMA department and elaborated in table. 4. For this, land cover and land use data is collected from google earth and required data is obtained by using Arch GIS through extraction tool. After getting this data, volume of peak floods is obtained from SCS curve number technique. For calculation of SCS curve number, necessary data for all catchments is elaborated in table. 5.

3.1 Data collection

The available rainfall data is collected from the concerned departments, where, the catchment details are attained from remotely sensed data. For collection of land data Arch GIS is used. First of all land cover data is taken from ESSRI website and then shape file is obtained from Arch GIS after performing analysis tool. The land cover map of Nasirabad division is given in the figure.2, which is obtained by mask extraction tool as shown in figure.3. The soil data is collected from Chief Minister Delivery Unit (CMDU) of Balochistan. The soil of in Baluchistan is is hilly gravel soil, Loamy and clayey soils, loamy & gravely soil and at some regions it is sandy soil, the detail of which is illustrated in the figure.3. Where, the soil in in Nasirabad Division is mainly loamy and clayey soil. The rainfall data is collected from Pakistan Meteorological department (PMD) and the map of rain gauge stations is generated by using the coordinates of rain gages in the GIS tool as given in figure.4.

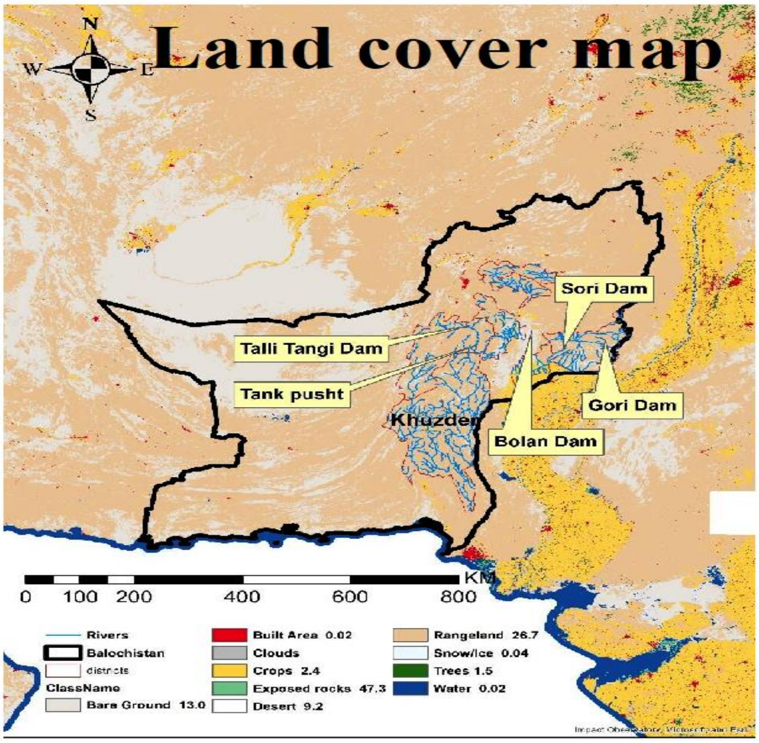

Figure. 2: Land cover map of Nasirabad Division

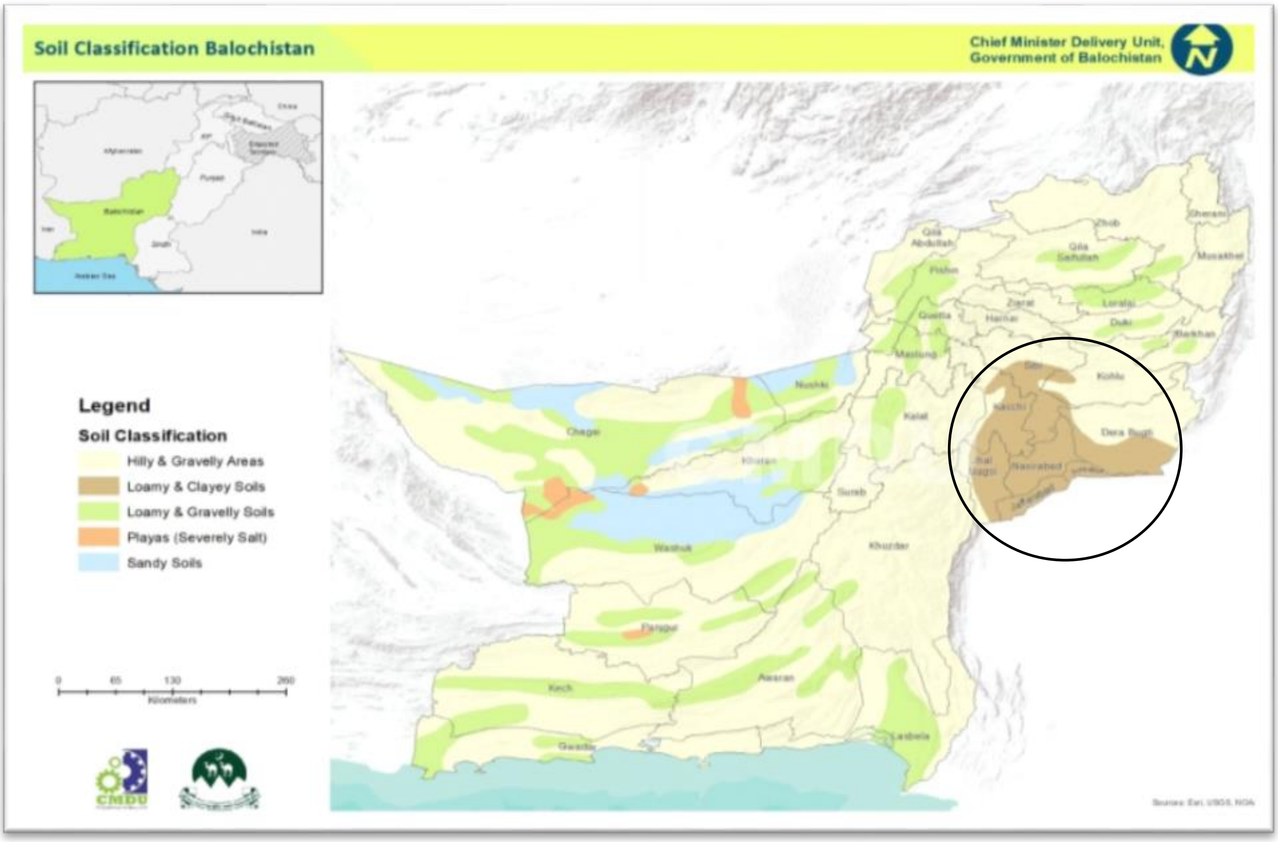

Figure.3: Soil Map Nasirabad Division (CMDU, 2023)

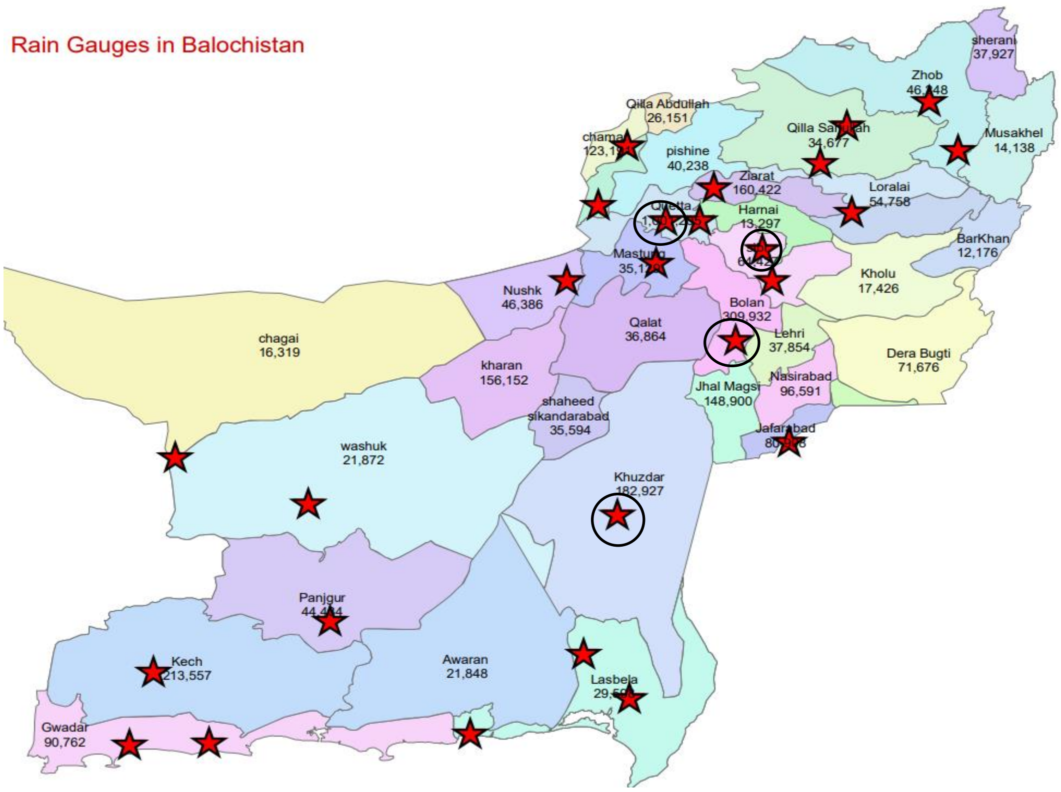

Figure.4: Rain gauge Stations of Balochistan

The basin map is also drawn using Arch GIS tool, after collecting raw catchment data from Baluchistan Irrigation Department (BID) as shown in figure.5.

