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Prediction of Annual One Day Maximum Rainfall for Andaman & Nicobar Islands

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Abstract

Rainfall is the primary source of water in Andaman and Nicobar Islands. The prior information about the expected rainfall in Andaman and Nicobar Islands is required in designing various hydraulic, hydrologic, and soil water conservation structures. This study focuses on the frequency analysis of annual one day maximum rainfall of Port Blair, South Andaman district of Andaman and Nicobar Islands. The daily rainfall data of 53 years (1970-2022) was used to evaluate the designed value of expected rainfall using different probability distribution models. A total of five different probability distributions were used to design the maximum daily rainfall. A goodness of fittest was used to evaluate the best probability distribution model. Results showed that Log-Normal distribution was found to be best based on the Chi-squared goodness of fit test. Further, annual one day maximum expected rainfall values for various return periods were determined in the study area.

Key words: *Probability, Distribution models, Frequency analysis, Port Blair, Weibull*

Introduction

The primary and major water supply source for primary, secondary, and tertiary sectors in Andaman and Nicobar Islands is rainfall. Rainfall's erratic nature and variation in both the spatial and temporal scales effect the agricultural production critically. In nature, most of the extreme hydrological events happens rarely and predicting them before happens using the past records in terms of probability of occurrence is utmost important. Probability analysis of rainfall and prediction of annual maximum daily rainfall is necessary for solving various water resources management problems and estimate crop failures due to deficit or excess rainfall. The probability analysis is performed using a method called frequency analysis and the output from such analysis helps us to determine the expected rainfall at various chances (Bhakar et al., 2008). Prior information on knowing the expected rainfall helps to prevent and control the floods and droughts and safe design of various hydraulic and soil-water conservation structures to sustain their life period.

Though the nature of rainfall is erratic and varies with time and space, yet it is possible to predict design rainfall accurately for certain return periods using various probability distributions. A good number of studies were available on frequency analysis of daily rainfall in many locations of India (Agarwal et al., 1995; Upadhaya and Singh, 1998; Kumar, 1999; Kumar and Kumar, 1999; Mohanty et al., 1999; Singh et al., 2001; Rizvi et al., 2001; Bhakar et al., 2006; Nemichandrappa et al., 2010; Manikandan et al., 2011; Vivekanandan, 2012; Kumar and Bhardwaj, 2015; Suribabu et al., 2015; Sreedhar, 2018). However, the studies on this aspect in Andaman and Nicobar Islands are limited (Srivastava and Ambast, 2009).

The most used probability distribution functions (PDFs) to estimate/predict the hydrological events like rainfall, flood, and drought are normal, log-normal, Pearson type-III, log-Pearson type-III, and Gumbel extreme value distributions. Th expected rainfall from above distributions can be compared with the observed rainfall using goodness fit tests for an accurate prediction. There is no universal PDFs to predict the expected rainfall and it varies as per the rainfall characteristics. In the present study, an attempt was made to predict the expected annual one-day maximum rainfall at various return periods using five probability distribution functions, *viz.*, normal, log-normal, Pearson type-III, log-Pearson type-III, and Gumbel extreme value distribution.

Materials and Methods

Study Area

The Andaman and Nicobar Islands are situated at South of Tropic of Cancer in the equatorial belt. They are surrounded by Andaman Sea in East and Bay of Bengal in West. They are exposed to marine influences and have a tropical, humid, warm, moist, and equable climate. The study area is this investigation is the Port Blair, the capital of Andaman and Nicobar Islands. The study area receives an average annual rainfall of about 3080 mm in 8-9 months in a year. These Islands are visited by South-West (SW) and North-East (NE) monsoons. Nearly 95% of annual rainfall is received during May to December (230 cm during SW monsoon and 65 cm during NE monsoon). The mean temperature fluctuates between 25 to 30.5 ^{o}C. The Islands are situated in mid-sea; hence humidity percentage (79-90%) and wind speeds (4.7-14.8 km/h) are high.

