Temporal Variation of Inflow to the Dams of Rajasthan State with Special Reference to Ramgarh and Bisalpur Dams

This thesis is submitted as a partial fulfilment of the Ph.D. programme in Engineering

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CERTIFICATE

This is to certify that the thesis report entitled "Temporal Variation of Inflow to the Dams of Rajasthan State with Special Reference to Ramgarh and Bisalpur Dams" which is being submitted by **Naveen Kumar Gupta, ID No.: 2011RCE7135**, for the partial fulfillment of the degree of Doctor of Philosophy in Civil Engineering in the Malaviya National Institute of Technology, Jaipur has been carried out by him under my supervision and guidance.

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled '**Temporal Variation of Inflow to the Dams of Rajasthan State with Special Reference to Ramgarh and Bisalpur Dams'** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Civil Engineering, Malaviya National Institute of Technology Jaipur, is an authentic record of my own work carried out at Department of Civil Engineering during a period from December 27, 2011 to July 08, 2016 under the supervision of Dr. Ajay Singh Jethoo, Associate Professor of Civil Engineering Department, Malaviya National Institute of Technology Jaipur.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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Abstract

The study aims to investigate the temporal variation of inflow to the existing dams of Rajasthan State especially related to Ramgarh and Bisalpur dams. Inflows to these dams in Rajasthan have been decreasing in recent decades. Population in the state is regularly increasing. Because of droughts, overuse of surface and subsurface water resources, construction of small water harvesting structures and changes in land use and other anthropogenic impacts, water levels have decreased tremendously. The attribution of inflow variability to anthropogenic activities is a challenging problem and an active research area.

Rajasthan is a semi-arid state with the highest of the geographical area of the Indian subcontinent. Rainfall variation is very high over the state, ranging from 190 mm to 1000 mm from west to south/east. Average rainfall over the state is 575 mm against the national average of 1182 mm. Matters of water resources planning are of prime importance for the state. There are 243 blocks, out of which 172 blocks are overexploited. Only 25 blocks, i.e. only 10% blocks in the state may be considered safe for groundwater withdrawal. The average inflow to the surface water reservoirs is around 39% only. It has been observed from the storage data of the dams of the Rajasthan State that there are temporal variations in inflows. Reduced inflows to the dams are creating a water stress condition in the state. Detailed study of Ramgarh and Bisalpur dams has been taken in this research because these two dams are related to the drinking water supply need of the capital city Jaipur.

Methodology to conduct the study includes the formation of the null hypothesis to test the observed dependabilities and inflows of the existing dams of various river basins. Results of t-test and Chi-square test infer the rejection of the null hypothesis, i.e. dependabilities have been changed, and inflow to the dams is not as per their expected standards. Simulated inflows have been computed with the help of Thiessen polygon and Strange's table, as per the prevailing practices of Water Resources Department of Government of Rajasthan. Performance statistics and Nash-Sutcliff Efficiency results infer that the observed mean values are better indicators than the simulated values. The analysis of rainfall, simulated yield and observed inflow showed that the inflow pattern is decreasing even after a slightly increasing pattern of rainfall. Time series analysis and sequential cluster analysis have been done

to find out the critical year, which divides two consecutive non-overlapping epochs' namely, pre-disturbance and post-disturbance.

The study revealed that 1994-1998 were critical years. Correlation matrix has been made to assess the mutual correlation of the factors with each other. The work is extended to determine the main factors, which reduce the inflow to the existing dams. Results of correlation and regression analysis along with Cosine Amplitude Method (CAM) showed the significance of land use changes over the inflow. Land use has a significant correlation with population density. The same analysis has been conducted for Rajasthan state as a whole and Ramgarh and Bisalpur dams specifically.

The study has highlighted that in spite of an increasing trend in rainfall witnessed during the last 113 years, the inflow to the dams is decreasing at a fast pace owing to a decrease in the percentage area contributing to surface runoff. In these circumstances, it becomes pertinent to plan conjunctively the storage and uses of the surface as well as subsurface water in the state of Rajasthan along with maintaining the ecological sustainability.

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LIST OF ABBREVIATIONS

A	20-year data series
Ag.	Agriculture
ANN	Artificial Neural Network
ASMO	Area Sown More than Once
Avg.	Average
B	10-year data series
BCM	Billion Cubic Metre
CAM	Cosine Amplitude Method
Cum	Cubic Metre
df	Degree of Freedom
Dn	Dependability
DNA	Data Not Available
E.C.D.	Earthen Check Dam
Ei	Expected Weighted Dependability
ET	Evapotranspiration
EWR	Environmental Water Requirement
GIS	Geographical Information System
GoR	Government of Rajasthan
GPS	Global Positioning System
GWD	Groundwater Department
GWL	Groundwater Level
GWL BGL	Groundwater Level Below Ground Level
ha	Hectare
hrs	Hours
ICOLD	International Commission On Large Dams
IF	Influence Factor

IMD	Indian Meteorological Department
INRM	Integrated Natural Resources Management
IWRM	Integrated Water Resources Management
LULC	Land Use Land Cover
Max.	Maximum
MCFT/mcft	Million Cubic Feet
MCK	Million Cubic Kilometre
MCM	Million Cubic Metre
MEF	Minimum Environmental Flow
mh	Million Hectare
Min.	Minimum
MLR	Multiple Linear Regression
NA	Not Applicable
NPS	Non Point Source
NSE	Nash-Sutcliffe Efficiency
Oi	Observed Weighted Dependability
Q & Q	Quality and Quantity
Resi.	Residential
RGS	Rain Gauge Station
RH	Relative Humidity
Ri	Relative Influence
R-R	Rainfall-Runoff
RWH	Rain Water Harvesting
sqkm	Square Kilometre
Temp.	Temperature
TMC	Thousand Million Cubic Feet

U/S	Upstream
WHS	Water Harvesting Structure
WRD	Water Resources Department
WT and WTRTBL	Water Table
Wtd	Weighted
Yr.	Year

1 INTRODUCTION

1.1 General

1.2 Study Area

1.2.1 Rajasthan

1.2.2 Ramgarh Dam

1.2.3 Bisalpur Dam

1.3 Need of the Study

1.4 Objective of the Study

1.5 Organization of Thesis

CHAPTER-1

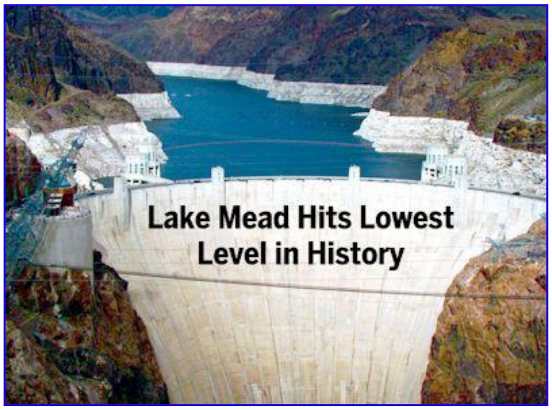
INTRODUCTION

1.1 General

The importance of water for life was well explained by Mikhail Gorbachev (2000) as cited by Draper (2008) as "Water, not unlike religion and ideology, has the power to move millions of people. Since the very birth of human civilization, people have moved to settle close to water. People move when there is too little of it; people move when there it too much of it. People move on it. People write and sing and dance and dream about it. People fight over it. And everybody, everywhere and every day, needs it. We need water for drinking, for cooking, for washing, for food, for industry, for energy, for transport, for rituals, for fun, for life. And it is not only we humans who need it; all life is dependent upon water for its very survival". Water stress or water scarcity is a burning problem being faced by the present world. It is a threat to mankind, but a bigger threat to the speechless creatures (Biodiversity i.e. animals and vegetations). The core issue is how scarce water is allocated to meet the various demands (Liu et al. 2005; Draper 2007a; Han et al. 2012). As per Human Development Report (UNDP 2006), as cited by Shah and Kumar (2008), against the average consumption of 580 l water per person per day in US and 500 l in the Australia, India gets 140 l only. Water demand is to be fulfilled keeping in view the water available and minimum d/s flow. All three factors are largely dependent upon precipitation, which is not under our control. Correct and dependable assessment of the inflow to the dams is the first and primary step in the field of water management.

"Dams are modern temples of India"- Pt. Jawahar Lal Nehru quoted this statement in 1952 and then a planned development of dams was taken up in India. Afterward because of various reasons, many of the temples i.e. dams are waiting for their Lords i.e. Water. Scientific research is required to answer the questions related to this issue. This phenomenon is being observed in many river basins in the world, and several researchers have studied this phenomenon (Liu et al. 2007; Wang et al. 2011; Hassanzadeh et al. 2012; Han et al. 2012). The effect of human activity on hydrology is becoming a point of focus in the world with the developing society (Sang et al. 2010). Runoff in major rivers in China has been decreasing in recent decades. The attribution to hydrologic variability to human activity is a challenging problem and an active research area. Human activity was the main driver behind 68% of the runoff reduction that occurred for the period of 1980 to 2008. A key aspect of anticipating and managing future variability is to understand its causes. Such information would support the sustainable use of water resources, but also inform efforts to maintain and restore natural ecosystem (Wang et al. 2011).

Temporal variations of inflow are being observed in many dams all over the world, creating a crucial condition for drinking as well as agricultural water supply besides the other demands of water (Fig. 1.1). Several field visits to the catchment areas of the dams including Ramgarh and Bisalpur dams have been made during the last couple of years. Drying up of wells and tube wells are showing lowering groundwater table. Huge anthropogenic changes in the land use like increased cultivation and ploughing up to the rock toe line, various form of encroachments and other infrastructural development, construction of field bunds/field dams/weirs/check dams, etc. within the catchment areas of the existing dams were observed. Drinking water supply of capital city Jaipur has been suffered very much. Earlier the Ramgarh dam was being used for drinking water supply to the city, but now it is completely dry even after a good rainfall. Now, Bisalpur dam is being used for drinking water supply to the city, but it is also facing the same situation of temporal variation of inflow. Therefore, it becomes essential to study the phenomenon of temporal variation of inflow to the dams in the state. The issue of water resources estimation and use has long been of particular scientific importance, but now it acquires extremely acute social and political character. This is due, on the one hand, to the increasing role of anthropogenic factors associated with water consumption by the population, industry, and agriculture and, on the other hand, to changes in global and regional climate (Shiklomanov et al. 2011). Piman and Babel (2012) explained the importance of reduction of uncertainty in hydrologic predictions for water resources development and management. The Ramgarh and Bisalpur dams are past and present drinking water sources for Jaipur city respectively, therefore, are ideal sites to evaluate the effects of changes in climate and human activities on the inflow to these dams.



(a) Hoover dam **(b) Bhakra dam**

(c) Ramgarh dam **(d) Bisalpur dam**

Fig. 1.1 Declining trend of inflow

The aim of this research study is to formulate and test the hypothesis for temporal variation of inflow to the dams of the state. Time scale data 1990-2013, 1983-2014, and 1979-2013 are used for inflow analysis of dams of Rajasthan state, Ramgarh dam, and Bisalpur dam respectively. Trends of rainfall, inflow, climatic factors, and land use factors are to be analyzed; correlated and most significant factor responsible for declining trend of inflow is to be determined. In the present study, an effort has been made to test the inflow trend and to assess the reasons for declining trend which may be attributed to some disturbances in rainfall pattern, catchment and climate characteristics. Sequential Cluster analysis has been done to get the critical year and to show the pre-disturbance and post-disturbance epochs. Correlation between water inflow and various factors has been developed in this study and found that declining trend of water inflow in Ramgarh and Bisalpur dams is attributed to various reasons like changes in land use land cover

(LULC), change in hydrogeological conditions, changes in climatic factors, and indiscriminate infrastructure development. Population in the state is regularly increasing. Ramgarh dam is situated near Jaipur city. Therefore, immigration of population in and around the city is very fast. The land area is limited, but the population is regularly increasing in and around the city. This situation is creating more and more value for every piece of land. Firstly, divisions of land are making the operational land holding per person very small and the secondly, the price hike is compelling every person to confine his or her share of the land by making any type of boundary demarcation. Due to the anthropogenic impacts and various types of human activities and infrastructure development works which are taking place regularly to give room to every person in the society, surface water availability is reducing. LULC is regularly changing at a very fast pace, increasing the surface roughness thereby regularly decreasing the surface flow to existing dams. Per capita water availability in the country is shown and compared in Fig.1.2.