3.2 Analysis by SCS-CN

As discussed before, for flood estimation, SCS-CN method, is adopted for which river catchment data and soil type of catchment is gathered from Baluchistan irrigation department. As far as land use land cover data (LULC) is concerned, it is obtained by spatial analysis that is performed on the land cover data, obtained from ESSRI website, by using Arch GIS tool. After that required data of curve number (CN) is selected by using hydrology soil group, and selecting AMC II from which AMC- I is calculated, partly because these catchment receive intermittent rainfall with long spells of dry period and partly to assess that even considering drying condition, what could be the potential of discharge storm volume. Formulation of flood estimation by the soil conservation method is given by;

$$P=I+F+Q \qquad \text{eq.1}$$

Where P= total precipitation, I = initial abstraction, F=Cumulative infiltration. The year wise data of peak storms is given in Table. 4. It is clear from this table that the occurrence of rainfall storm is irregular in time and varies from catchment to catchment. Unlike, conventional procedure of taking daily rainfall value and computing separately and then accumulating the daily flow flumes by SCS-CN method, the peak storms depths are computed by adding the rainfall of consecutive days assuming that the continuous rainfall period in a single stretch is a result of single rainstorm. Then this accumulated rainfall is used to estimate peak discharge volume by using Equ-1 to 6. It may be that the duration of summated rainfall depths resulted from this calculation varies from case to case and in the discharge calculation the duration should be accounted but this procedure is computation effective in calculating discharge volumes in one go by using SCS-CN method.

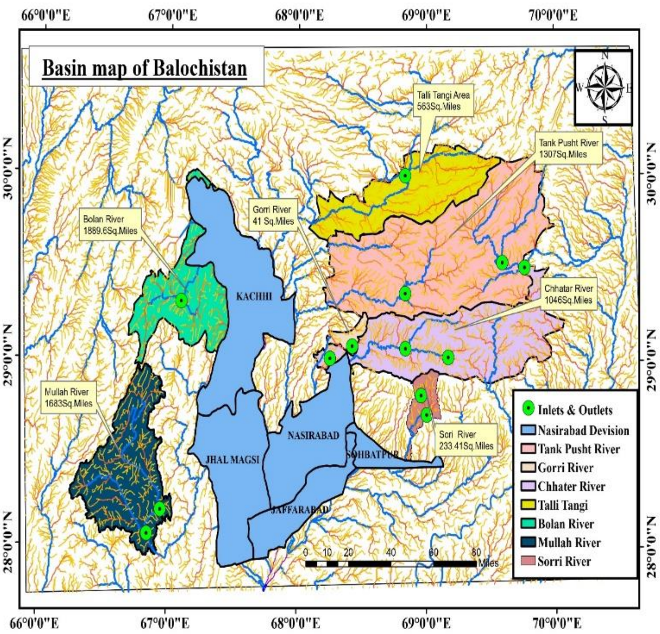

Figure. 5: Basin Map of Balochistan

The second step, however, is the amount of initial abstraction is some of the potential maximum retention (S).

I =F/S+Q/P eq.2

For process purposes generally a time interval of 1 day is assumed. Thus P-daily rainfall and Q = daily runoff from the catchment can be computed (K. Subramanya, 2008). However, in this study, the time duration of rainfall varies from case to case. Curve number is used in Equation-3 to calculate S. The notation S express the potential maximum retention, depends upon the soil-vegetation-land use composite of the catchment and also upon the antecedent soil moisture condition.

S = (1000/CN)-10 eq.3

The constant 254 is used to express S in mm. CN has a range of 0-100. A CN value of 100 represents a condition of zero possible retention (i.e. impermeable catchment) and CN= 0 represents an infinitely abstracting catchment with S0. This curve number CN depends upon Antecedent moisture condition, Soil type and Land use/cover. Soil conservation service method is more efficient method for the flood estimation. Used relations are given below;

AMC -I:

$$CN1 = \frac{CN_{II}}{2.281-0.01281CN_{II}} \quad \text{eq.4}$$

$$S = \frac{25400}{CN} - 254 \quad \text{eq.5}$$

$$Q = \frac{(P-0.2s)^2}{P+0.8s} \quad \text{eq.6}$$

Where, CN = curve number selected on the base of soil type and hydrology soil groups and formula is selected on the bases of AMC condition.