Data Collection and Analysis

Rainfall gauging stations in South Andaman district are Port Blair and Hut Bay. In North & Middle Andaman and Nicobar are Mayabunder & Long Island and Car Nicobar & Nancowrie, respectively. The monthly rainfall data collected from the above rain gauge networks during different periods is used for generating the average annual rainfall map as shown in Fig.1. However, the daily rainfall data of Port Blair is used to carry out the frequency analysis due to availability of long-term daily data. Time series rainfall records of Port Blair for the period of 53 years (1970-2022) were collected from Indian Meteorological Department, Pune were used for carrying out this study. This collected data was processed for missing records using arithmetic average method and sorted out for annual maximum daily rainfall.

Descriptive Statistics

The characteristics of annual daily maximum rainfall was analysed using various statistical indices such as mean, standard deviation, coefficient of variation, standard error, coefficient of skewness, and Kurtosis. The annual maximum daily rainfall in Port Blair is vary as 152.6 ± 53.8 (Mean ± Standard deviation). The coefficient of skewness (γ_s) and kurtosis (K_s) tells us the nature of rainfall's distribution. If γ_s is positive, negative and zero then the distribution is skewed to the right, left, and follows the normal distribution, respectively. For kurtosis, if the number is greater than +1 and less than -1 indicates that the distribution is too peaked and too flat, respectively. From Table 1, it is interpreted that rainfall distribution in the study location is positively skewed and too peaked.

Table 1: Computation of statistical parameters of annual one day maximum rainfall

Statistics	Formula	Computed value
Mean	$\mu = \frac{1}{N}\sum_{i=1}^{N} X_i$	152.6
Standard deviation	$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i-\mu)^2}$	53.8
Coefficient of variation	$C_v = \frac{\sigma}{\mu}$	0.352
Standard error	$SE = \frac{\sigma}{\sqrt{N}}$	7.38
Coefficient of Skewness	$\gamma_s = \frac{N\sum_{i=1}^{N}(X_i-\mu)^3}{(N-1)(N-2)\sigma^3}$	1.44
Kurtosis	$K_s = \frac{\sum_{i=1}^{N}(X_i-\mu)^4}{N\sigma^4}$	3.68

X_i = Rainfall, N = total number of observations.

Frequency Analysis

Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances. Frequency analysis is performed to know the probability occurrence of extreme weather events like heavy rainfall and floods. In the literature mainly there are two methods such as empirical method and frequency factor method were used for performing frequency analysis of rainfall data. Th empirical method is also known as plotting position method, which is used to estimate the probability exceedance of rainfall. Several plotting position formulas were available and in that 'Weibull' formula is the most commonly used plotting position formula (Subramanya, 2013). As the Weibull method is empirical in nature, it will give better results only for small return periods. As the amount of extrapolation increases, the errors will also increase. Therefore, to avoid the errors and for more accurate results, the analytical methods like frequency factor methods are used. The prediction of rainfall using the analytical methods is a significant tool for better economic returns to farmers by mitigating crop failures (Bhakar et al., 2008).

Empirical Weibull Method

Probability of exceedance of rainfall (P) whose magnitude is equal to or more than a specified magnitude is defined as:

$$P = \frac{m}{N+1} \tag{1}$$

Return period or recurrence interval (T) is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once.

$$T = \frac{1}{P} \tag{2}$$

Where m = rank assigned to the rainfall data after arranging them in the descending order, N= number of data points.

In the Weibull method, after calculating T for all rainfall events, the T is plotted on x-axis and rainfall is plotted on y-axis of log-log paper. By extrapolating, the magnitude of rainfall for any return period can be easily estimated.

Frequency Factor Methods

According to Chow (1951), the general equation for hydrological frequency analysis is:

$$x_T = \bar{x} + K\sigma \tag{3}$$

Where, x_T = value of rainfall at return period (T), $\bar{x}$ = mean of the rainfall, σ = standard deviation, K = frequency factor which depends on the return period (T) and probability density function (PDF) of assumed distribution.

The availability of probability density functions (PDF) is huge and the most used PDFs in hydrology are explained below.

i) Normal distribution

This distribution is also called as 'Gaussian distribution', which has a symmetrical and bell-shaped probability density function ($f(x)$). It has two parameters: mean (μ) and standard deviation (σ). The PDF of this distribution and can be written as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{4}$$

$x = \mu + K_T\sigma$, Where $K_T = \frac{x-\mu}{\sigma}$

$$F(x) = \int_{-\infty}^{x} f(x)dx \qquad -\infty < x < \infty \tag{5}$$

$$\text{or } f(z) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{z^2}{2}\right) \tag{6}$$

Where $z = \frac{(x-\mu)}{\sigma}$, called the standard normal variate. The standard variate z has 0 mean and unit variance.

