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Vijay P. Singh
Shalini Yadav
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Hydrologic Modeling

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Preface

Fundamental to sustainable economic development, functioning of healthy ecosystems, reliable agricultural productivity, dependable power generation, maintenance of desirable environmental quality, continuing industrial growth, enjoyment of quality lifestyle, and renewal of land and air resources is water. With growing population, demands for water for agriculture and industry are skyrocketing. On the other hand, freshwater resources per capita are decreasing. There is therefore a need for effective water resources management strategies. These strategies must also consider the nexus between water, energy, environment, food, and society. With these considerations in mind, the International Conference on Water, Environment, Energy and Society (WEES-2016) was organized at AISECT University, Bhopal, Madhya Pradesh, India, from March 15 to 18, 2016. The conference was fifth in the series and had several objectives.

The first objective was to provide a forum to not only engineers, scientists, and researchers, but also practitioners, planners, managers, administrators, and policy makers from around the world for discussion of problems pertaining to water, environment, and energy that are vital for the sustenance and development of society.

Second, the Government of India has embarked upon two large projects one on cleaning of River Ganga and the other on cleaning River Yamuna. Further, it is allocating large funds for irrigation projects with the aim to bring sufficient good quality water to all farmers. These are huge ambitious projects and require consideration of all aspects of water, environment, and energy as well as society, including economics, culture, religion, politics, administration, law.

Third, when water resources projects are developed, it is important to ensure that these projects achieve their intended objectives without causing deleterious environmental consequences, such as waterlogging, salinization, loss of wetlands, sedimentation of reservoirs, loss of biodiversity.

Fourth, the combination of rising demand for water and increasing concern for environmental quality compels that water resources projects are planned, designed, executed, and managed, keeping changing conditions in mind, especially climate change and social and economic changes.

Fifth, water resources projects are investment-intensive, and it is therefore important to take a stock of how the built projects have fared and the lessons that can be learnt so that future projects are even better. This requires an open and frank discussion among all sectors and stakeholders.

Sixth, we wanted to reinforce that water, environment, energy, and society constitute a continuum and water is central to this continuum. Water resources projects are therefore inherently interdisciplinary and must be so dealt with.

Seventh, a conference like this offers an opportunity to renew old friendships and make new ones, exchange ideas and experiences, develop collaborations, and enrich ourselves both socially and intellectually. We have much to learn from each other.

Now the question may be: Why India and why Bhopal? India has had a long tradition of excellence spanning several millennia in the construction of water resources projects. Because of her vast size, high climatic variability encompassing six seasons, extreme landscape variability from flat plains to the highest mountains in the world, and large river systems, India offers a rich natural laboratory for water resources investigations.

India is a vast country, full of contrasts. She is diverse yet harmonious, mysterious yet charming, old yet beautiful, ancient yet modern. Nowhere can we find as high mountains as snowcapped Himalayas in the north, the confluence of three seas and large temples in the south, long and fine sand beaches in the east as well as architectural gems in the west. The entire country is dotted with unsurpassable monuments, temples, mosques, palaces, and forts and fortresses that offer a glimpse of India's past and present.

Bhopal is located in almost the center of India and is situated between Narmada River and Betwa River. It is a capital of Madhya Pradesh and has a rich, several century-long history. It is a fascinating amalgam of scenic beauty, old historic city, and modern urban planning. All things considered, the venue of the conference could not have been better.

We received an overwhelming response to our call for papers. The number of abstracts received exceeded 450. Each abstract was reviewed, and about two-thirds of them, deemed appropriate to the theme of the conference, were selected. This led to the submission of about 300 full-length papers. The subject matter of the papers was divided into more than 40 topics, encompassing virtually all major aspects of water and environment as well energy. Each topic comprised a number of contributed papers and in some cases state-of-the-art papers. These papers provided a natural blend to reflect a coherent body of knowledge on that topic.

The papers contained in this volume, "Hydrologic Modelling," represent one part of the conference proceedings. The other parts are embodied in six companion volumes entitled, "Energy and Environment," "Groundwater," "Environmental Pollution," "Water Quality Management," "Climate Change Impacts," and "Water Resources Management." Arrangement of contributions in these seven books was a natural consequence of the diversity of papers presented at the conference and the topics covered. These books can be treated almost independently, although significant interconnectedness exists among them.