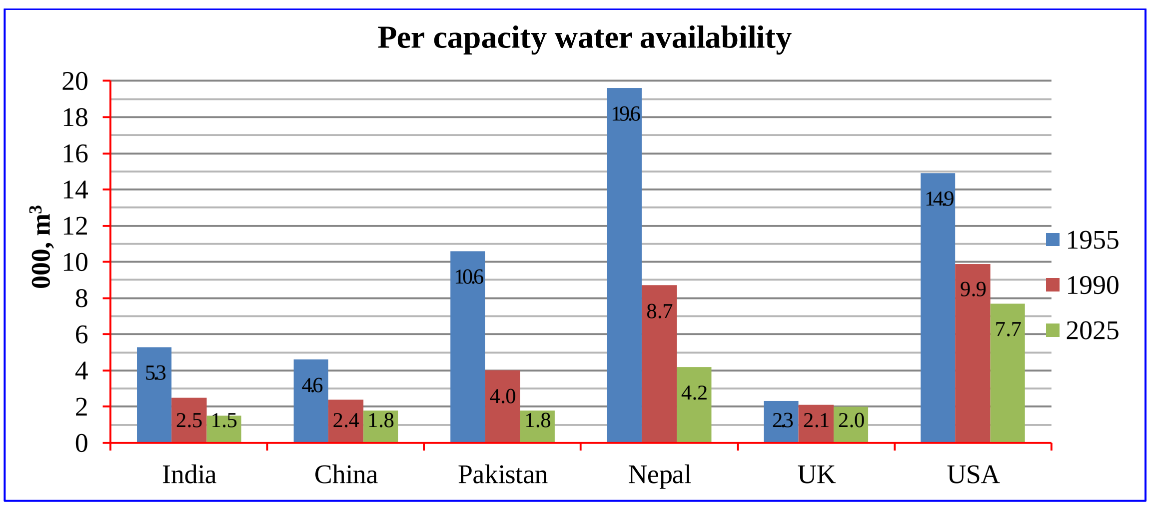


Fig. 1.2 Per capita water availability

The sample is selected through cluster sampling (Major and Medium dams in the state); hypotheses have been framed and tested by applying the Chi-Square test and found that there exist temporal variations of inflow to the dams of Rajasthan state. Detailed study of Ramgarh and Bisalpur dams has been undertaken in this research because these two dams are related to the drinking water supply need of the capital city Jaipur. Temporal variations of inflow to Ramgarh and Bisalpur dams are also tested and found that there exist declining trend of inflow to these dams. This is a descriptive type of research describing the phenomenon in nature incorporating inferential statistics. Both types of approach have been adopted to portray a complete picture of the problem.

1.2 Study Area

Study area comprises the Rajasthan state in general with special reference to Ramgarh and Bisalpur dams.

1.2.1 Rajasthan State

The study area comprises the western part of India, with a geographical area of 3,43,000 km^2, in a region of flat terrain that includes 15 different river basins, 33 districts, and Ramgarh and Bisalpur dams (Fig. 1.3).

State parameters in comparison to the country parameters are shown in Table 1.1. Western districts of the state are part of the Great Thar Desert. The study area always faces the problems of runoff variability. There are no major and medium dams in four river basins. Therefore, only 11 river basins are considered for testing the hypothesis.

Table 1.1 State parameters in comparison to the country

Parameter	Country (India)	State (Rajasthan)	Percentage (%)
Area (km^2)	3,287,300	343,000	10.40
Population 2011 (million)	1210	68.50	5.66
Live stock (million)	292	54.7	18.70
Cultivable area (km2)	1,843,700	257,000	13.90
Food production (MT)	211	13.82	6.50
Average rainfall (mm)	1182	575	48.65
Per capita water availability (Cum)	1760	740	42.05
Total precipitation (BCM)	4000	197	4.90
Water availability (BCM)	1869	21.71	1.16
Utilizable water availability (BCM)	1121	16.05	1.43
Surface water utilization (BCM)	690	12.55	1.82
Replenishable groundwater (BCM)	431	8.13	1.89
Over-exploited blocks as on 2009 (nos.)	802	166	20.70
Desert blocks	142	85	60

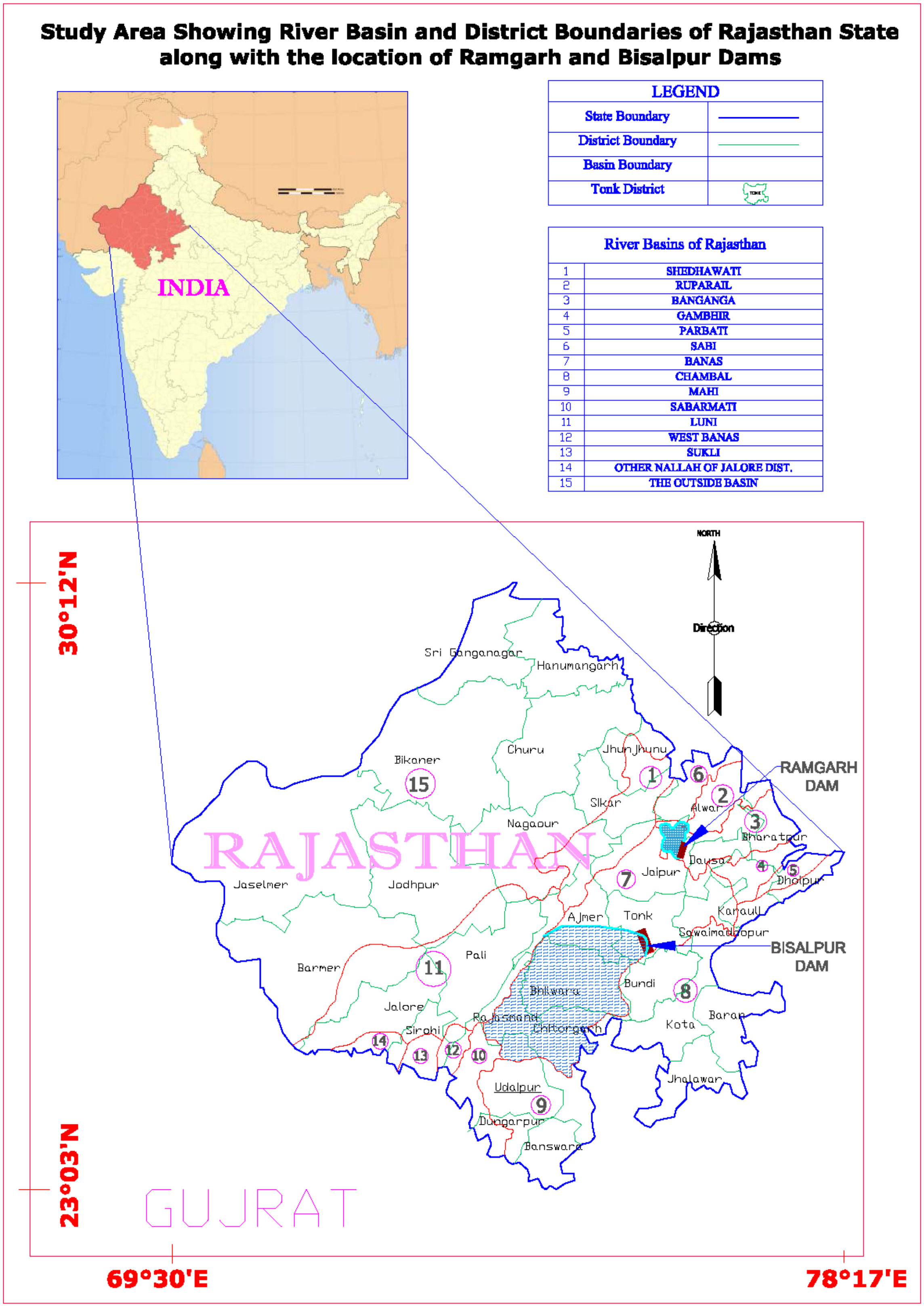


Fig 1.3 Study area

There are 3302 minor, medium and major dams in the state. Total 2609 dams having culturable command area up to 300 ha have been transferred to the 'Gram Panchayats' (Village Government). Remaining 693 dams are under the jurisdiction of Water Resources Department of Government of Rajasthan state (Table 1.2). There are 214 dams classified in Large Dams as per definition of International Commission on Large Dams (ICOLD). There are 22 major and 93 medium dams making a total of 115 major and medium dams in the state, which are used for drinking water supply schemes for various districts and towns of the Rajasthan state. Detail of 115 dams is given in Appendix-1.

Table 1.2 Details of basin wise dams in Rajasthan state

S.N.	Name of Basin	Dams transferred to villages governments			Dams under Water Resources Department			Total Dams		
		Nos.	Storage (MCM)	CCA (ha)	Nos.	Storage (MCM)	CCA (ha)	Nos.	Storage (MCM)	CCA (ha)
1	Shekhawati	47	30	5311	16	60	10917	63	90	16228
2	Ruparail	32	31	2229	22	71	32869	54	102	35097
3	Banganga	134	70	11854	62	342	55333	196	412	67187
4	Gambhir	75	46	8997	23	185	31591	98	232	40587
5	Parwati	9	7	794	8	151	30669	17	157	31463
6	Sabi	55	37	5252	12	71	14570	67	108	19821
7	Banas	1092	606	102367	222	3033	640289	1314	3640	742656
8	Chambal	135	112	18481	115	2795	1034932	250	2907	1053414
9	Mahi	190	133	19062	54	2594	222630	244	2727	241692
10	Sabarmati	39	101	4862	15	99	9117	54	200	13979
11	Luni	785	240	47947	119	897	162253	904	1137	210200
12	West Banas	4	2	456	15	77	14481	19	79	14937
13	Sukli	0	0	0	8	44	11194	8	44	11194
14	Other Nala	0	0	0	0	0	0	0	0	0
15	Out side	12	6	1085	2	3	818	14	9	1903
	Total	2609	1421	228697	693	10421	2271662	3302	11842	2500359

1.2.2 Ramgarh dam

Ramgarh dam was being used as the major source of water supply in Jaipur city, but due to some negligence and lack of proper management and maintenance, at present, the dam is dry. This problem needs intensive study and research into the area. Keeping this view in mind, the Ramgarh dam has been chosen as the study area.

It is an artificial dam created by constructing a dam across Banganga River. There are hills on both side of the dam and have good storage space. The dam is situated at 25

Km. in the northeast direction from Jaipur city. The River Banganga rises from the northeast part of the catchment area as a head-stream and flows down through southern and then eastern sinuous path towards its destination to meet the dam near Ramgarh. The Madhobini River accounts as another contributory to the Ramgarh dam, whereas the Gumti ka Nala and its tributaries are lying towards its south. Salient features of the Ramgarh dam are as shown in Table 1.3.

Table 1.3 Salient features of Ramgarh dam

S.N.	Particular	Detail
1	Catchment area (km^2)	832.00
2	Average monsoon precipitation (mm)	559.00
3	Gross storage capacity (MCM)	75.00
4	Live storage capacity (MCM)	74.30
5	Length of dam (m)	1143 m
6	Height of dam (m)	23.16 m
7	Maximum flood discharge (m^3/sec)	962.00
8	Culturable Command area (ha)	12125.00

1.2.3 Bisalpur Dam

Bisalpur dam is constructed in Banas basin. The catchment area of Banas basin is bounded by the Luni basin in the west, the Shekhawati, Banganga and Gambhir basins in the north, the Chambal basin in the east, and the Mahi and Sabarmati basins in the south. The basin extends over parts of Jaipur, Dausa, Ajmer, Tonk, Bundi, Sawai Madhopur, Udaipur, Rajsamand, Pali, Bhilwara and Chittorgarh districts. Geographically, the western part of the basin is marked by hilly terrain belonging to the Arawali chain. East of the hills lies an alluvial plain with a gentle eastward slope. The main tributaries of Banas are Berach and Menali on the right, and Kothari, Khari, Dai, Dheel, Sohadara, Morel and kalisil on the left. The Berach, Kothari, Khari are the rivers which flow through districts Bhilwara, Chittorgarh, and Ajmer. Salient features are shown in Table 1.4.