From Eq. 4, it is seen that $f(x) \to 0$ as $x \to \pm\infty$ and f(x) is maximum at $x = \mu$. Here, f(x) is symmetrical about mean.

The CDF (cumulative density function) is written as:

$$F(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\Pi}} e^{-u^2/2} d \tag{7}$$

This function is approximated as:

$$B = \frac{1}{2}\left[1 + 0.196854|z| + 0.115194|z|^2 + 0.000344|z|^3 + 0.019527|z|^4\right]^{-4} \tag{8}$$

F (z) = B for z < 0
F (z) = 1-B for z >= 0

ii) Log Normal distribution

It is a normal distribution of log of random variable 'x'. Therefore, the following quantities can be substituted in PDF of normal distribution (Eq. 4):

$$y = \log(x); \quad \sigma \to \sigma_y; \quad \mu \to \mu_y$$

Thus, y can be written as:

$$y = \mu_y + K_T \sigma_y$$

iii) Pearson Type III distribution

Its PDF is given by the following formula:

$$f(x) = \frac{1}{a\Gamma(b)} \left(\frac{x-c}{a}\right)^{b-1} e^{-\left(\frac{x-c}{a}\right)} \tag{9}$$

$$F(x) = \int_{c}^{\infty} f(x) d(x) \tag{10}$$

$\mu = ab + c$; $\sigma = a\sqrt{b}$; $\gamma_s = \frac{2}{\sqrt{b}}$; c<x<∞

where, a = scale parameter, b = shape parameter, c = location parameter, and γ_s = coefficient of skewness.

iv) Log Pearson Type III Distribution

It is a Pearson Type III distribution of log of random variable 'x'. Therefore, the following quantities can be substituted in PDF of Pearson Type III distribution (Eq. 9):

$$y = \log(x); \quad \sigma \to \sigma_y; \quad \mu \to \mu_y$$

Thus, y can be written as $y = \mu_y + K_T \sigma_y$

v) Gumbel/Extreme Value Type I Distribution

The PDF and CDF for extreme value type I distribution are given below:

$$f(x) = \frac{1}{\alpha} \exp\left[-\left(\frac{x-\beta}{\alpha}\right) - \exp\left(\frac{x-\beta}{\alpha}\right)\right] \tag{11}$$

$$F(x) = \int_{-\infty}^{x} f(x) d(x) = \exp\left[-\exp\left(\frac{x-\beta}{\alpha}\right)\right] \tag{12}$$

$$\alpha = \frac{\sqrt{6}}{\mu}\sigma; \quad \beta = \mu - 0.5772\alpha$$

Tests for Goodness of Fit

The goodness of fit of a model describes how well it fits a set of data points. Measures of goodness of fit typically summarize the discrepancy between observed values and the values expected under the model in question. In this study, to conclude whether a distribution fits sufficiently a data set and to determine whether there is a significant difference between the expected frequencies and the observed frequencies, Chi-square (χ_c^2) tests is used.

$$\chi_c^2 = \sum_{i=1}^{n} \frac{n[f(x_i) - f'(x_i)]^2}{f'(x_i)} \tag{13}$$

Where, n = number of class intervals decided using eq. (14), N = number of sample data to be tested, $f(x_i)$ = observed relative frequency at i[th] interval, $f'(x_i)$ = expected relative frequency at i[th] interval.

$$n = 1 + 3.3 \times Log(N) \tag{14}$$

The calculated value χ_c^2 should be less than $\chi_{\nu,\alpha}^2$ (from statistical table) for a given confidence interval (α, generally at 95%) with ν degree of freedom (n-p-1), where p = number of parameters in distribution.

