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# Dam Overtopping Risk Analysis Modeling
## Case Study: Bhatsa Dam, Thane

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*Abstract*— **More appropriately, hydrologic analysis of the dam depends upon probabilistic assessment of rainfall, runoff and flood routing analysis. Therefore hydrologic risk analysis and uncertainty analysis use statistical and mathematical models (mostly probabilistic) to provide useful data for conclusion. This study presents the application of risk and uncertainty analysis to dam overtopping due to various inflows for the Bhatsa dam in Thane. The scope of study includes univariate flood frequency analysis and reservoir routing to derive the maximum water elevation of the reservoir. Then the probability distributions of multiple independent and random variables are set in order to evaluate the appropriate probability of dam overtopping risk. The probability of overtopping is analysed by uncertainty analysis method or Monte Carlo simulation method and goodness of fit test. It considers the flood peak discharge, initial depth of water in the reservoir, and spillway discharge coefficient as uncertain variables. The rising water elevation in the reservoir is the most important factor in overtopping risk analysis. Hence, in this study, the application of risk and uncertainty analysis including various distribution types of different parameters of dam overtopping due to various inflows in reservoir for the dam is presented. It is also intended to the study which aims to develop better distribution model of uncertainty events**

**Keywords- overtopping; hydrologic; univariate; distribution; simulation.**

## I. Introduction

A dam is a barrier across flowing water that obstructs, directs or slows down the flow, often creating reservoir, lake or impoundments. Dam is one of the very important components of infrastructure in India. Dam provides range of economic, environmental, and social benefits, including hydroelectric power, irrigation, water supply, flood control, and tourism [6]. However, like all pieces of infrastructure, dams get old and get deteriorated, posing a potential threat to life, health, economy and the environment [1]. Dam failure means such failure in the structures or operation of a dam which may lead to uncontrolled release of impounded water resulting in downstream flooding. Therefore, the safety of dam is a matter of great concern to the public and become a national responsibility to take steps to ensure the safety of dams.

Unfortunately, there are some cases which happened in India dew to overtopping. Kaddam Project Dam, Andhra Pradesh, was a composite structure, gravity dam. It was 30.78 m high and 3.28 m wide at its crest. The dam was overtopped by 46 cm of water above the crest, inspite of a free board allowance of 2.4 m that was provided, causing a major breach of 137.2 m wide that occurred on the left bank. Two more breaches developed on the right section of the dam. The dam failed in August 1958. Kodaganar Dam, Tamil Nadu, was constructed in 1977 on a tributary of Cauvery River as an earthen dam with regulators, with five vertical lift shutters each 3.05 m wide. The dam was 15.75 m high above the deepest foundation, having an 11.45 m of height above the river bed. The storage at full reservoir level was 12.3 million $m^3$, while the flood capacity was 1275 $m^3/s$. A 2.5 m free board above the maximum water level was provided. The dam failed due to overtopping by flood waters which flowed over the downstream slopes of the embankment and breached the dam along various reaches. Machhu II dam was built near Rajkot in Gujarat, on River Machhu in August, 1972, as a composite structure. It consisted of a masonry spillway in river section and earthen embankments on both sides. The dam failed on August 1, 1979, because of abnormal floods and inadequate spillway capacity. Consequently, overtopping of the embankment caused a loss of 1800 lives. Tigra Dam, Madhya Pradesh, was a hand placed masonry gravity dam of 24 m height, constructed for the purpose of water supply. 0.85 m of water overtopped the dam over a length of 400 m. The dam was reconstructed in 1929. The Khadkawasla Dam, near Pune in Maharashtra, was constructed in 1879 as a masonry gravity dam, founded on hard rock. The upstream dam released a tremendous volume of water into the downstream reservoir at a time when the Khadkawasla reservoir was already full, with the gates discharging at near full capacity. This caused overtopping of the dam because inflow was much above the design flood [7].