Table 1.4 Salient features of Bisalpur dam

S.N.	Particular	Detail
1	Catchment area (km^2)	27726.00
2	Average monsoon precipitation (mm)	588.00
3	Gross storage capacity (MCM)	1095.84
4	Live storage capacity (MCM)	1040.95
5	Length of dam (m)	574 m
6	Height of dam (m)	39.5 m
7	Maximum flood discharge (m^3/sec)	33800.00
8	Culturable Command area (ha)	81800.00

The water stored in the dam is used for drinking water supply in Ajmer & Jaipur districts (Table 1.5). The stored water is also used for irrigation of 81800 ha of agricultural land in 256 villages of Tonk district for which 226.63 MCM water has been allocated.

Table 1.5 Drinking water requirements from Bisalpur dam (MCM)

District	1991	2001	2011	2021
Ajmer	50.98	73.63	104.79	144.44
Jaipur	62.31	135.94	215.24	314.36
Total	113.28	209.57	320.02	458.79

Summary detail of the study area comprising Rajasthan state, Bisalpur dam, and Ramgarh dam are shown in Table 1.6.

Table 1.6 Summary detail of study area

Particular	Rajasthan state	Bisalpur dam	Ramgarh dam
Catchment area (Km^2)	343,000	27,726	832
Latitude	23^{0}03’00’’ to 30^{0}12’00” N	24^{0}15” to 26^{0}15’ N (Dam: 25^{0}55’20’’ N)	26^{0}55’40” to 27^{0}26’22” N (Dam: 27˚02’43” N)
Longitude	69^{0}30’00” to 78^{0}17’00” E	73^{0}25’ to 75^{0}30’E (Dam: 75^{0}27’30’’ E)	75^{0}40’05” to 76^{0}16’37” E (Dam: 76˚03’38” E)
River basin	15 River basins	Banas basin	Banganga basin

1.3 Need of the Study

The dams in the Rajasthan state are receiving less water than their theoretical yield/ designed capacity. The probable reasons are to be explored that have changed the hydrological characteristics of water inflow to the dams. The regular phenomenon of decreased water inflow to the dams has resulted in disruption of water resources planning of the state. Non-receipt of computed water results in failure of water management plan of the state. It leads to formation and execution of contingency plan on war footing every year. No scientific research has been undertaken to investigate these issues and to develop strategies, particularly in Rajasthan.

Due to less water inflow to the dams and an increase in the number of dark zone blocks, the state is facing the severe water stress problem. With the increasing population in the future, it will become more severe with the passage of time. Earlier Ramgarh dam, which is now completely dry, had been used as drinking water source of Jaipur city. Since the year 2000, the water level in the Ramgarh dam remains around zero level (Fig. 1c). Bisalpur dam is being used for the same purpose, but Fig. 1(d) is showing the alarming situation of this dam also. This has put water administrators, stakeholders, and decision makers in an extremely problematic situation because of its severity and length. Ramgarh and Bisalpur dams are related to the drinking water supply of capital city Jaipur; therefore, special attention to Ramgarh and Bisalpur dams is needed. It is necessary to manage decreasing water resources & increasing demand of water by maintaining the ecological sustainability (Saito *et al.* 2012; Andrew *et al.* 2011; Takayanagi *et al.* 2011). The author could not find any previous papers that studied scientifically the temporal variation of inflow, causes, effects, and management specifically for Rajasthan state.

1.4 Objectives of the Study

Presently, the Water Resources Department (WRD) uses Strange's Table for computations of theoretical yield and dependability analysis to assess the performance of existing dams. Temporal variation of inflow has not been tested and scientifically analyzed especially in Rajasthan. Moreover, the Ramgarh dam, a past source of the drinking water supply to Jaipur city, has completely dried up. Bisalpur dam, the present source of the drinking water supply is also facing the phenomenon of temporal variation of inflow. Groundwater sources have been extracted and gone to the level of the dark zone. Future of the city's drinking water supply is uncertain.

This thesis is aimed to test the hypotheses, whether there is an appreciable change in water inflow to the dams of Rajasthan state with special reference to Ramgarh and Bisalpur dams, determination of critical year which divides two consecutive non-overlapping epochs- pre-disturbance and post-disturbance, to test the applicability of prevailing method of inflow determination, and factors responsible for temporal variation of inflow.

Looking to the gap in the existing knowledge and a burning issue to be investigated, this research study has been carried out. The main objectives of this study are (i) to test the temporal variation of inflow to the dams (ii) to analyze and estimate changes in the inflow to the dams and various parameters affecting it (iii) to check the applicability of the prevailing method of computation of theoretical inflow (iv) to find out the critical year to bifurcate pre and post-disturbance period and to find out the principal factor responsible for temporal variation of inflow.

By getting the critical year and principal components responsible for temporal variation of inflow to the dams, results of this thesis will be useful to arrive at a preventive and curative measure for less water inflow to the dams and for maintaining the ecological sustainability.

1.5 Organization of Thesis

The thesis is documented in seven chapters. General introduction, study area, the need of the study, and objectives of the present study are given in chapter 1.

Chapter 2 presents a comprehensive review of the literature, contains the various research work undertaken in India and other parts of the world.

Chapter 3 consists material and methods, includes the data collection part and method adopted for analysis.

Chapter 4 deals with the analysis, results, and discussion for the dams of Rajasthan state. This chapter covers the data analysis adopting the methods discussed in chapter 3 along with their results and discussion.

Chapter 5 deals with the analysis, results, and discussion for Ramgarh dam. This chapter covers the data analysis adopting the methods discussed in chapter 3 along with their results and discussion.

Chapter 6 deals with the analysis, results, and discussion for Bisalpur dam. This chapter covers the data analysis adopting the methods discussed in chapter 3 along with their results and discussion.

Chapter 7 presents the conclusions, highlights the significant conclusions derived by the results and discussions.

These are followed by a list of references which are mentioned in this thesis and appendices of some important tabulated data.

2 LITERATURE REVIEW

2.1 Introduction

2.2 Data Period and Data Collection

2.3 Runoff and Inflow Variability to the Dams

2.4 Rainfall Variability and Trends

2.5 Climatic Factors and Climate Changes

2.6 Human Interventions and LULC changes

2.7 Ground Water Recharge/Depletion

2.8 Population Growth and Economic Expansion

2.9 Critical Year and Sensitive Analysis

2.10 Environmental Flow and Ecological Sustainability

2.11 Water Resources Planning and Management

- 2.11.1 Conjunctive Use of Surface and Subsurface Water
- 2.11.2 River Basin Management
- 2.11.3 Small WHS and Large Dams
- 2.11.4 Micro Watershed Planning
- 2.11.5 IWRM and INRM
- 2.11.6 Transboundary Water Transfer and Water Sharing
- 2.11.7 Water Pricing, Water Market, Water Trading, and Water Privatization
- 2.11.8 Rain Water Harvesting

2.11.9 Reuse and Recycle of Waste Water

2.11.10 Water Balance

2.11.11 Water Use Efficiency

2.12 Summary

CHAPTER-2
LITERATURE REVIEW

2.1 Introduction

Water is central to the survival of life itself, and without it plant and animal life would be impossible. Water is a central component of Earth's system, providing important controls on the world's weather and climate. Water is also central to our economic well-being, supporting rain-fed and irrigated agriculture, forestry, navigation, waste processing, and hydroelectricity. Recreation and tourism are other primary uses supported by water (Draper 2007). United Nation estimates as cited by Central Water Commission (CWC 2000), the total amount of water on earth is about 1400 million cubic kilometers (MCK) which is enough to cover the earth with a layer of 3 km depth. Fresh water constitutes only 2.7 percent of this enormous quantity, i.e. 37.5 MCK. About 75.2 percent of this available fresh water, i.e. 28.43 MCK lies frozen in Polar Regions, and another 22.6 percent, i.e. 8.54 MCK is present as deep groundwater. The rest, 2.2 percent of available freshwater or 0.06 percent of total available water, i.e. 0.83 MCK is in lakes, rivers, the atmosphere, moisture, soil and vegetation of which small proportion i.e. 0.0487 MCK (48700 BCM) is effectively available for consumption and other uses.

Average annual precipitation in India is 1182 mm which estimates about 4000 BCM precipitation over the country. The geographical area of the country is 3,287,300 km^2. Average annual natural runoff in the rivers is 1869 BCM. Due to various constraints of topography, uneven distribution of resources over space and time, it has been estimated that only 1122 BCM can put to beneficial use. India is a second highest populated country in the world, i.e. about 16.5 percent of world population (1.21 billion out of 7.35 billion of the world population) resides in the country while utilizable water availability is only 2.3 percent.

Average annual precipitation of Rajasthan State is only 575 mm against the national average of 1182 mm, i.e. less than half of the national average. As reported by Majaya and Srinivasa (2014), Kerala receives an average rainfall of 3600 mm with summer rains constitute about 10%. Spatial distribution of this rainfall is highly uneven ranging 190 mm in Jaisalmer district (Western Rajasthan) to more than 1000 mm in

Jhalawar district (Southern Rajasthan). The geographical area of the state is 343,000 km^2, which is 10.4% of the country's geographical area. The population of the state is 68.6 million, which is 5.67% of the country's population. Livestock in the state is 60 million, which is 20.5% of the country's livestock (292 million). After having this large proportion of geographical area, population, and livestock the state is having only 16.05 BCM i.e. 1.43% of country's utilizable surface water resource. The crisis about water resources development and management thus arises in Rajasthan firstly because of the disproportionate availability of utilizable water and secondly it is characterized by its highly uneven spatial distribution. Accordingly, the importance of water has been recognized in the state, and greater emphasis is being laid on its economic use and better management.

Changes in water level of the dams and reservoirs have been observed in different parts of the world. Although the water in the dams, lakes and reservoirs represents a relatively small percentage of total available water on earth, dams are used as a reliable source of drinking water supply. Water availability in the dams is also an important source of agricultural water need, power generation, and recreation. Changes in the water levels are because of temporal variation of inflow to the existing dams. These changes mainly reflect changes in rainfall, evapotranspiration (ET), infiltration, runoff and human activities over the catchment area. Tiercelin et al. (1988) as cited by Yildirim et al. (2011) observed that these fluctuations constitute a sensitive indicator of past and present climate and human activity changes at a local and regional scale.

Many investigations in different parts of the world (De et al. 2001, Yan et al. 2002; Penny and Kealhofer 2005; Legesse and Ayenew 2006; Kiage et al. 2007; and Kravtsova et al. 2009 as cited by Yildirim et al. 2011) have noted shrinkage of lakes due to anthropogenic activities such as land cover and land use changes, deforestation, rising water demands for agriculture and livestock, urbanization, water abstractions upstream of the lakes, dam construction and irrigation. However, further drying of dry areas in Asia is very likely (Kravtsova et al. 2009). Han et al. (2012) revealed the fact that today, 1.4 billion people live in river basins where water utilization exceeds sustainability thresholds; of this 4 % live in China. More than 70% of the waters in these basins (Hai, Huai, and Yellow river basins of China) are polluted, runoff decreased 60%, and groundwater withdrawal is 150% of the sustainability threshold. In some cases, changes in climatic fluctuations, especially precipitation, are believed to be the major causes of lake shrinkages (Birkett 1995; 2000; Moln'ar et al. 2002; Mercier et al. 2002; Mendoza et al. 2006; Medina et al. 2008 as cited by Yildirim et al. 2011). The hydrological-environmental changes that took place in the recent decades in the Indus Delta can serve as an example of the catastrophic consequences that can be expected to take place in the deltas of world rivers with anthropogenic drop in water and sediment runoff, especially under the conditions of extremely dry climate and progressive global warming accompanied by sea level rise and increasing sea waves. In recent years, the population suffered from freshwater deficiency. Part of the population had to leave the sites of their former residence (Kravtsova et al. 2009). Analysis of temporal variations of inflow to the dams is an important task that has applications in different fields of water resources planning and management.

Various recent studies, literature, newspapers (Rajasthan Patrika, Dainik Bhaskar), water experts and even Rajasthan High Court are continuously reporting about the great concern of less water inflow in the dams, lakes and reservoirs in the state. All land as drainage channels like streams, rivers, tributaries, etc. as of 15.08.1947 should be declared as Government land. Any conversions made after 15.08.1947 should be declared illegal. The relevant rules and act must be amended accordingly (Decision Rajasthan High Court 2004). The major concern was put forward by the expert committee constituted by the Court towards restricting the encroachment in the drainage channels and catchment area of the existing dams in the state. A scientific study is essential to be conducted about the problem cited above.