This volume contains seven parts. The first part deals with some aspects of rainfall analysis, including rainfall probability distribution, local rainfall interception, and analysis for reservoir release. Part 2 is on evapotranspiration and discusses development of neural network models, errors, and sensitivity. Part 3 focuses on various aspects of urban runoff, including hydrologic impacts, storm water management, and drainage systems. Part 4 deals with soil erosion and sediment, covering mineralogical composition, geostatistical analysis, land use impacts, and land use mapping. Part 5 treats remote sensing and GIS applications to different hydrologic problems. Watershed runoff and floods are discussed in Part 6, encompassing hydraulic, experimental, and theoretical aspects. Water modeling constitutes the concluding Part 7. SWAT, Xinanjiang, and SCS-CN models are discussed.

The book will be of interest to researchers and practitioners in the field of water resources, hydrology, environmental resources, agricultural engineering, watershed management, earth sciences, as well as those engaged in natural resources planning and management. Graduate students and those wishing to conduct further research in water and environment and their development and management may find the book to be of value.

WEES-16 attracted a large number of nationally and internationally well-known people who have long been at the forefront of environmental and water resources education, research, teaching, planning, development, management, and practice. It is hoped that long and productive personal associations and friendships will be developed as a result of this conference.

College Station, USA — Vijay P. Singh, Conference Chair

Bhopal, India — Shalini Yadav, Conference Organizing Secretary

Hazaribagh, India — Ram Narayan Yadava, Conference Co-Chair

Sponsors and Co-Sponsors

The International Conference on Water, Environment, Energy and Society was jointly organized by the AISECT University, Bhopal (M.P.), India, and Texas A&M University, Texas, USA, in association with ICE WaRM, Adelaide, Australia. It was partially supported by the International Atomic Energy Agency (IAEA), Vienna, Austria; AISECT University, Bhopal; M.P. Council of Science and Technology (MPCOST); Environmental Planning and Coordination Organization (EPCO), Government of Madhya Pradesh; National Bank for Agriculture and Rural Development (NABARD), Mumbai; Maulana Azad National Institute of Technology (MANIT), Bhopal; and National Thermal Power Corporation (NTPC), Noida, India. We are grateful to all these sponsors for their cooperation and providing partial financial support that led to the grand success to the ICWEES-2016.

Acknowledgements

We express our sincere gratitude to Shri Santosh Choubey, Chancellor, and Dr. V. K. Verma, Vice Chancellor, Board of Governing Body, and Board of Management of the AISECT University, Bhopal, India, for providing their continuous guidance and full organizational support in successfully organizing this International Conference on Water, Environment, Energy and Society on the AISECT University campus in Bhopal, India.

We are also grateful to the Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas, USA, and International Centre of Excellence in Water Management (ICE WaRM), Australia, for their institutional cooperation and support in organizing the ICWEES-2016.

We wish to take this opportunity to express our sincere appreciation to all the members of the Local Organization Committee for helping with transportation, lodging, food, and a whole host of other logistics. We must express our appreciation to the Members of Advisory Committee, Members of the National and International Technical Committees for sharing their pearls of wisdom with us during the course of the conference.

Numerous other people contributed to the conference in one way or another, and lack of space does not allow us to list all of them here. We are also immensely grateful to all the invited keynote speakers and directors/heads of institutions for supporting and permitting research scholars, scientists and faculty members from their organizations for delivering keynote lectures and participating in the conference, submitting and presenting technical papers. The success of the conference is the direct result of their collective efforts. The session chairmen and co-chairmen administered the sessions in a positive, constructive, and professional manner. We owe our deep gratitude to all of these individuals and their organizations.

We are thankful to Shri Amitabh Saxena, Pro-Vice Chancellor, Dr. Vijay Singh, Registrar, and Dr. Basant Singh, School of Engineering and Technology, AISECT University, who provided expertise that greatly helped with the conference organization. We are also thankful to all the heads of other schools, faculty member and staff of the AISECT University for the highly appreciable assistance in different organizing committees of the conference. We also express our sincere thanks to all the reviewers at national and international levels who reviewed and moderated the papers submitted to the conference. Their constructive evaluation and suggestions improved the manuscripts significantly.

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About the Editors

Prof. Vijay P. Singh is a Distinguished Professor, Regents Professor, Caroline and William N. Lehrer Distinguished Chair in Water Engineering, Department of Biological and Agricultural Engineering & Zachry Department of Civil Engineering, Texas A&M University, USA. He received his B.S., M.S., Ph.D., and D.Sc. degrees in engineering. He is a registered professional engineer, a registered professional hydrologist, and an Honorary Diplomate of American Academy of Water Resources Engineers.

Professor Singh has extensively published the results of an extraordinary range of his scientific pursuits. He has published more than 900 journal articles; 25 textbooks; 60 edited reference books, including the massive Encyclopedia of Snow, Ice and Glaciers and Handbook of Applied Hydrology; 104 book chapters; 314 conference papers; and 72 technical reports in the areas of hydrology, ground water, hydraulics, irrigation engineering, environmental engineering, and water resources.