In India, a sound foundation was laid for a nation-wide dam safety surveillance programme in 1979 and maintenance and upkeep of the dams have been started recognizing dam safety as an important activity. The Government of India, keeping the importance of safety of dams, constituted a Committee in 1982, under the

Chairmanship of Chairman, Central Water Commission, to review the existing practices and to evolve unified procedure for safety of dams in India. The Committee in its report dated 10th July, 1986 has recommended for dam safety procedures for all dams in India and the necessary legislation on dam safety

## II. DAM OVERTOPPING RISK

Risk is a chance of encountering loss or harm to the project. Risk is always in future [5]. It is an uncertain event that can harm project objective. It is the likelihood of a specified event occurring within a specified period and consequences. Risk is the combination of the likelihood and the consequence of a specified hazard being realized. It is a measure of harm or loss associated with an activity. It can be one or more. Once they are identified they do not remain risks but they become management problems.

Due to severe combination of meteorological and hydrologic conditions amount of flood that may be expected to be overtop the crest of dam is known as dam overtopping. It leads to uncontrolled release of impounded water resulting in downstream flooding. It also leads to dam failure [4].

## III. STUDY AREA AND DATA COLLECTION

Assuming increase in water supply, Maharashtra government had appointed a committee in year 1961, for efficiently supplying of water and to find new water recourses. Taking all aspects into account, committee had suggested plan about construction of dam to Maharashtra government. Maharashtra Government had accepted suggestions in year 1964. Maharashtra administration agreed this project dated 28$^{th}$ July 1968. Dam site was located near confluence of Bhatsa and Chorana River, near Sajivali, Maharashtra.

TABLE 1: SALIENT FEATURES OF BHATSA DAM

| **General** | |
|---|---|
| a) Name of river | Bhatsa |
| b) Location | Thane, State:Maharashtra |
| c) Latitude | $19^0$- 31' – 00" |
| d) Longitude | $73^0$ – 25' – 15" |
| **Water storage** | |
| a) Catchment area | 388.5Sq.km |
| b) Gross storage | 976.10 Mcum |
| c) Live Storage | 942.10 Mcum |
| **Controlling levels** | |
| a) River bed level | 59.87 m |
| b) MDDL | 79.20 m |
| c) Full reservoir level | 142.07 m |
| d) High flood level | 145.05 m |
| e) Top of dam | 146.07 m |
| **Dam and Spillway** | |
| a) Length of dam | 959 m |
| b) Length of spillway | 72 m |
| c) Radial gates | 12 x 8 m, 5nos |
| f) Water Supply | 426.8 M cum |
| g) Irrigation | 220.82 M cum |

## IV. RISK ANALYSIS

There are many tools and techniques available for the quantitative risk analysis. Conventionally, the approach to dam design focuses deterministic approach on extreme events, such as probable maximum flood (PMF). PMF can be defined as amount of flood that can be expected from the most severe combination of meteorological and hydrologic conditions that are logically possible. But standard dam design has not been absolutely solved because of the uncertainty in variables and remains a difficult issue. By improving the mathematical and statistical models, the increasing ability of computer programs, and the availability of data records for longer periods, it is time to move from the deterministic approaches in engineering design to probabilistic methods that consider higher order uncertainty in variables and models [3]. The concepts of acceptable and tolerable risk are contrasted for use in the dam safety. An acceptable or tolerable risk are which, for the purposes of life or work, everyone who might be impacted is prepared to accept assuming no changes in risk control mechanisms. In other word it is willingness to live with a risk [2]. This study presents a probability-based method for estimating dam overtopping probability by taking into account the uncertainty arising from peak discharges, initial water levels, and spillway discharge coefficient. The Monte-Carlo simulation (MCS) can be applied to perform the uncertainty analysis. These results can be analysed statistically to predict system behaviour. As the accuracy of these methods strongly depends on sample size, large sample numbers were considered in this study to increase calculation precision.

