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Flood Hazard Assessment of Water-front Geosynthetic Reinforced Soil Wall for Dam Regulation Rule Level

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ABSTRACT

The flood hazard parameter of peak discharge and prolonged inundation due to change in dam regulation is estimated for a water front Geosynthetic Reinforced Soil (GRS) wall on the downstream of large dam. Dam regulation rule level is pre-emptying the reservoir with lower peak discharge to protect the expanding downstream city intruding the flood plain. Present study is to test the hypothesis that rule level has significantly changed peak discharge and inundation duration and also to estimate these two important parameters of flood hazard for different flood return periods. The methodology consists of three parts: first is the categorization of flood data according to major event of flood regulation, second is the distribution test and third is the estimation of design maximum peak discharge and duration of flood. The estimated value of peak discharge and flood duration clearly indicate the implication of dam regulation rule level; the estimated value of peak discharge for 200 years return period is 13.9 lakh Cusecs, which is lower than the flood discharge for year 1968, which was 15 lakh Cusecs, and the estimated flood duration for 10 years return period is 41 days. The most important finding of this study is the substantial increase in duration of flood due to implementation of rule level which will add one more flood hazard parameter for water front geotechnical structure that is prolonged inundation.

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1. INTRODUCTION

The use of geosynthetic materials to increase soil tensile load has been extensively reported in recent decades [1-3]. One of the more common traditional structures, geosynthetic reinforced soil (GRS) walls are reinforced with either geotextile, geogrid, steel strip, or geo-strip in order to increase tensile strength. GRS walls have gained popularity from an environmental standpoint because of their increased flexibility, speed of construction, affordability, and potential for employing locally sourced materials [4]. Because they are affordable, quick and simple to construct, better acceptable to differential settlement, and more tolerant against seismic stresses, GRS walls have occupied a significant amount of area as retaining structures [5, 6]. The rivers are tamed by big size dams mostly upstream of big cities. The cities expand geometrically and covers the flood plain which increases the flooding area and depth at the same flood discharge. To moderate the flood, dam authority has to take decision of pre-empting the reservoir for anticipation of flood to come which is called rule level. This reduces peak discharge but duration of flood increase. Flood related hazards are; hydrostatic and hydrodynamic forces, flood-borne debris impact loads, internal and site drainage considerations, and site-specific soil and geotechnical considerations such as soil pressure, bearing capacity, land subsidence, erosion, scour, and shrink-swell potential [7]. For walls potentially subject to inundation, such as those located adjacent to rivers, canals, detention basins or retention basins, a minimum hydrostatic pressure, effective unit

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weights below the equivalent surface of the pressure head line and rapid drawdown conditions are added in analysis [6]. Normally, reinforced soil structures are not designed for hydrostatic pressures. Where hydrostatic pressures are likely due to submergence; the design should account for such pressure. Proper drainage and prescribed free draining materials are used [8]. Polemio and Lollino [9] observed that upstream water impoundment is generally not considered in the design procedure, probably because this kind of event is believed as exceptional, temporary and without relevant consequences on the embankment stability. Yoo and Jung [10] revealed that the wall failure was mostly caused by poor design and low-quality back fill, despite the fact that rainfall infiltration was the principal triggering mechanism. Flood hazard is one of the major causes of failure if not taken into consideration. The failure database of GRS wall concludes that the maximum number of failures are due to fine grain soil or water ingress either externally or internally [11-13]. The probability analysis for Tapi River has been carried out to estimate peak flood with return periods by different methods [14]. Identification of trend and probability distribution for time series of annual peak, HEC-RAS based hydrodynamic model in prediction of stages and one-dimensional hydrodynamic modelling of flooding and stage hydrographs in the lower Tapi River [15]. A two-dimensional HEC-RAS model was used to analyze the propagation of the flood wave and to assess failure risk on dam downstream areas [16]. A reliable, remote, Early Warning System (EWS) specifically designed for lava flood detection, along with its disaster communication system was successfully implemented in Mount Merapi, Indonesia, coordinated with the local Disaster Deduction Risk (DDR) forum [17]. Fitzgerald et al. [18] gave explanation of how and under which circumstances nonparametric statistics are used. Bargegol et al. [19] used F-distribution in statistical analysis of railway accident in Japan. Samantaray and Sahoo [20] used statistical methods to forecast the stream-flow from four flow data of different stations. Majority of researchers have investigated about peak discharge, it's destroying impact, area of submergence and how to reduce the intensity by diversion, early warning system and flood routing. Dam regulation by rule level is pre-emptying the reservoir in such a way that at no point of time maximum outflow exceeds the pre-decided value. This pre-decided value which is decided by the area of submergence in downstream city or town, further swells and occupy the space through which the flood has to pass. So, this is a viscous circle. When we limit the peak discharge, to pass same volume of flood, the duration of flow will increase. This duration may be prolonged in such a way that it may affect the bearing capacity and metric suction of geotechnical structure in the course of flood line. Perhaps no literature is available which investigated this aspect of dam regulation. The aim of the study is; firstly, to categorize the flood data on the basis of major event on river Tapi upstream of study area; secondly, to verify the hypothesis that the difference in category is significant or just random for both flood discharge and flood duration; thirdly, to estimate design maximum value of above two parameters for different flood return period; and finally, to consider prolonged inundation as additional flood hazard for geotechnical structure on the bank of non-perennial river.