Results and Discussion

Table 2 shows the one-day maximum daily rainfall data with corresponding date for the period of 53 years (1970 to 2022). The maximum (374.3 mm) and minimum (86.9 mm) annual one day maximum rainfall was recorded during the year 1976 (31st December) and 1987 (11th November), respectively. This indicates that the mostly fluctuations were observed during the decade 1976-87.The average for these 53 years rainfall was found to be 152.56 mm. Fig. 2 shows the deviation of annual one day maximum rainfall from its average during 1970-2022 years. It was observed that about 23 years (43.4%) received one day maximum daily rainfall above the average (Fig. 2). The distribution of one day maximum rainfall received during different months in a year is presented in Fig. 3. From the figure, it is seen that 'June' month received the highest amount of one day maximum rainfall (19%) followed by May (15%), July (15%), August (13%), and September (13%). This is due to fact that the study area received most of its rain from SW monsoon (75% of annual rainfall).

Table 2 : Occurrence of one day maximum rainfall for the period of 1970 to 2022

Sl. No.	Year	Date & Month	One Day Maximum RF (mm)	Remarks
1	1970	20th September	191.1	SW monsoon
2	1971	25th September	106	SW monsoon
3	1972	8th June	205.4	SW monsoon
4	1973	13th August	120.8	SW monsoon
5	1974	29th April	187.2	-
6	1975	15th October	88.5	NE monsoon
7	1976	31st December	374.3	NE monsoon
8	1977	28th July	144.5	SW monsoon
9	1978	17th May	112.5	SW monsoon
10	1979	26th September	92.6	SW monsoon
11	1980	13th December	222.9	NE monsoon
12	1981	20th September	111.2	SW monsoon
13	1982	13th June	132.6	SW monsoon
14	1983	26th August	100.1	SW monsoon
15	1984	6th June	181.9	SW monsoon
16	1985	8th October	98.7	NE monsoon
17	1986	7th August	164.5	SW monsoon
18	1987	11th November	86.9	NE monsoon
19	1988	14th July	183.8	SW monsoon
20	1989	21st July	107.6	SW monsoon
21	1990	12th June	99.3	SW monsoon
22	1991	25th July	183	SW monsoon
23	1992	29th July	129.5	SW monsoon
24	1993	24th July	103.3	SW monsoon
25	1994	5th June	184.3	SW monsoon
26	1995	6th June	243.2	SW monsoon
27	1996	19th November	120.1	NE monsoon
28	1997	16th July	204.2	SW monsoon
29	1998	3rd October	120.3	NE monsoon
30	1999	4th September	108.7	SW monsoon

31	2000	12th May	112.5	SW monsoon
32	2001	25th May	138.3	SW monsoon
33	2002	26th September	124.4	SW monsoon
34	2003	31st May	107.8	SW monsoon
35	2004	12th June	108.2	SW monsoon
36	2005	10th June	197.3	SW monsoon
37	2006	7th October	156.5	NE monsoon
38	2007	21st August	114.7	SW monsoon
39	2008	10th May	206.8	SW monsoon
40	2009	24th August	125.2	SW monsoon
41	2010	22nd June	95.3	SW monsoon
42	2011	17th March	163.5	-
43	2012	7th September	179.1	SW monsoon
44	2013	25th November	212.9	Lehar cyclone
45	2014	8th October	204.9	NE monsoon
46	2015	24thMay	119.3	SW monsoon
47	2016	8th December	212.4	Vardah cyclone
48	2017	6th June	214.7	SW monsoon
49	2018	30th May	230	SW monsoon
50	2019	31st August	130.5	SW monsoon
51	2020	3rd August	180	SW monsoon
52	2021	9th July	107.4	SW monsoon
53	2022	18th May	135	SW monsoon