The probability of overtopping was assessed by applying MCS. MCS method is dependent on random variables, so flood discharge at different return periods are taken as the random variables. The goodness of fit test such as Kolmogorov–Smirnov was applied. This paper considered dams often pose low probability high consequences risk. A risk is tolerably low if it is similar to the risk of life loss due to natural hazard, because its return period is high. A risk is unacceptably high if it is similar to the risk of life loss due to disease, for which return period is less. Paper has given some examples of tolerable risk such as economic/financial criteria and legal considerations.

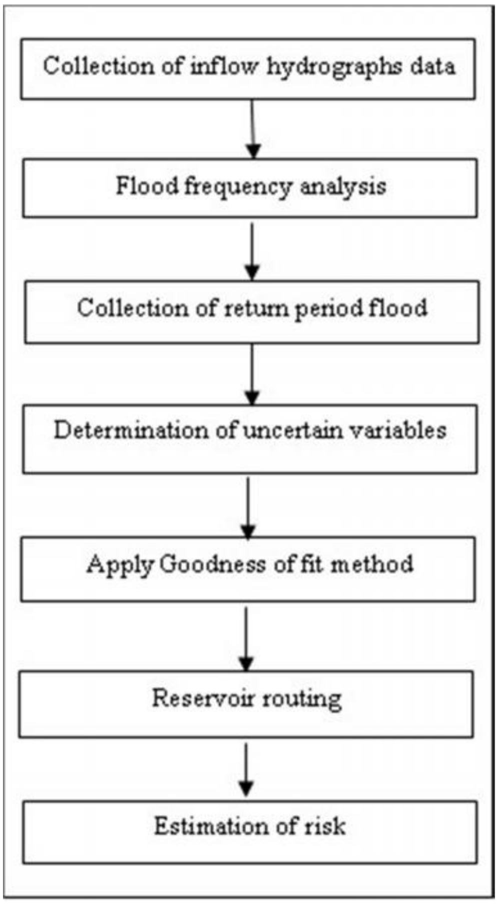


Figure 1: Flow chart of risk analysis

## V. MAXIMUM FLOW BY GUMBELS METHOD FOR RETURN PERIOD

This method is useful for obtaining values of flood discharge for high recurrence interval. According to Gumbel (1941), the probability of occurrence of an event equal to or larger than a value $x_0$ is given by,

$$P(X \geq x_0) - 1 - e^{-e^{-y}}$$

$$y_T = -\left[ln.\,ln\frac{T}{T-1}\right]$$

According to Chow (1951), most frequency distribution functions can be expressed as following general equation:

$$x_T = \bar{x} + K_T\sigma_{n-1}$$

Where,

$\sigma_{n-1}$ = standard deviation of sample size $N = \sqrt{\frac{\sum(x-\bar{x})^2}{N-1}}$,

$K_T$ = Modified frequency factor= $\frac{y_T-\bar{y}_n}{S_n}$,
$\bar{y}_n$ = Reduced mean for sample size N,
$S_n$ = Reduced standard deviation.