S= potential maximum retention depends upon the soil-vegetation-land use composite of the catchment and also upon the antecedent soil moisture condition.

Q = Discharge generated from these calculations.

In using the CN, the data of land cover and soil type is approximated through remotely sensed maps. In the computation of CN, the weighted CN technique is used, since in each catchment there were different soil values. Data of daily rainfall of years 2014 to 2022 four four rainfall gages, Bolan, Narri Sibi, Khuzdar and Quetta, was available to approximate the discharge in seven rivers (Mullah river, Bolan river, Sorri river, Gorri river, Tank Pusht river, Chhatar river and Talli Tangi river) causing flooding in Nasirabad division and its surrounding.. During rainfall data analysis, the peak storm of each year is selected. In the selection of peak storm, the consecutive rainfall of several days is summed up with an assumption that same storm has resulted in the rainfall that lasted continuously for several days. The accumulated rainfall of all the rainstorms occurred from year 2014 to 2022 is given in Table. 4 for the mentioned rainfall stations. Among, these rainstorms, peak rainfall storm are selected for each year per station. These peak-storm rainfall values are used to compute peak discharges in the catchment of mentioned seven rivers.

4. Results and Discussion

The peak storm data from 4 gauging stations available in selected seven catchments for the project duration (2014-

2022) was worked out to attain the corresponding peak flow volumes through SCS-CN method. These were catchments of Bolan, Mula, Chattar, Tank Pusht, Gorri, Sorri and Talli Tangi Rivers covering 1889 sq.mi, 1683 sq.mi, 1046 sq.mi, 1307 sq.mi, 41 sq.mi, 233.41 sq.mi, 563 sq.mi respectively. Since, the occurrence of rainfall is not uniform in these catchments, therefore, the peak rainfall value also varies from catchment to catchment. Table-5 present the peak rainfall values in the region and catchment of their occurrence along with catchment area. It can be seen that frequent peak storms occurred in Talli Tangi and Mula River Catchment, however, the catchment area of Talli Tangi is comparatively smaller, therefore even with high rainfall comparatively less flood discharge is generated in comparative terms. Also there is an abrupt increase in storm events in Bolan catchment during the recent years resulting in huge flow volumes, this situation is possibly due to changing rainfall pattern owing to climate change.

Table.3: Peak Storm Rainfall

Sr. No	Year	Peak Storm (mm)	Catchment	Catchment Area (sq.mi)
1	2014	108	Talli Tang	563
2	2015	95	Talli Tang	563
3	2016	82.5	Mula River	1683
4	2017	60.5	Chattar	1046
5	2018	97.4	Talli Tang	563
6	2019	84	Talli Tang	563
7	2020	99.8	Mula River	1683
8	2021	115.2	Mula River	1683
9	2022	155	Bolan	1889

Table.4: Rainfall data collected at different Stations of Balochistan

No. of Storm		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Peak Storm (mm)
Station Name													BOLAN									
	2022	80	29	22	15	71	45	66	3	61	15	23	22	89	155							155
	2021	2	15	3	24	18	15	13														24
	2020	38	8	10	3	3	8	8	3	27												38
	2019	37	3	9	52	108	25	3	35	9	4	4	7	7	7	4	6	8	2	13	4	108
Year	2018	21	11	12	5	3	4	3	15	5	7											21
	2017	1.5	23	28	7	1	3	3.5	16	26	48	4	15	37								48
	2016	1	6	17	1.5	29	6	3	1.5	4.5	2	3.5	11	7								29
	2015	11	9.7	1	27	36	1.5	9	1	1	20	5.5	2	1	1	1.5	7.5					36
	2014	1	10	2	3	3	2	8.5	4	1.5	1	2	5	2.5	1.5	7.5	3.5	3.5	3	1.5		10
Station Name													NARI AT SIBI									
	2022	4	45	12	8	5	84	7	38	87	38	65	28									87
	2021	11	5	5	12	47	7.5															46.5
	2020	39	6	5	22	8	76	25	21	12	70	12	91	5								91
	2019	2.5	24	72	2.5	4	30	50	3.5	15	9	4	26	7.5								72
Year	2018	10	3.5	4.5	3.5	16																15.8
	2017	46	2.5	4.2	2.5	14	61	13	36	55	13											60.5
	2016	46	2.5	4.2	2.5	14	61	13	36	55	13											60.5
	2015	6.5	3.5	3.5	4	30	14	6.4	12	1	2	31	2.5	56								55.5
	2014	7.5	2	7.5	12	16	15	5														15.5
Station Name													KHUZDAR									
	2022	2.3	2.3	16	16	4.5	23	2.2	2.6	25	1	11	30	127	24	8.6	8.6	98				127.2
	2021	1	7	3.1	2	14	12	25	115	3.2	9	3.2	81									115.2
Year	2020	3	3.3	2	4	13	5	100	10	80	21	18										99.8
	2019	2	5	4	33	55	2	2	3.6	3.8	3											55.3
	2018	4	2	5	23	4	31	12	2	5.8	12											31