2. STUDY AREA

For study purpose, a waterfront geosynthetic reinforced earth wall on the bank of river Tapi in the area of south Gujarat in India, which survived several numbers of floods in past has been selected. It lies in the town of Mandavi which is in the proximity of the city Surat in the state of Gujarat of western India. The coordinates of the site are 21.25˚N and 73.33˚E. The site is on the northern bank of river flowing from east to west. Its chainage from Ukai dam is 3.1 km in lower Tapi Basin. Figure 1 shows lower Tapi basin and Mandavi town in which study area is located.

A gabion facing wall along three sides, 3m to 6m high was constructed to make a large size plain multipurpose raised and paved platform. Figure 2 presents aerial and localized view of study wall. This Riverfront wall's construction was started in July 2017 and completed in February 2018. The completed wall with top platform and side railing is also shown in Figure 2.

The wall is constructed on sloping ground, immediately next to approach road, joining the bank to river. The waterway is touching the wall face in monsoon. A typical sectional view including details of the tallest section of the wall with acting forces is shown in Figure 3. All the de-stabilizing lateral forces and stabilizing vertical forces acting on the wall is shown in Figure 3. These forces are; the active earth pressure force of submerged soil (P_1), the water pressure force (P_2), the active earth pressure force due to surcharge load (P_3), the water pressure force from river side (P_4), the at rest

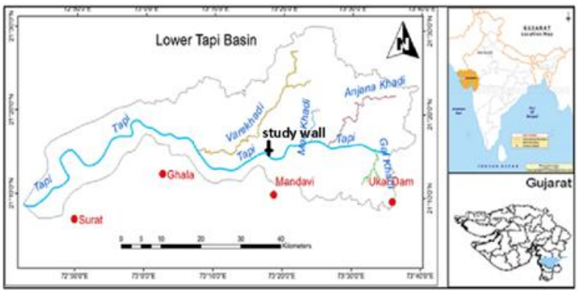


Figure 1. Location of study area in Mandavi town, lower Tapi basin

(a)

(b)

Figure 2. Study wall: (a) aerial view, (b) actual view

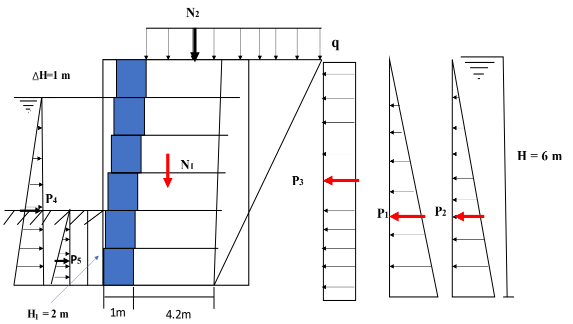


Figure 3. Wall detail with acting forces (tallest section facing waterways)