TABLE 2 : MAXIMUM FLOW BY GUMBELS DISTRIBUTION

| **Years** | **(T/T-1)** | **ln(T/T-1)** | **$Y_T$ = -ln(ln($\frac{T}{T-1}$))** | **$S_n$** | **Extra Discharge** | **Total Discharge** |
|---|---|---|---|---|---|---|
| 5 | 1.25 | 0.223143551 | 1.500 | 1.133 | 893.89 | 1073.89 |
| 10 | 1.11111 | 0.105360516 | 2.250 | 1.883 | 1485.98 | 1665.98 |
| 50 | 1.02041 | 0.020202707 | 3.902 | 3.535 | 2789.07 | 2969.07 |
| 100 | 1.0101 | 0.010050336 | 4.600 | 4.233 | 3339.95 | 3519.95 |
| 150 | 1.00671 | 0.006688988 | 5.007 | 4.640 | 3661.19 | 3841.19 |
| 200 | 1.00503 | 0.005012542 | 5.296 | 4.929 | 3888.83 | 4068.83 |
| 250 | 1.00402 | 0.004008021 | 5.519 | 5.152 | 4065.29 | 4245.29 |
| 300 | 1.00334 | 0.003338901 | 5.702 | 5.335 | 4209.4 | 4389.4 |
| 350 | 1.00287 | 0.002861232 | 5.857 | 5.490 | 4331.22 | 4511.22 |
| 400 | 1.00251 | 0.00250313 | 5.990 | 5.623 | 4436.72 | 4616.72 |
| 450 | 1.00223 | 0.002224695 | 6.108 | 5.741 | 4529.76 | 4709.76 |
| 500 | 1.002 | 0.002002003 | 6.214 | 5.847 | 4612.97 | 4792.97 |
| 550 | 1.00182 | 0.001819837 | 6.309 | 5.942 | 4688.24 | 4868.24 |
| 600 | 1.00167 | 0.001668057 | 6.396 | 6.029 | 4756.96 | 4936.96 |
| 650 | 1.00154 | 0.001539646 | 6.476 | 6.109 | 4820.16 | 5000.16 |
| 700 | 1.00143 | 0.001429593 | 6.550 | 6.183 | 4878.68 | 5058.68 |
| 750 | 1.00134 | 0.001334223 | 6.619 | 6.252 | 4933.15 | 5113.15 |
| 800 | 1.00125 | 0.001250782 | 6.684 | 6.317 | 4984.1 | 5164.1 |
| 850 | 1.00118 | 0.001177163 | 6.745 | 6.378 | 5031.96 | 5211.96 |
| 900 | 1.00111 | 0.001111729 | 6.802 | 6.435 | 5077.09 | 5257.09 |
| 950 | 1.00105 | 0.001053186 | 6.856 | 6.489 | 5119.77 | 5299.77 |
| 1000 | 1.001 | 0.0010005 | 6.907 | 6.540 | 5160.26 | 5340.26 |

## V. RANDOM EVENTS AND VARIABLES

For practical requirements of applying probability theory and statistics to hydrology, a simple definition of random variables are introduces in the text. Any quantity X is a random variable if for provided real number x, which the quantities X may or may not assume by observations, a probability P exists that X is equal to or less than x. In other words, this statement is donated by $P(X \leq x)$. It can be applied only in condition that, the sequence of various observation of X is governed by the law of chances or stochastic process.
For practical requirements of applying probability theory and statistics to hydrology, a generation of random number is essential part. Any quantity of data sample random variable can be generated. Random numbers can be generated in Mathwave's EasyFit v.5.5 software. A set of normally distributed random numbers of inflow is generated by using software.

TABLE 3 : RANDOM NUMBERS

| | | | | |
|---|---|---|---|---|
| 5286 | 3848 | 4522 | 1504 | 2909 |
| 2407 | 1374 | 1615 | 3980 | 3434 |
| 1336 | 1410 | 1342 | 3884 | 2893 |
| 5294 | 4783 | 5085 | 3781 | 1304 |
| 2329 | 2520 | 4206 | 2847 | 3149 |
| 2951 | 4373 | 5066 | 1108 | 3320 |
| 3832 | 3824 | 3434 | 3585 | 3359 |
| 2582 | 1823 | 3545 | 1671 | 5150 |
| 2473 | 3475 | 2457 | 4025 | 5203 |
| 1235 | 4378 | 3226 | 5000 | 2796 |

