2013

Department of Civil Engineering 2013, NIT Rourkela

Environmental Flow

A PROJECT SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
Bachelor of Technology
In
Civil Engineering

BY

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109CE0098

UNDER THE GUIDANCE OF
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DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

2013

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that the Project Report entitled “**Environmental Flow”** submitted by **Mr. Preetam Sundaray (109CE0098)** in partial fulfilment of the requirements for the award of Bachelor Of Technology Degree in **Civil Engineering** at National Institute Of Technology, Rourkela (Deemed University) is an authentic work carried out by them under our supervision and guidance.

To the best of my knowledge the matter demonstrated in this Project Report has not been submitted to any other University for the award of any Degree or Diploma.

DATE:

Prof. Ramakar Jha **Prof. Somesh Jena**

ACKNOWLEDGEMENTS

I would like to thank NIT Rourkela for giving me the opportunity to use their resources and work in such a challenging environment. My heart pulsates with the thrill for tendering gratitude to those persons who helped me in completion of the project.

I extend my deep sense of gratitude and indebtedness to my guide **Prof. Ramakar Jha** and **Prof. Somesh Jena** Department Of Civil Engineering National Institute of Technology, Rourkela for their invaluable guidance, keen interest, help, inspiration and encouragement which helped us in carrying out our present work.

It is my great pleasure to acknowledge and express my gratitude to my friends for their understanding, support and endless encouragement during our study.

CONTENTS

ABSTRACT

Environmental flow defined as minimum flow that should be maintained in the river for the protection and maintenance of the environment as well as river morphology, ecology, aquatic life and pollution. Environmental flow is essential like blood circulation in human body. In this research 24 years daily discharge of lower part of the Mahanadi River are taken for the analysis. Analysis is based on two methods i.e. flow duration curve analysis method and range of variability analysis method. Flow duration curve analysis method includes 1-day, 3-day and 7-day flow. Range of variability of analysis method analyses by IHA (Indicators of Hydrologic Alteration) and calculates 67 statistical parameters (33 IHA, 34 EFC). Results obtained from both the methods are discussed.

Chapter-1
Introduction

1. INTRODUCTION:

River is known as natural watercourse (Merriam-Webster, 2010) containing usually fresh water which flowing towards a sea, an ocean, a lake or another river. The source of every river is its spring which generally found in the higher grounds of mountain range that receive large amounts of precipitation. The other source of river may also be due to the melting water of a glacier. When ground is fully saturated, the water flows in the form of tiny runlets. Little runlets and channels formed by the water join into water stream to form riverbed.

Environmental flow is defined as the minimum flow that should be maintained in the river basin to protect and maintain the environment, river morphology, ecology, aquatic life, pollution and water transfer among surface water and ground water. Environmental flow is not only the quantity of flow that is flowing in the river but also structural and functional diversity of the river which affects the flow variability i.e. at a particular time or situation ,how much water is flowing in the river. As flow of blood is necessity for a human body to live; flow of water is an essential part of the river for its self-purification, water quality improvement etc. (Jha, 2010)

1.1 Evolution of environmental flow concept:

In 1960s the water management developed nations focused largely on maximizing flood protection, hydropower generation and water supplies. During 1970s economic and ecological effects of these projects swift scientists to modify the dam operations to maintain fish species. It is primarily focusing on the determination of minimum flow necessary to preserve individual species such as trout in river. The environmental flow is evolved from this concept of minimum flow that emphasized the need of water within the rivers.

By the 1990s, scientists realized biological and social systems are complicated to be described by single minimum flow. (Bunn et al., 2002; Richter et al., 2008). Since 1990s restoring and maintaining environmental flow has gained increasing support. More implementation has evolved from dam reoperation. (Richter et al., 2008) to an integration of all aspects of water management (Dyson et al., 2003) including groundwater and surface water diversions.

In global survey taken in 2003 on environmental flow 88% of the 272 respondents agreed that the environmental flow concept is important for managing water resources and meeting the needs of people over long period of time. (Moore and M., 2004). By 2010 many countries adopted the concept of environmental flow. (Le Quesne et al., 2010).

1.2 Indian Scenario:

The present research on environmental flow in India may be characterized as in its beginning. The National Commission for Integrated Water Resource Development Plan (NCIWRDP 1999) estimated the environmental needs as 5 km^3, 10 km^3 and 20 km^3 in the years 2010, 2025 and 2050 respectively. The overall water requirement for "environment and ecology" is estimated about 2 % of total national water requirements. The given values were not referenced. In 1999 as per the judgment of the Supreme Court of India the minimum flow in the Yamuna River is 10 m^3/s. Since then the minimum flow of 10 m^3/s is adopted throughout the all rivers in India.

1.3 Objectives:

The basic objective of this thesis was to find out environmental flow i.e. minimum flow in the Mahanadi River by analyzing 24 years of daily discharge taken at different stations. Fifteen gauge stations namely Andhiyarkore, Bamnidhi, Basantpur, Boranda, Ghatora, Kantamal, Kesinga, Kurubhata, Manendragarh, Rajim, Rampur, Salebhata, Simga, Sundargarh and Tikarpara have been chosen. These stations belong to the lower part of Mahanadi River. The goal was to determine 1-day, 3-day, 7-day and environmental flow by using flow duration curve analysis method and range of variability analysis method and then the results obtained from both the methods were to be compared.

Thesis Organization:

The thesis has been organized in 6 chapters**.**

Chapter 1: introductory chapter outlining the objectives of research work.

Chapter 2: review of literature.

Chapter 3: deals with study area including its climate, temperature, soil quality, rainfall and different projects working on the Mahanadi River.

Chapter 4: discuss about the different methodologies used.

Chapter 5: the results and discussion about the results.

Chapter 6: includes conclusion as well as references collected.

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Chapter-2

Literature Review

2. Literature Review:

Hydrological alteration of rivers based on a global scale and resultant environmental degradation has led to the establishment of the science of environmental flow assessment whereby the quantity and quality of water required for ecosystem conservation and resource protection are determined. Application of methodologies is typically at two or more levels. First one is Reconnaissance-level initiatives relying on hydrological methodologies are the largest group applied in all world regions. A modified Tennant method or arbitrary low flow indices is adopted but efforts to enhance the ecological relevance and transferability of techniques across different regions and river types are underway. Second one is at more comprehensive scales of assessment; two avenues of application of methodologies exist. In most of the developed countries the in stream flow incremental methodology (IFIM) or other similarly structured approaches are used.(R.E. Tharme,2003).

In the study of linking flows , services and values Louise has developed a simple and transparent decision support tool for assessing various environmental flows scenarios and arriving at a negotiated environmental flows allocation and thereby a negotiated river condition and economic trade-off between water uses. is based on an existing river basin simulation model, MIKE BASIN, and calculation procedures developed in MS Excel. The core of the tool is the development of the service provision index known as SPI. (Louise Korsgaard, 2006).The above approach links environmental flows to socio economic values by focusing on ecosystem services.

Glauco developed methods and tools for defining environmentl flow in 2008. The study includes overview of methods for flow assessment, examples of practical applications and choosing the right method. (Glauco Kimura de Freitas, 2008). The expected outcomes are understand what is an environmental flow assessment, when to use and why, know the differences between the four categories of environmental flow assessment methodologies with advantages and disadvantages of each method by a real example application and to choose the right method.

The BBM is essentially a prescriptive approach designed to construct a flow regime for maintaining a river in a predetermined condition. (JM King et al., 2008) The manual for building block methodology describes its basic nature and main activities and provides guidelines for its application and also introduces the links between the methodology and the procedures for determination of the ecological Reserve as embodied in the Water Act. The BBM has further provided the impetus for the evolution of several alternative holistic environmental flow methodologies, notably the Downstream Response to Imposed Flow Transformations (DRIFT) methodology. The DRIFT methodology is an interactive and scenario-based approach designed for use in negotiations, and contains a strong socioeconomic component, important when quantifying subsistence use of river resources by riparian peoples.

The paper Critical Appraisal of Methods for the Assessment of Environmental Flows and their Application in Two River Systems of India discuss about (i) critically evaluates the applicability of existing approaches (ii) provides values of environmental design flows at different locations of Brahmani and Baitarani River systems, and (iii)suggest a suitable scientific approach for the assessment of environmental flows. (R. Jha et al., 2008)

To understand and predict the potential effects of climatic change on the water resources and stream flow it is necessary to understand the nonlinearity and complexity of the interactions between the climate and the land surface, and to consider the dependence of the scale on which these interactions are investigated. Based on the Indian climate scenario, this paper presents the overall procedure for estimating low flows under different climatic scenarios in Brahmani River Basin, Orissa, India.Methodologies used are flow duration, Low Flow Frequency. (K.D. Sharma et al., 2008).

The overall goal of the Environmental Flows in Water Resources Policies, Plans, and Projects is to advance the understanding and integration in operational terms of environmental water allocation into integrated water resources management based on the economic and sector work. The specific objectives of this report are understanding of environmental flows both by water resources practitioners and by environmental experts, draw lessons from experience in implementing environmental flows by the bank and develop an analytical framework to support more effective integration of environmental flow. (Rafik Hirji et al., 2009)

Reliable estimation of low-flows for rivers is vital for the proper planning and design of water resources projects and this paper explores the various low-flow measures/indices, their application and estimation techniques currently in use in Ireland and elsewhere in the world. A simple regression based generalised model for the flow-duration curves (FDC) for Irish rivers has been developed which can be used for predicting FDC for any ungauged catchment from the known catchment physiographic and climatological characteristics (Uzzal Mandal et al., 2009).

The parameters of the proposed model had been estimated from the easily measurable or obtainable catchment climatological characteristics, such as mean annual rainfall (SAAR) or mean annual potential evapotranspiration in addition to catchment area.

The present study has been carried out using both desktop analysis and field investigations covering two modules for the assessment of the environmental flows in Bhadra River, Karnataka, India. The two modules are Biophysical assessment and Socio-economic assessment. The study area is the Bhadra River. Biophysical assessment gives the physical status of the river flow over a period of time. The objective of Socio-economic assessment is to predict how the people have been affected by specified river changes (B. K. Harish Kumara et al., 2010).

The studies discuss about the Environmental Flow Requirements (EFR) methodologies. More effort and time spent lead to valuable result obtained from an Environmental Flow Assessment (EFA). There are two categories of Environmental flow assessment methods, one is prescriptive approaches and other is interactive approaches (Md. Shofiul Islam, 2010). In prescriptive approaches hydrological index method is used to determine minimum discharge. In interactive approaches flow assessment methods are used.

In Detailed Environmental Impact Assessment (DEIA), modeling of environmental flows is one of the main studies that need to be delivered in the report. The model is important to the project proponent to engage suitable designs that can be suited to environmental needs future water resources management. Environmental Flow Assessment (EFA) is used to estimate the quantity and timing of flows to sustain the ecosystem values (Mohd Ekhwan Toriman, 2010).

The proposed of hydropower projects in Sg Pelus, The aim of Perak was to evaluate existing river flow characteristics and to model EFA due to river diversion of Sg Pelus. Daily river flow (m3/s) recorded at Sg Pelus and Sg. Yum gauging stations were used to design the flow duration curve. 7Q10 equation was used to estimate the lowest 7-day average flow that occurred on average once every 10 years.

Many reports are prepared by IITs to describe the methodology, analysis and suggestions and recommendations in developing Ganga River Basin: Environment Management Plan (GRB EMP) and Environmental Flows State-of-the-Art with special reference to Rivers in the Ganga River Basin report is one of them (Dr Vinod Tare, 2011). Many of the E-Flows group members participated in a two year long study on estimation of E-Flows in selected stretch of the river Ganga sponsored by WWF.

The assessment framework followed here relies heavily on existing knowledge. It is the same approach as that adopted in other pilot projects within the River Health and Environmental Flow in China Project and is similar to existing holistic approaches to the assessment of environmental flows used elsewhere in the world. The approach involves: (1) Dividing the river into reaches (2) Identifying the key ecological assets (3) Identifying the flow issues that affect each of those ecological assets (4) Establishing broad objectives (5) Using hydrologic and hydraulic models and analyses to specify the requirements for different flow components to meet those objectives, and (6) Consolidating the flows required to meet the different objectives into a single set of recommended flows. The report draws on existing published literature concerning the environmental flow needs of the Li River, especially with respect to fish and vegetation, and combines this with analysis of existing hydrological and biological data to derive the flow objectives. (IWC and PRWRC, 2012)

Chapter-3

Study Area

3. STUDY AREA:

The study area is the lower part of the Mahanadi river. The Mahanadi basin lies within geographical co-ordinates of 80° 30' to 86° 50' East longitudes and 19° 20' to 23° 35' North latitudes as shown in Fig. 1. The source of the Mahanadi River is very difficult to pinpoint as it is a combination of many mountain streams. However its farthest source lies 6 km from Pharsiya village which is 442 m above sea level and situated south of Nagri town in Dhamtari district of Chhattisgarh. The drainage area of the Mahanadi River is around 141600 km^2. The average elevation of drainage area is 426 m. It has a course of 858 km starting from its origin to confluence of Bay of Bengal, of which 494 km is in Odisha and rest part is in Chhattisgarh.