pressure force of submerged soil from river side (P_5), the gravity force of reinforced earth wall (N_1), and the vertical force due to surcharge load (N_2). The wall is maximum 6m in height from the base, and it is reinforced with Geo-strip of ultimate tensile strength 100 kN/m. The foundation soil below the wall is silty sand (SM) having C=0, and φ =30˚. Corrected SPT value of 11 at 1.5m depth and 30 at 4.5m depth shows soil is medium dense to dense below. The satellite image of the study area investigated since year 2002 does not show major scour near the bank.

2. 1. Flood in Lower Tapi Basin Many of the most serious floods have resulted from heavy rainfall in the Tapi River's catchment area. The monsoon generally starts in this area during the third week of June and there are occasional heavy rainstorms from the beginning of August to the end of September. The catchment area receives around 90 per cent of its annual rainfall between June and October and most floods occur in August/September. To prevent repeated floods in Surat, a major Dam was constructed in 1972 at village Ukai, which is located about 100 km upstream of Surat. Immediately after the construction of the Ukai dam in 1975, Central Water Commission (CWC) prepared detailed guidelines for the flood control operation of the Ukai reservoir. The guidelines recommended that up to the end of August, the reservoir should be filled maximum up to the level of 103.33m and thereafter be gradually raised up to Full Reservoir Level (FRL) of 105.16m by the end of September. It also prescribed that the reservoir level would not be allowed to go above the full reservoir level FRL of 105.16m. Later, due to increased demand for water and absence of major flood, the State Government relaxed the rule levels and recommended that the reservoir may be filled up to the level of 104.55m by the end of August and then filled up to FRL by 15th September. This consequently reduced the available flood cushion in the reservoir and thus aggravated the problem of flood management. After the major flood of 1994 and 1998, a joint committee with CWC, Central Design Organization, Department of Narmada and Water Resources, Government of Gujarat was formed in 1999 to review the procedure for dam operation for flood control and prepared manual to provide clear guidelines for dam operation. The committees come out with a 'Manual on Flood Control Operation of Ukai dam in July 2000, which continued to be used in operation of the dam. Table 1 provides compilation of rule level recommended by nodal agency.

The flood of 2006 caused greater damage and affected badly the Surat and Hazira twin-city of Gujarat. It is documented fact that no decision related to rule level was taken till the dam level reached 105.16 m. Then government of Gujarat made strict implementation of rule level after 2006.

After strict implementation of rule level, the flood situation changed for the downstream of the dam. Therefore, a study was needed to assess the flood hazard parameters in this changed scenario. This study is limited to two flood hazard parameters of flood discharge and flood duration.

3. METHODOLOGY

Data for statistical analysis were collected from Ukai dam authority; which were accurately measured and

TABLE 1. Recommended Rule Level of Ukai reservoir [21]

Date	Recommended rule level in m		
	Original Rule Level by CWC, 1975	Later Correction before 1994 flood	New Level by GOG, 2000
1st July	-	-	97.84 (Min.)
1st August	-	-	101.50 (Min.)
1st September	Max. 103.33	104.55	103.63 (Max.)
15th September	-	FRL 104.55	103.63 (Max.)
1st October	FRL 105.16	-	105.16 (Max.)