2.2 Data Period and Data Collection

Accurate and reliable data and information of source water supplies are key requirements in effective water planning and management (Draper and Kundell 2007). Fulp and Frevert (1998) and Davidson et al. (2002) as cited by Frevert et al. (2006) explained the data-centered approach allows for a variety of data sets to be used. The required datasets are rarely available, even in the highly instrumented watersheds (Pundik 2014). The most commonly used is the Hydrologic Data Base (HDB), HDB is a relational database designed for the storage of hydrologic time series data, attribute data, statistical information, and other data related to water resources management activities. HDB is capable of maintaining over 100 types of data, including, for example, stream flow, reservoir content and releases, water demands, temperature, snow water equivalent, precipitation, evaporation, power generation, and total dissolved solids. In so doing, it provides a reliable and consistent view of the past, present, and the future state of the river system. Only a few quantitative analyses have been performed due to lack of information (data), have been mentioned in the respective research article (Kim et al. 2012). Information technologies provide significant support in the management of lakes and reservoirs. The aim of the data analysis is to determine still unknown relations (dependence) between entity attributes, their mutual characteristics, and prediction of future behaviour. Data analysis enables making conclusions and conducting appropriate measures within managing lakes and reservoirs according to proposed objectives. Information System (IS) provides all forms of management and sustainable exploitation of water resources in whole and enables the transfer of information and knowledge as well as the creation of a network of researchers. It is a necessary step towards improving the current situation in the management of lakes and reservoirs (Stefanovic et al. 2012).

The question of reliability of past hydrologic records may be a significant problem. Even what appear to be long-duration records (say 50 or 100 years) may not be representative of the cycles of hydrologic variation. Man-made changes in flow conditions (from storage, diversions, and changes to impervious surfaces) may skew the reliability of historical data (Guo 2006 as cited by Dourte et al. 2012, Draper 2007a). A case study of Chicago urban drainage systems showed that drainage system using updated IDF relationships, using shorter records of more recent data, performed significantly better than those developed from older rainfall records (Dourte et al. 2012). Karamouz et al. (2010) used 23 years length of historical data as a planning horizon of the model. The task of data collection is difficult, time-consuming and can be impossible for a huge region when using traditional ground survey techniques. Remotely sensed data acquired by operational satellites are more and more widely used for the identification, monitoring, and delineation of lake mapping at regional or global scales (Yildirim et al. 2011). The government conducts regular ground survey for day to day activity and events happening within the state. Directorate of Economics and Statistics (DES) publishes various forms of data and information every year for the state and every district within the state. The government of India through its various departments, e.g. Indian Meteorological Department (IMD), Planning Department, Agriculture Department, and Forest Department, etc. also publishes various forms of information and data. Frevert et al. (2006) suggest that it takes the full 3 to 4 year time frame to conduct the new research and development, demonstrate the applicability, and deploy the system. Hassanzadeh et al. (2012) used 40 years data set for system dynamic modeling. Section 4.2 of IS 5477 (Part-3): 2002 recommends stream flow data at the site of interest or for upstream, downstream or nearby station for 25 to 40 year period. In the present study, around 25-35 years of data has been used for input-output analysis. Some of the data available are irregular, which has been filled up by interpolation technique. State Water Resources Department measures daily rainfall; therefore, hourly rainfall data is not available.

2.3 Runoff and Inflow Variability to the Dams

Surface runoff and inflow assessment to the dams is important for study of hydrological behavior of any reservoir. Runoff variability and changes in water inflow to the dams have been observed by many researchers all over the world. At many places catchments are found ungauged. At many places hydrological models have been developed for runoff computations. Performance statistics have also been applied at many places.

River runoff in Africa has reportedly declined by about one-third in the last ten years (Draper 2007a). In a recent study by Selyutin et al. (2007) explained that hypertrophic withdrawal and consumptive use of surface waters, results in a decline in the volume and qualitative characteristics of freshwater runoff, and wide occurrence of soil erosion. A commonly used ranking describes three levels of severity (i.e. Can be named pre-alarm, alarm, and emergency). Ground water resources play a vital role in meeting water demands, not only as regards quality and quantity, but also in space and time, and are of vital importance for alleviating the effects of droughts. Ground water reserves have been and continue to be the largest buffer in water scarcity situations, but a large range of negative effects has been documented for its overuse (Iglesias et al. 2007, Sang et al. 2010). As reported by Shah and Kumar (2008), many dams in India do not get sufficient storage, due to inadequate inflows from their catchments. Reliable data on Indus sediment runoff are practically impossible to obtain (Kravtsova et al. 2009). Annual discharge records on the Akarçay River and its tributaries decreased over the basin during the same period. Irrigation systems, three dams and seven pounds built in recent decades for agricultural irrigation and domestic use, made the major impact on lowering the lake levels because they derive water from the river for human use upstream of the lake catchments. Human activities related to water resources management under dry farming conditions sometimes lead to a considerable decrease in river water runoff; therefore, dry farming is included into the group of water consumers. Intensive agricultural practices, the organization of field protective forest strips, special technical methods meant to retain moisture in the soil (deep fall ploughing, high stubble left after harvesting, snow detention, and contour ploughing) result in an increase in soil moisture capacity, and crop yields and, thus in a decrease in surface flow discharge into water receivers (Denim 2010). According to an assessment of N.I. Koronkevich as cited in Denim A.P. (2010), under the impact of agrotechnical methods and agricultural afforestation "the river water runoff decrease in the entire Russian plain was less than five km^3/year, including the Volga river water runoff decrease equaling two km^3/year.

In China, with the development of the economy, increasing population and improved standard of living, the industrial and living water use is increasing, which is affecting the runoff (Sang et al. 2010). Russia is also observing inflow changes at global warming in the 21st century (Lemeshko 2011). Sun et al. (2012) reported that the water level of Three Gorges Dam (TGD) decreased 2.03 m in 2006 and 2.11 m in 2009 at the outlet of the lake, with an extreme decrease up to 3.30 m and 3.02 m, respectively. For an ungauged basin to be similar to a gauged basin, it is not sufficient to have basin characteristics only. Soil type, land use, as well as climatic conditions are equally essential to be similar (Piman and Babel 2012). Zhao and Xu (2013) state that biocrusts play an important role in soil erosion control from water erosion in semiarid regions, although there was a potential increase in runoff yield. The percentage coverage of biocrusts may be 70% in such regions, which play several critical roles in arid and semiarid ecosystems, such as increasing soil fertility, inhibiting or promoting surface water infiltration, influencing soil moisture evaporation, and improving soil properties, e.g. fertility, texture, and so on. There is less certainty on how the presence of biocrust actually influences the water infiltration and runoff relationships. A major part of the state and its river are ungauged and therefore very less, and irregular data are available for river discharges over different time and space. According to Parmar et al. (2014), runoff information is needed for a multitude of purposes such as water resources management, assessment of hydropower potential, the design of spillways, culverts, dams, and levees, for reservoir management, water quality issues, etc. Most of the river basins are ungauged and predicting runoff in these catchments need to adopt an alternative approach. Surface runoff has been computed with the help of inflow data of the existing dams. Predicting hydrologic quantities (rainfall, runoff, sediment, nutrients, etc.) is a major challenge for hydrologists and water resources managers since hydrological observations are either absent, insufficient or of questionable quality and reliability (Chunale et al. 2014a). Estimation of peak flow and the total volume of water becomes a difficult task for the ungauged catchment (Nayak 2014). The relationship between rainfall and runoff is uncertain. There are two types of relationships, i.e. linear and non-linear. The linear relationship between rainfall and runoff is found for small catchments while the non-linear relationship for large catchments. The non-linear relationship may be in power, logarithmic or exponential form (Parmar et al. 2014).

Runoff computation is one of the most requirements in hydrology. The rational method $\left(Q_{peak} = K \times C \times I \times A\right)$ is one of the simplest and well-known methods of hydrology. It computes peak discharge for a drainage area based on rainfall intensity and hydrograph shape. Williams et al. (2008) evaluated hydrological response from watersheds influenced by various agricultural land management practices using a daily time step hydrology model based on the temple water yield model with evapotranspiration (ET) and percolation components added. Dune (1978) as cited by Alfa et al. (2011) proposed saturated excess overland flow (SOF). If rainfall intensity exceeds infiltration capacity of the soil, rain will accumulate on the surface depending upon the surface roughness, the gradient of the land surface and the available depression storage, Hortonian Overland Flow (HOF) may occur, which is also termed as infiltration excess overland flow (IOF). Different catchments respond differently to rainfall in terms of the hydrological processes on the land surface. The nature of the overlying soil and the type of bedrock determine the amount of runoff that will be generated and the path it will follow to reach a stream channel (Alfa et al. 2011). Wang et al. (2011) describe the VIC model (Variable Infiltration Capacity) that is used to simulate the physical exchange processes of water and energy in the soil, vegetation and atmosphere in a surface vegetation atmospheric transfer scheme. Three types of evaporation are considered: evaporation from the wet canopy, evapotranspiration from the dry canopy, and evaporation from bare soil. The total runoff estimates consist of surface flow and base flow. Soil column is divided into three layers. Surface flow, including infiltration excess flow and saturation excess flow, is generated in the top two layers only (Wang et al. 2011). Chang et al. (2011) used System Dynamics model, which is a computer-aided approach to evaluating the interrelationships of components and activities within complex systems Hydrological model component is applied in SWAT using the Thiessen weighting technique (Kim et al. 2012). The SCS-CN is also an empirical, event-based rainfall-runoff model. The dimensionless curve number (CN) takes into account, in a lumped way, the effect of land use/cover, soil type, and hydrologic conditions on surface runoff and relates direct surface runoff with rainfall (Migliaccio and Srivastava 2007, Chunale 2014a, Nayak 2014). However, using software like Watershed Modeling System (WMS) requires both knowledge and experience on watersheds and physical hydrology, as well as computer skills (Erturk et al. 2014). Mortin et al. (2006) as cited by Laxminarayana et al. (2014) found that complex interactions exist between the spatiotemporal distributions of rainfall systems and hydrological responses in a watershed. Artificial Neural Network (ANN) and other soft computing techniques are inherently suited to the problems that are mathematically difficult to describe. Due to acceptable performance in R-R modeling, ANN remains a topic of continuing interest. Radial Basic Function (RBF) ANN has mostly used a type of ANN in hydrological modeling. Levenberg-Marquardt (L-M) algorithm is much more robust and outperformed other algorithms. Most commonly used transfer functions are sigmoidal type in hidden layers and linear type in output layer due to its advantage in extrapolation beyond the range of the training data. Early stopping approach (split sampling method) & so called batch training approach, i.e. the whole training data set is presented once, after which the weights and biases are updated according to the average error, was used (Pundik et al.

2014). Hydrological modeling for inflow using Water Evaluation and Planning System (WEAP), ET Toolbox, River ware, Stochastic Analysis Modeling and Simulation (SAMS), System Dynamic and Impact Analysis, Sensitivity Analysis, Storm Water Management Model (SWMM), Multivariate Statistical Methods (MSM), Soil and Water Assessment Tool (SWAT/modified SWAT), General Circulation Model (GCM), SCS-CN methods, TOPMODEL (a type of saturation excess runoff prediction model), MODFLOW, HEC-HMS, Implicit Stochastic Optimization(ISO), Water Resources Yield Model (WRYM) etc. techniques can be undertaken. These techniques have been used by many researchers (Frevert et al. 2006; Migliaccio and Srivastava 2007;, Jain et al. 2008; Wang et al. 2008; Yates et al. 2009; Karamouz et al. 2010; Mantel et al. 2010; Sang et al. 2010; Carrasco et al. 2011; Chang et al. 2011; Hen et al. 2011; Wang et al. 2011; Bobba A. G. 2012; Hassenzadeh et al. 2012; Kim et al. 2012; Lany et al. 2012; Piman and Babel 2012; Chunale et al. 2014a; Chunale 2014b; Nayak 2014; Sadeghi et al. 2014). For limited availability of regional data, conceptual or empirical methods like Strange's Table were also suggested (Water Resources Department 2002; Reddy n.d.; Sharma and Sharma n.d.; Punmia n.d.; Satyanarayana murty 2006; State Water Resources Planning Department 2011; Subramanya 2013). Due to limited availability of regional data, the Strange's table method of computation of theoretical inflow has been adopted in this thesis and applicability of this method has also been tested using various statistical parameters.