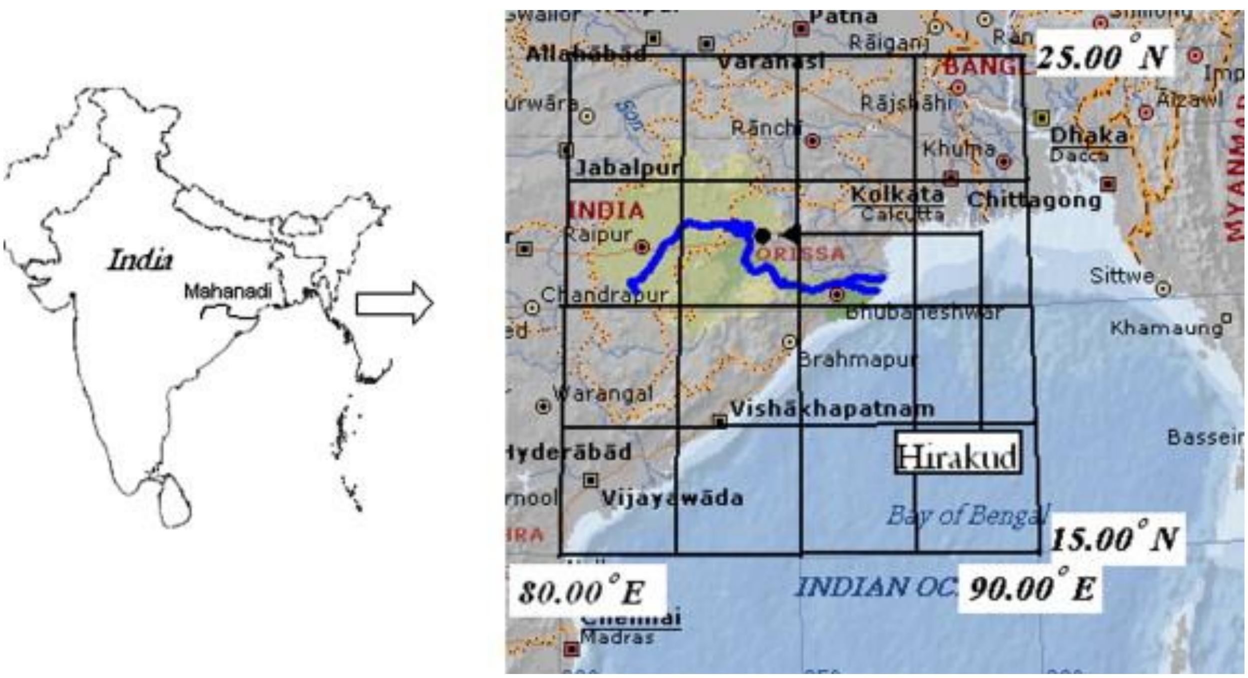


Fig 1(Source: Internet)

3.1 Climate:

In north region of the Mahanadi River the climate is sub-tropical with summer temperature of around 29^{o} C and winter temperature of around 21^{o} C. First week of June is the normal time of monsoon. The precipitation around 800 to over 1600 mm falls in the period from July to September over the basin while during January to February, less than 50 mm precipitation is received.

The geographical location of the catchment with respect to Bay of Bengal, where from most of the weather systems originate influence the meteorological and climatology of the catchment. The south-west monsoon contributes 91% of annual rainfall during June to October. December is known as the driest month as it is contributing less than 10% of annual rainfall.

3.2 Temperature:

May and December are the hottest and the coldest month in the Mahanadi catchment. The temperature varies from 12^{o}C to 40^{o} C at Sambalpur while at Cuttack it varies from 14^{o}C to 40^{o} C. Temperature variation at Puri is 16^{o}C to 32^{o} C as it is nearer to sea.

3.3 Soil Quality:

Red and yellow soils are mainly found in the basin. Mixed red and black soils are found in the parts of Sambalpur, Bolangir and Sundargarh districts of Odisha. In the lower parts of Odisha laterite soil is found. Black soil and sandy soil with kankar are the soils found in Chhattisgarh basin area.

3.4 Rainfall:

The annual rainfall of the Mahanadi catchment is about 141.7 cm. The normal annual rainfall above Hirakud and below Hirakud is about 139.6 cm and 145.8 cm respectively. According to historical records highest monthly rainfall was 1405.9 mm in July 1936 and annual rainfall was 3669.8 mm in 1944 at Bulandarpara.

Table No.1 Rainfall received during Monsoon Season (June-October)
(Cumulative rainfall (in mm) from 01-Jun upto 30-Oct)

Sl no.	Rain Gauge Station	River Basin	Comparison of Cumulative Rainfall (in mm)					
			Year 2012	Year 2011	Year 2010	Year 2009	Year 2008	Year 2007
1.	ANDHIYAKORE	LOWER MAHANADI	824.2	911.0	58.0	344.0	194.0	1137.0
2.	BAMANDIHI	LOWER MAHANADI	1155.2	1034.0	261.0	1112.0	1162.0	1305.0
3.	BASANTPUR	LOWER MAHANADI	1363.6	827.0	233.0	1077.0	891.0	1214.0
4.	BORANDA	LOWER MAHANADI	1053.2	1103.0	223.0	1113.0	1072.0	918.0
5	GHATORA	LOWER MAHANADI	727.9	1207.0	52.0	1413.0	826.0	1034.0
6	KANTAMAL	LOWER MAHANADI	1492.6	1299.0	258.0	1623.0	1487.0	1403.0
7	KESINGA	LOWER MAHANADI	1210.0	991.0	71.0	1587.0	1505.0	1097.0
8	KURUBHATTA	LOWER MAHANADI	1298.8	1289.0	314.0	801.0	1134.0	1094.0
9	MANINDRAGARH	LOWER MAHANADI	1094.0	1358.0	257.0	755.0	937.0	675.0
10	RAJIM	LOWER MAHANADI	961.8	1247.0	269.0	1179.0	895.0	1061.0
11	RAMPUR	LOWER MAHANADI	1247.1	839.0	141.0	822.0	980.0	1214.0
12	SALEBHATA	LOWER MAHANADI	1586.4	986.0	343.0	1315.0	1371.0	1380.0
13	SIMGA	LOWER MAHANADI	926.2	1196.0	147.0	986.0	895.0	1278.0
14	SUNDERGARH	LOWER MAHANADI	1709.5	1517.0	420.0	1281.0	1668.0	1559.0
15	TIKERPARA	LOWER MAHANADI	998.6	788.0	184.0	1105.0	1135.0	1066.0

Source: Central Water Commission

3.5 Projects in Mahanadi Basin:

Due to the large size of the Mahanadi basin and availability of plenty of water a number of projects have been constructed to utilize these resources. Brief descriptions of these projects are as follows.

3.5.1 Hirakud Dam:

Hirakud is one of the major river projects that commissioned in 1957. The reservoir is situated downstream of the Mahanadi River with its tributary Ib, 15 km upstream of Sambalpur. Its geographical ordinates are 21^o 30' and 21^o 50' N, 83^o 30' and 84^o 05' E. The reservoir has water spread area of about 719.63 km^2 at FRL. The maximum and minimum annual runoff was 91900 Mm^3 and 12400 Mm^3 at the dam site. The catchment area of dam is 83400 km^2 with gross storage capacity of 5818 Mm^3.

3.5.2 Hasdeo Bango:

Hasdeo Bango at 70 km from Korba in Korba district, Chhattisgarh is a multipurpose storage reservoir on Hasdeo River, tributary of the Mahanadi River. The catchment area is 6730 km^2. It has a capacity of 3040 Mm^3 with mean annual inflow 3540 Mm^3.

3.5.3 Tandula:

The dam is about 5 km from Balod city, Chhattisgarh which was completed in 1921. Catchment area of Tandula is about 827.2 km^2. The gross storage capacity of the reservoir is 312.25 Mm^3.

3.5.4 Ravishankar Sagar:

The Ravishankar Sagar Project dam at 20^o 38' N, 81^o 34' E was constructed in 1978 on the Mahanadi River which is about 92 km south of Raipur city. The total catchment area of the dam is 3620 km^2 and has storage capacity of 909 Mm^3.

3.5.5 Dudhawa Reservoir:

The Dudhawa reservoir constructed during 1953 to 1964 at 81^o 45' E, 20^o 18' N across Mahanadi River near Dudhawa village in Dhamtari district of Chhattisgarh state. The catchment area of the Dudhawa reservoir is about 625.27 km^2.

3.5.6 Sondur Reservoir:

The Sondur reservoir was constructed in 1988 at 82^o 6' E, 20^o 14' N across Sondur Rver a tributary of Mahanadi.The catchment area of Sondur River is about 518 km^2.

Table 2: Features of Existing Projects in Mahanadi Basin in Odisha

Name of the Project	**Year of completion**	**Gross Storage capacity (Mm^3)**	**Live storage capacity (Mm^3)**
Budha Budhani	1976	14.98	12.50
Damar Bahal	1983	22.30	19.32
Lurada	1990	31.98	28.29
Russel Konda	1901	51.66	38.75
Saipala	1982	21.28	18.35
Surada	1902	35.16	28.29
Sundar Dam	-	26.35	23.55
Upper Dahuka	-	29.60	23.44

Chapter-4

Methodologies

4. METHODOLOGIES:

4.1 Hydrological Index Methodologies:

4.1.1 Montana or Tennant Method:

The Montana method suggested by Water Quality Assessment Authority (WQAA) has been used by 25 countries either in original or modified for. It is common hydrological method developed in 1976 and applied worldwide. The Tennant method is based on percentage of the mean annual flow (MAF) calculated for two different six month periods. It is used to define conditions of flow as shown in table 3.

Table 3: The Montana Method

Description of General condition of flow	Recommended flow regimes (% of MAF) October to March	Recommended flow regimes (% of MAF) April to September
Flushing or maximum	200%	200%
Optimum range	60-100%	60-100%
Outstanding	40%	40%
Excellent	30%	30%
Good	20%	20%
Fair or degrading	10%	10%
Poor or minimum	10%	10%
Severe degradation	<10%	<10%

Source: Journal Of Hydrological and Development (Vol 25, 2010)

4.1.2 Flow Duration Curve Analysis (FDCA):

Flow duration curve known as FDC is a plot showing the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest in abscissa and discharge in ordinate. The discharge may be daily, monthly, annual or entire period of record depending on our interest. In FDC flow records are analyzed over specified durations to produce flow duration curves which display the relationship between range of discharges and percentage of time that each of them is equaled or exceeded. Q17, Q40, Q75, Q80, Q84, Q90, Q95, Q96, Q97, Q98 and Q99 are known as flow indices among which Q90 and Q95 are known as low flow indices. Q95 means the discharge equaled or exceeded on 95% of the time on record.

The 7Q10 Flow:

7Q10 flow means 7 days average flow per 10 years period. 7Q10 flow for regulation purposes ranging from

- Water quality protection from waste water discharge.
- Habitat protection during drought condition.
- Chronic criteria for aquatic life.
- A local extinction flow.

Procedure for computing 7Q10 flow curve:

1. Flow duration curve of each water year was constructed by the following method

   - The discharges are arranged in the descending order and then ranked.
   - Probability of each discharge is calculated by the Weibull ploting formula i.e.

   $$P = \frac{m}{n+1} * 100$$

   Where P is probability of all events less than or equal to each discharge value, m is the rank of the event and n is the number or events on record.

Table 4: Probability calculation (Illustration)

Date	Discharge (m^3/s)	Discharge (m^3/s) in descending order	Rank	Probability
1/06/1991	140	120	1	$\frac{1}{4+1} * 100 = 20\%$
2/06/1991	145	140	2	$\frac{2}{4+1} * 100 = 40\%$
3/06/1991	120	145	3	$\frac{3}{4+1} * 100 = 60\%$
4/06/1991	150	150	4	$\frac{4}{4+1} * 100 = 80\%$

   - FDC is obtained by plotting probability of exceedance in abscissa and discharge in ordinate.

2. Values of discharge at every 5% probability of exceedance are taken after the construction of FDC for each year.
3. Separate table was made for each year discharge vs probability of exceedance.
4. Table obtained in step 3 was transverse and then discharges were arranged in ascending order in a table.
5. The table obtained in step 4 was again transverse and the discharges were arranged in descending order. First row of the table indicates the return period and first row of the table indicates probability of exceedance.
6. The desired return period was selected and corresponding discharges and probability of exceedance were taken.
7. The data were plotted by taking probability of exceedance in abscissa and discharge in ordinate. If we take 10 year return period and 7-day mean discharge are used to construct FDC then we will get 7Q10 flow curve.
8. Similarly we can construct 1-day, 3-day and 7-day flow duration curve for different return periods.

4.1.3 Range of Variability Analysis:

The Range of Variability Approach (RVA) developed by Richter et al. (1996, 1997) provides a comprehensive statistical characterization of ecologically relevant features of the flow regime. The method is intended application to rivers where protection of natural ecosystem functioning and conservation of natural biodiversity are the primary management objectives. The methodology is based on six steps in which fist is the characterization of the natural range of hydrological variation using hydrological indices termed as Indicators of Hydrological Alteration (IHA).

The IHA calculates 67 statistical parameters subdivided into 2 groups. One is the IHA parameters and other one is the Environmental Flow Component (EFC) parameters. There are 33 IHA parameters and 34 EFC parameters. Based on virgin regime characteristics the IHA statistics are grouped into five categories:

1. The magnitude of the water condition at any given time i.e. the volumetric flow rate or level.
2. The timing of occurrence of particular water conditions(e.g. May)
3. The frequency of occurrence of specific water conditions.(e.g. 2-4 years)
4. The duration of time over which a specific water condition exists.(e.g. 2 weeks)
5. The rate of change in water conditions. (e.g. a 0.3 meter/day flood recession rate)

IHA parameters can be calculated using parametric and non-parametric statistics. In Parametric statistics we include mean or standard deviation and in non-parametric statistics we include percentile.

The IHA calculates five different types of Environmental Flow Components (EFCs) parameters which are low flows, high flow pulses, small floods and large floods. The parameters used in EFCs and their values are given below:

- High flow upper percentile threshold: 75% of all flows. All flows above this threshold are known as high flow events.
- High flow lower percentile threshold: 50% of all flows. All flows below this threshold are known as low flow events.
- High flow start rate threshold: 25%. This parameter controls the start of high flow events when flows are between the upper and lower percentile thresholds. It also controls whether the ascending limb of an event is started from the descending limb.
- High flow end rate threshold: 10%. This parameter is used to end high flow events during their descending limb when flows are between the upper and lower percentile thresholds.
- Small flood return interval and large flood return interval: 2 and 10 years. It is used to control to classify small floods and high floods.
- Extreme low flow threshold: 10^{th} percentile of all low flows. This controls what percentage of low flows are classified as extreme low flows.

Chapter-5

Results and Discussion

6. RESULTS & DISCUSSION:

6.1 7Q10 method:

The data of 24 years starting from 1986 to 2010 is used to determine the minimum flow. In the determination of 7Q10 flow first flow duration curve for each year was obtained. The flow duration curve for station tikerpara is shown in Fig 2. In fig. 2 the abscissa represents the percentile and the ordinate represents the discharge in m^3/s.