provided on request for purely study purpose. Daily outflow data of Ukai (1972-2020) and other peak discharge data (1939-1971) from literature [14] were collected. First, the flood data were categorized on the basis of two major event and tested for its distribution whether it is parametric or non-parametric. Descriptive statistics, histogram, normal and log-normal probability test are carried and graph plotted in excel programming. Hypothesis test of significance, one way ANOVA test for parametric and Chi-square test for non-parametric distribution is conducted. ANOVA test is suitable in analysis of simple random, parametric and independent data, it is using F-test to check the hypothesis, F distribution (Fisher-Snedecor distribution) is also called as variance ratio distribution as it usually defines the ratio of the variance of two normally distributed population. Chi-square is robust for distribution of data and can be used for which parametric assumption cannot be met. It is also flexible in handling data from both two groups and multiple group studies. Therefore, this non-parametric test was used to find significance of flood duration data even with the limitation of sample size. Category with significant difference is selected for estimation of design maximum value. For sample size 30 or less t-value is used, therefore in the estimation of peak discharge and flood duration t-value is taken. These estimated values will be considered for analysis and rectification of flood design parameters of study wall. Main aim of data analysis is whether two basic flood parameters (flood discharge and duration) are significantly changed or the changes are just random after implementation of rule level. Figure 4 shows a flow chart of the methodology adopted in the present study.

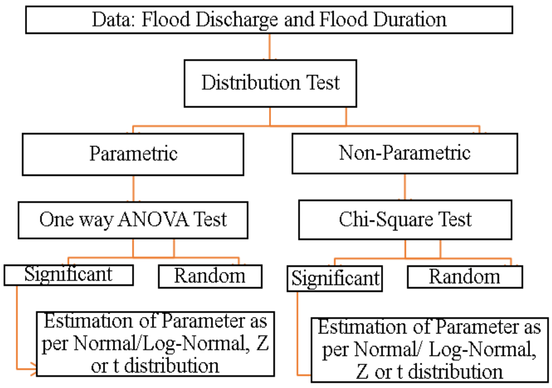


Figure 4. Flow chart showing methodology

TABLE 2. Peak Discharge Data

Year	Discharge (Lakh cusecs)	Year	Discharge (Lakh cusecs)	Year	Discharge (Lakh cusecs)
1939	5.15	1967	4.55	1995	4.01
1940	2.43	1968	15	1996	2.12
1941	4.81	1969	8.56	1997	4.94
1942	7.58	1970	13.14	1998	10.53
1943	1.79	1971	0.66	1999	3.3
1944	9	1972	2.47	2000	2.38
1945	7.22	1973	5.29	2001	3.09
1946	3	1974	3.06	2002	4.32
1947	2.91	1975	4.56	2003	3.32
1948	2.55	1976	3.81	2004	3.89
1949	6.62	1977	3.09	2005	4.68
1950	3.98	1978	8.88	2006	12.05
1951	1.62	1979	8.58	2007	6.37
1952	1.12	1980	3.17	2008	2.08
1953	0.64	1981	5.73	2009	2.15
1954	6.89	1982	1.33	2010	2.32
1955	2.36	1983	0.78	2011	2.31
1956	3.06	1984	0.5	2012	3.35
1957	1.58	1985	0.5	2013	4.33
1958	6.2	1986	2.86	2014	2.47
1959	13.16	1987	0.5	2015	0.77
1960	2.55	1988	3.3	2016	0.24
1961	7.36	1989	3.1	2017	0.1
1962	7.99	1990	4.9	2018	0.11
1963	2.7	1991	3.68	2019	1.94
1964	2.15	1992	1.84	2020	1.65
1965	1.55	1993	3.35	2021	2.05
1966	3.66	1994	8.87		

4. RESULT AND DISCUSSION

4. 1. Flood Catalog and Categorization of Data

Peak flood discharge data since year 1939 till date is tabulated in Table 2. In the table years, 1972 and 2006, having major event related to flood regulation, are highlighted. In year 1972, multipurpose Ukai dam was constructed with basic purpose of irrigation which changed its focus to more on flood control in coming years. Another major event was strict implementation of flood control after the devastating flood of 2006 which made havoc in downstream city of Surat.

Flood duration data since year 1972 till date with separation of year 2006 is also tabulated in Table 3 for prolonged inundation analysis. In this table "number of days" are taken when the flood just exceeds the base of study wall. The purpose of taking only those days of a year is to know, for how many days the wall will be under inundation.