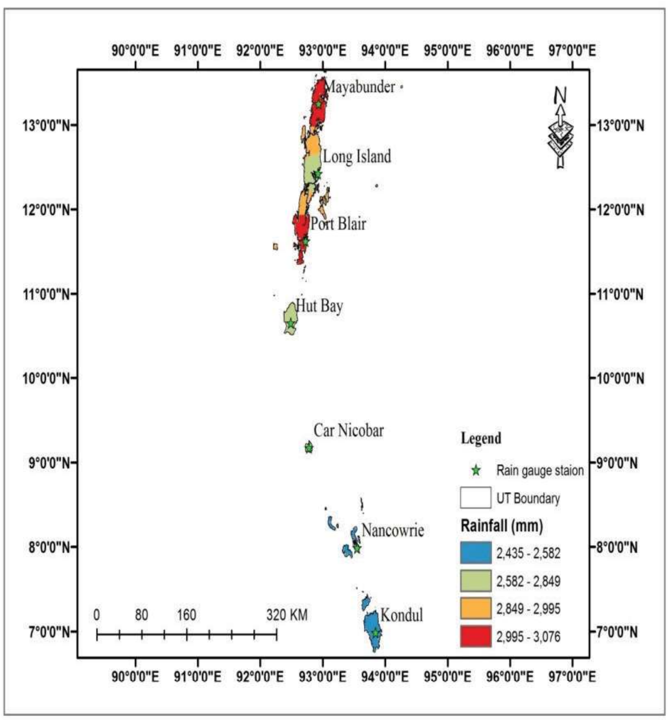

Fig. 1. Average annual rainfall map of Andaman and Nicobar Islands

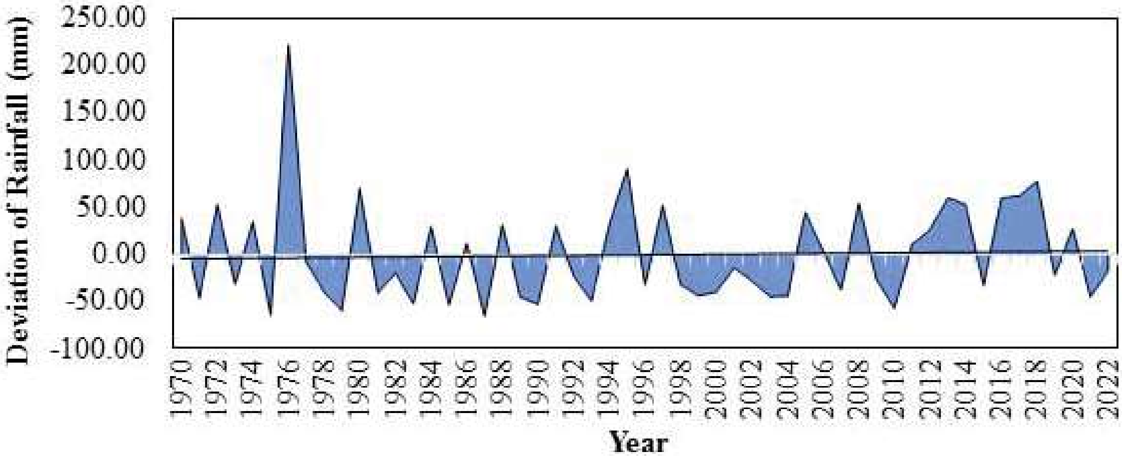

Fig. 2. Deviation of one day maximum annual rainfall from the average during 1970-2022

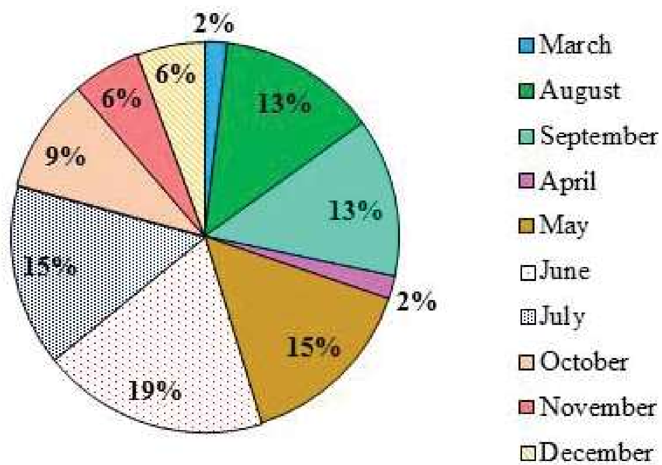

Fig. 3. Month wise distribution of one day maximum annual rainfall in a year

Weibull Method

The annual daily maximum rainfall for the period of 53 years was plotted against return period in years, which was calculated from Weibull's method and presented in Fig. 4. It was observed that the logarithmic trendline fitted well with high R^2 (0.93) for the analysed data after trial with linear, exponential, polynomial, and power functions. Accordingly, the prediction equation for the expected rainfall was developed as $y = 58.56 \ln(x) + 96.11$, where y = annual maximum one day rainfall (mm), x = return period (Years).