For his scientific contributions to the development and management of water resources and promoting the cause of their conservation and sustainable use, he has received more than 90 national and international awards and numerous honors, including the Arid Lands Hydraulic Engineering Award, Ven Te Chow Award, Richard R. Torrens Award, Norman Medal, and EWRI Lifetime Achievement Award, all given by American Society of Civil Engineers; Ray K. Linsley Award and Founder's Award, given by American Institute of Hydrology; Crystal Drop Award, given by International Water Resources Association; and Outstanding Distinguished Scientist Award, given by Sigma Xi, among others. He has received three honorary doctorates. He is a Distinguished Member of ASCE and a fellow of EWRI, AWRA, IWRS, ISAE, IASWC, and IE and holds membership in 16 additional professional associations. He is a fellow/member of 10 international science/engineering academies. He has served as President and Senior Vice President of the American Institute of Hydrology (AIH). Currently, he is editor-in-chief of two book series and three journals and serves on editorial boards of 20 other journals.

Professor Singh has visited and delivered invited lectures in almost all parts of the world but just a sample: Switzerland, the Czech Republic, Hungary, Austria, India, Italy, France, England, China, Singapore, Brazil, and Australia.

Prof. Shalini Yadav is a Professor and Head of the Department of Civil Engineering, AISECT University, Bhopal, India. Her research interests include solid and hazardous waste management, construction management, environmental quality, and water resources. She has executed a variety of research projects/consultancy in environmental and water science and technology and has got rich experience in planning, formulating, organizing, executing, and management of R&D programs, seminars, and conferences at national and international levels. She has got to her credit guiding an appreciable number of M.Tech. and Ph.D. students. She has published more than 10 journal articles and 30 technical reports. Dr. Shalini has also visited and delivered invited lectures at different institutes/universities in India and abroad, such as Australia, South Korea, and Kenya.

Professor Shalini Yadav graduated with a B.Sc. in Science from the Bhopal University. She earned her M.Sc. in Applied Chemistry with specialization in Environmental Science from Bhopal University, and M.Tech. in Civil Engineering with specialization in Environmental Engineering from Malaviya National Institute of Technology, Jaipur, India, in 2000. Then she pursued the degree of Ph.D. in Civil Engineering from Rajiv Gandhi Technical University, Bhopal, India, in 2011. Also, she is a recipient of national fellowships and awards. She is a reviewer for many international journals. She has been recognized for one and half decades of leadership in research, teaching, and service to the Environmental Engineering Profession.

Dr. Ram Narayan Yadava holds position of Vice Chancellor of the AISECT University, Hazaribagh, Jharkhand. His research interests include solid mechanics, environmental quality and water resources, hydrologic modelling, environmental sciences, and R&D planning and management. Yadava has executed a variety of research/consultancy projects in the area of water resources planning and management, environment, remote sensing, mathematical modelling, technology forecasting, etc.

He has got adequate experience in establishing institutes/organizations, planning, formulating, organizing, executing, and management of R&D programs, seminars, symposia, conferences at national and international levels. He has got to his credit guiding a number of M.Tech. and Ph.D. students in the area of Mathematical Sciences and Earth Sciences. Dr. Yadava has visited and delivered invited lectures at different institutes/universities in India and abroad, such as USA, Canada, United Kingdom, Thailand, Germany, South Korea, Malaysia, Singapore, South Africa, Costa Rica, and Australia.

He earned an M.Sc. in Mathematics with specialization in Special Functions and Relativity from Banaras Hindu University, India, in 1970 and a Ph.D. in Mathematics with specialization in Fracture Mechanics from Indian Institute of Technology, Bombay, India, in 1975. Also, he is the recipient of Raman Research Fellowship and other awards. Dr. Yadava has been recognized for three and half decades of leadership in research and service to the hydrologic and water resources profession. Dr. Yadava's contribution to the state of the art has been significant in many different specialty areas, including water resources management, environmental sciences, irrigation science, soil and water conservation engineering, and mathematical modelling. He has published more than 90 journal articles; 4 textbooks; and 7 edited reference books.