	2017	6	2	1	5	46	2	10	5.9	22	2											46.3
	2016	5	2	2	0.3	29	83	5	16	18	71	8										82.5
	2015	3	5	14	93	12	2.3	27														92.9
	2014	1	4	2.6	6.4	2	60	12	12	1												59.9
Station Name													QUETTA									
	2022	4	45	24	7	3.3	2	1.5	0.5	13	33	7	1	2	4	11	1	3	1	69	106	106
	2021	2	21	17	1	5	0.3	0.5	7	35	2.3	2	11	1	3	1	65	102				102
	2020	4	1.2	12	14	25	57	92	54	8.9												92
	2019	9	5	0.2	1	60	84	3	2													84
Year	2018	6	0.4	97	80	19	7															97.4
	2017	4	1	3	2	28	19	6	23	9												28
	2016	3	1	26	36	12	9.6	5	3	6.3	9	0.3	0.8									36
	2015	10	2	5	2	50	1	0.3	0.9	95	17	0.9	0.4	1								95
	2014	0.4	2	7	16	108	9.6	9	7.8													108

Table. 5: LCLU data & CN-II for AMC-I Condition for selected Catchment

Catchment Name	Land cover	Soil Type	HSG	Soil Area %	CN - II	Product	CN - II
	Built-up area	fractured lime stone	C	45	90	41	
	Gravel /Exposed rock	fract. Sandstone, shale	D	25	91	23	
Bolan	croop/grass/trees/ rangeland	Alluvial	B	30	69	21	84
	Built-up area	fractured lime stone	C	10	91	9	
	Gravel /Exposed rock	fract. Sandstone, shale	D	70	93	65	
Khuzdaar	crop/grass/trees /rangeland	Alluvial	B	20	86	17	91
	Built-up area	fractured lime stone	C	24	90	22	
	Gravel /Exposed rock	fract. Sandstone, shale	D	58	91	53	
Chattar	crop/grass/trees/ rangeland	Alluvial	B	18	69	12	87
	Built-up area	fractured lime stone	C	70	90	63	
	Gravel /Exposed rock	fract. Sandstone, shale	D	10	91	9	
Tank pusht	crop/grass/trees/ rangeland	Alluvial	B	20	69	14	86
	Built-up area	fractured lime stone	C	20	90	18	
	Gravel /Exposed rock	fract. Sandstone, shale	D	45	91	41	
Gorri	crop/grass/trees/ rangeland	Alluvial	B	35	69	24	83
	Built-up area	fractured lime stone	C	35	90	32	
	Gravel /Exposed rock	fract. Sandstone, shale	D	40	91	36	
Sorri	crop/grass/trees/ rangeland	Alluvial	B	25	69	17	85
	Built-up area	fractured lime stone	C	70	90	63	
	Gravel /Exposed rock	fract. Sandstone, shale	D	10	91	9	
Tali Tangi	crop/grass/trees/ rangeland	Alluvial	B	20	69	14	86

The maximum flow volumes generated against the corresponding peak storms in various catchments for the project duration is shown in Fig-6. The data reveals that the instance of peak storm events and resulting maximum flow volumes in Bolan catchment was higher in recent years. Where, the Bolan river catchment is largest catchment among all the selected catchments.

Fig-6 clearly indicates that year 2014 to 2016 were wet years followed by couple of dry years and then again well spell started from 2019 and lasted till 2022. Although, the data is limited to indicate cyclicity but apparently two to three years wet dry and then wet cycle has been repeated in these catchments. Where, the peak discharge volumes were maximum and rising from 2014 to 2016 in Mula River. But in wet years of 2019 to 2022, the peak rainfall is rising in Bolan river catchment together with steady rise in flood volume from Mula River too.