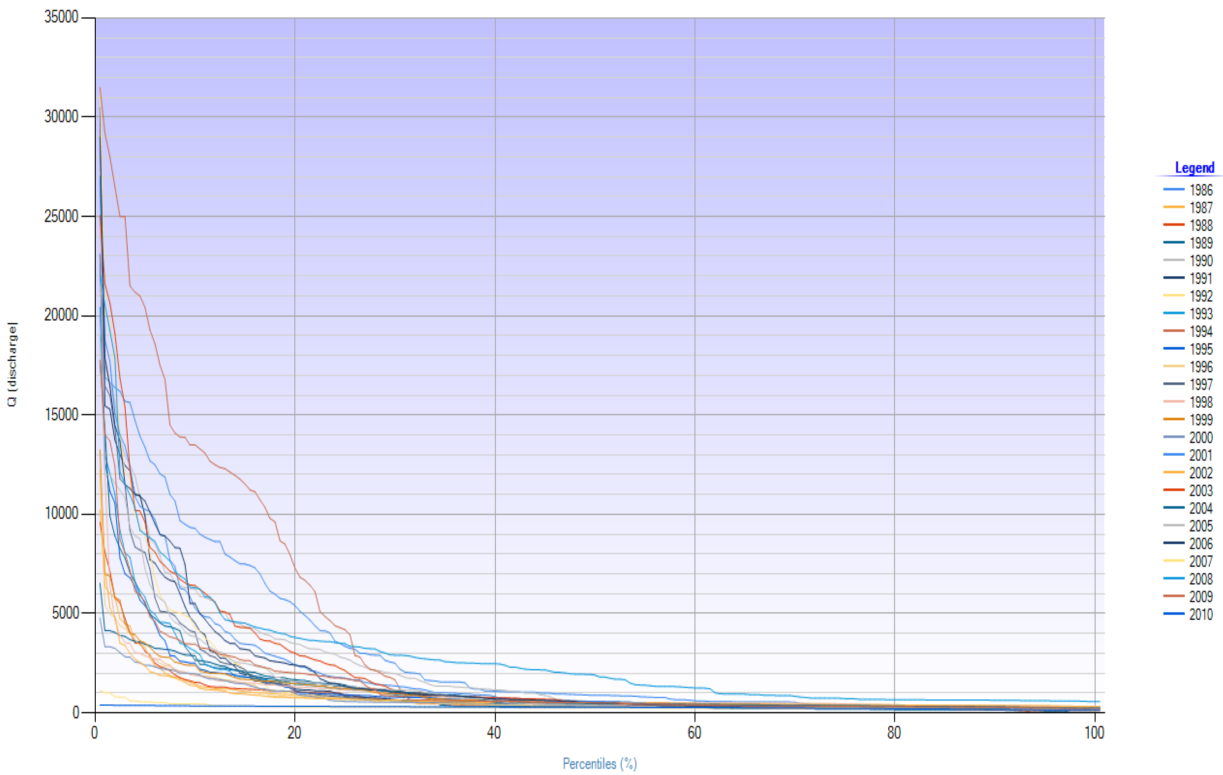


Fig. 2: Flow Duration Curve For Tikerpara Station

The discharges at every 5% probability of exceedance for different years are taken and arranged in a table as shown in table no 5.

Table no 5: Discharge for every 5% probability of exceedance (Tikerpara station)

Percentile	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
5	2593.8	324.8	460	833.92	2790	1986	1666	1200	2992	1113.6	612.39	1214.08
10	1435.6	230.13	361.7	509.8	1920	1225	846	659.4	1683	788	396.56	705.81
15	991.5	185	299.358	373.7	1317	633.6	540.2	500.2	1206	593.8	208.9	418.2
20	841.8	140	240.23	280.11	860.9	426	230.8	356	875.75	395.7	131.9	166.04
25	685.01	109.57	171.77	218.2	627.7	324.1	148.6	242.4	550.18	317.4	60.5	122.2
30	410	81.15	111.69	162.37	480.2	190.9	102.1	200.8	300.42	241.2	42.4	107.9
35	300.12	67	45.52	76.2	380.5	141	77.96	142.8	180	200.4	35.36	99.54
40	265.52	49.41	39.61	54.8	305.3	90.93	63.05	116.8	132.6	162.42	29.64	90.06
45	203.9	37.51	32.24	45.2	191	64.36	49.97	78.29	117.4	125.3	24.07	85.03
50	155.43	22.82	14.6	28.4	125.6	51.91	35.67	43.8	84.12	108	20.53	30.58
55	122.494	14.5	8.65	9.4	83.5	42.92	27.35	32.97	38.06	80	17.92	18.71
60	82.45	11.38	7.09	3	51.69	32.9	23.19	16.07	17.8	61.2	15.93	14.02
65	67.71	8.8	5.78	1.49	16.602	24.53	19.27	13.36	13.45	39.18	14.21	10.95
70	64.12	6.17	3.51	0.247	11.74	19.96	10	8.564	8.07	28.2	12.69	7.908
75	49.144	3.78	2.13	0.247	8.767	14.75	8.701	4.124	3.7	20.08	9.712	4.857
80	38.6	2.26	1.37	0.247	6.083	11	5.538	2.863	2.27	12.9	7.547	2.538
85	29.29	1.28	0.95	0.247	4.378	8.25	4.7	1.97	1.09	9.47	6.073	1.48
90	20.83	0.57	0.563	0.247	2.745	5.513	2.2	1.233	0.746	6.981	4.136	0.973
95	2.5	0.23	0.12	0.247	2.124	4.04	1.927	0.778	0.438	4.396	2.22	0.496
100	0.352	0.01	0.028	0.247	0.473	3.091	1.457	0.192	0.274	1.94	0.9	0.1

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
425.9	865.5	600.6	2800	486.424	1775	1373.926	776.87	2560.152	1974.054	2084.765	1026.64	124.623
304.9	600	398	1722	250	1025.432	750.04	450.053	1193.11	1258.324	1080.684	616.112	86.144
245.14	393.1	279.9	1187.134	182.154	780	616.7	319.385	662.255	795.6	831.507	403.753	80
200.55	300.73	200.7	743.7	158	598.7	456.658	245.75	555.147	635.568	500	267.789	71.995
173.97	230.9	170	494.6	138.9	464.7	400	204.989	349.19	500	271.231	207.131	65.658
158.67	180.8	155.73	340.685	120	368.3	378.567	180	288	291.019	190.999	151.967	62.903
132.6	131.87	150.2	280.776	116.4	235	350	153	226.864	182.721	166.316	127.919	60
107.12	104.99	135.61	240.909	110	206.9	234.407	130	190.6	169.653	150	110.631	50
67.871	66.013	123.46	200.4	92.7	189.1	206.532	114.188	168.409	158.707	139	101.205	49.067
37.2	53.32	111.6	172.395	62.359	119.4	175.291	109.429	149.053	154.789	124.614	93.118	47.586
32.25	15.02	102.87	152.8	53.22	75.76	139.437	99.871	133.231	143.639	114.01	83.079	46.721
27.75	13.71	97.525	94.37	48.264	68.09	114.13	90.051	121.611	111	107.52	72.787	44.145
21.35	6.961	87.63	83.56	44.26	61.569	98.511	80	114.96	82.492	99.032	64.636	40.764
17.97	4.092	69	79.49	42.511	35.479	90	74.883	106.896	70.369	82	54.639	38.443
16.08	1.749	62.61	74.47	39.303	24.278	84.238	64.397	100.454	60.989	63.17	50	36.96
15.18	0.367	60.03	70.58	37.33	17.885	82.289	53	98.264	57.791	52	44.788	33.035
14.14	0.367	57.61	69	33.938	15	79.92	39.927	92	52.511	44.705	39.426	31.404
12.45	0.367	52.97	65	30.806	11.36	77.671	36.674	80.067	49.322	38	32	30.179
4.694	0.367	34.87	61.66	18	10.92	73.28	34.209	64	46.734	32.181	25.523	28.207
2.18	0.367	10.24	39.78	13.314	7.505	55	25.127	35.843	29.604	20.7	15	21.057

Transpose of table no 5 was taken to find out the discharge against percentage of non-exceedance and then data were shorted in ascending order as shown in table no 6.

Table no 6: Discharge against percentage of non-exceedance (Tikerpara station)

Rank	% nonexceedance	5	10	15	20	25	30	35	40	45	50
1	3.846153846	367.598	347.526	333.893	301.057	299.013	291.952	283.681	260.8	241.989	240.429
2	7.692307692	552.105	443.436	338.214	322.845	316	304	293.794	285.962	282.298	275.273
3	11.53846154	2073.983	1243.399	912.666	748.508	570.405	530	353.8	320	305.9	292.4
4	15.38461538	2389.998	1329.4	1062	783.95	685.653	552.1	417.9	344.7	313.98	303.76
5	19.23076923	2763.4	1519.1	1191.1	800	688.46	573.39	451.2	355.8	325.4	305.1
6	23.07692308	2790	1851	1365.475	884.1	724	575	452	405.6	374	360.5
7	26.92307692	2819	1853.5	1444	900	728.9	600.8	505.7	467.28	422.983	379.7
8	30.76923077	2912.9	1901.533	1500	1001	750	625	520	470	438.67	380
9	34.61538462	3311	2100	1684	1039.8	811.03	638.031	523	493.483	446.37	423.67
10	38.46153846	3385.4	2201	1746.19	1059	899.4	644.8	556.316	519.218	478.19	450.47
11	42.30769231	4824	2450.5	1774.52	1175.55	904.3	785.4	561.99	521.97	481.6	457.34
12	46.15384615	4972.874	2635	1778	1299	1135	832.428	621.891	525	481.601	464.488
13	50	5016	2930.24	1871.4	1427	1176	867.2	667.4	540	484	467.395
14	53.84615385	5171	3200	1895.14	1453	1200	950	680	569.795	502.665	474.278
15	57.69230769	6447.019	3285.872	1912	1522.208	1273.567	993.4	681.58	582.662	523.539	480.785
16	61.53846154	7239	3712.651	2055.8	1560.537	1279	1001.723	804.5	594.9	543.5	500.9
17	65.38461538	7720.08	4098.13	2432.57	1641	1307.835	1042.1	814.1	626.9	550.9	501.421
18	69.23076923	8118.19	4100	2629.061	1992.033	1326.3	1052	823.347	672.2	580.3	508.2
19	73.07692308	8338	4977.773	3150	2337.294	1684.507	1090	864.5	695.557	586.6	523.059
20	76.92307692	8775.12	5000	3444.414	2345.608	1690.149	1155.747	873.041	738.4	613.366	530.4
21	80.76923077	8819.897	5876.28	4264.43	2875	1943.183	1200	887.381	740.504	618.3	532
22	84.61538462	10107.42	6212	4291.59	3446.17	2656.65	1315.267	999.453	769.9	673.105	550
23	88.46153846	10143.8	6239.571	4417.62	3750.162	3250	1900	1336	1070.8	820	575
24	92.30769231	12698.9	9000	7421.4	5125	3354.052	2200	1552.6	1145	990.5	880.4
25	96.15384615	19300	13300	11229	6834	3930	2903.607	2561.031	2459.461	2100	1804.39

55	60	65	70	75	80	85	90	95	100
238.916	234.609	203.3	194.4	186.2	156.4	149.8	137.6	33.12	22.74
268.253	257.019	232.144	227.7	214.683	202.917	193.432	176.6	93.65	23.49
282.9	262	242.354	230.747	217.5	204.992	195.152	180	148.56	121.8
284	269.9	252.847	231.848	218.835	209.884	200	184.93	151.317	128.6
296.9	274.366	261.7	235.212	220.765	211.6	201.5	190	169.76	132.8
351.9	280.1	266.627	239.8	228.16	226.361	221.1	208	179.852	145.067
355.4	281.2	269.3	255.8	248.38	230	225.419	221.96	185.71	146.718
356.1	330	270	258	249.1	238	230	222.078	191	149.338
358.738	339.109	315	270	250.8	248	242	227.04	201.87	154.27
364.3	340	320	296.68	276.1	262	248.007	228.8	202.7	175.002
374.96	341.3	323.68	298.9	289.51	278.8	260.762	233.2	218.259	179
387.674	345.942	325.547	302	290	279.173	261.9	243.2	228.375	186.961
394.091	349.9	335	325.4	298	285	264.711	247.964	231.225	192
398.96	357.19	340	327.7	310.5	294.8	268	251.477	232.45	200
425.649	363.4	342.8	330.1	318.78	296.837	278.1	268.5	239.229	200.92
426.1	400.097	348.674	335.35	324.8	301.2	281.02	268.94	239.6	202.1
442	410.7	390	371.726	343.144	306.378	289.809	272.4	241.5	208.3
442.42	422.93	400	377.19	354.8	312	294	277.233	258.02	210
445.4	426.013	404.081	378.8	356	328.1	301.2	284.3	260.608	221.9
445.513	426.758	404.27	380.47	357.4	338.146	317.3	288.1	265.5	239.89
464.669	449.105	432.229	390.1	364.81	338.5	319.563	308.5	300.8	285.6
487.9	459.9	433.5	422.935	378.8	350.53	338	329.88	319.3	297.08
517.4	500	496.8	469.6	410.305	388.7	370.9	360	345	311.1
790.6	597.4	549.1	481.5	436.1	400	379.999	368.957	349.505	313.636
1367.333	1249.915	919.12	795.88	699.837	664.108	647.545	630.21	605.269	559.531

Discharges for every 5 % probability were obtained for different return period by transpose the table no 6. The obtained discharges were shown in table no 7.