Part I
Rainfall Analysis

Rainfall Probability Distribution Analysis in Selected Lateral Command Area of Upper Krishna Project (Karnataka), India

N. K. Rajeshkumar, P. Balakrishnan, G. V. Srinivas Reddy, B. S. Polise Gowdar and U. Satishkumar

Abstract In India, occurrence and distribution of rainfall is erratic, seasonally variable, and temporal in nature, which is one of the most important natural input resources for agricultural production. To study the behavior of rainfall variability, the rainfall data of 37 years (1978–2014) were analyzed for Gabbur, Raichur (Karnataka), India. Hence, frequency analysis was carried out for best-fit distribution through software for probability density functions viz Weibull, lognormal, Gamma, log-Pearson type III, Gumbel, and Weibull 3 parameter (3P) distributions. The expected values were compared with the observed values, and goodness of fit was determined by chi-square test. The results showed that the log-Pearson type III distribution was the best-fit probability distribution to forecast annual weekly rainfall for different return periods. Based on the best-fit probability distribution, the minimum rainfall of 141.3 mm in a year can be expected to occur with 99% probability at one-year return period. The maximum of 515-mm rainfall can be received with 50% probability for every 2-year return period, and 1160.1-mm rainfall can be received by 0.5% probability at every 200-year return period. The results of this study would be useful for agricultural scientists, decision makers, policy planners, and researchers in agricultural crop planning, canal constructions, and operation management for irrigation and drainage systems in the semiarid plain region of the Karnataka.

Keywords Rainfall · Return period · Frequency · Probability distribution

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Introduction

Rainfall is one of the major precipitation forms of hydrological events occurring as stochastic natural phenomena occurring in India. Unequal rainfall variation throughout the year is one of the important problems in hydrology which deals with the interpreting past records of hydrological events in terms of future probabilities of occurrence through time series and probability models. Analysis of rainfall and determination of variation in annual, seasonal, monthly, and weekly rainfall of a region and time is well known, and this inter-annual variability of monsoonal rainfall has considerable impact on agricultural production, water management, and energy generation, estimating design command area and cropping pattern. Similarly, the weekly rainfall analysis gives more useful information in crop planning.

Though the rainfall is erratic and varies with time and space, it is very much essential to predict return periods using various probability distributions (Upadhaya and Singh 1998). Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances (Bhakar et al. 2008). Such information can also be used to prevent floods and droughts and applied to crop planning and designing of water resources related to hydrological engineering such as reservoir capacity and canal carrying capacity design, flood control work, and soil and water conservation planning (Agarwal et al. 1988; Dabral et al. 2009). Therefore, probability analysis of rainfall is necessary for solving various water management problems and to access the crop failure due to the deficit or excess rainfall. Scientific prediction of rain and crop planning done analytically may prove a significant tool in the hands of farmers for better economic returns (Bhakar et al. 2008). Frequency analysis of rainfall data has been attempted for different return periods (Nemichandrappa et al. 2010; Vivekananda 2012). Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances. The probability distribution functions most commonly used to estimate the rainfall frequency are Weibull, normal, lognormal, log-Pearson type III, and Gumbel distributions (Bhim et al. 2012; Mahdavi et al. 2010; Subudhi et al. 2012; Mandal et al. 2013; Mishra et al. 2013).

Earlier workers work out the weekly rainfall probabilities for different agroclimatic regions (Ray et al. 1980; Kar et al. 2014). Gupta et al. (1975) suggested that the rainfall at 80% probability can safely be taken as assured rainfall, while that of 50% probability is the medium limit for taking dry risk. According to Von Braun (1991) recommended that a 10% decrease in monsoonal rainfall for a long period there is 4.4 % decrease in the national food production. Therefore, an attempt has been made for probability analysis of long-term rainfall data of Gabbur station for decision support system risk proof technologies for irrigated agriculture of Upper Krishna Project (UKP) of Raichur district.

Materials and Methods

The study area is the command area of the branch distributary 5 of the tail-end distributary 18, starting at chainage of 23.33 km in the UKP Narayanapur Right Bank Canal (NRBC) starting at the right flank of Narayanapur dam. The study area is located in Gabbur village at an altitude of 389 m from mean sea level, Devadurga taluk, Raichur district between 16° 16′52.280″ to 16° 17′50.895″N latitudes and 77° 09′20.312″ to 77° 30′50″E longitudes (Fig. 1). The soils of the study area are sandy soils in the head region and black soils in the tail region (clay content 46–55%). The climate is semiarid tropical with an average rainfall of 534.3 mm. The monthly evaporation varies from 141 to 273 mm and is maximum during April–May. The area receives 86% of annual rainfall during southwest monsoon (*kharif*), i.e., from June to October, 6% during *rabi,* and 8% during summer. The annual mean maximum and minimum monthly relative humidity of the region are 73.7% (Sept) and 39.6% (April), respectively. The annual mean maximum and minimum monthly mean daily temperatures in the study area are 39.7 °C (May) and 15.5 °C (Dec), respectively.