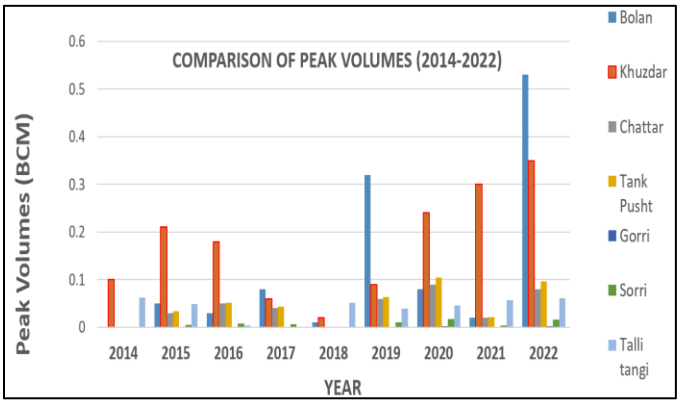

Figure. 6: Comparison of Peak Storm in different River Catchments of Baluchistan

The 7 graphs plotted in figure 7 to 13 represent the generation of largest Flow volumes (m3) corresponding to the Peak storm events during the year (2014-2022). Refer to fig-7, the Bolan river catchment, a sharp increase in peak storm rainfall and discharge has been noted in year 2022. In fig-8, a cyclic behavior can be seen in the peak discharges of Mula river catchment with maximum discharge volume going up to 0.35 MCM. Overall this catchment has shown increasing trends of peak discharges. In spite of limited time series data, the ascending trend of peak storm events during the selected duration provide a reliable likelihood of excessive increase of such peak storm events resulting in excessive flow volumes in future years.

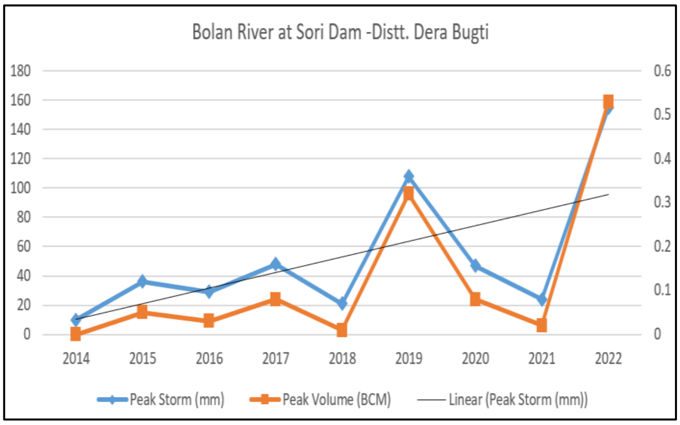

Figure.7: Peak Rainfall and Discharge Volume in Bolan River Catchment

The peak rainfall storm values and the peak discharge values estimated by SCS-CN method are plotted in Figure-7. Naturally, the peak discharge volumes estimated from the peak rainfall storm values follow the trend of rainfall. Noteworthy point, however, are the spikes observed in the peak rainfall data in years 2019 and then in 2022 that resulted in the discharge surge in these years that goes upto 0.55 MCM which is above average and in comparison to fact that discharges remained under 0.2 MCM in most of the year in the observed history. Evidently, year 2022 was the flood year caused by heavy rainfall storm. The discharge surges in 2019 and 2022 has given the upward trend to peak discharge volumes, nevertheless, the data is not of reasonable length to support the clear long term upward trends in discharges. Similar pattern of rising trend has been noticed in Mula River catchment shown in Fig-8. However, here, the dip and rise in annual peak storm and computed discharge volumes are gradual forming sag in 2018 and summit in 2022. Clearly, year 2022 was flood year in the entire region.

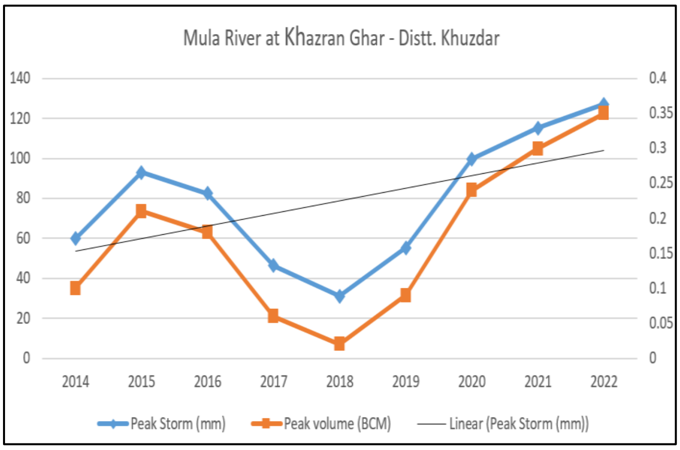

Figure.8: Peak Rainfall and Discharge Volume in Mula River Catchment

Refer to Fig-9, the rainfall steady does up from 20 mm to 60 mm from 2014 to 2016 and decreased in year 2018 and increased in two consecutive years, i.e. 2019 and 2020 followed by sharp decrease in year 2021. However, in consistent to regional trend of rainfall and discharge volume peaking, 2022 is giving high rainfall and discharge volume peak in the case of Chatter River. Refer to Fig- 10, 11 and 12, same rainfall pattern can be seen in Tank Pusht, Gori and Sorri rivers. This similarity is due to the fact that data of same rainfall gauge is used to approximate the areal average rainfall of Chatter, Tank Pusht, Gori and Sorri rivers catchments.