Table no 7: Discharges for every 5 % probability for different return periods. (Tikerpara station)

Percentile	3.846154	7.692308	10	11.53846	15.38462	19.23077	23.07692	26.92308	30.76923	34.61538	38.46154	42.30769	46.15385
5	367.598	552.105	1465.232	2073.983	2389.998	2763.4	2790	2819	2912.9	3311	3385.4	4824	4972.874
10	347.526	443.436	923.4138	1243.399	1329.4	1519.1	1851	1853.5	1901.533	2100	2201	2450.5	2635
15	333.893	338.214	682.8852	912.666	1062	1191.1	1365.475	1444	1500	1684	1746.19	1774.52	1778
20	301.057	322.845	578.2428	748.508	783.95	800	884.1	900	1001	1039.8	1059	1175.55	1299
25	299.013	316	468.643	570.405	685.653	688.46	724	728.9	750	811.03	899.4	904.3	1135
30	291.952	304	439.6	530	552.1	573.39	575	600.8	625	638.031	644.8	785.4	832.428
35	283.681	293.794	329.7976	353.8	417.9	451.2	452	505.7	520	523	556.316	561.99	621.891
40	260.8	285.962	306.3848	320	344.7	355.8	405.6	467.28	470	493.483	519.218	521.97	525
45	241.989	282.298	296.4592	305.9	313.98	325.4	374	422.983	438.67	446.37	478.19	481.6	481.601
50	240.429	275.273	285.5492	292.4	303.76	305.1	360.5	379.7	380	423.67	450.47	457.34	464.488
55	238.916	268.253	277.0412	282.9	284	296.9	351.9	355.4	356.1	358.738	364.3	374.96	387.674
60	234.609	257.019	260.0076	262	269.9	274.366	280.1	281.2	330	339.109	340	341.3	345.942
65	203.3	232.144	238.27	242.354	252.847	261.7	266.627	269.3	270	315	320	323.68	325.547
70	194.4	227.7	229.5282	230.747	231.848	235.212	239.8	255.8	258	270	296.68	298.9	302
75	186.2	214.683	216.3732	217.5	218.835	220.765	228.16	248.38	249.1	250.8	276.1	289.51	290
80	156.4	202.917	204.162	204.992	209.884	211.6	226.361	230	238	248	262	278.8	279.173
85	149.8	193.432	194.464	195.152	200	201.5	221.1	225.419	230	242	248.007	260.762	261.9
90	137.6	176.6	178.64	180	184.93	190	208	221.96	222.078	227.04	228.8	233.2	243.2
95	33.12	93.65	126.596	148.56	151.317	169.76	179.852	185.71	191	201.87	202.7	218.259	228.375
100	22.74	23.49	82.476	121.8	128.6	132.8	145.067	146.718	149.338	154.27	175.002	179	186.961

50	53.84615	57.69231	61.53846	65.38462	69.23077	73.07692	76.92308	80.76923	84.61538	88.46154	92.30769	96.15385
5016	5171	6447.019	7239	7720.08	8118.19	8338	8775.12	8819.897	10107.42	10143.8	12698.9	19300
2930.24	3200	3285.872	3712.651	4098.13	4100	4977.773	5000	5876.28	6212	6239.571	9000	13300
1871.4	1895.14	1912	2055.8	2432.57	2629.061	3150	3444.414	4264.43	4291.59	4417.62	7421.4	11229
1427	1453	1522.208	1560.537	1641	1992.033	2337.294	2345.608	2875	3446.17	3750.162	5125	6834
1176	1200	1273.567	1279	1307.835	1326.3	1684.507	1690.149	1943.183	2656.65	3250	3354.052	3930
867.2	950	993.4	1001.723	1042.1	1052	1090	1155.747	1200	1315.267	1900	2200	2903.607
667.4	680	681.58	804.5	814.1	823.347	864.5	873.041	887.381	999.453	1336	1552.6	2561.031
540	569.795	582.662	594.9	626.9	672.2	695.557	738.4	740.504	769.9	1070.8	1145	2459.461
484	502.665	523.539	543.5	550.9	580.3	586.6	613.366	618.3	673.105	820	990.5	2100
467.395	474.278	480.785	500.9	501.421	508.2	523.059	530.4	532	550	575	880.4	1804.39
394.091	398.96	425.649	426.1	442	442.42	445.4	445.513	464.669	487.9	517.4	790.6	1367.333
349.9	357.19	363.4	400.097	410.7	422.93	426.013	426.758	449.105	459.9	500	597.4	1249.915
335	340	342.8	348.674	390	400	404.081	404.27	432.229	433.5	496.8	549.1	919.12
325.4	327.7	330.1	335.35	371.726	377.19	378.8	380.47	390.1	422.935	469.6	481.5	795.88
298	310.5	318.78	324.8	343.144	354.8	356	357.4	364.81	378.8	410.305	436.1	699.837
285	294.8	296.837	301.2	306.378	312	328.1	338.146	338.5	350.53	388.7	400	664.108
264.711	268	278.1	281.02	289.809	294	301.2	317.3	319.563	338	370.9	379.999	647.545
247.964	251.477	268.5	268.94	272.4	277.233	284.3	288.1	308.5	329.88	360	368.957	630.21
231.225	232.45	239.229	239.6	241.5	258.02	260.608	265.5	300.8	319.3	345	349.505	605.269
192	200	200.92	202.1	208.3	210	221.9	239.89	285.6	297.08	311.1	313.636	559.531

The 7-day mean flows were obtained for a return period of 10 year and a graph was plotted between percentile and discharge in m^3/s. The curve obtained in the graph represents the 7Q10 flow curve. The 7Q10 flow curve for tikerpara station was shown in fig 3.

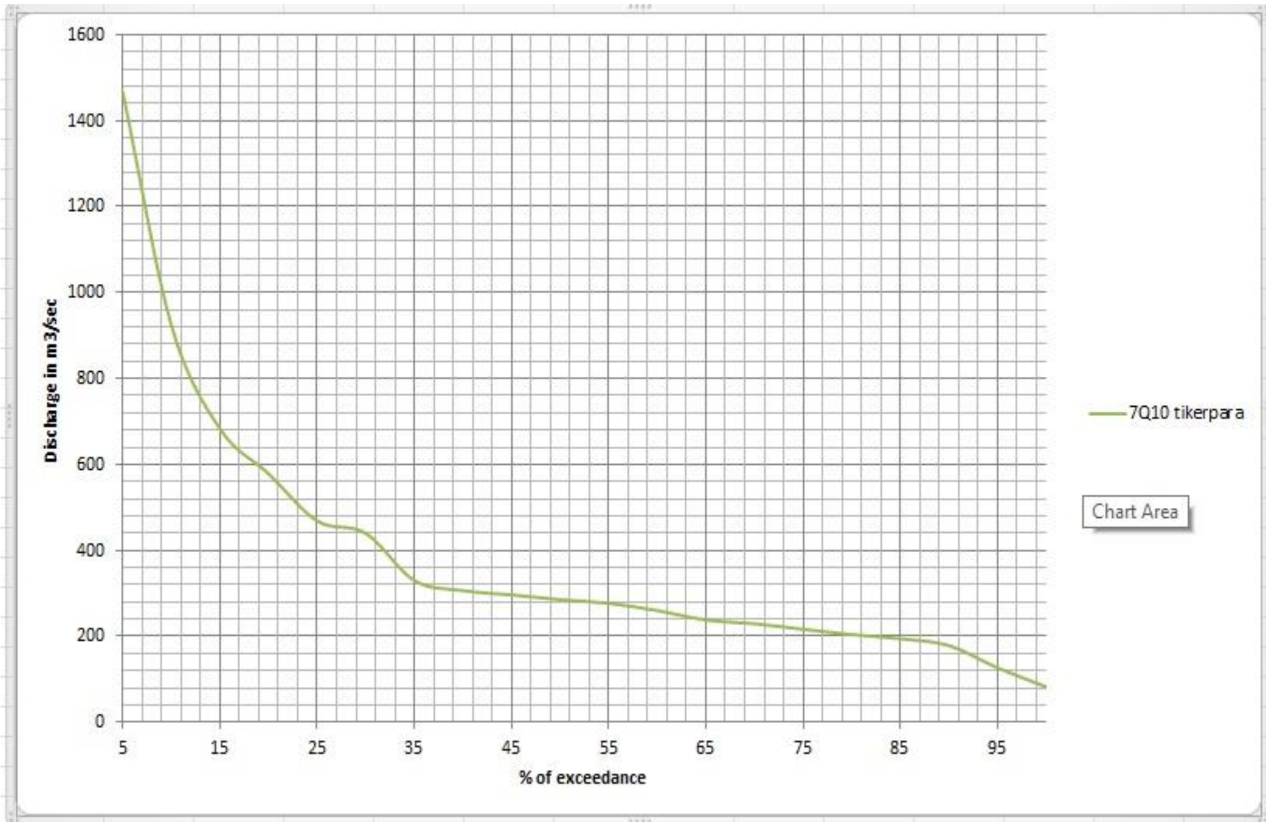
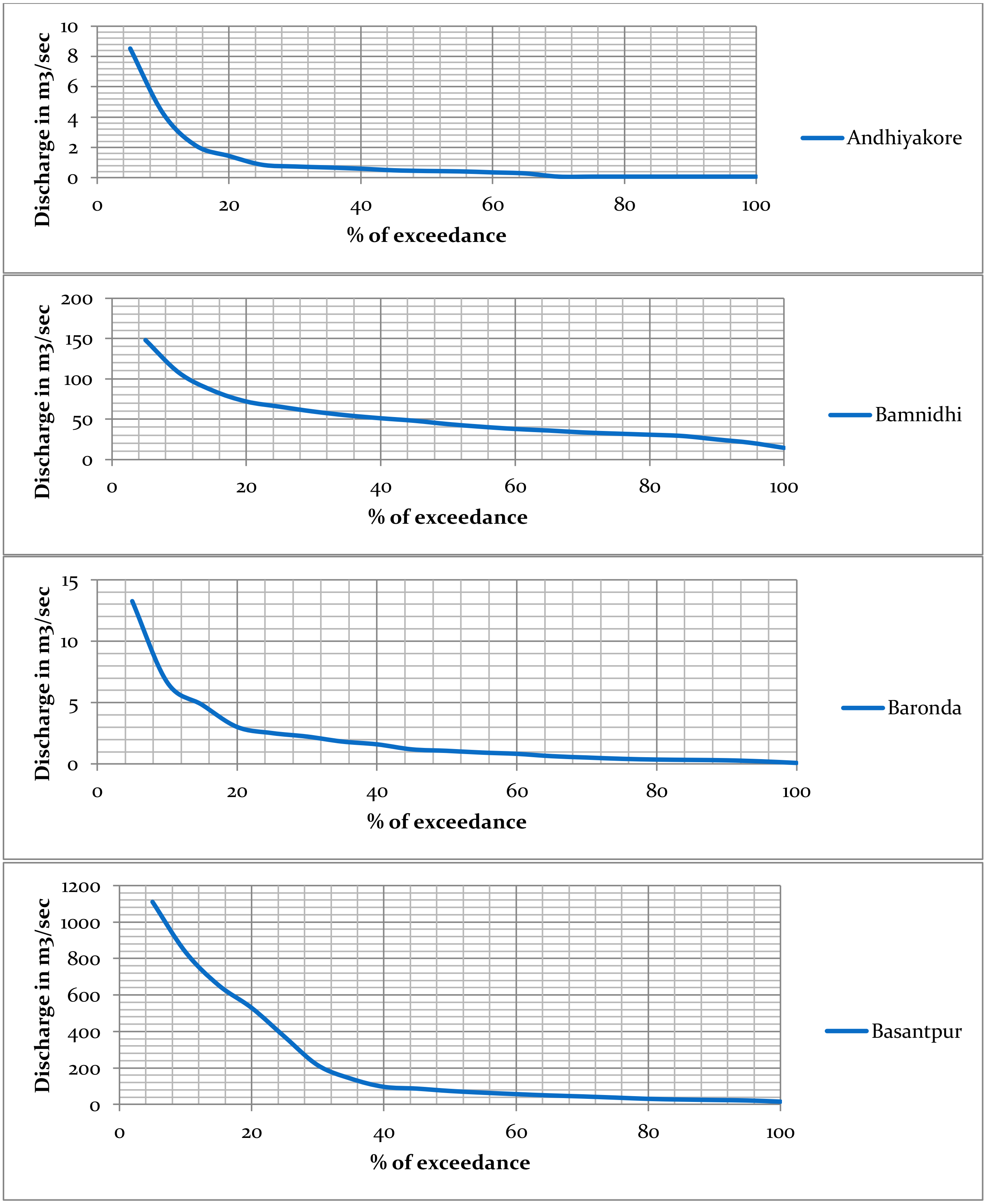
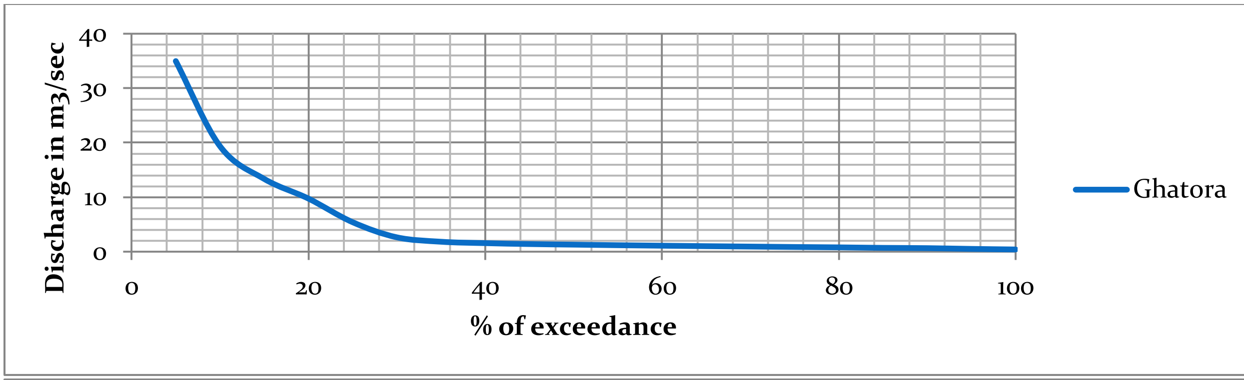