The region as a whole lies in a low rainfall area, and the annual average rainfall was 534.3 mm. Time series rainfall records for the period of 1978–2015 (37 years) was analyzed to study the behavior daily rainfall data from Gabbur rain gauge station. Hence, frequency analysis was carried out for best-fit distribution through VT-fit software. The probability analysis can be used for predicting the occurrence of rainfall events of the available data with the help of statistical analysis. Several distributions have been suggested for hydrological analysis. Based on the theoretical probability distributions, it could be possible to predict the rainfall of different magnitudes and return periods. The most suitable distribution to represent the observed data may depend on rainfall pattern of the place.

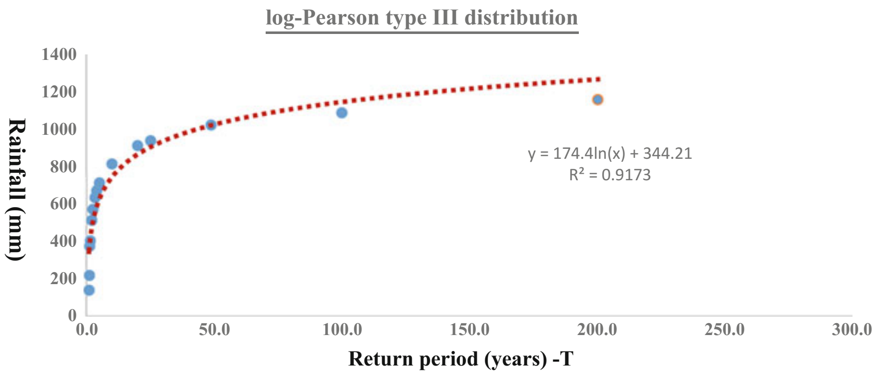

Fig. 1 Annual rainfall analysis for Gabbur by log-Pearson type III distribution

Test for Goodness of Fit for Probability Distributions

Out of the selected four probability distribution methods, the best-fitting probability density function was selected based on goodness-of-fit test procedure. A number of statistical tests are available for testing the best-fit distribution. In this study, chi-square test was selected among the most commonly useful procedures for testing goodness-of-fit test. The test statistic (χ^2) has been estimated from the expression:

$$\chi^2 = \sum_{h=1}^{k} \frac{(O_h - E_h)^2}{E_h} \tag{3.2}$$

where

k number of years,
O_h observed values in hth year,
E_h expected value in hth year.

The data were analyzed by computer-based VT-fit software used for fitting probability distribution functions that also provide goodness-of-fit tests. The probability density functions viz Weibull, Gamma, Gumbel, lognormal, 3-parameter Weibull, log-Pearson type III distributions which were used for analysis and compared with the Weibull (observed one) for deciding the best-fit distribution are shown below.

Distribution	Probability density function
Weibull distribution	$P = \left(\frac{m}{N+1}\right)$
Gamma distribution	$P(X) = \left(\frac{X^a e^{\frac{-x}{b}}}{b^{a+1}\Gamma(a+1)}\right)$
Gumbel distribution	$f(X) = \frac{e^{-\frac{(X-\gamma)}{\beta}} - e^{-\frac{(-X-\gamma)}{\beta}}}{\beta}$
Lognormal distribution	$P(X) = \frac{1}{\sigma_y e^y \sqrt{2\pi}} e - \left(\frac{y}{\mu y}\right)^2 / 2\sigma_y^2$
Log-Pearson type III distribution	$f(X) = \frac{e^{\frac{\gamma}{\beta}} X^{\beta-1}}{\beta \Gamma(\alpha)} \left(\frac{\ln X - \gamma}{\beta}\right)^{\alpha-1}$
Three-parameter Weibull distribution	$f(x) = \frac{\beta}{\eta} \left(\frac{X-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{X-\gamma}{\eta}\right)\beta}$

Using the best-fit distribution identified for rainfall, the lowest chi-square value distribution was considered to be the best-fit distribution, and the rainfall magnitudes at different probabilities were computed.

Confidence Limits

Since the value of the variate for a given return period, 'x_t' determined by the above-said probability best-fit distribution values can have errors due to the limited sample data used as an estimate of the confidence limits of the desirable. The confidence interval indicates the limits about the calculated value between which the true value can be said to lie with a specific probability. Based on sampling errors for confidence probability '*c*', the confidence interval of the variate $\mathrm{x_t}$ is bounded by values x_1 and x_2 given by the following equation.

$$x_{1/2} = x_T \pm f(c)S_\mathrm{e}$$

where

$f(c)$ = function of the confidence probability '*c*' determined by using the table of normal variates.

$$\mathrm{Se} = \text{probable error} = b\left(\sigma \frac{n-1}{\sqrt{\mathrm{N}}}\right)$$

$$b = \sqrt{1 + 1.3K + 1.1K^2}$$

$$K = \text{frequency factor given by } K = \frac{y_T - y_n}{S_n}$$

σ_{n-1} Standard deviation of the sample,
N Sample size.