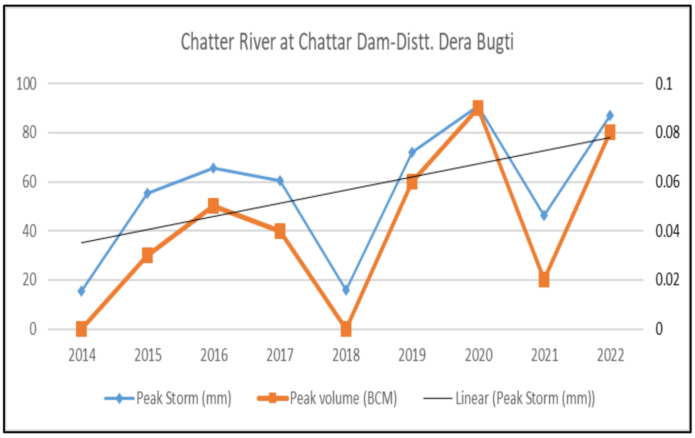

Figure.9: Peak Rainfall and Discharge Volume in Chattar River Catchment

Where, the difference in discharge volumes is partly because difference in catchment size and partly due to different top soil type that leads to difference is CN and discharge volumes. With difference in peak discharge volumes, the rising and falling pattern of discharges is same in these catchments. The trend line reveals the upward trend in rainfall and discharge volumes estimated by SCS-CN method.