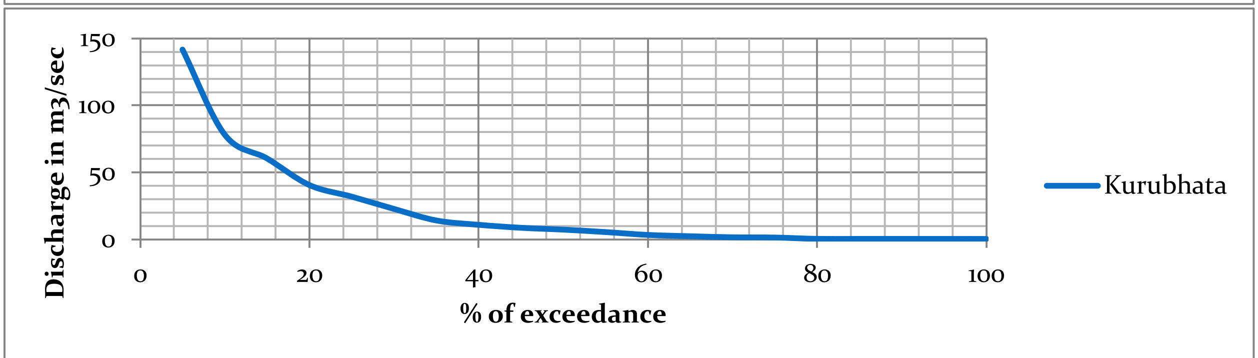
Fig.3: 7Q10 Curve For Tikerpara Station

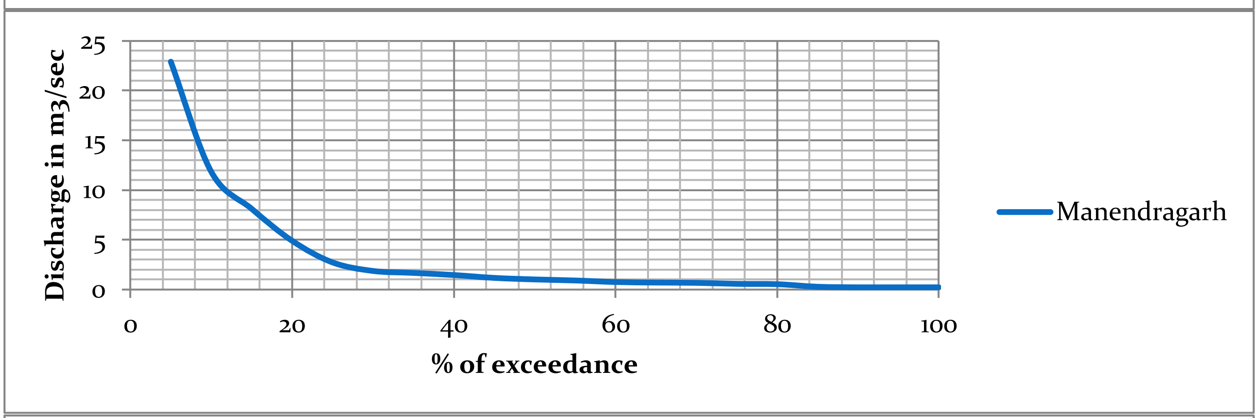
The 7Q10 flow curve for stations Andhiyarkore, Bamnidhi, Basantpur, Boranda, Ghatora, Kantamal, Kesinga, Kurubhata, Manendragarh, Rajim, Rampur, Salebhata, Simga and Sundargarh and shown in next page.

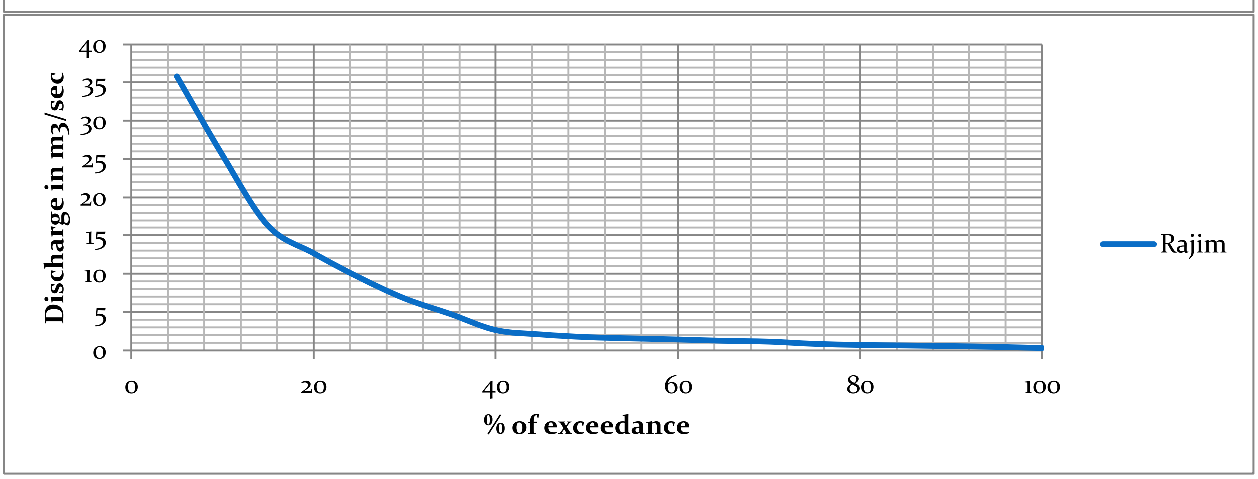
Fig 4: 7Q10 flow curve for differnet stations

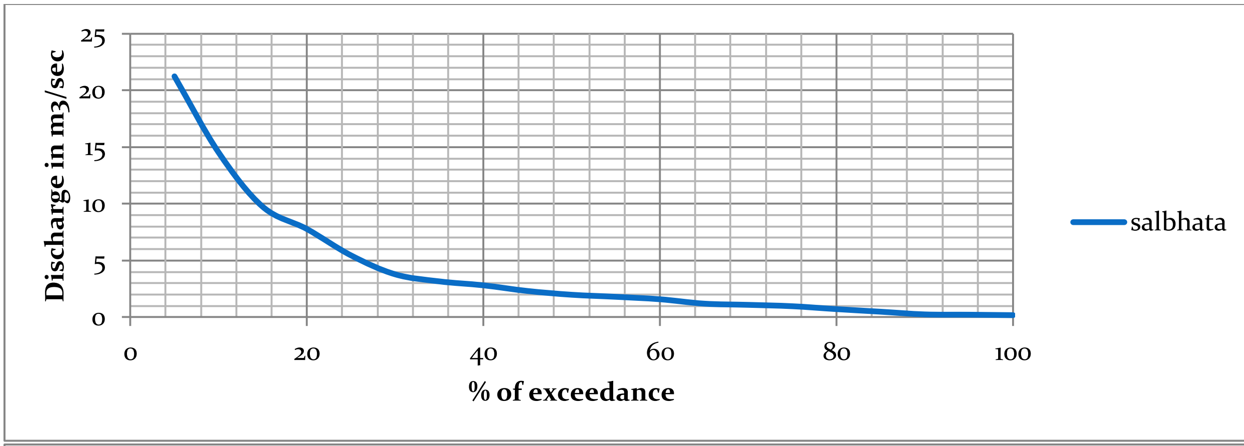


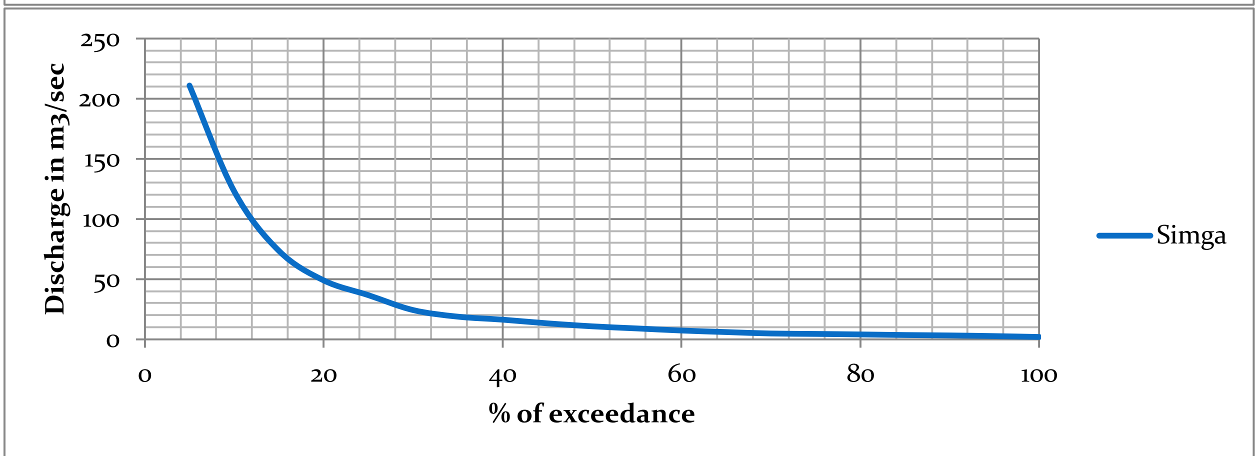

Discharge in m3/sec
40
30
20
10
0
0
20
40
60
80
100
% of exceedance
Ghatora

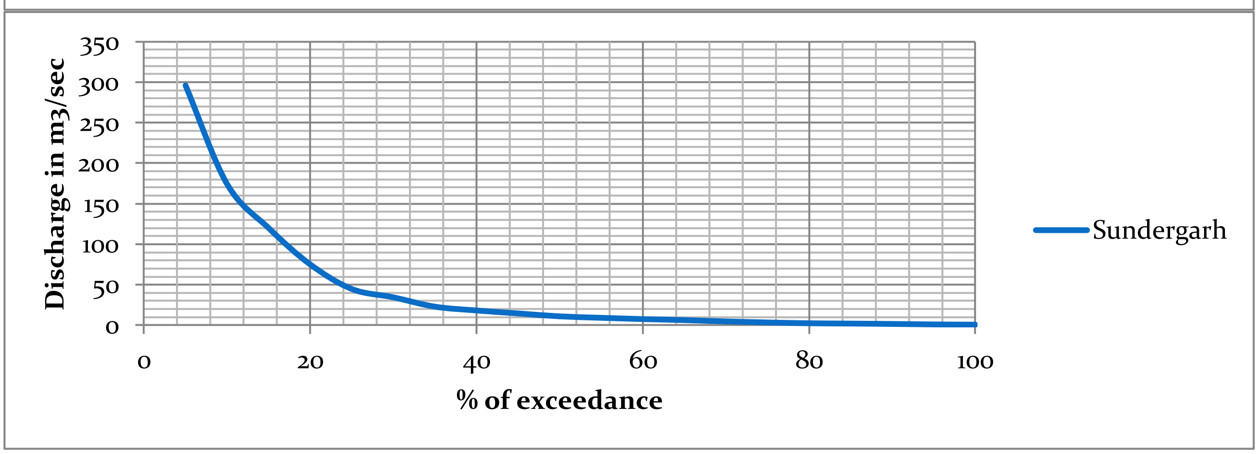

Discharge in m3/sec
150
100
50
0
0
20
40
60
80
100
% of exceedance
Kurubhata

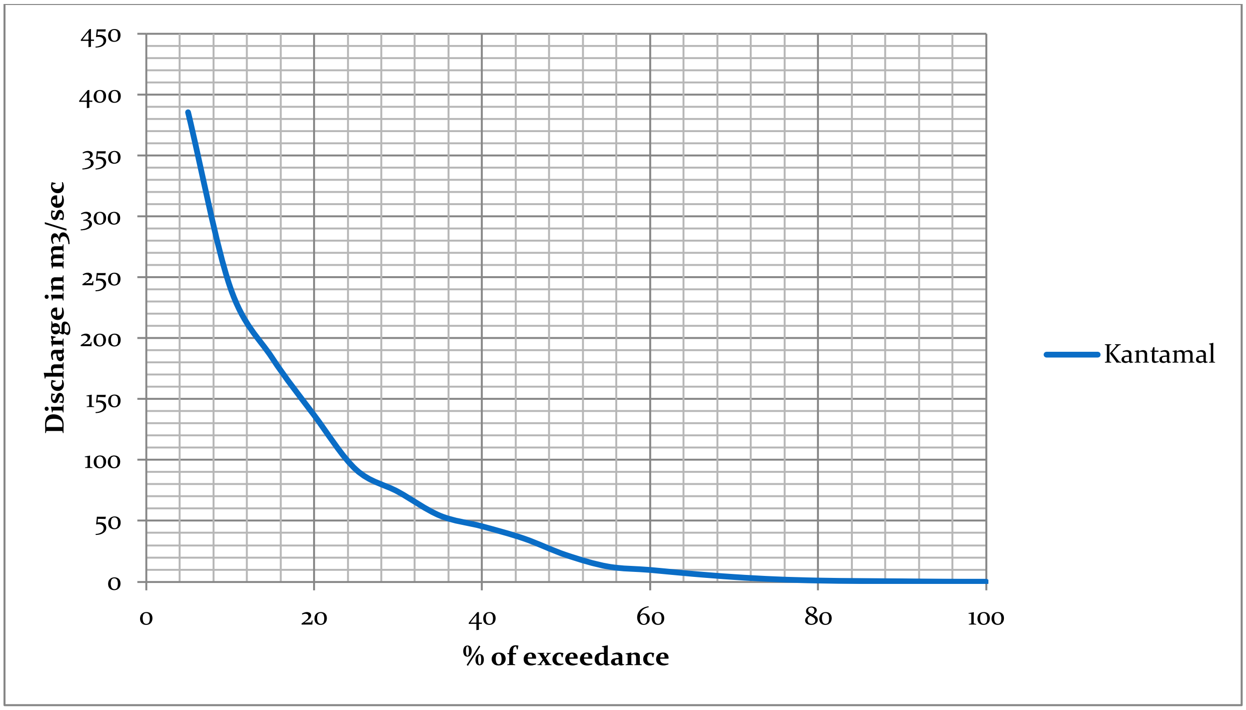

Discharge in m3/sec
25
20
15
10
5
0
0
20
40
60
80
100
% of exceedance
Manendragarh