T-test, Chi Square test and some other statistical test are applied to test the hypothesis whether the existing dams are getting the designed water or not. Six different statistical parameters were employed in judging the performance of the simulation model. Several researchers have used many of the following statistical parameters for judging the performance of simulation model: Sum of Square Error (SSE), Relative Error (RE), Percent Error, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Nash-Sutcliff Efficiency (NSE), Coefficient of Correlation (R), root mean square error of the observation's standard deviation ratio (RSR), Normalized Mean Bias Error (NMBE), Percentage of Peak flow Error (PPE), and Percentage of runoff Volume Error (PVE) (Hayashi et al. 2008; Wang et al. 2011;

Hassanzadeh et al. 2012; Piman and Babel 2012; Kumar et al. 2014; Chunale 2014a; Chandwani et al. 2015).

A positive NMBE indicates over-prediction, and a negative NMBE indicates under-prediction of the model (Srinivasulu and Jain 2006). The coefficient of efficiency (E) or Nash-Sutcliffe efficiency (Nash and Sutcliffe 1970) is a ratio of residual error variance of measured variance in observed data. A value close to unity indicates the accuracy of the model. RSR statistics was formulated by Moriasi et al. (2007). RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor so that the resulting statistic and reported values can apply to various constituents (Chen et al. 2012). The optimal value of RSR is zero. Hence, a lower value of RSR indicates good prediction. RMSE statistic compares the observed values to the predicted values and computes the square root of the average residual error. A lower value of RMSE indicates good prediction performance of the model. But RMSE gives more weight to large errors (Kisi et al. 2013). MAPE is a dimensionless statistic that provides an effective way of comparing the residual error for each data point on the observed or target value. Smaller values of MAPE indicate better performance of the model and vice versa. Pearson's correlation coefficient (R) and coefficient of determination (R^2) measure the strength of association between the two variables. R and R^2 statistics are dependent on the linear relationships between the observed, and predicted values may sometimes give biased results when this relationship is not linear or when the values contain many outliers. In perfect association between the observed and predicted values, the value of R^2 is unity. The t-test can be conducted to test the hypothesis (H_0: r=0). NMBE measures the ability of the model to predict a value which is situated away from the mean value. A combined use of the performance metrics narrated above can provide an unbiased estimate for prediction ability of any simulation model (Chandwani et al. 2015).

2.4 Rainfall Variability and Trends

Accurate and current rainfall characterization is an important tool for water-related system design and management. To study the hydrology of any catchment area or any basin, it is the first requirement to get an idea about the existing rain gauges in and around the catchment. Rainfall data of the stations are collected from authentic sources for further analysis and various related computations. General terminology used by Indian

Meteorological Department (IMD) in weather bulletins is mentioned in Table 2.1 & Table 2.2.

Table 2.1 Classification of intensity of rainfall

S.N.	Rainfall	Period	Type of rain
1	00.1 mm to 02.4 mm	In 24 hrs.	Very Light Rain
2	02.5 mm to 07.5 mm	In 24 hrs.	Light Rain
3	07.6 mm to 34.9 mm	In 24 hrs.	Moderate Rain
4	35.0 mm to 64.9 mm	In 24 hrs.	Rather Heavy Rain
5	65.0 mm to 124.9 mm	In 24 hrs.	Heavy Rain
6	Exceeding 125 mm	In 24 hrs.	Very Heavy Rain

Table 2.2 Spatial distribution of weather phenomenon (percentage area covered)

S.N.	Percentage	Terminology used
1	01 to 25	Isolated
2	26 to 50	Scattered
3	51 to 75	Fairly Wide Spread
4	76 to 100	Wide Spread

Dourte et al. (2012) classifies high-intensity events if daily rainfall ≥ 50 mm/day and low to moderate in case of 5-50 mm/day. Precipitation over the state is very scanty and non-uniform over time and space. Annual rainfall varies from 190 mm in the west to 1000 mm in the south/east. As cited by Iglesias et al. (2007), climate change projections for the Mediterranean region derived from global climate model driven by socio-economic scenarios result in an increase of temperature (1.5 to 3.6^{0}C in the 2050s) and precipitation decreases in most of the territory (about 10 to 20% decreases, depending on the season in the 2050s). Climate change projections also indicate an increased likelihood of droughts and variability of precipitation – in time, space, and intensity – that would directly influence water resources availability.

Daily precipitation data of 48 years were analyzed by Erturk et al. (2014) to obtain average annual rainfall, average monthly rainfall, and average daily rainfall for integrated management of a watershed in Turkey. Daily precipitation data are available in Rajasthan state also, and the same have been used in this study. However, some other researchers like Dourte et al. (2012) developed IDF curves for return periods of 2, 5, 10, 15, 20, 50, 75, and 100 years for 1, 2, 4, 8, and 24-hour duration. Thiessen polygon technique can be used to compute the weighted rainfall (Jain et al. 2008, Piman and Babel 2012); the same has been used in this study. In the present study IDF curves could not be prepared because of non-availability of hourly precipitation record in WRD. Piman and Babel (2012) emphasizes that a number of rain gauges for rainfall estimates affects the magnitude of rainfall estimates significantly and, subsequently has a considerable effect on calibrated model parameters. The linear relationship is the most common method used for detecting rainfall trends. Besides Man Kendall test can be used to assess the significant trends in hydrological and climatological data sets (Laxminarayana et al. 2014).

2.5 Climatic Factors and Climate Changes

The intergovernmental panel on climate change (IPCC 2007) as cited by Draper and Kundell (2007) published a report substantiating the argument that global warming is occurring. The IPCC reported that while sustainable water yields may or may not be reduced in long-term average, they will almost certainly be less reliable in the short term. The climate change challenges existing water resource management practices by adding uncertainty. Climate change will substantially reduce available water in many of the water-scarce areas of the world, but will increase it in some other areas. Freshwater availability in central, south, east and southeast Asia, particularly in large river basins are projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by 2050's. Runoff and water availability is expected to decrease in arid and semiarid Asia (Cosgrove 2005; Wurbs et al. 2005;, Draper and Kundell 2007; Shiklomanov et al. 2011; Acharya et al. 2011; Keng et al. 2012). Climate change and overuse of surface water resources, constructing four dams in u/s, less precipitation are the main factors responsible for declining Urmia Lake's level in the recent years (Hassanzadeh et al. 2011). Effect of climate change resulted in decreased annual rainfall leading to drought. Water inflow into Bhakra and Pong dams remains low (BBMB Report as cited by www.dnaindia.com). The impact of global warming is uncertain

(Draper 2007, Lemeshko 2011). A study done by Comair et al. (2012) showed that 88% of all precipitation within the Jordan River Basin is lost to ET. This matches well with estimates in the literature, which ranges 85 to 90%. The basin-wide ET average is 247 mm/year. Kar D. (2011) pointed the effect of global warming, climate change and various other factors that availability of water in the rivers and lakes in India is diminishing at an alarming rate and also mentioned that impact of global climate change is making the prediction of rainfall pattern quite uncertain. Because of the dry climate, water resources in this region serve as a factor that limits the socio-economic development (Selyutin et al. 2009). Both water availability by storage in small reservoirs and the yield of large reservoirs are strongly sensitive to plausible climate change (Krol et al. 2011). Five daily climatic parameters viz. max. temp., min. temp., precipitation, wind speed, relative humidity, and solar radiation have been used in this thesis.

2.6 Human Interventions and LULC Changes

Rapidly increasing population and economic development in many basins often tightly constrain the allocation of limited water supply (Rebecca and Teasley 2011). Population growth, rising water consumption for agricultural and domestic purposes and building dams has led to lake levels declining (Unal et al. 2010; Sang et al. 2010; Lemeshko 2011; Shiklomanov 2011). Kim et al. (2012) shown that changes in streamflow responses attributable to the farm dam development were not easily distinguishable from those attributable to land use and a more mechanistic loss module that accounts for direct losses caused by farm dams is required. A Study done by Petrov and Normatov (2010) reveals that excessive development of irrigated farming in the region in 1960's-1990's, resulting in a strict demand for practically complete regulation of river runoff, both seasonally and over years, and its complete consumption for irrigated farming. It was this approach that has resulted in drying of the Aral Sea with catastrophic environmental consequences. Due to the effects of man-made structures, the recharge quantity for impermeable zones is zero (Chang et al. 2011). The type of anthropogenic impact that are hazardous to the reproduction of water resources include excessive water withdrawal (from both surface and subsurface sources), mine workings, melioration systems, hydraulic structures, road construction, pollution of water bodies by wastewater discharges, washout of pollutants from agricultural lands and urban areas by floods or rains, airborne pollution, and the like.

The mechanism of such impacts is not completely understood (Danil'yan 2005). The response of river channels of TGD to human intervention has been long recognized and well documented (Sun et al. 2012).

Population rise is giving impetus to agricultural development and agriculture is the lion's share of overall water use, with substantial in-stream and environmental requirements, while urban water use is only about 5% of the total annual requirement (Yates et al. 2009). The consequences of large-scale hydraulic engineering activity (large dams and reservoirs, numerous low head barrages on the Indus and its tributaries and an increase in water withdrawal for dry land irrigation are a subject of intense studies in recent decades (Kravtsova et al. 2009). According to an assessment of Hayashi et al. (2008), approximately half of the world's population is living in urban areas. Land use modification associated with urbanization, such as removal of vegetation, replacement of previously areas with impervious surfaces and drainage channel modification invariably results in changes to the characteristics of the surface runoff hydrology. In a basin, reservoir density is considered high, when the capacity of reservoirs exceeds 40% of average runoff, a situation plausibly nearing basin closure, as an indicator for unsustainable human interferences in the river basin. Hayashi et al. (2008) classified the land cover into seven types: forest, bush and shrubs, grassland, farmland, paddy field, urban area, and wastelands such as bare land and rocky land. A key objective of water use regulation in foreign documents is the achievement of a "good condition of water bodies" by which is meant their general state when equilibrium is attained between variations and anthropogenic impact on the one hand, and the ecological functions of water on the other hand (Kravtsova et al. 2009; Khaustov and Redina 2010). Since the 1960s, water depletion in the Western Inner Mongolia basin has increased very rapidly due to intensive irrigation development in the middle stream area of the basin. As a result, the downstream Erjina Oasis gradually receded and the destination inland lake disappeared. Xu and Li (2010) as cited by Han et al. (2012) show that water demands in Chinese river basins are increasing by 2-10% annually. At the same time, flow in the Hai, Huai, and Yellow Rivers is decreasing due not only to water demands, but potentially due to climate change, construction of dams and reservoirs, and land use change. As human activity intensifies changes in land cover and disturbs the natural hydrological cycle, the behaviour of the of the runoff time series will change (Wang et al. 2011). Human interventions, anthropogenic changes, and LULC changes has been considered in this study as a principal component responsible for temporal variation of inflow to the dams.

2.7 Groundwater Recharge/Depletion

In the study of Hayashi et al. (2008), it is explained that soil layer is vertically divided into three storages (upper zone, lower zone, and active groundwater) in each hydrological response unit (HRU). Runoff and evapotranspiration are calculated by the moisture condition in each of the storage. Three runoff components- surface runoff, interflow, and active groundwater runoff are considered in the hydrological processes. Each runoff volume is obtained according to a nonlinear function of the storage volume in each zone. When groundwater resources are not very much reliant and irrigation, major urban and industrial uses in the basin are extremely reliant upon surface water, the groundwater resources may not be considered in the study (Wang et al. 2008).

In an average year, a larger share of demand is met from surface supplies, where in times of shortage, groundwater supplies make up a larger share, and there is greater water shortage or unmet demand (Yates et al. 2009). Karamouz et al. (2010) used the method of Thiessen area for computation of drawdown of groundwater level as shown below:

$$\Delta h = \frac{\Delta V}{S \times A} \quad (2.1)$$

Where A= Thiessen area; Δh= drawdown of groundwater level; ΔV= change in aquifer volume; and S= storage coefficient.

Chang et al. (2011) used the following equations for the determination of recharge quantity as shown below:

$$R = A_4 \times \Delta t \times \Phi \quad \text{(For wetlands)} \quad (2.2)$$

Where A_4 is the total area of wetland, Δt is a time interval of each time step, Φ denotes the constant infiltration rate of saturated soil (L/T) varies according to soil coverage type.

$$R = A_5 \times P \times \alpha \quad \text{(For dry lands)} \quad (2.3)$$

Where A_5 is the total area of dry land, P is the total rainfall quantity in the time interval, α denotes rainfall recharge coefficient varies according to soil type.