Both the flood data are categorized as per the major event. Peak discharge data is having three categories: First category is "A" (before construction of Ukai dam when there was no flood control to Ukai dam constructed), second category is "B" (after construction of Ukai dam to strict implementation of rule level), third category is "C" (after strict implementation of rule level till date). Category A is from year 1939 to year 1971, category B is from 1972 to 2006 and category C is from 2007 to 2020. Flood duration data is also divided into two categories; First category is "A" (after construction of Ukai dam to strict implementation of rule level) and second category is "B" (after strict implementation of rule level till date).

TABLE 3. Flood duration data

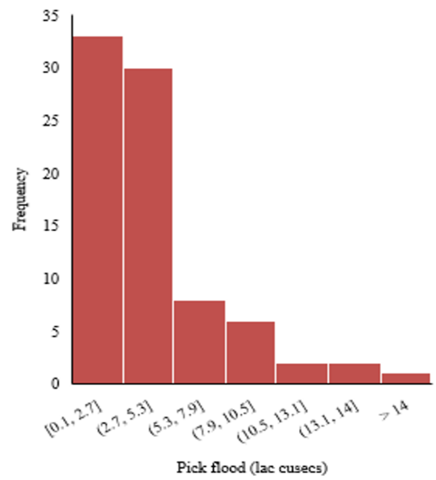
Criteria- A (1972 to 2006)				Criteria-B (2007 to 2020)	
Year	**No of Days***	**Year**	**No of Days***	**Year**	**No of Days***
1972	0	1990	28	2007	30
1973	14	1991	0	2008	3
1974	7	1992	0	2009	0
1975	0	1993	0	2010	19
1976	37	1994	22	2011	11
1977	0	1995	0	2012	23
1978	7	1996	0	2013	59
1979	10	1997	0	2014	12
1980	0	1998	18	2015	6
1981	3	1999	0	2016	4
1982	0	2000	0	2017	0
1983	25	2001	0	2018	0
1984	1	2002	8	2019	63
1985	0	2003	14	2020	22
1986	0	2004	3	2021	14
1987	0	2005	5		
1988	21	2006	33		
1989	1				

*When the flood just reached above base of study wall in a year

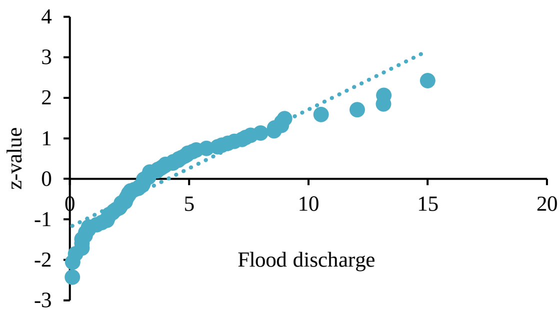
4. 2. Distribution Test All four data set of peak discharge, (1939-2020), (1939-1972), (1973-2006) and (2007-2020) and two data set of flood duration, (1972-2020) and (2007-2020) are checked for discriptive statistics to know the characteristics of the data (Table 4). The Peak discharge data of Table 2 is plotted in form of histogram showing peak discharge and its frequency, and it is also tested for probability plot test. Both the plot confirms that this data is following log-normal distribution (Figure 5). Similarly flood duration data is plotted as histogram and also tested for probability plot test, but this data does not show any distribution (Figure 6). When this data is taken separately, category C which was flood duration from year 2007 to year 2020 shows log-normal distribution (see Figure 7).

TABLE 4. Estimated flood discharge for different return period

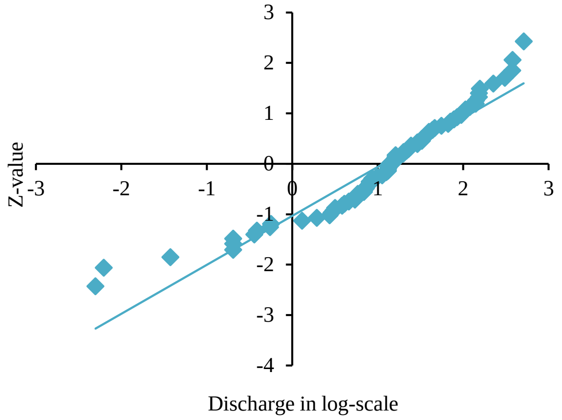
Sr. No.	Return Period	t -value	Discharge (Q) in lakh Cusecs
1	Once in 200 years	3.01	13.9
2	Once in 100 years	2.65	10.8
3	Once in 40 years	2.16	7.70
4	Once in 20 years	1.77	5.80
5	Once in 10 years	1.35	4.32