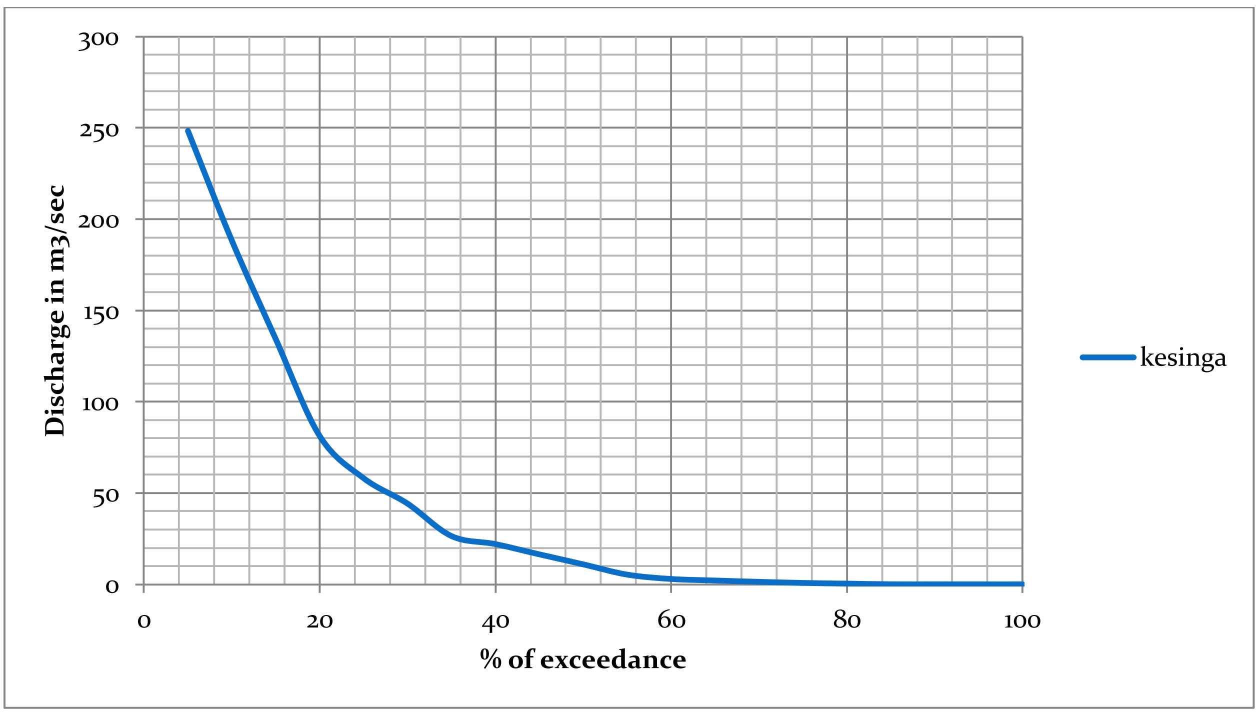

Discharge in m3/sec
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
% of exceedance
Rajim


Discharge in m3/sec
25
20
15
10
5
0
0
20
40
60
80
100
% of exceedance
salbhata


Discharge in m3/sec
250
200
150
100
50
0
0
20
40
60
80
100
% of exceedance
Simga

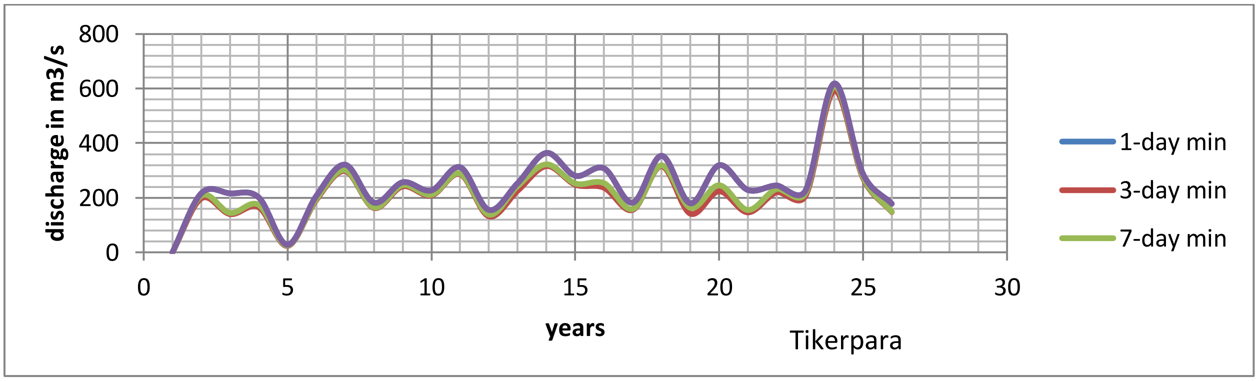

Discharge in m3/sec
350
300
250
200
150
100
50
0
0
20
40
60
80
100
% of exceedance
Sundergarh

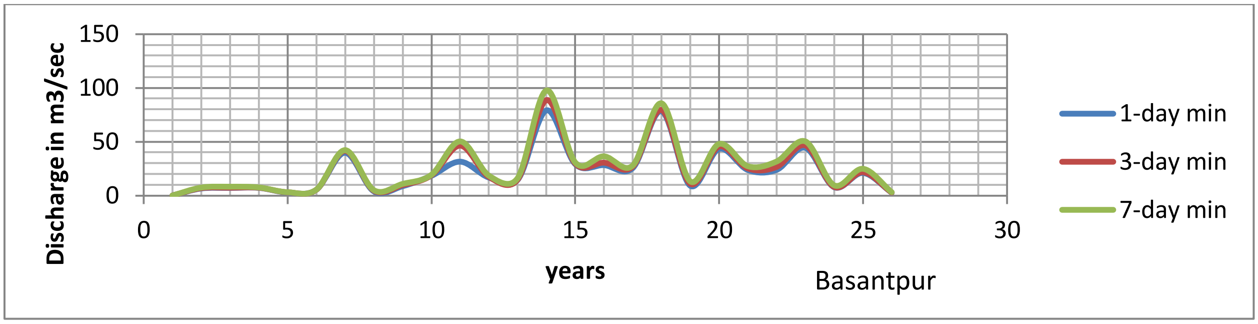

450
400
350
300
250
200
150
100
50
0
Discharge in m3/sec
0
20
40
60
80
100
% of exceedance
Kantamal

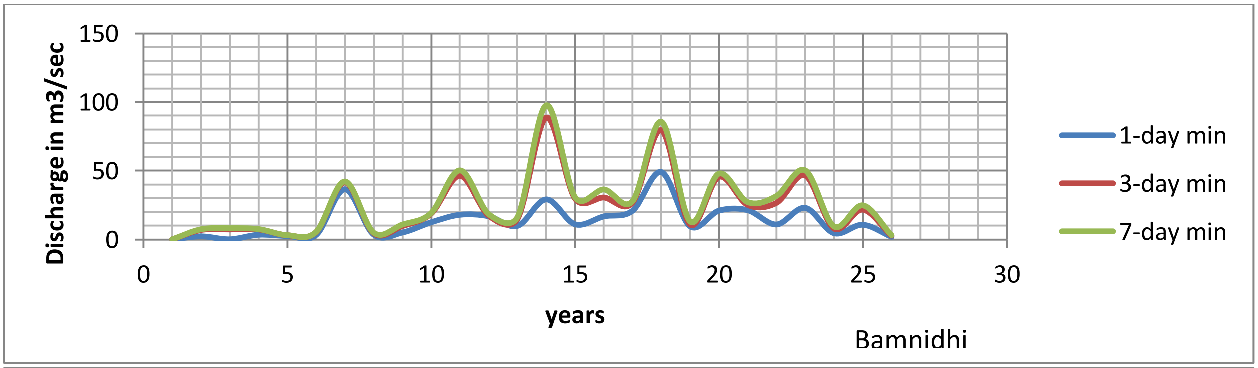

300
250
200
150
100
50
0
Discharge in m3/sec
0
20
40
60
80
100
% of exceedance
kesinga

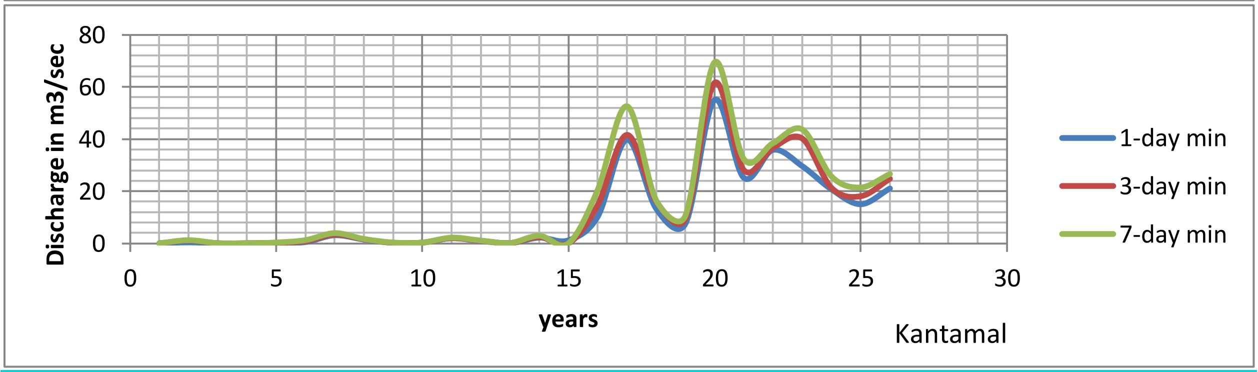
6.2 Range of Variability Analysis method:

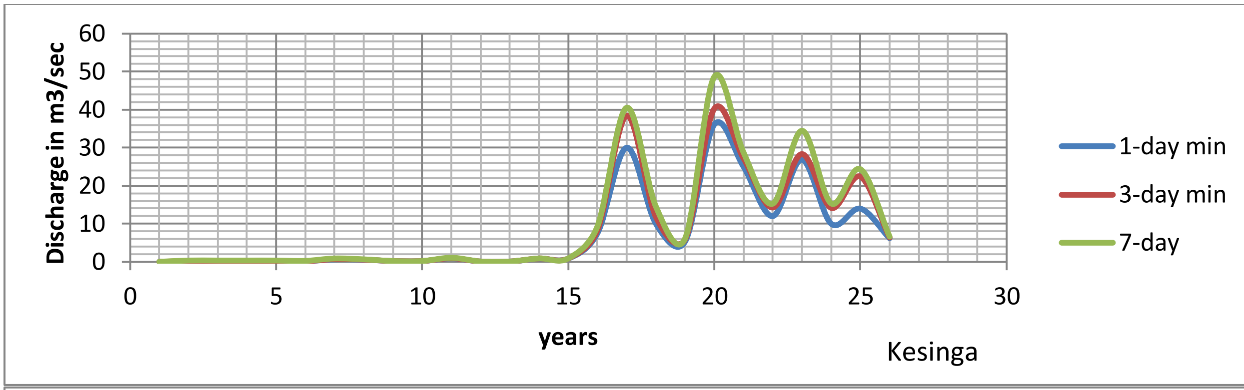
Fig 5: 1-day, 3-day, 7-day minimum flow

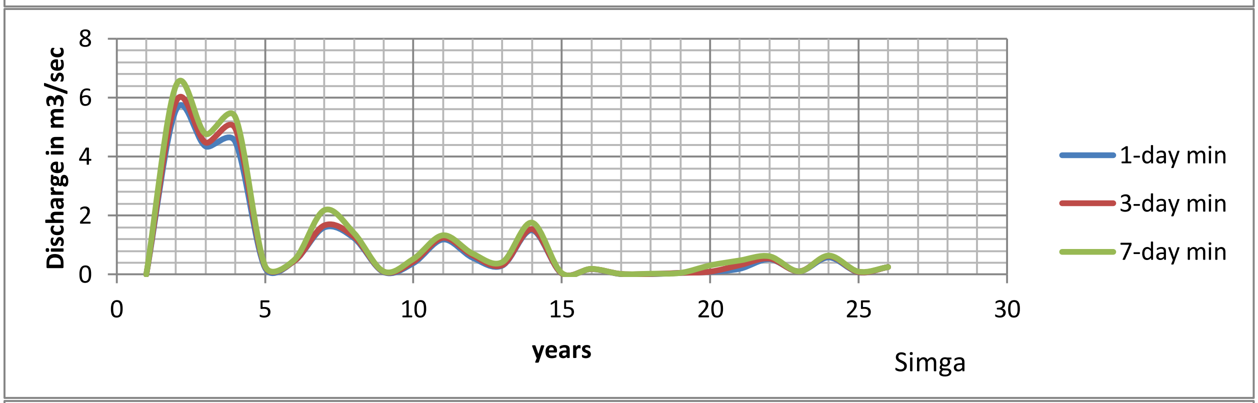


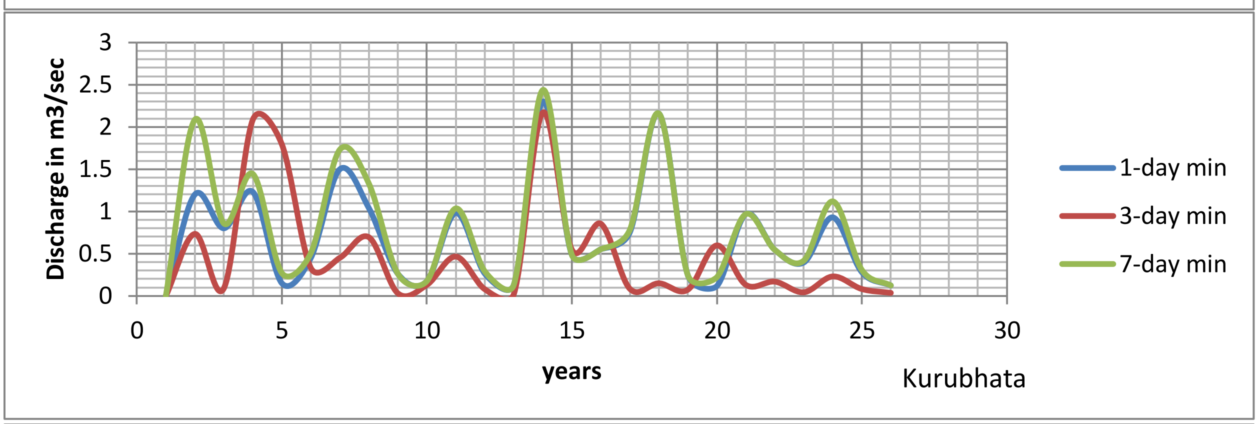


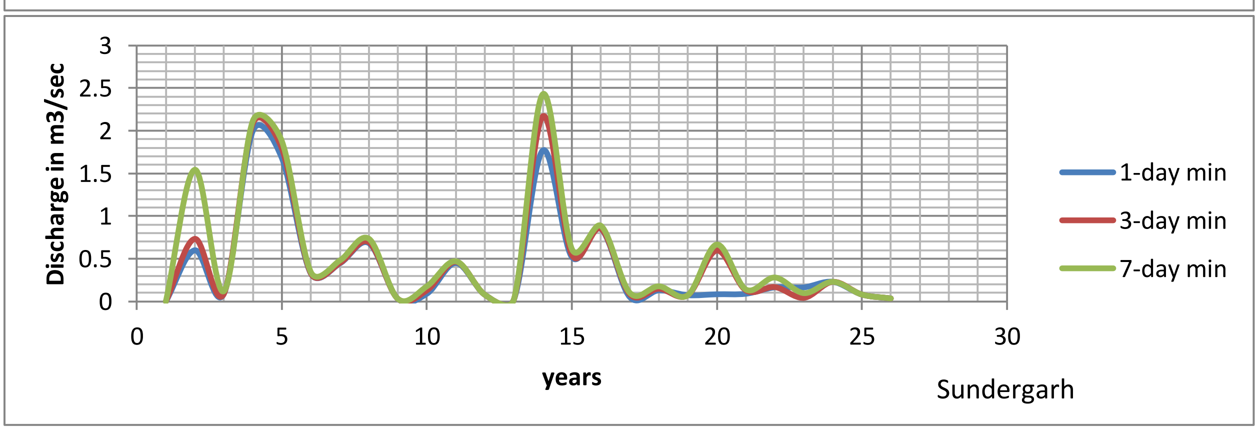


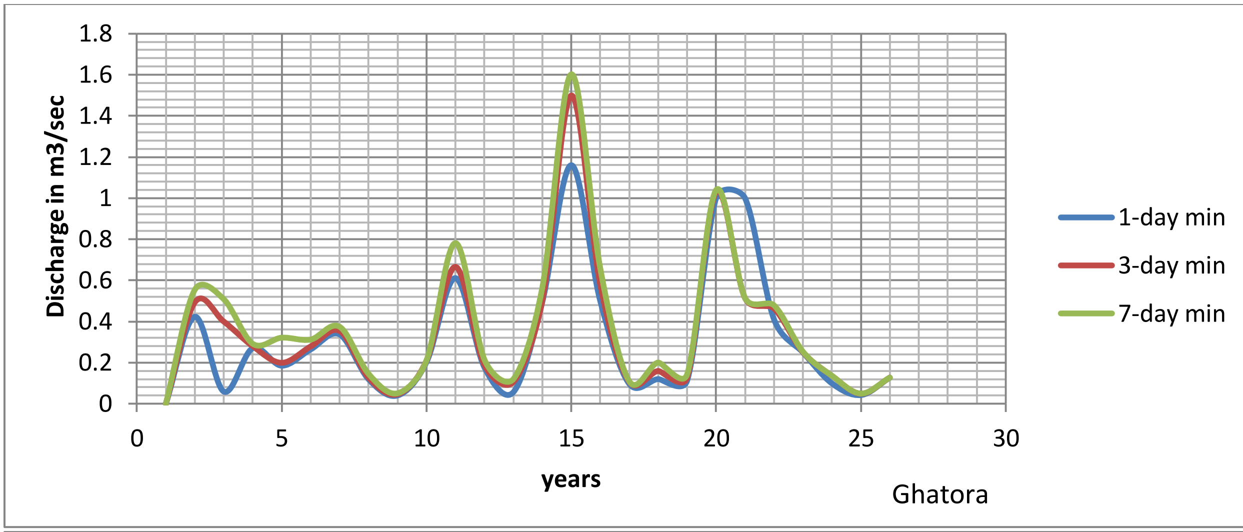


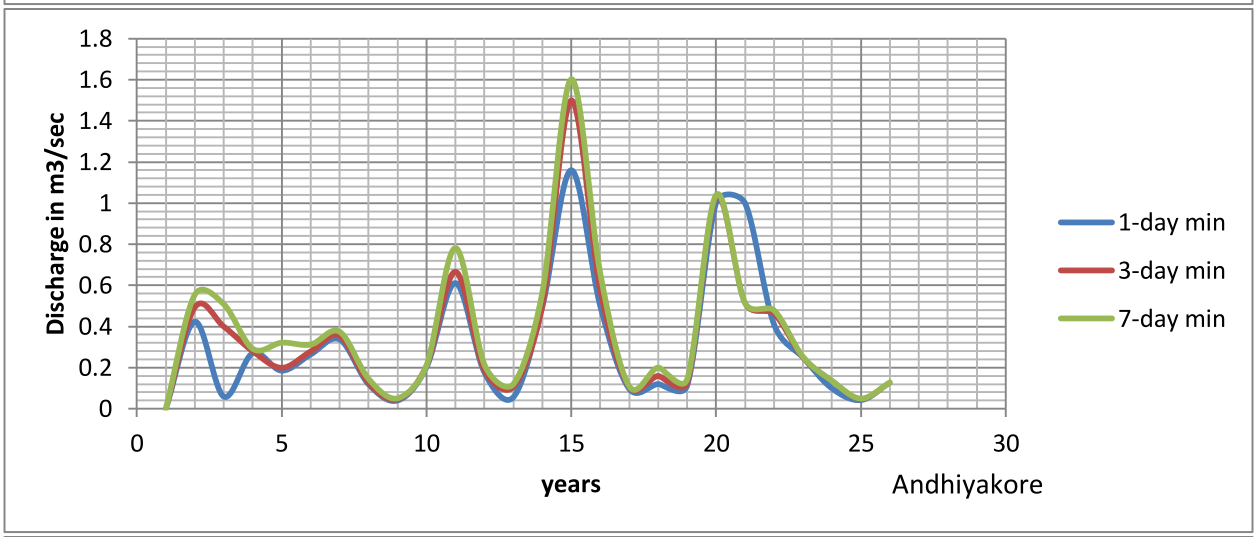

Discharge in m3/sec
0
10
20
30
40
50
60
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day
Kesinga

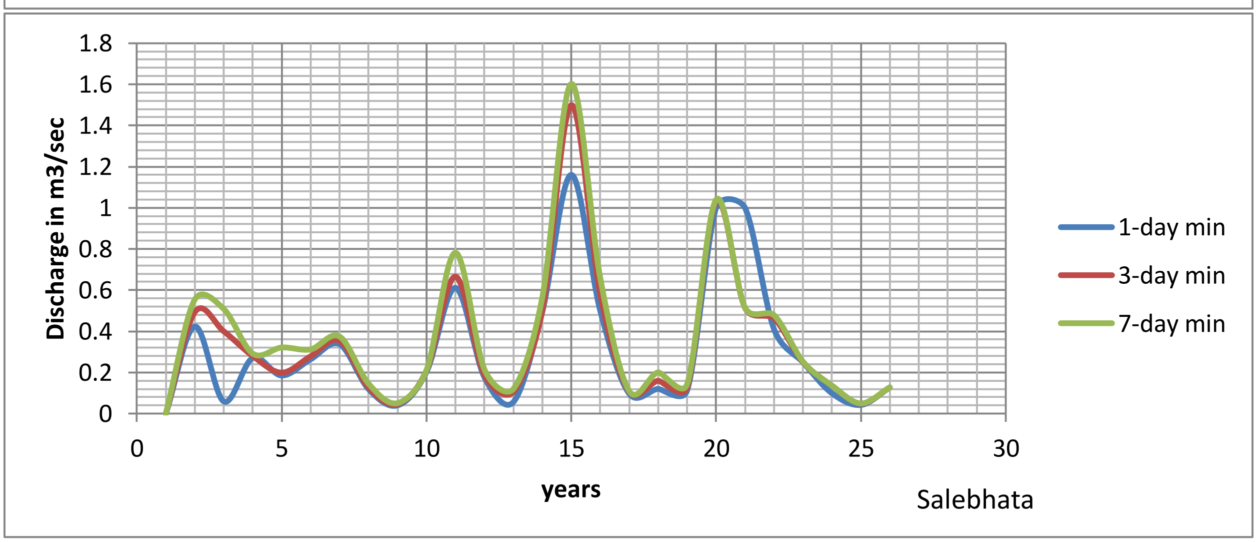

Discharge in m3/sec
0
2
4
6
8
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Simga

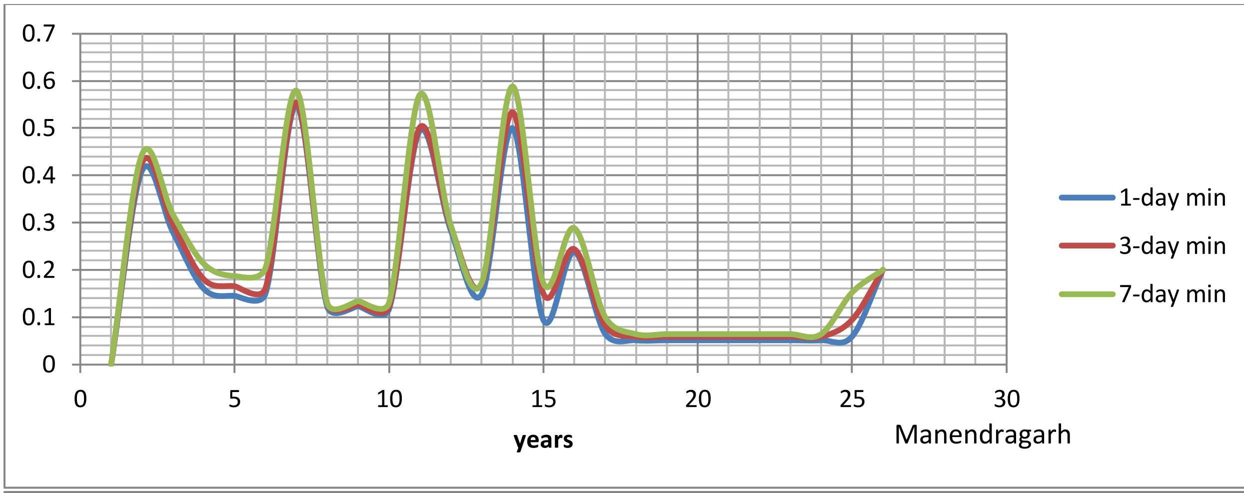

Discharge in m3/sec
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Kurubhata

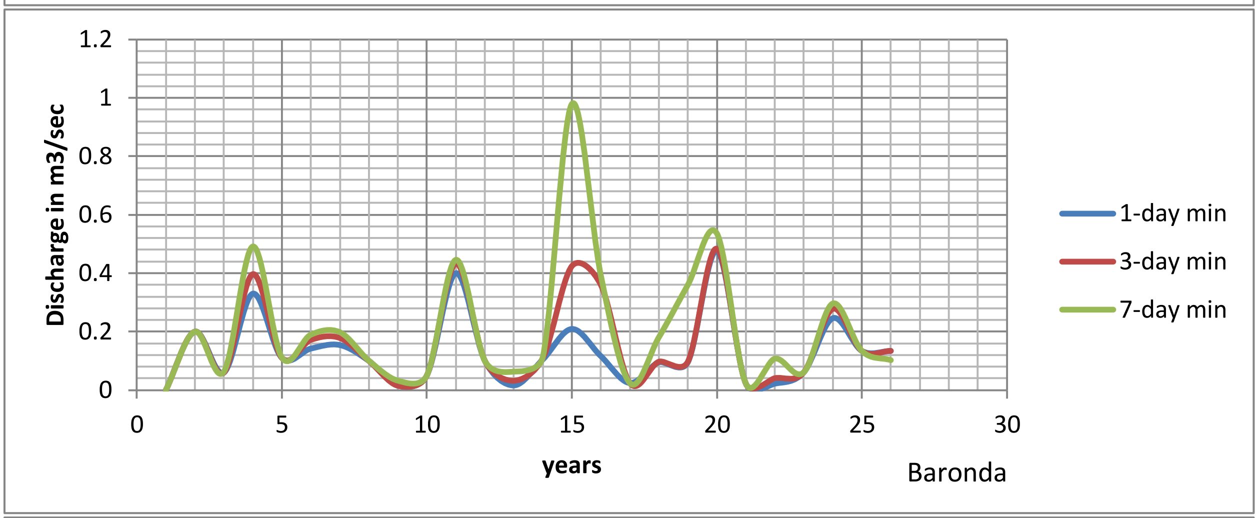

Discharge in m3/sec
0
0.5
1
1.5
2
2.5
3
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Sundergarh

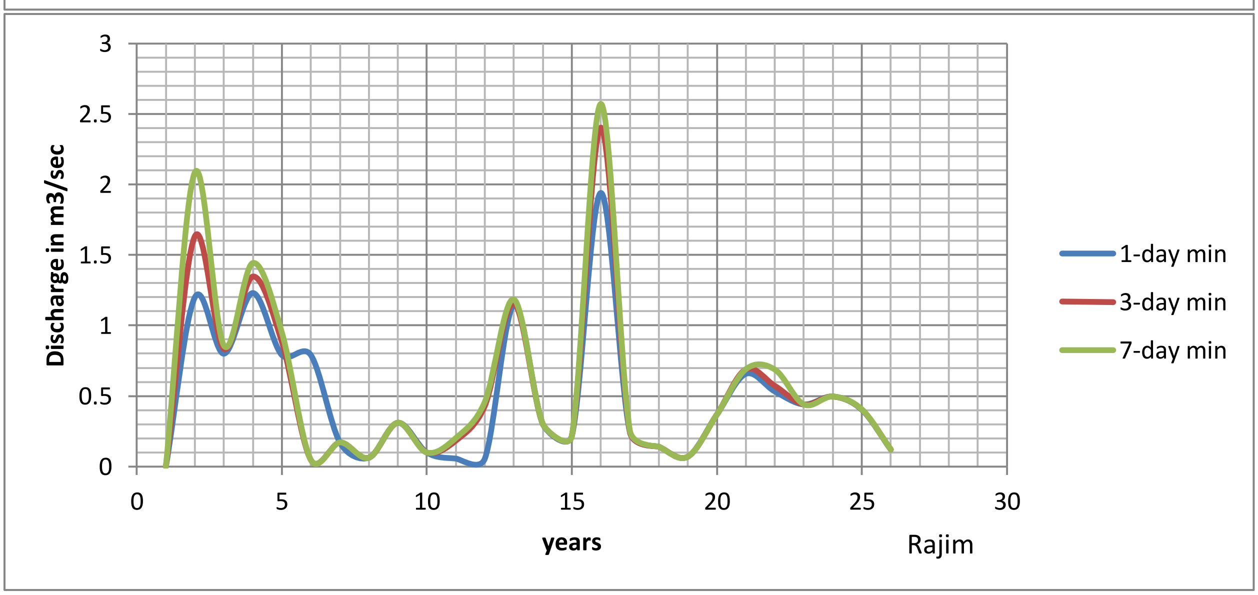

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Discharge in m3/sec
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Ghatora


1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Discharge in m3/sec
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Andhiyakore


1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Discharge in m3/sec
0
5
10
15
20
25
30
years
1-day min
3-day min
7-day min
Salebhata


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
years
Manendragarh
1-day min
3-day min
7-day min


Discharge in m3/sec
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
years
Baronda
1-day min
3-day min
7-day min


Discharge in m3/sec
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
years
Rajim
1-day min
3-day min
7-day min

The low flow duration indicates the drought period and shown in table no 10.