Ground water resources may be termed as subsurface hydrosphere resources. It includes all waters below land surface and in the saturation zone that are in direct contact with soil or grounds (Khaustov and Redina 2011). Due to this situation, infiltration and further percolation are increasing, making less contribution of base flow to the surface flow and thereby reducing the surface runoff. Due to excessively pumped withdrawal of groundwater and corresponding negligible recharge by a natural process, the groundwater is steadily dropping. Also, contamination of groundwater due to arsenic, various salts and saline water intrusion in the coastal areas is a great hazard to public health (Kar D. 2011, Dourte et al. 2012). The water planning and management policies of the Rio Grande basin, one of the most stressed basins, not only due to the increase of population and industry, but because of the natural water scarcity in the region, no longer respond to the sustainable needs of economy, environment, health and quality of life for the people and international commitments of this transboundary basin between Mexico and the United States. In these circumstances, results (Solis et al. 2011) show that groundwater banking can significantly improve water management in the basin, increasing system storage, improving water supply for users in the basin, and enhancing compliance with the treaty obligations. Thomas et al. (2001) as cited by Solis et al. (2011) pointed out that since the 1970s; groundwater banking studies have considered the economic and the hydraulic feasibility of storing water in aquifers in wet periods and recovering it later in dry periods. The development of groundwater banks requires the assessment of hydrogeology and water quality, legal and financial issue, as well as proper water planning and management. We should also think of cities that are green with vegetation that effectively and substantially reduces the need for stormwater, sewers and instead promotes runoff infiltration into the ground (Saito et al. 2012). With urbanization, the permeable soil surface area through which recharge by infiltration can occur is reducing. An infiltration trench alone or in combination with another stormwater management practice is a key element in present-day sustainable urban drainage system (Chahar et al. 2012). Intensive use of groundwater resources for agricultural production is proving to be catastrophic in many arid and semiarid regions of the world, including some developed countries like Spain, Mexico, Australia, and parts of the US, and developing countries like India, China, and Pakistan, etc. (Shah and Kumar 2008). Total (761BCM) and agricultural (688 BCM) water withdrawals in India are highest in the world. More than half of the irrigation requirements of India are met from groundwater, and the number of mechanized bore wells in India increased from 1 million in 1960 to more than 20 million in 2000. A recent groundwater depletion study in the northwestern Indian states of Haryana, Punjab, and Rajasthan, is illustrative of common regional groundwater depletion problem in India. For the agricultural regions of semi-arid India, groundwater recharge is of major concern: groundwater depletion is common as a result of large withdrawals. Given the scarcity and seasonality of surface water resources in the region, increased rainfall variability increases the reliance on groundwater resources for irrigation (Dourte et al. 2012).

With the increasing demand for water due to population growth and resulting increase in agricultural and economic activities, groundwater extraction is increasing at a very fast pace, resulting in rapidly lowering of water table year after year (Parmar et al. 2014, Nayak 2014). Decline of ground water level below ground level is assessed in this study as one of the principal component responsible for less water inflow to Ramgarh and Bisalpur dam.

2.8 Population Growth and Economic Expansion

India is having one-sixth of world mankind and showing a steady growth in the economy and technology. By 2050, India's population will grow to approximately 2.0 billion. The population of Rajasthan state is 70 million and will grow to 125 million by 2050. Urban population has increased from 10.84% to 31.16% and 15.6% to 24.89% from 1901 to 2011 in India and Rajasthan respectively. An important recommendation of Ministry of Water Resources, China, as cited by Lui et al. (2005), has been made for considering the carrying capacity "determining the size of grasslands, according to water availability and determining the stockbreeding size according to the stock-carrying capacity of grasslands. **Considering the rate of increasing population and the improving economy, it is necessary to have long-term planning to balance the supply and the demand distribution. As the water demand keeps increasing, the available water supply in some years will be unable to meet the high demand which is also described by Liu et al. (2005) and by Danil'yan (2005) as shown in fig 2.1.**

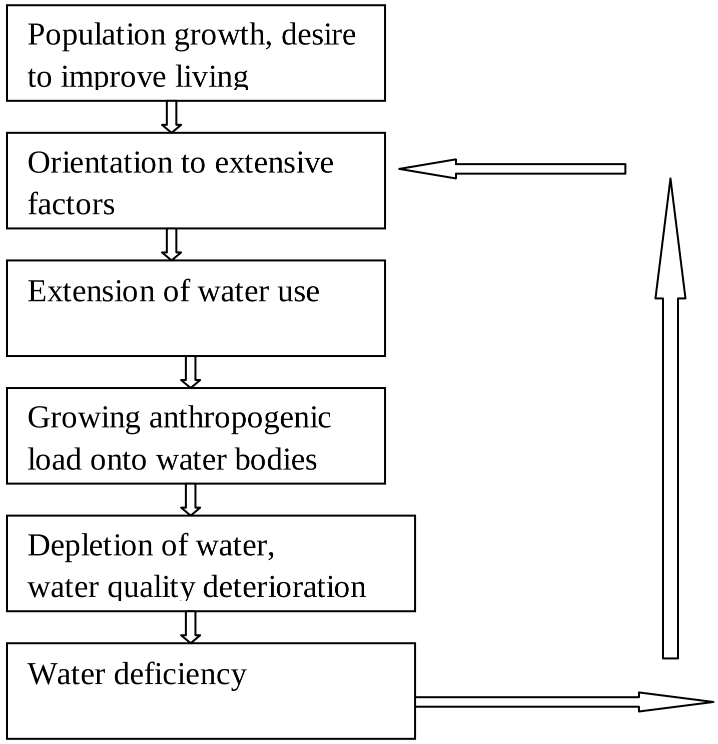


Fig. 2.1 Scheme of formation and aggravation of freshwater deficiency (Danil'yan 2005)

Some analysts have concluded that globally, water availability has declined twofold during the past 25 years because of population growth and drier trends in the climate (Draper 2007a). A study done by Kar D. (2011) shows the country is heading towards rapid urbanization inhabitation pattern whereby 50% of the Indian population will perhaps be living in cities and urban conglomerates in the near future. The problem of water resources planning and implementation is somewhat unique in nature because of its very high population density and its well established democratic set-up. India and China together constitute about one-third of mankind. They are frequently compared as both are having the mega population, little realizing that China has three times the area with a marginally higher population hence, a much thinner population density. China has strict land acquisition act for national projects while such laws are yet to be enacted in India. Many researchers (Liu et al. 2005; Iglesias et al. 2007; Wang et al. 2008; Karamouz et al. 2010; Wang et al. 2011; Shiklomanov et al. 2011; Han et al. 2012; Lany et al. 2012; Uniyal et al. n.d.) have emphasized the negative impact of population growth and economic expansion of water resources management. This study also highlights the effect of increase in population density on inflow to the Ramgarh and Bisalpur dams.

2.9 Critical Year and Sensitivity Analysis

Time series analysis and sequential cluster analysis are applied to determine the critical year, which divides two consecutive non-overlapping epochs; pre-disturbance and post-disturbance (Wang et al. 2001).

Karamouz et al. (2010) conducted a sensitivity analysis to evaluate the effects of agricultural price and the crop per drop (CPD) coefficient on the net benefit. International norms for CPD coefficient is above 1 kg/m^3 of water use. Several researchers (Wang et al. 2008, Karamouz et al. 2010) conducted the sensitivity analysis to see the impacts of various input parameters in the output parameter. In this study critical year has been identified using the time series analysis and sequential cluster analysis. Cosine amplitude method of sensitivity analysis has been used in this study to determine the principal components responsible for temporal variation of inflow to the dams of the Rajasthan state and specifically to Ramgarh and Bisalpur dams.

2.10 Environmental Flow and Ecological Sustainability

Reduced water inflows to the dams not only affect the human society but also adversely affect the ecology also. It becomes very difficult to release the minimum environmental flow (MEF) for ecological sustainability, which allows the fish to reach the spawning sites in the periods of mass spawning run. There are many evidences when MEF was not released because of the reduced inflow to the dams and requirement of irrigated farming resulting in catastrophic environmental consequences with negative implications towards current and future sustainability (Liu et al. 2005; Iglesias et al. 2007; Jain et al. 2008; Yates et al. 2009; Petrov and Normatov 2012; Sun et al. 2012; Kumar 2014). Riverine ecosystems and riparian rights should be appropriately considered during water resources planning and management (Liu et al. 2005; State Water Policy 2010). Ecological runoff (unregulated river) and ecological release (regulated river) along with admissible water withdrawal (AWW, which varies from 5 to 20% of the annual mean value of the natural river runoff) is computed for ecological equilibrium. Twice of the AWW is termed as crisis state and more than twice is considered as disaster state (Danil'Yan et al. 2006). Lee et al. (2008) conducted a study and concluded that hog farming and municipal waste water are the major causes of the deterioration of water quality. GIS and GPS were applied to aid in non-point source (NPS) pollutants investigation and analysis. Both GIS and GPS systems are important means for catchment land use identification. Use of water banks, water exchange, and other best management practices (BMP) and enforcement of relevant regulations are essential to manage effectively the river and control the pollution (Frevert et al. 2006; Lee et al. 2008). The concentration of population and industrial production in the region, unpractical industrial specialization, the anti-environmental structure of the economy along with the degradation of resource-saving and high technology plants have resulted in a heavy environmental pollution (Demin 2005). Neumann et al. (2002) as cited by Frevert et al. (2006) specified the key issues in the Truckee River basin and the Columbia Basin Project are Native American water rights, endangered species issues, competing uses of water including agricultural, municipal, recreational, and hydropower, and water quality. Applications of technology and development work in these basins have been on a need-driven basis. Hernandez et al. (2011) developed a hydrologic-economic-institutional model of environmental flow strategies for environmental flow allocations in managing river systems to protect or restore river ecosystems. Several methodologies have been applied worldwide to estimate flows for environmental requirements. Specification of flow can range from a simple, fixed percentage of annual discharge to a more complex matching of historical frequencies, durations, timing, and rate of change of discharges. In South Africa, environmental water requirement (EWR) as laid out in the National Water Act (Act no. 36 of 1998), refers to the amount of water, both quantity, and quality, required to protect the aquatic ecosystems is released (Mantel 2010). In most of the developing countries in Asia and Africa, the development of irrigation to alleviate hunger and poverty has primarily been the dominant goal. Because of this, there is little use of EWR at the policy level, which has led to an overdraft of rivers and aquifers and significant ecological degradation (Liu et al. 2005).

In Rajasthan State, the policy is not being strictly enforced to ensure the MEF. However, provision to release water in downstream of irrigation projects has been mentioned in subsection 1.4.9 of State Water Policy of Rajasthan (2010). Regulatory reservoirs could be used to mimic natural flows that are needed for ecosystem health. Matteau et al. (2009) as cited by Kim et al. (2012) mentioned a new paradigm, the "natural flow regime" concept, was developed in the 1990s for the ecological restoration of rivers altered by anthropogenic activities. Liu et al. (2005) mentioned in their study that in the late 1990s, the Chinese government initialized activities for the ecological restoration of the region, including annual flow release to downstream by administrative order. In particular, research on the determination of environmental flow requirement and livestock carrying capacity will be important for decision-making support in the sustainable development of the region. In these situations drinking water needs become the first priority and even agricultural releases have to be curtailed. Danil'Yan et al. (2006) and Lany et al. (2012) reaffirmed that, a critical moment for the assessment of the admissible water withdrawal is the assessment of the quantitative values of the environmental runoff (release) of the small rivers, i.e. the minimum runoff that should persist in the river permanently for the preservation of the environmental equilibrium within its watershed and prevention of degradation of aquatic and riverbank ecosystem. Yildirim et al. (2011) have pointed out that besides the scientific and ecological points of view, knowledge of the size and shape of lake level changes has social effects because the lakes' resources support the economy of communities settled around them. The environmental health of the Big Bend National Park is affected by the quantity, quality, and timing of the Rio Grande stream flows (Solis et al. 2011). By the environmental release is meant the flow of a regulated river, which ensures the reproduction and functioning of aquatic and on-shore ecosystems in the lower pool of water works (Frevert et al. 2006, Denim 2010). The forest is an intricate device for catching, holding, using and recycling water. The forest wealth must be preserved and protected and expanded through planned large-scale plantation (Kar D. 2011). In this study MEF has been discussed in detail looking to the importance of this parameter for sustainability of bio-diversity. Presently in Rajasthan state this phenomenon is not being followed and adhered.