Probability Distribution Functions (PDFs)

The expected annual maximum one day rainfall for different probability distributions such as normal, log-normal, Pearson type-III, log-Pearson type-III, and Gumbel extreme value were calculated and presented in Table 3 for different return periods (1 to 100 years). Moreover, the plotted annual maximum one day rainfall for the 1 to 100 return periods using Weibull method were also included in Table 3. All five probability distribution functions were compared by Chi-square test of goodness of fit.

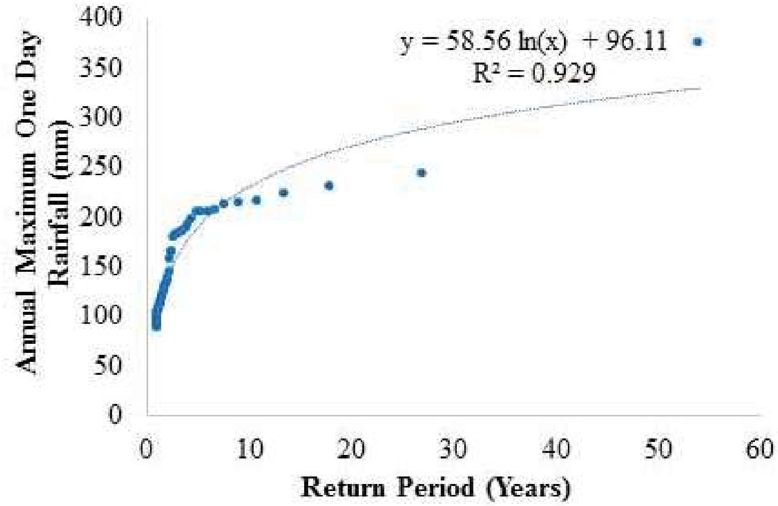

Fig. 4. Annual one day maximum rainfall vs return period by Weibull's method

Table 3: Magnitude of expected maximum one day rainfall for various return periods

Return period (Years)	Observed Rainfall (mm)	Expected Rainfall (mm)				
	Weibull	Normal	Log Normal	Pearson Type III	Log Pearson Type III	Gumbel/ Extreme value type I
1	96.11	66.518	49.369	42.829	29.704	65.704
2	136.71	152.560	144.471	139.712	140.753	130.730
5	190.37	231.661	212.888	237.842	264.295	248.168
10	230.96	273.048	260.764	297.063	373.090	325.922
20	271.56	307.217	308.303	350.283	499.898	400.506
25	284.62	317.169	323.714	366.544	545.110	424.165
50	325.22	345.663	372.231	415.046	700.880	497.046
75	348.96	360.95	401.191	442.279	803.760	539.408
100	365.81	371.288	422.044	461.185	882.513	569.390

The test was performed at 5% significance level. The Log-normal distribution provided the best-fit probability distribution with the least score for the test. Based on the best fit probability distribution, the minimum rainfall of 49.369 mm in a day can be expected to occur with 99% probability and one year return period and maximum of 422.044 mm rainfall can be received with 1% probability and 100-year return period. Similar kind of results were observed by Kumar (2000), Singh (2001), and Kalita et al. (2017) that the log-normal distribution is the best probability model for predicting annual maximum daily rainfall for Ranichauri (Tehri-Garhwal), Tandong (Sikkim), and Ukiam (Brahmaputra River) respectively.

Conclusions

In this study, the annual maximum daily rainfall of Port Blair location was analysed for its chances of occurrence in various return periods using plotting position and frequency factor methods. Out of five different probability distributions fitted to 53 years rainfall data, the log normal distribution found to be best based on Chi-square goodness statistical criteria. Results revealed that at 99% (1 year return period) and 1% (100 years return period) probability, minimum of 40.4 mm and maximum of 422 mm of rainfall may be expected, respectively in Port Blair location of Andaman and Nicobar Islands. The results of this study would be useful for designing safely various soil and water conservation structures and irrigation and drainage systems as per their life period.

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