Table no 8: Low Flow Duration

Year	station	Low flow duration in julian days
1986	Rajim	61
1987	Rajim	61
1988	Rajim	98
1989	Basantpur	202
1990	Basantpur	91
1991	Manendragarh	120
1992	Kesinga	143
1993	Kesinga	184
1994	Kesinga	159
1995	Ghatora	96
1996	Manendragarh	90
1997	Sundargarh	122
1998	Kesinga	25
1999	Kurubhat	96
2000	Kurubhat	87
2001	Simga	101.5
2002	Salebhata	101.5
2003	Simga	177
2004	Andhiyarkore	61
2005	Kurubhat	100
2006	Manendragarh	160
2007	Manendragarh	212
2008	Simga	9.5
2009	Andhiyarkore	319.5
2010	Andhiyarkore	319.5

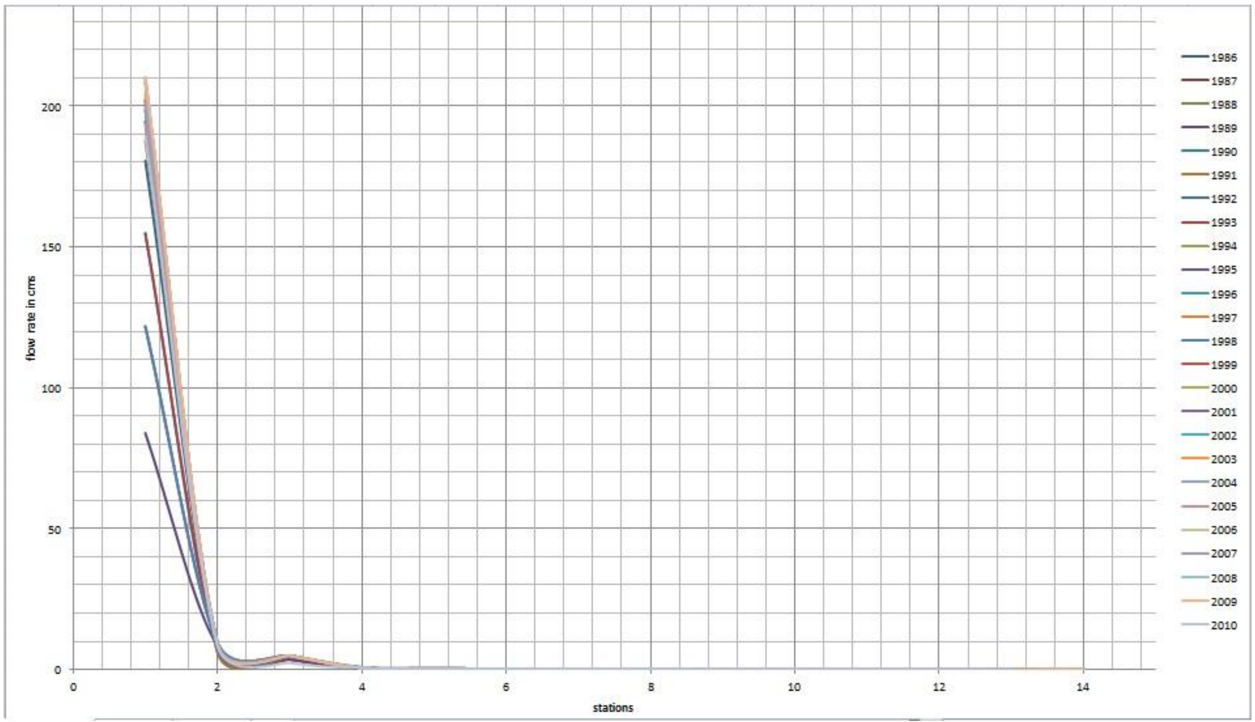


Fig 6: extreme low flow peak

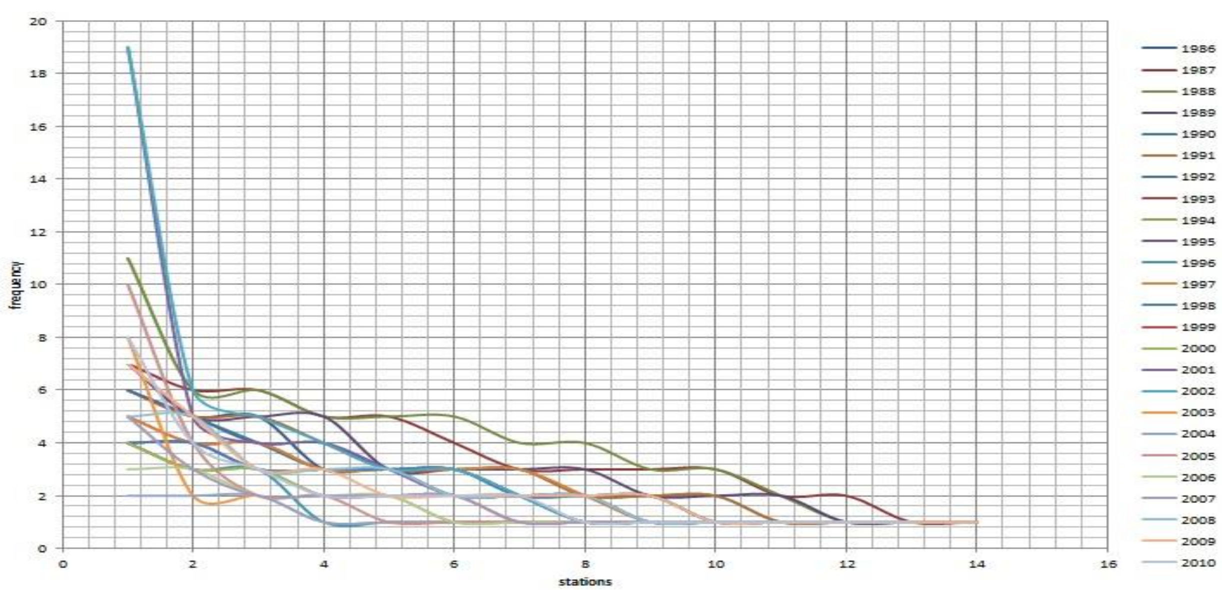


Fig 7: extreme low flow frequency

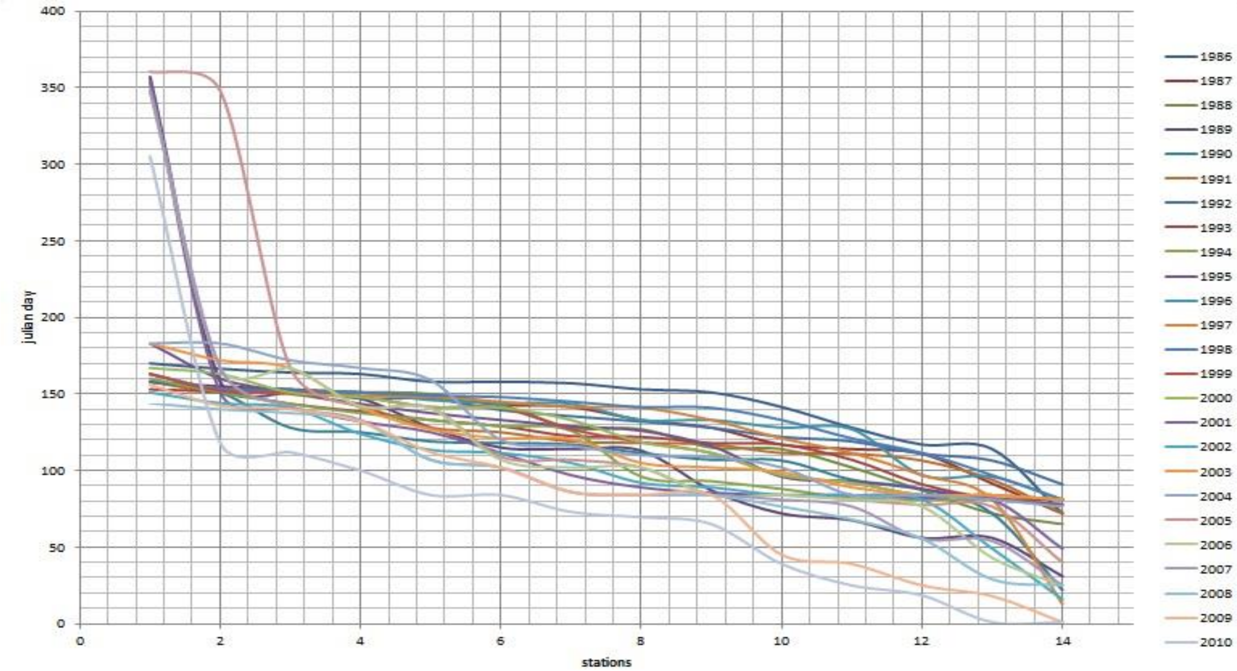


Fig 8: extreme low time

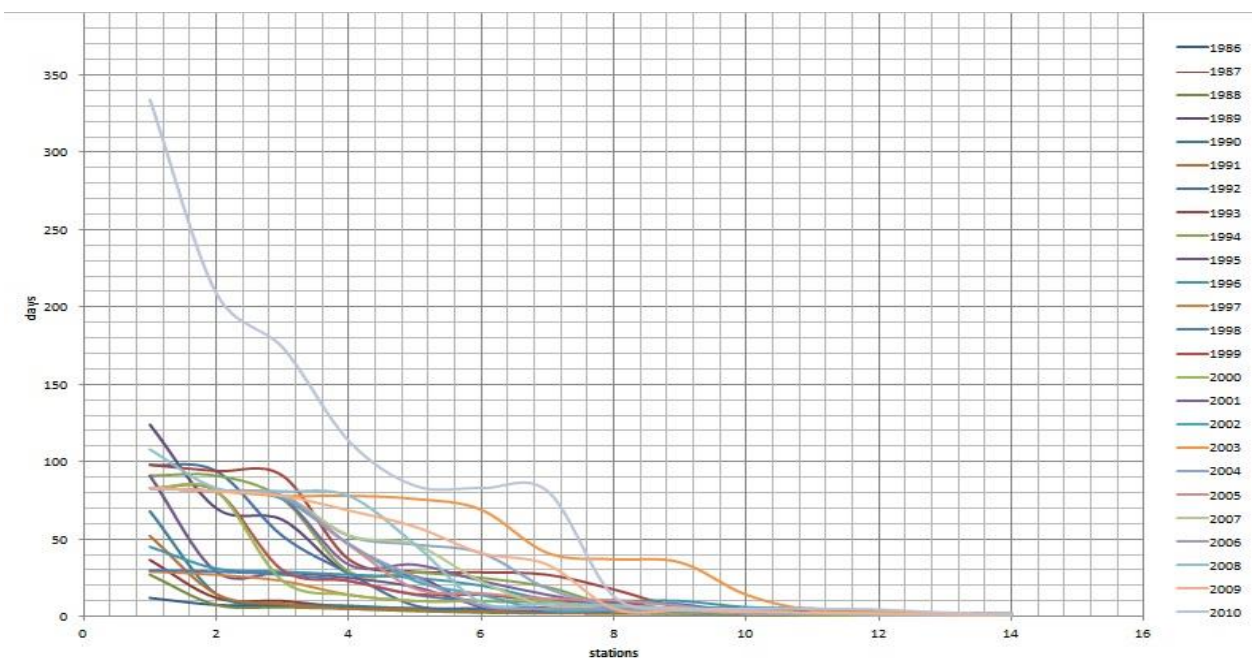


Fig 9: extreme low flow duration

Chapter-6
Conclusion

6. CONCLUSION:

In flow duration curve analysis the high zone is centered at the 5th percentile and the low zone is centered at the 95th percentile. In the low zone flow is due to base flow or snow melt but in the high zone peak flow is due to the rain. Flow duration curve analysis identifies intervals which can be used as a general indicator of hydrologic conditions (i.e., wet versus dry and severity).Duration curve is divided into 5 zones

- high flows (0-10%)
- moist conditions (10-40%)
- mid-range flows (40-60%)
- dry conditions (60-90%)
- low flows (90-100%)

Q90 and Q95 indicate 90% and 95% probability thath such discharge will be available in the river respectively..As Q90 and Q95 are known as low flow indices the values of Q90 and Q95 are 178.64 m^3/s and 126.596 m^3/s for Tikerpara station respectively. For Basantpur and Bamanidhi station the values of Q90 and Q95 are 21.808 m^3/s and 1.076 m^3/s respectively. For other stations Q90 and Q95 values remain same as 1.076 m^3/s. The value of Q90 and Q95 is higher at Tikerpara station because it is the lower stream of the Mahanadi River. The environmental flow at Andhiyakore 0.388 m3/s, Bamnidhi 23.19 m3/s, Baronda 0.213 m3/s, Basantpur 36.28 m3/s, Ghatora 0.04m3/s , Kantamal 14.72,m3/s, Kesinga 5.12 m3/s, Kurubhata 0.9 m3/s, Tikerpara 298m3/s, Manendragarh 0.43 m3/s, Rajim 0.99 m3/s, Salebhata 0.7 m3/s, Simga 1.5, Sundergarh 0.96 m3/s.

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