2.11 Water Resources Planning and Management

Water management is the branch of science and technology covering the account, studies, use and conservation of water resources as well as control of adverse effect of water , OR a sphere of activities responsible for water resources management with a view to meet the demands of population and national economy for water, to ensure rational use of water resources and their protection from pollution and depletion, to ensure operation of water management schemes, as well as to prevent and eliminate the adverse effect of water

(Demin 2010). Human activities have played a conclusive role in the water cycle. The management of decreasing water resources, as a result of the climate changes within the Mediterranean region, is challenged in particular, as climate change coincides with high development pressure, increasing population, and high agricultural demands. Effective measures to cope with long term, drought and water scarcity are limited and difficult to implement due to a variety of stakeholders involved and lack of adequate means to negotiate new policies (Iglesias et al. 2007). Without water survival of mankind is impossible. Therefore, water resource plans and management policies are essentially be adopted to manage this scarce resource with maintaining the environmental sustainability. Water allocation under conditions of water scarcity is looming issue that threatens the economic well-being and quality of life of many of the world's people. Mexico has some similarity with Rajasthan state viz. Arid to a semi-arid climate with an average rainfall of 527 mm/year and a mean temperature of 22^{o}C. Water scarcity issues in the basin were highlighted during the 1994-2003 droughts when reservoir storage dropped below 20% of capacity, and agricultural planting was severely curtailed. The main crop within the basin is wheat. 13% of the Mexican federal budget was allocated to subsidies in agriculture. Water Users Associations (WUA) has been transferred the control of water to a local group of farmers. Crop prices and crop costs are derived from the database compiled by the Mexican government. Competition among water use sectors is expected to increase in the next several decades, as the urban population increases and variability in precipitation may increase due to climate change. Historically, the majority of the flow in the basin has been allocated to human uses without regards to ecological impacts (Hernandez et al. 2011). The main difference between the two states is attributed to the Mexican people, who have a willingness to pay (WTP) for uses of water. World Bank (2001), Wang (2003), and Cai (2008) as cited by Han et al. (2012) defines, Water resources management efforts have been shifted from engineering (e.g. Dam and water channel construction) to economic/resource based water management approach (Han et al. 2012).

Kar D. (2011) pointed out that India's water crisis, particularly in the cities is mainly due to poor management and water management in the urban areas of India is said to be the worst in the world. The UN Charter of the year 2002 accepts the Rights to Safe Water with respect to safety, affordability and accessibility as a basic human right. Water is the most precious natural resource and is a critical element in any development planning. We should aim at providing adequate water supply at a suitable pressure for various uses such as domestic, irrigation, drinking, sanitation, industrial, commercial, construction and other uses and at the same time protecting the environment. Irrigation activities in India alone consume about 80% of available water as the practices adopted are outdated and largely wasteful. Improved methods of irrigation are available today whereby the same amount of crops can be grown using only about 20% of the irrigation water presently being used. So, water conservation is an urgent necessity with enough storage by rainwater harvesting, economizing on water use, reducing waste to the minimum, recycling, and reusing of used water (Kar D. 2011). Water savings from agriculture are considered the most critical measure for long-term, sustainable management of the watershed (Lui et al. 2005; Sun et al. 2012). The major components of the water management system should include assessment and optimization of supply, demand management, participatory and transparent management operating system, market-based regulatory mechanism, and combining authority with responsibility taking care of ecological sustainability. Zajac (1995) as cited by Draper (2008) described two important characterizations: Rule Fairness (or Procedural Justice) and Outcome Fairness (or Distributive Justice) for effective water management. Sustainable plans and policies are more likely to be those that reflect a consensus, to the extent possible, among all impacted stakeholders. Compromises are often necessary for participatory water resources planning and management (Takayanagi et al. 2011). The various demands for water are all essential to our way of life: economic growth and prosperity, agriculture, and improved quality of life.

In many river basins in the western United States, water management agencies are charged with tracking the legal ownership of water in storage and water delivered to users who have legal rights to the water. An independent panel of technical experts meets on a regular basis to review the progress of the program and provide recommendations for future directions. The Stochastic analysis, modeling, and simulation (SAMS) program can also be very useful for policy planning studies. For water resource planning and management, we have to consider our stakeholders and their interest; our legal and political constraints; and technical information and knowledge, which has also been described by Liu et al. (2005); Frevert et al. (2006); Lemeshko (2011). Kar D. (2011) emphasizes to use benchmarking techniques to improve the operating efficiency of the entire distribution system. Some of the possible solutions to the problem of safe water as suggested by Kar D. (2011) are: Water conservation; Technological up-gradation; Innovation; Making more water available by finding new sources; Recycling and Reusing used water; Equitable access and distribution; Desalination of sea water; Eliminating contamination in storage and distribution network; Growing awareness amongst the common people and developing a change in mindset; Privatization in selected areas; Decentralization and reduce Government intervention. The long term holistic planning is a must but is becoming all the more difficult due to uncertainties in forecasting the oncoming weather pattern. Permeable Pavement System (PPS), which are sustainable and cost effective processes, is suitable for a wide variety of residential, commercial and institutional applications. Infiltration supports groundwater recharge, decrease groundwater salinity, allows smaller diameters for sewers (resulting in cost reduction), and improves the water quality of receiving waters. Therefore, Best Management Practices (BMP's) based on infiltration are the foundation of many low-impact development and green infrastructure practices (Chahar et al. 2012). Groundwater banking is one approach leading to better water management. Deficits occur when the bank is empty, and the other two sources are unable to satisfy the demand. Municipal and industrial accounts have the highest priority, and they are guaranteed an amount for each year. The rest of the users are not guaranteed, and their allocation depends on the water remaining in their accounts from the previous years. If there is surplus water remaining, it is allocated to agricultural users, then mining, and finally other uses (Solis et al. 2011). State Water Policy (2010) of Rajasthan State fixes water use priority for water resources management and planning purposes:

1. Human drinking water
2. Livestock drinking water
3. Other domestic, commercial and municipal water uses
4. Agriculture
5. Power generation
6. Environmental and ecological

7. Industrial
8. Non-consumptive uses, such as cultural, leisure, and tourism uses.
9. Others

All existing problems become even more acute in low-water periods, the large lengths of which, along with extreme runoff deficiencies have a strong effect on the strategy and tactics of water management (Danil'Yan et al. 2006)

2.11.1 Conjunctive Use of Surface and Subsurface Water

In watersheds with stressed water balance, as well as with the purpose to enhance the utilization efficiency of water resources, admissible runoff withdrawals can be estimated based on a combined or joint use of surface and subsurface water resources. It is highly desirable that the groundwater reserves exhausted during the low-flow period will be replenished almost completely in the subsequent high-flow period before the following low-water period (Danil'Yan et al. 2006). Sinovic and Li (2003) as cited by Chang et al. (2011) represented that the climate changes caused by global warming have made hydrological conditions increasingly unstable spatially and temporally. Because surface water resources are highly related to climate changes global warming increases the risk of water deficits. Tsur (1990) as cited by Chang et al. (2011) states that groundwater provides a more stable water resource, and rich groundwater areas play a vital role in regional water resources. Therefore, the conjunctive use of surface and subsurface water can enhance the water supply reliability.

It is the best way to manage the scarce water resource by conjunctive use of surface and subsurface water. Simulation results indicate that conjunctive use with artificial recharge indeed reduces the frequency of extreme water shortages (Valazquez et al. 2006; Yates et al. 2009; Chang et al. 2011; Bolgov et al. 2012). Solis et al. (2011) developed water evaluation and planning system (WEAP) software to evaluate the groundwater banking policy. In lieu groundwater banking is a conjunctive water allocation policy applicable to water users supplied from surface water and groundwater sources. Chang et al. (2011) and Oel et al. (2011) infers from the study that conjunctive-use with artificial recharge indeed reduces the frequency of extreme water shortages.

Groundwater and surface water are in a continuous dynamic interaction. They interact in a variety of physiographic and climatic landscapes. Thus, alteration or contamination of one commonly affects the other. For instance, pumping of groundwater can deplete the quantity of water in streams, lakes or wetlands; and withdrawal from surface water bodies can degrade groundwater quality and vice versa. It is true that the interaction between surface water and groundwater system is very complex, and it is a very difficult task to simulate the interaction. Quantity and quality of one system eventually affect the other. Streams interact with many types of in streams and subsurface storage zones with varying sizes and time scales of exchange. Lakes are surface water systems which impound water and either form a hydrological link between groundwater up gradient and down gradient to the lake or uniformly recharge or discharge into groundwater. Lakes interact with groundwater in a complex fashion, allowing for many different flow regimes (Hassanzadeh et al. 2012; Nield et al. 1994 as cited by Bobba 2012 found 39 distinct flow regimes) and seepage patterns. Stable isotopes have been used fairly extensively in understanding lake-groundwater interactions (Bobba 2012).

2.11.2 River Basin Management

River basin management is as varied as each basin (Teasley and McKinney 2011). Frevert et al. (2006) pointed out that efficient management of resources is critical, particularly as the competing demands for water in the river system increase. Improved watershed and river system operational decision-making is an integral part of improving efficient use of our limited resources, and decision support systems are necessary. Water management must respect political boundaries, but effective planning and management requires consideration of hydrologic realities that water functions in a watershed and river basin framework. Unfortunately, there is no incentive for the marketplace to engage in river basin planning (Draper 2008).

Walker (2006) shown that many political factors impacted the development of the Colorado River Basin Water Agreement (CRBWA). These political factors included politicians, political agencies, legislation, and political pressure groups/lobbyists. Politics will always be present in government; there is no way to separate completely it from the administration. Recommendations have been formulated that will minimize the impact of politics on the agreement and assist in the attainment of the goals of CRBWA (equitable water distribution and removal of interstate controversy). Due to record population growth and drought, river basin management becomes very significant. The United State Bureau of Reclamation‘s mission was to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. The present use of water resources should take account of future generations. It is fair to say that the number of stakeholders involved in the negotiations probably helped to reduce the nature of any political impact that occurred. A Political process can have a positive impact when knowledgeable, fair politicians are involved in the process and are willing to reach consensus, this can be a very positive process and the impacts can be beneficial to all involved. It was mentioned that there was excitement about the drought because, in the long run, we will have learned to utilize better this resource that we have all taken for granted. History has shown that we cannot continue to take and waste without consequence. The current drought is teaching us to be more responsible which will make us successful when we are challenged by any real ‘doom and gloom’ and to that point of consequence. For a semiarid state like Rajasthan, it is essential to conserve every drop of rain water. River basin management by micro watershed planning should be done and finally any surplus water of the basin, leaving the MEF, should be stored at the terminal dam of the basin. In Rajasthan State, Isarda dam of capacity 305 MCM is sanctioned on the same principal as a terminal dam of Banas Basin.

2.11.3 Small WHS and Large Dams

In water resources management, a dam is useful for ensuring a stable water supply and mitigating floods. Semiarid river basins like Rajasthan often rely on reservoirs for water supply. To ensure the availability of water near small habitations, public need to construct small Water Harvesting Structures (WHS). There is a great debate on the issue of small v/s large dams all over the world. Small reservoirs get silted up much faster than the large dams. Krol et al. (2011) explain that small reservoirs may impact on large-scale water availability both by enhancing availability in a distributed sense and by subtracting water for large downstream user communities, e.g. served by large reservoirs. Large scale distributed water availability supplied by storage in small reservoirs is more vulnerable than large scale availability towards downstream, supplied by storage in large scale strategic reservoirs. Upstream small reservoirs would enhance the climate change effect on strategic reservoirs. There is also a debate on 'Dams or No Dams'. The greatest opposition which dam builders around the world face is on environmental, financial, economic, and human rights front, whereas the proponents of large dam push their agenda on the ground of enhanced food and drinking water security, hydropower generation, and flood control. Large dams are important for human development and economic growth. (Shah and Kumar 2008). When people are allowed to construct small WHS in a decentralized manner over a large catchment, then it shows a tremendous impact on the inflow to the large dams downstream. A study conducted by Mantel et al. (2010) proved that the cumulative effect of a high number of small dams is impacting the quality and quantity of waters in South African rivers and that these impacts need to be systematically incorporated into the monitoring protocol of the environmental water requirements. South Africa receives 497 mm of rainfall against a global average of 860 mm. High potential evaporation rates (1100 to 3000 mm), leading to a value of mean annual runoff to mean annual precipitation of only 8.6%, similar to Australia (9.8%) but much lower than other parts of the globe (e.g. Canada 65.7%). Interbasin transfers and large dams have been emphasized as solutions to improve water security in the past in South Africa. Regional and global surveys have hypothesized that small dams can have a significant impact on river systems because of their large number and the total area covered. Numbers of farm dams (i.e. Small dams that do not require a license) are not accounted in the inventory of dams. There is a paucity of analyses of cumulative impacts of small dams and weirs on quantity and quality of rivers and river ecosystems. It is widely recognized that dams usually have negative impacts on the downstream flow regime required by riverine ecosystem (Liu et al. 2005). Recently, the population of the Indus delta area has carried out demonstrations of protest under the slogan "No more dams in the Indus! Protect the Indus delta (Kravtsova et al. 2009). The World Commission on Dams has emphasized the wide range problems associated with dams (Sun et al. 2012). However, the importance of dams for providing water for human use in a semi-arid country cannot be underestimated (Mantel et al. 2010).