Rainfall at various probability levels (25, 50, 75, and 90) based on the above methodology rainfall at various probability levels (50, 60, 70, 75, 90, and 99%) for annual basis has been worked out and are presented in Table 1. The rainfall at 70% probability was generally used for agricultural planning, and hence, the same is considered in the present investigation to suggest crop planning.

Results and Discussions

Rainfall Analysis

The analysis of annual rainfall data of the 37-year period for the study area Gabbur revealed that the log-Pearson type III distribution was the best-fit distribution with minimum chi-square value (23.7). This function was useful for studying the rainfall pattern among the various probability distribution functions considered viz log-normal, log-Pearson type III, Gamma, Gumbel, and Weibull 3 parameter (3P) distributions in comparison with the Weibull distribution as observed one. The best-fit distributions followed by log-Pearson type III distribution were Gumbel,

Table 1 Computation of annual rainfall in the study area at different probabilities for finding best-fit distribution

Return period	Probability	Rainfall (mm)						Chi-square value $(O - E)^2/E$				
		Log normal	Gamma	Log-Pearson type III	Gumbel	Weibull	Weibull three parameter	Log normal	Gamma	Log-Pearson type III	Gumbel	Weibull three parameter
1	99	180.8	150.9	141.3	198.7	122.1	188.3	19.1	5.5	2.6	29.5	23.3
1	95	242.3	211.9	219.7	267.2	214.6	231.0	3.2	0.0	0.1	10.4	1.2
1	75	367.6	341.5	376.1	390.0	389.7	355.4	1.3	6.8	0.5	0.0	3.3
1	70	392.1	370.2	405.0	412.4	419.8	382.1	1.9	6.6	0.5	0.1	3.7
2	50	491.2	449.8	515.0	500.4	528.2	489.9	2.8	13.7	0.3	1.5	3.0
3	40	547.7	502.9	572.7	549.0	581.8	549.8	2.1	12.4	0.1	2.0	1.9
3	30	615.4	560.1	636.0	606.3	639.4	619.0	0.9	11.2	0.0	1.8	0.7
4	25	656.4	625.8	673.0	640.5	671.4	659.4	0.3	3.3	0.0	1.5	0.2
5	20	705.2	664.3	715.0	681.0	707.0	706.1	0.0	2.7	0.1	1.0	0.0
10	10	852.0	709.0	816.0	800.5	800.2	836.9	3.1	11.7	0.3	0.0	1.6
20	5	995.9	835.7	914.0	915.2	876.5	952.6	14.3	2.0	1.5	1.6	6.1
25	4	1042.2	986.0	940.0	951.6	898.5	987.5	19.8	7.8	1.8	3.0	8.0
50	2	1187.2	1091.6	1020.2	1063.7	961.2	1090.3	43.0	15.6	3.4	9.9	15.3
100	1	1334.7	1192.4	1090.0	1174.9	1017.1	1186.1	75.6	25.8	4.9	21.2	24.1
200	1	1485.7	1289.5	1160.1	1285.7	1067.6	1276.2	117.7	38.2	7.4	37.0	34.1
								305	163.3	23.7	120.5	126.4

O observed, *E* expected total

Weibull 3 parameters (3P), and Gamma distributions with the chi-square values of 120.5, 126.4, 163.3, and 305.2 as shown in Table 1.

The best-fit regression analysis equation for the study area was developed using the log-Pearson type III distribution which is given by the formula.

$$y = 174.4 \ \ln(x) + 344.21$$

where

- y Rainfall mm
- x Return period.

The equation was used to estimate rainfall at different probabilities in the study area, and then the same was shown in Fig. 2. As the value of the regression coefficient is R^2 = 0.9173 in log-Pearson type III distribution-based on regression models, which can be used to predict probable rainfall for different return periods. The log-Pearson type III distribution estimated the probable annual rainfall magnitudes of 1160.1, 1090.0, 1020.2, 940.0, 914.0, 816.0, 715.0, 673.6, 636.9, 572.6, 515.0, 405.0, 376.1, 219.7, and 141.3 mm for the return periods 200, 100, 50, 25, 20, 10, 5, 4, 3.3, 2.5, 1.4, 1.3. 1.05 and 1.01 years respectively.