(a) Histogram

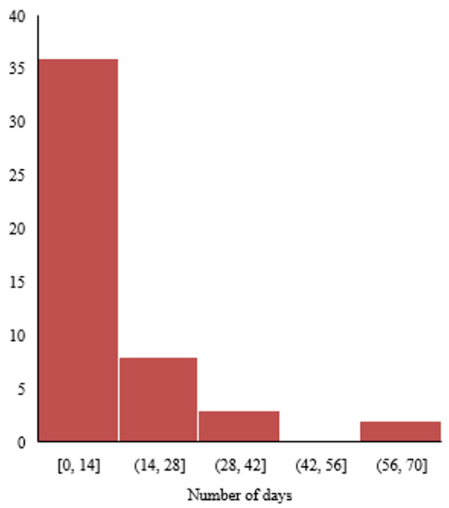


(b) Normal probability plot

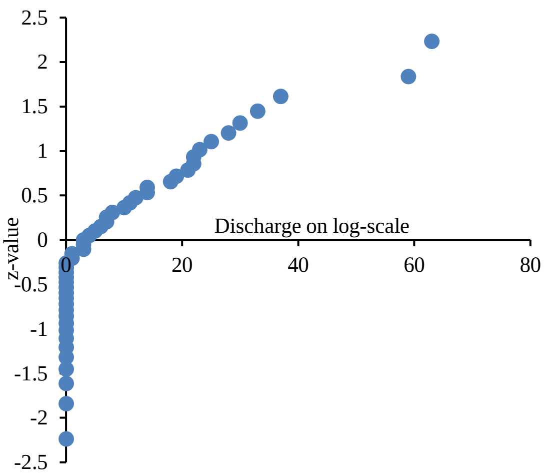


(c) Log-normal probability plot

Figure 5. Distribution test of Peak Flood Discharge (1939-2020): a) Histogram, b) Normal probability plot) Log-normal probability plot

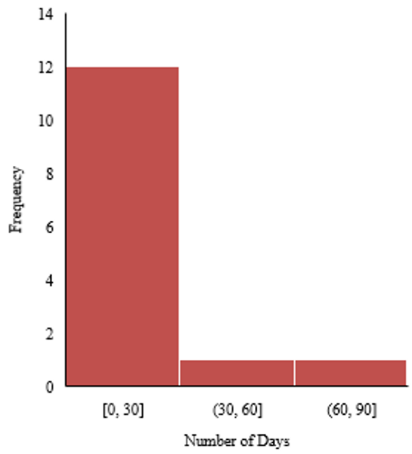


(a) Histogram

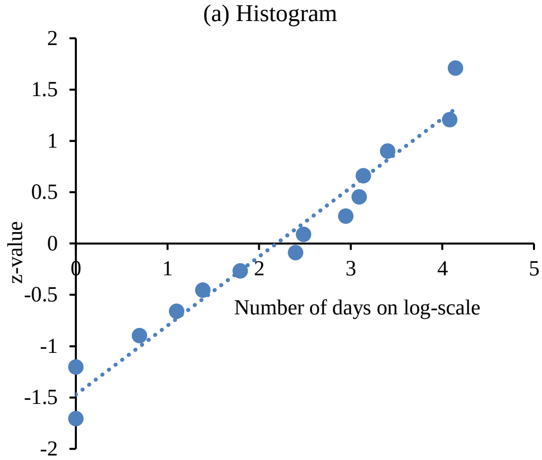


(b) Normal probability plot

Figure 6. Distribution test for Number of Days of Flooding (1972-2020): a) Histogram, b) Normal probability plot