## VI. INFLOW HYDROGRAPHS

Consider a concentrated storm producing a fairly uniform rainfall of duration D over a catchment. After the initial losses and infiltration losses are met, the rainfall excess reaches the stream through overland and channel flows. In the process of translation a certain amount of storage is built up in the overland and channel flow phases. This storage gradually depletes after the cessation of the rainfall. Thus there is a time lag between the occurrence of rainfall in the basin and the time when that water passes the gauging station at the basin outlet. The runoff measured at the stream gauging station will give a typical hydrograph. The hydrograph of this kind which results due to an isolated storm is typically single peaked skew distribution of discharge and is known variously as storm hydrograph, flood hydrograph or simply hydrograph.
Since we have generated the set of random numbers we need to produce hydrographs based on these random numbers. Now separation of base flow is important as the flow contains both flows. The ordinates of unit hydrographs can be calculated as

a) From records or available data unit period of inflow (in this case a year) is selected
b) Further with available data the graph is plotted with time interval on x axis and discharge on y axis.
c) The discharge is separated from the groundwater flow or base flow.
d) The direct runoff can be calculated as per formula

$$\text{Direct runoff,} \qquad \mathrm{n} = \frac{0.36 \text{ x } \sum 0 \text{ x t}}{\mathrm{A}} \text{ cm}$$

Where,

O = Discharge ordinate
T = time interval
A= Area of the catchment

e) Further the ordinates of unit hydrograph can be calculated as,

$$\text{Ordinate of unit hydrograph} = \frac{\text{Ordinate of direct hydrograph}}{\text{Direct run off in cm}}$$

TABLE 4 : INFLOW UNIT HYDROGRAPH

| Discharge | Base flow | Ordinates of Direct run off | Direct runoff | Ordinates of Unit hydrograph |
|---|---|---|---|---|
| 5286 | 150 | 5136 | 145.144 | 35.38554312 |
| 2407 | 150 | 2257 | 145.144 | 15.5500722 |
| 1336 | 150 | 1186 | 145.144 | 8.171194342 |
| 5294 | 150 | 5144 | 145.144 | 35.44066079 |
| 2329 | 150 | 2179 | 145.144 | 15.01267493 |
| 2951 | 150 | 2801 | 145.144 | 19.29807365 |
| 3832 | 150 | 3682 | 145.144 | 25.36790689 |
| 2582 | 150 | 2432 | 145.144 | 16.7557712 |
| 2473 | 150 | 2323 | 145.144 | 16.00479296 |
| 1235 | 150 | 1085 | 145.144 | 7.475333778 |
| 3848 | 150 | 3698 | 145.144 | 25.47814222 |
| 1374 | 150 | 1224 | 145.144 | 8.433003267 |
| 1410 | 150 | 1260 | 145.144 | 8.681032774 |
| 4783 | 150 | 4633 | 145.144 | 31.92001972 |
| 2520 | 150 | 2370 | 145.144 | 16.32860927 |
| 4373 | 150 | 4223 | 145.144 | 29.09523921 |
| 3824 | 150 | 3674 | 145.144 | 25.31278922 |
| 1823 | 150 | 1673 | 145.144 | 11.52648241 |
| 3475 | 150 | 3325 | 145.144 | 22.90828093 |
| 4378 | 150 | 4228 | 145.144 | 29.12968775 |
| 4522 | 150 | 4372 | 145.144 | 30.12180579 |
| 1615 | 150 | 1465 | 145.144 | 10.09342303 |
| 1342 | 150 | 1192 | 145.144 | 8.212532593 |
| 5085 | 150 | 4935 | 145.144 | 34.0007117 |
| 4206 | 150 | 4056 | 145.144 | 27.94465788 |
| 5066 | 150 | 4916 | 145.144 | 33.86980724 |
| 3434 | 150 | 3284 | 145.144 | 22.62580288 |
| 3545 | 150 | 3395 | 145.144 | 23.39056053 |
| 2457 | 150 | 2307 | 145.144 | 15.89455763 |
| 3226 | 150 | 3076 | 145.144 | 21.1927435 |
| 1504 | 150 | 1354 | 145.144 | 9.328665378 |
| 3980 | 150 | 3830 | 145.144 | 26.38758375 |
| 3884 | 150 | 3734 | 145.144 | 25.72617173 |
| 3781 | 150 | 3631 | 145.144 | 25.01653175 |
| 2847 | 150 | 2697 | 145.144 | 18.58154396 |
| 1108 | 150 | 958 | 145.144 | 6.600340792 |
| 3585 | 150 | 3435 | 145.144 | 23.66614887 |
| 1671 | 150 | 1521 | 145.144 | 10.47924671 |
| 4025 | 150 | 3875 | 145.144 | 26.69762064 |