Further, using the log-Pearson type III distribution, the magnitudes of weekly rainfall at different probability levels were worked out. The mean annual rainfall of 534.3 mm was found to occur at the probability of 42.4%. Generally, the rainfall at 70% probability is considered for agricultural planning. The estimated weekly rainfall values at this probability ranged from 0 to 25.1 mm. The mean standard weekly rainfall and the estimates of standard weekly rainfall over a year at different probability levels were calculated. The analysis revealed that the mean maximum weekly rainfall values at 50, 70, 75, 90, 95, 99% probability levels were 28.6, 25.1, 23.6, 14.7, 10.9, 8.9, 2.8, and 1.4 mm during the 38th week, respectively (Fig. 2).

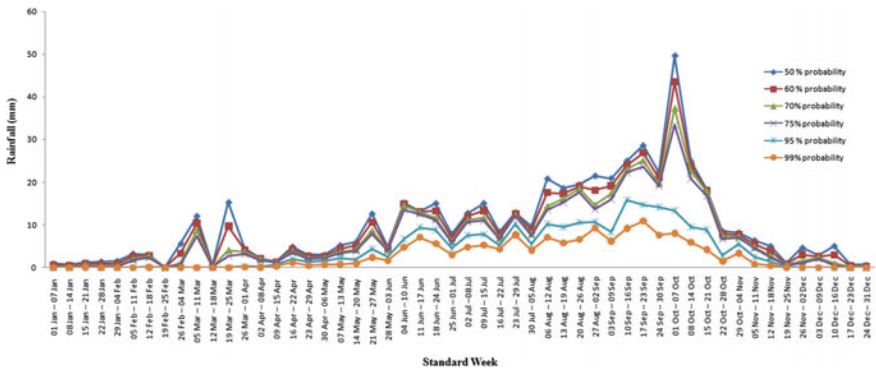

Fig. 2 Mean standard weekly rainfall over a year at different probability levels

During the period between 23rd and 42nd weeks except 26, 29, and 31st weeks, 17 weeks in a year the rainfall equal to or more than 10 mm could be received. As expected, these periods coincided with the southwest monsoon season. The monsoon in this part of the region starts from June first/second week, which was clearly revealed from the rainfall analysis that the 23rd week (04–10 June) coincided with that period with a mean rainfall of 16.3 mm and at an acceptable 70% probability, the rainfall of 14.6 mm could be expected during that week.

The mean weekly rainfall was >10 mm during the period from 23rd week to 42nd week (15–21 Oct). Further, it was noticed that even >15 mm could be anticipated during the same period, except during 26th (25–01 Jul), 29th (16–22 Jul), and 31st weeks (30 Jul–05 Aug), which coincided with *kharif* season. On an average, maximum peak weekly rainfall of 41.3 mm could be expected during the 38th week (17–23 Sep). At 70% probability, >15 mm rainfall could be expected during the period from 33rd (13–19 Aug) to 42nd week (15–21 Oct) except 35th week (27 Aug–02 Sep).

During the years wherein average weekly rainfall is >15–30 mm, *kharif* crops could be expected to be sown during the beginning of the month of June (23rd week) onwards. Later, during the month of October till the third week, i.e., 42nd week, the southwest monsoon promises wet spells (35.4–18.2 mm), around that time the sowing of *rabi* crops could be expected to be taken up. The recession of southwest monsoon would start during week (22–28 Oct) and continue. Later on even during northeast monsoon, no significant rains useful for crop growth would be expected. This trend was found to continue till the summer by the end of May month. The analysis also gave information on probable rainfall excesses help in the canal water operation for saving water in the canal command area, harvested in farm ponds and utilized during lean periods. Based on this, the effective rainfall could be estimated and appropriate cropping pattern for upper, middle, and tail reaches arrived at with consideration of the canal water availability and irrigation requirement to be met out from the canal flow in the study area.

The confidence limit analysis regarding rainfall pattern following the log-Pearson type III distribution indicated that as the confidence probability increased, the confidence interval also increased and an increase in return period caused the confidence band to spread on either side of the value as shown in Table 2 which is helpful for finding out errors in the probability distribution.

The rainfall analysis would be useful in finding out the best-fit distribution representing the rainfall pattern, which in turn would be helpful in arriving at the magnitudes of weekly rainfall at different probabilities. For agricultural planning, the rainfall at 70% probability with a 30% risk could be taken up for evolving appropriate cropping pattern for upper, middle, and tail reaches by considering both the availability of canal water supplies and effective rainfall. This information is helpful for judging the suitable time of sowing of crops, intercultural operation planning and harvesting of crops at suitable time during kharif and rabi seasons. The irrigation water requirements to be met out from canal water supplies could be estimated accordingly.