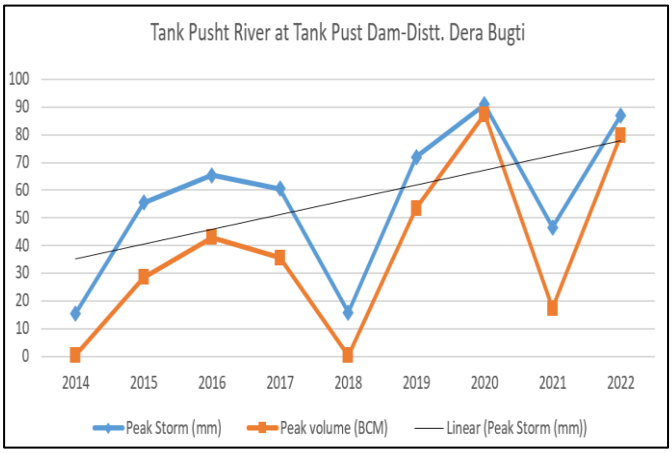

Figure.10: Peak Rainfall and Discharge Volume in Tank Pusht River Catchment

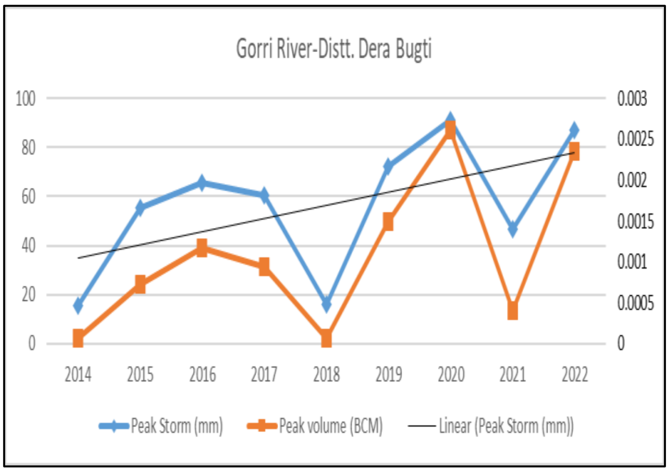

Figure.11: Peak Rainfall and Discharge Volume in Gorri River Catchment

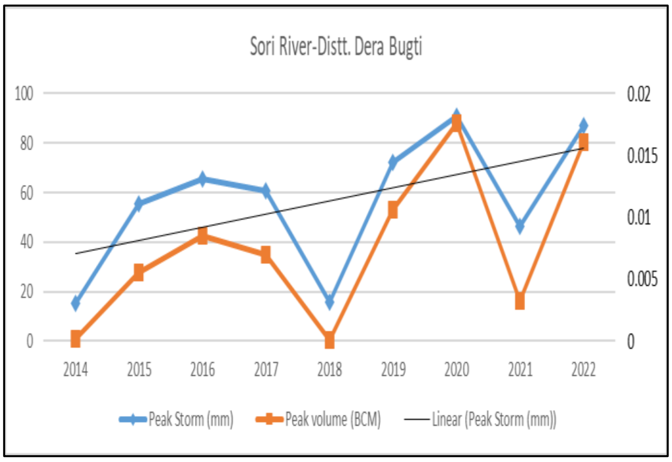

Figure.12: Peak Rainfall and Discharge Volume in Sori River Catchment

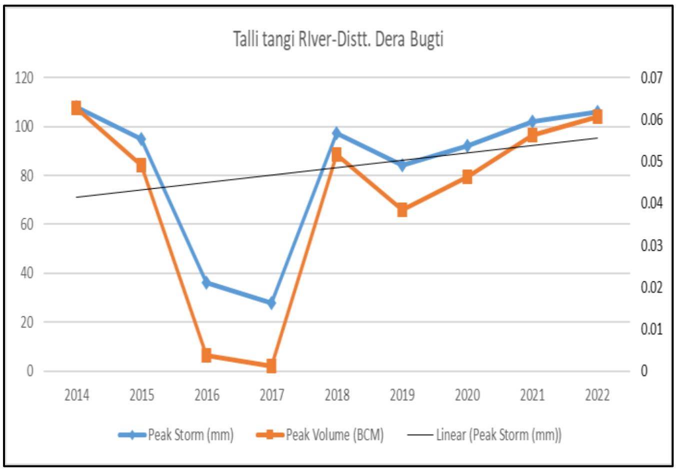

Figure.13: Peak Rainfall and Discharge Volume in Talli Tangi River Catchment

5. Conclusion and Recommendations

The frequent occurrences of floods have been reported in Baluchistan possibly due to increased precipitation due to climate change. The resilience against the frequent flooding could be raised by effective flood management including estimation of flood occurrence frequency of different rivers hitting Baluchistan.

Mullah River, Chatter River and Bolan River, Khuzdar, Bolan, Soori, Gorri, Chatter, Tank Phust and Tali Tangi located in the surrounding of and hitting Naseerabad division therefore these have been selected in this study for sustainable flood management in the region.

The Peak storm precipitation in Bolan River, Mullah river, Chattar River, Tank Pusht River, Gorri river, Sorri River and Talli Tangi river catchment was recorded as 125mm, 127.2mm, 91mm ,91mm, 91mm, 91mm and 108mm respectively in a period between 1914 to 2022. Where, data of same gage is used to approximate the rainfall of Chattar, Tank Pusht, Gorri and Sorri River,

SCS-CN Method has been adopted to estimate yearly Peak Discharge of peak storms occurred in a period between years 1914 to 2022. In this period, the estimated peak discharge volume by SCS-CN Method is given as under.

The estimated Peak Discharge in the 1889.7 Sq. mile catchment of Bolan River is 0.68 BCM against the peak precipitation of 155 mm.

The estimated Peak Discharge in the 1683 Sq. mile catchment of Mulla River is 0.49 BCM against the peak precipitation of 127 mm.

The estimated Peak Discharge in the 1046 Sq. mile catchment of Chattar River is 0.20 BCM against the peak precipitation of 91mm.

The estimated Peak Discharge in the 1307 Sq. mile catchment of Tank Pusht River is 0.25 BCM against the peak precipitation of 91mm.

The estimated Peak Discharge in the 41 Sq. mile catchment of Gorri River is 0.01 BCM against the peak precipitation of 91mm.

The estimated Peak Discharge in the 233.41 Sq. mile catchment of Sorri River is 0.04 BCM against the peak precipitation of 91mm.

The estimated Peak Discharge in the 563 Sq. mile catchment of Talli Tangi River is 0.13 BCM against the peak precipitation of 108mm.

The maximum peak discharge volume is generated by Bolan River followed by Mulla and Tank Pusht Rivers.

Analysis of the estimated yearly peak runoff of all the mentioned rivers revealed that there is rising trend in the volumes of peak discharge of all the rivers from year 2014 to 2022 which necessitate a detailed study analyzing trends and the impacts of climate changes on the patterns of rainfall occurrences.

Flood frequency analysis of historic floods will further assist the policy makers in decisions regarding planning and design of hydraulic structures, flood protection measures as well as holistic flood risk management.

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