| Discharge | Base flow | Ordinates of Direct run off | Direct runoff | Ordinates of Unit hydrograph |
|---|---|---|---|---|
| 5000 | 150 | 4850 | 145.144 | 33.41508647 |
| 2909 | 150 | 2759 | 145.144 | 19.00870589 |
| 3434 | 150 | 3284 | 145.144 | 22.62580288 |
| 2893 | 150 | 2743 | 145.144 | 18.89847056 |
| 1304 | 150 | 1154 | 145.144 | 7.950723668 |
| 3149 | 150 | 2999 | 145.144 | 20.66223594 |
| 3320 | 150 | 3170 | 145.144 | 21.84037611 |
| 3359 | 150 | 3209 | 145.144 | 22.10907474 |
| 5150 | 150 | 5000 | 145.144 | 34.44854276 |
| 5203 | 150 | 5053 | 145.144 | 34.81369731 |
| 2796 | 150 | 2646 | 145.144 | 18.23016883 |

## VI. APPLICATIONS OF GOODNESS OF FIT TESTS AND CONCLUSION

The Goodness of fit test was applied to check the fitting of distribution based on the Kolmogorov–Smirnov tests. This testing is done by Mathwave's EasyFit v.5.5 software. The P-value, in contrast to fixed α values, is calculated based on the test statistic, and denotes the threshold value of the significance level in the sense that the null hypothesis ($H_0$) will be accepted for all values of α less than the P-value.

In India the rain which is dependent on monsoon, is having uncertain characteristic. Hence it is necessary to do research for uncertainty analysis. Risk and uncertainty analysis can be employed to evaluate the probability of dam failure regarding overtopping, internal erosion, geological instability, and earthquakes. This partially demonstrated the process of estimating overtopping probability due to various inflows.

The data collected from Bhatsa dam, Maharashtra. It is observed that for given data the below distributions are giving good results. The probability of overtopping was assessed by applying uncertainty analysis method (MCS) and considering the quantile of flood peak discharge, initial depth of water in the reservoir, and spillway discharge coefficient as uncertain variables. This work demonstrated the process of estimating risk of overtopping based on univariate flood frequency analyses. The selected uncertainty method (MCS) is categorized as sampling techniques and they are the most widely used method by hydrosystem engineers. In addition, univariate flood frequency analyses were carried out using the Gumbel logistic distribution and hydrographs with different return period of 1000-yr have been determined. All in all, risk analysis provides an expanded range of risk values in different return periods such that the dam administrator can identify the events that indicate a developing failure mode, understand the critical parameters needed to effectively monitor, and determine how to use a warning system for evacuating the downstream community.

TABLE 5 : APLLICATION OF GOOODNESS OF FIT TEST

| Sr. No. | Probability Distribution | Statistic value | P-Value | Remark |
|---|---|---|---|---|
| 1 | Beta | 0.08856 | 0.989 | Ok |
| 2 | Exponential | 0.2042 | 0.27819 | Ok |
| 3 | Gamma | 0.13001 | 0.80554 | Ok |
| 4 | General Extreme Value | 0.14242 | 0.71154 | Ok |
| 5 | Gumbel Max | 0.13503 | 0.76861 | Ok |
| 6 | Gumbel Min | 0.10862 | 0.93281 | Ok |
| 7 | Log-Pearson | 0.05029 | 1.0 | Ok |
| 8 | Logistic | 0.10959 | 0.92841 | Ok |
| 9 | Lognormal | 0.18422 | 0.39592 | Ok |
| 10 | Normal | 0.08695 | 0.99102 | Ok |
| 11 | Uniform | 0.05058 | 1.0 | Ok |
| 12 | Triangular | 0.16093 | 0.16093 | Ok |

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