(a) Histogram



(b) Log-normal probability plot

Figure 7. Distribution test of Number of Days of flooding (2007-2020): a) Histogram, b) Log-normal probability plot

4. 3. Hypothesis Verification For both the flood data, the question was whether difference in data which are divided as per major event i.e., dividing into category A, B, C in case of peak discharge and category A, B in case of flood duration, is significant or random. The meaning of categorization is only there if the difference is significant. Therefore, the hypothesis was whether the difference in category was significant or just by chance. For peak discharge data one-way ANOVA test is carried twice, one taking all three categories and another taking last two categories. In first case the calculated value of "F" equals to 4.78 which is more than value of 3.24 at 5% level of significance, while in another case the calculated value is 5.9, higher than value of 4.21 at 5% level of significance. Therefore, it can be said that the difference is significant so the categorization based on major event for peak discharge is justified.

Since overall flood duration data doesn't follow any distribution, it is tested on non-parametric Chi-Square test for the hypothesis. The calculated Chi-Square value is 23.21, while the value for 5% level of significance is

9.49 [22]. This shows that the difference is significant and implementation of rule level in year 2006 has changed the scenario of flood in lower Tapi basin i.e., lower discharge with larger duration.

4. 4. Estimation of Flood Parameters Estimation of flood parameters are on the basis of category "C" because after implementation of rule level the pattern of dam outflow changed. Since for category "C" only 14 sample data is available and this category is following log-normal distribution, estimation is based on log-normal t-distribution. Both the values of design maximum flood discharge and design maximum duration of flood are calculated for different flood return period.

4. 5. Design Maximum Peak Discharge The design flood is the most severe of the 100-year event or overtopping flood of lesser recurrence interval [6]. The estimated value of flood discharge in lakh Cubic feet per second (Cusecs) for different return period is listed in Table 4. The flood discharge for 200 years return period is 13.9 lakh Cusecs which is lower than year 1968 flood of 15 lakh Cusecs when Ukai dam was not there. Further this value is just higher than 12.05 lakh Cusecs flood of year 2006 after Ukai dam construction. The reason behind this is flood regulation on the basis of rule level i.e., pre-empting the reservoir in anticipation of possible flood has reduced the peak discharge and increased the duration of flood.

4. 6. Design Maximum Duration of Flood Number of days of wetting is very important parameter in analysis of geotechnical structure for prolonged inundation. If number of days is more than 40 days [10]. There are chances of reduction in bearing capacity, metric suction and shear strength of soil which will ultimately decrease the stability factor of safety of waterfront geotechnical structure. Chances of prolonged inundation has been examined by three ways: First, estimating number of days of wetting using log-normal t-distribution for different return period as shown in Table 5. Second, plotting the graph of flood dispersion throughout monsoon period for major flood as shown in Figure 8, third, comparing average outflow volume of major flood as shown in Table 6.

TABLE 5. Estimated number of days of wetting for different return period in lower Tapi basin

Sr. No.	Return Period	t -value	No of Days of wetting
1	Once in 200 years	3.012	186
2	Once in 100 years	2.65	134
3	Once in 40 years	2.16	85
4	Once in 20 years	1.771	60
5	Once in 10 years	1.35	41

TABLE 6. Average outflow volume of major flood

Year	1994	1998	2006	2013	2019
Total Flood Release in "MCM"	10760	8303	17243	14457	12080
Duration of Flood in Number of Days	22	18	33	59	63
Average Flood Release in "MCM/day"	489	461	522	245	192

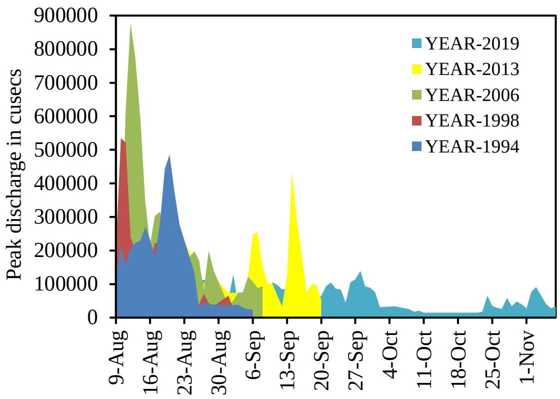


Figure 8. Flood duration graph showing dispersion of flood

For return period of 10 years the wetting days is 41, therefore the downstream waterfront structure must be analyzed for prolonged inundation. The wetting days for return period 200 years is abnormally high, more than 6 months which is higher than monsoon period of 4 months. This shows that once in 200 years, situation will be critical and dam authorities have to go for higher discharge for few days to balance the outflow.