Table 2 Confidence limits for annual rainfall at different probability levels using log-Pearson type III distribution

Parameter confidence limits	Different probability levels (%)								
	Mean	50	70	75	95	99	99.5	99.8	99.9
XT, mm	534.3	515.9	405.6	376.0	219.6	141.7	101.6	22.7	1.4
T, Yr	2.25	2.00	1.43	1.33	1.05	1.01	1.01	1.00	1.00
Y_T	0.53	0.37	−0.19	−0.33	−1.10	−1.53	−1.67	−1.83	−1.93
K	−0.02	−0.16	−0.63	−0.75	−1.41	−1.78	−1.90	−2.04	−2.13
B	0.99	0.91	0.79	0.80	1.17	1.48	1.59	1.71	1.80
Se	73.35	64.90	44.21	41.87	35.54	29.0	22.3	5.38	0.36
X_1 mm, 80%	628.3	599.1	462.3	429.7	265.1	178.9	130.2	29.6	1.9
X_2 mm, 80%	440.2	432.7	348.9	322.4	174.0	104.5	72.9	15.8	1.0
X_1 mm, 95%	678.0	643.1	492.3	458.1	289.2	198.6	145.3	33.2	2.1
X_2 mm, 95%	390.5	388.7	319.0	294.0	149.9	84.8	57.8	12.1	0.7

Conclusion

By considering best-fit probability distribution, the weekly rainfall observation, the effective rainfall and net irrigation requirement were estimated by after meeting all the losses required for meeting the irrigation requirements could be supplied from the canal water. This would not only minimize the deep percolation losses in the upper and middle reaches thereby would facilitate declining of the water table to solve drainage problems, but also would enhance the canal water supplies to the lower reaches to reduce the tail-end problems and also help in developing cropping planning decisions and estimating the design flow rate for maximizing crop production.

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References

Agarwal MC, Katiyar VS, Rambabu (1988) Probability analysis of annual maximum daily rainfall of U.P., Himalaya. Indian J Soil Conserv 16(1):35–42

Bhakar SR, Iqbal M, Mukesh D, Bansal AK (2008) Probability analysis of rainfall at Kota. Indian J Agric Res 42:201–206

Bhim S, Deepak R, Amol V (2012) Probability analysis for estimation of annual one day maximum rainfall of Jhalarapatan area of Rajasthan, India. Plant Arch 12(2):1093–1100

Dabral PP, Mautushi P, Singh RP (2009) Probability analysis for one day to seven consecutive day's annual maximum rainfall for Doimukh (Itanagar), Arunachal Pradesh. J Indian Water Resour 2:9–15

Gupta RK, Rambabu, Tejwani KG (1975) Weekly rainfall of India for crop planning programme. Soil Conserv Digest 3:31–39

Kar SK, Sahoo DP, Subudhi CR (2014) Weekly analysis for crop planning using markovs chain model for Kandhamal district of Orissa, India. Int J Eng Res Appl 9(4):139–145

Mahdavi M, Khaled O, Sadeghi SAN, Bakhtiar K (2010) Determining suitable probability distribution models for annual precipitation data (a case study of Mazandaran and Golestan Provinces). J Sustain Develop 3(1):157–168

Mandal KG, Padhi J, Kumar A, Sahoo DK (2013) Analysing rainfall events and soil characteristics for water resources management in a canal irrigated area. J Water Res Ocean Sci 2(1):1–8

Mishra PK, Khare D, Kandu S, Shukla R (2013) Statistical and probability analysis of rainfall for planning in a canal command area. Agric Sustain Develop 1(2):45–52

Nemichandrappa M, Ballakrishnan P, Senthilvel S (2010) Probability and confidence limit analysis of rainfall in Raichur region, Karnataka. J Agric Sci 23(5):737–741

Ray CR, Senapati PC, Lal R (1980) Rainfall analysis for crop planning, Gopalpur (Orissa). J Agric Eng 17:1–8

Subudhi CR, Sahoo M, Senapati SC (2012) Rainfall probability analysis for crop planning in Kandhamal district of Orissa, India. Indian J Soil Cons 40(3):247–251

Upadhaya A, Singh SR (1998) Estimation of consecutive day maximum rainfall by various methods and their comparison. Indian J Soil Conserv 26:193–201

Vivekananda N (2012) Intercomparison of extreme value distributions for estimation of ADMR. Int J Appl Eng Technol 2(1):30–37

Von Braun J (1991) A policy agenda for famine prevention in Africa. Food Policy Statement No.13, IFPRI, Washington DC