The concentration or dispersion of flood throughout monsoon period for different major flood shown in Figure 8, demonstrated that flood after 2006 are widely dispersed. The highest dispersion is of the flood year 2019 and lowest for the flood year 1994.

Total outflow of water in MCM (Million Cubic Meter) throughout the monsoon season for major floods are taken from Ukai dam data and it is converted into average outflow by dividing it with number of days of flooding. This value can be compared for the parameter of prolonged inundation. Here it can be said that, although in year 2019 total outflow was only 70% of year 2006 outflow, duration of flood was almost double. Therefore, it is finally established that implementation of rule level has increased prolonged inundation.

4. CONCLUSIONS

In this study, flood hazard assessment of water-front GRS wall has been investigated for dam regulation rule level. Flood data released by Ukai dam authority for lower Tapi basin has been analyzed and tested for hypothesis of strict implementation of rule level in 2006. This was needed to know whether it has changed two main flood hazard parameters; peak discharge and flood duration. It is found that estimated flood discharge for 100 years return period is reduced (10.8 lac cusecs). This value is much lower than year 1968 flood of 15 lakh Cusecs when Ukai dam was not there and also, lower than 12.05 lakh Cusecs flood of year 2006 after Ukai dam construction. Further, it is observed that duration of flood has significantly increased due to implementation of rule level which was not studied before. The estimated value of inundation days is more than 40 for 10 years return period, which is sufficient to create loss of metric suction inside geotechnical structure. Major findings of the study are useful in forecasting the flood discharge and flood duration for Lower Tapi Basin. Other flood parameters, socio-economic impact and change in submergence pattern owing to dam regulation are the future scope of work.

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Persian Abstract

چکیده

پارامتر خطر سیل با دبی اوج و طغیان طولانی‌مدت به دلیل تغییر در مقررات سد برای دیواره خاک تقویت‌شده ژئوسنتتیکی (GRS)جلوی آب در پایین دست سد بزرگ برآورد شده است. سطح قانون تنظیم سد، مخزن را با دبی اوج کمتر تخلیه می کند تا از شهر در حال گسترش پایین دست که به دشت سیلابی نفوذ می کند، محافظت کند. مطالعه حاضر به منظور آزمون این فرضیه است که سطح قانون به طور قابل توجهی دبی اوج و مدت طغیان را تغییر داده است و همچنین تخمین این دو پارامتر مهم خطر سیل برای دوره های مختلف بازگشت سیل است. روش شناسی شامل سه بخش است: اول طبقه بندی داده های سیل بر اساس رویداد اصلی تنظیم سیل، دوم آزمایش توزیع و سوم برآورد حداکثر دبی پیک طراحی و مدت زمان سیل. ارزش تخمینی دبی اوج و مدت سیل به وضوح نشان دهنده مفهوم سطح قوانین تنظیم سد است. ارزش تخمینی پیک دبی برای ۲۰۰ سال دوره بازگشت ۱۳.۹ لک کیوسک است که کمتر از دبی سیلاب در سال ۱۹٦۸ که ۱۵ لک کوزک بوده است و مدت زمان تخمینی سیل برای ۱۰ سال دوره بازگشت ٤۱ روز است. مهمترین یافته این مطالعه افزایش قابل توجه مدت سیلاب به دلیل اجرای سطح قاعده است که یک پارامتر خطر سیل دیگر را برای سازه ژئوتکنیکی جبهه آب که طغیان طولانی مدت است، اضافه می کند.