Kar D. (2011) suggests preserving and protecting wetlands and new ponds, lakes and reservoirs created in a planned manner. This helps in aquaculture, fishery and raising the sub-soil water table apart from generating employment for the local people. Since annual evaporation losses in the state are to the tune of 1.8m, therefore, the proposal of large dams is preferred for any virgin catchment remaining in the state. However, after considering the recharge strata, consent of the local village government and ecological and forest aspects, small dams in the form of WHS are also constructed in the state. A large terminal reservoir can be made at low dependability to store the surplus water of the basin as cited by Shah and Kumar (2008) that in Narmada basin, the Sardar Sarovar reservoir being the terminal reservoir, it can receive all surplus flows from the reservoirs upstream.

2.11.4 Micro Watershed Planning

To ameliorate the situation of water scarcity and environmental degradation, watershed restoration is being contemplated for the Western Inner Mongolia region as the fundamental element of a new ecosystem management philosophy (Liu et al. 2005). The popularity of watershed models is no surprise due to their ability to provide holistic interpretation of how natural systems that are driven by hydrologic processes are impacted by anthropogenic disturbances (Migliaccio and Srivastava 2007). River basin and watershed planning and management have been acknowledged as one of the most important techniques to be used in managing water (Draper 2008). It was felt (Kim et al. 2012) to identify the effects of flow regulation on dams on the downstream flow regimes of a basin. In Rajasthan, micro watershed planning is being adhered before sanctioning any new surface water storage project.

2.11.5 IWRM and INRM

Integrated water resources management is simply the management of available water for allocation to stakeholders keeping in view the environmental sustainability. Integrated water resources planning and management typically involve the considerations of multiple economic, environmental, social, financial, institutional; and technical impact and the participation of multiple interest groups and stakeholders (Liu et al. 2005; Selyutin et al. 2009; State Water Policy 2010 (2.0); Takayanagi et al. 2011; Maheshwari et al. 2012; Nayak 2014). Singh (1995) as cited by Wang et al. (2008) stated that because of increasing demand for water in the face of deteriorating water quality, it is essential to adopt an integrated water resources management (IWRM). Water allocation models possess common deficiencies, they only consider quantity constraints, and do not include water quality constraints. Gupta and Zaag (2008) as cited by Karamouz et al. (2010) have assessed the interbasin water transfers from a multidisciplinary perspective and attempted to answer whether such transfers are compatible with the concept of integrated water resources management and the criteria for assessing such transfers. We should consider sustainability and how we develop and manage our natural and cultural resources to benefit both us and future generations. It is essential to plan and manage water and environmental resources with adaptable, robust and integrated approaches (Saito et al. 2012). Integrated watershed modeling approaches provide methods to link groundwater and surface water systems in the model hydrologic domain. The development of the integrated model is at present hindered by the lack of efficient algorithms for coupling both water masses whose time steps are very disparate (Bobba 2012). Winter (1999) as cited by Bobba (2012) explained that several factors have a significant effect on groundwater-surface water interactions. These can be enumerated as (a) regional physiographical framework; (b) local water table configuration and geologic characteristics of surface water beds, such as the distribution of sediment types possessing different hydraulic conductivities and orientation of sediment particles; and (c) climatic effects on seepage distribution in surface water beds.

2.11.6 Transboundary Water Transfer and Water Sharing

Sharing water across political boundaries is not an unusual phenomenon. There are 268 transboundary river basins worldwide. Two hundred fifty major rivers are shared between and among two or more nations. Over fifty rivers are shared by three or more nations, with the Danube being shared by 13 riparian countries. These basins cover almost two-thirds of the global landmass; forty percent (40%) of the world's population depends on these shared river basins for water (Draper 2007a). Several writers (Draper 2007b; Draper and Kundell 2007; Eleftheriadou and Mylopoulos 2008; Wang et al. 2008; Karamouz et al. 2010; State Water Policy 2010 (1.5); Teasley and McKinney 2011; Shiklomanov et al. 2011; Bhandari and Liebe 2012; Lany et al. 2012) stated that transboundary water sharing agreements provide a solution for water scarce areas and management of transboundary water resources has been the focus of many studies due to the observed water stress all over the globe combined with the continually increasing water demand. Teasley and

McKinney (2011) shows the usefulness of the agreement on the allocation of water and energy resources of the Syr Darya basin considering transboundary cooperation and benefits sharing using the river basin model and game theory concept. Water-sharing agreements increase benefits to all countries in the basin if they follow the agreement. The shapely allocation provides each country with increased economic benefits. Likely actions of the upstream countries have to be considered, and provision of compensatory payment for compliance with the treaty should be made. Transboundary water allocation and sharing in river basins that border or pass through two or more countries can be difficult because they are subject to politics, laws, and regulations. It is sometimes observed that trade policies, military affairs, immigration, and a host of other issues might come into play in water negotiations (Teasley and McKinney 2011). The effectiveness of any law, regulation, contract, or legally enforceable agreement, regardless of the subject matter, depends on how effectively it is administered and how rigorously its provisions are enforced. Without an effective institutional framework, the parties will spend much of their time and resources in dispute resolution rather than effective water management. The institutional provisions must provide for effective cooperation, coordination, and communication. They can ensure that conflicts are resolved in a timely and cost-effective manner. These institutional provisions will involve far more than just engineering management of the water resources in question. They must also involve establishing procedures to manage the complicated coordination among a number a private and public institutions, addressing critical social issues, responding to complex environmental and ecological sustainability needs (Draper 2007b). International water laws (Comair et al. (2012) such as Helsinki Rules on the uses of the waters of international rivers of 1966 (ILA 1966) and the 1997 United Nations Convention on the law of the non-navigational uses of international watercourses, mention main components to be considered for water allocations in international river basins. Eleftheriadou and Mylopoulos (2008) used game theoretical approach (negotiation analysis or science of strategy) and multi-criterion decision analysis (MCDA) for conflict resolution in transboundary water resources. At the point of Nash equilibrium all players profit the most (i.e. Have high payoffs), taking into account all possible moves of the counter-players. An early study of Rogers (1969) as cited by Eleftheriadou and Mylopoulos (2008) on the cooperation of India and Pakistan in the Lower Ganges case is one of the first attempts to implement the game theory in the sector of water resources management. Russia has 37 large water management systems, which are used for interbasin river flow redistribution from water abundant areas to water deficit areas. The total length of water transfer canals on the territory of Russia exceeds 3000 km, the volume of transferring flow approximates 17 BCM.

Transferring water from an area may cause a variety of negative impacts, social and environmental impacts; the water quality simulation model was used to consider environmental impacts of the water transfer model. In the national arena, water is equity for all. Equity for those who are in need of water and do not have access to water and those who have the water rights and may have a surplus that is wasted in a variety of ways. When water is intended to be used in another basin, water rights could be traded for financial resources. Temporal and spatial distribution of water resources pose a challenge to the demand and supply management of this scarce resource. The interbasin water transfer project is an alternative to balance the non-uniform temporal and spatial distribution of water resources and water demand, especially in arid and semiarid regions, but it should be environmentally and economically justified. Water transfer leads to pollution of sending river due to withdrawal water and wastewater discharge as already taking place (Karamouz et al. 2010). Feng et al. (2007) as cited by Karamouz et al. (2010) developed a decision support system (DSS) for accessing the social-economic impact of china's South to North water transfer project. To determine the operating rules, a KNN model is developed to be used in real time operation. It is cited by Shah and Kumar (2008) that bulk water transfer in China from water rich Yangtze River basin to seven provinces, including Beijing for drinking water needs and the Yellow River for ecological needs.

In Rajasthan, for the sake of state water resources planning and management, following transboundary water transfer proposal are under investigation:

- Transfer of 355 MCM surplus water by the interlinking of Chambal and Brahmani Rivers to Bisalpur dam to augment the drinking water supply of Jaipur city and other nearby towns.
- Transfer of 1077 MCM surplus water by interlinking of Parwati and Kalisindh Rivers to Banas, Gambhir and Parbati Rivers.

- Transfer of 328 MCM surplus water by interlinking of Mej River to Ramgarh and en route dams.
- Transfer of 107 MCM surplus water by interlinking of Chambal River to Jaisamand dam of Alwar district.
- Parwati-Kalisindh-Chambal link scheme under National River Linking Project to transfer 1085 MCM surplus water.
- Sharda-Yamuna Link, Yamuna-Rajasthan Link, and Rajasthan-Sabarmati Link are also proposed to be investigated for transboundary water transfer from outside surplus water to the state.

2.11.7 Water Pricing, Water Market, Water Trading, and Water Privatization

Water cannot be considered as a common article of merchandise subject to purchase and sell. This is an inherited good, which should be preserved, protected, and treated appropriately. Surface and subsurface waters are regarded as natural resources, renewable in principle (Khaustov and Redina 2011). A major problem of public allocation is that no mechanism exists for public water allocation to shift water from older, lower-valued uses to newer, higher-valued uses. The artificially low cost of water, due to government subsidies, certainly lowers the incentive to conserve and may result in a waste of water. The unwillingness of the public to pay for essential infrastructure maintenance lead to sacrifice long-term vision and our political leaders fail to demonstrate that long-term vision and tend to pander to short-term, self-interests (Saito et al. 2012). The Dublin statement that water is an economic good prompted the World Bank, among others, to propose the privatization of a source water; that nations and states introduce tradable property rights to water in order to "increase the productivity of water use, improve operations and maintenance, stimulate private investment and economic growth, reduce water conflicts, rationalize ongoing and future irrigation development, and free up government resources. Under such conditions, demand and supply forces will determine the quantities to be traded and the unit price of the commodity in this market. A sense of “willingness to pay” is developed in the society. Market institution models have been implemented in Chile, Canada, Australia, Western United States and Mexico. Draper (2008) advocated the water privatization stating “Although the causes of water scarcity are varied, many assert the inefficiencies and failures of water allocation by the public sector are to blame. One solution offered by proponents is to privatize the water allocation process, thereby allowing the efficiencies of the marketplace to resolve these issues. While the legal right to the use of water may be placed in the hands of the private sector, these rights along with core functions must be closely controlled and managed by public institutions. The central theme of some books, professional journals, and magazine articles on water scarcity is that inefficient water management is an inherent consequence of the inefficiencies and failures of water management by the public sector. The solution in their views is to privatize water allocation. The scarce water resource will, consequently, be used for the “highest and best” uses. Freshwater is a finite and vulnerable resource; essential to sustain life, development, and the environment. Water has an economic value in all its competing uses and should be recognized as an economic good. Mechanisms for water allocation exist across a wide continuum of strategies. At one end of the continuum is the public allocation and the other end is private allocation”. Some authors as cited by Draper (2008) have suggested that water can be managed in more productive and efficient manner when treated as a “tradable standardized commodity” rather than as a product of engineering or an integral part of nature. The argument for tradable rights to water is based on the principles of the economics of scarcity and neoclassical economic theory. Australian’s Water Policy Agreement in 1994 endorsed the adoption of tradable water entitlements and clarification of property rights in water. Water as a product requires large expenses for its transportation in comparison with its use. The increase in the cost of a resource is undoubtedly an incentive to its economy and more efficient use though the efficiency of this incentive is essentially dependent on the elasticity of demand with respect to cost (Danil'yan 2005).

Water intra stakeholder transfer and inter-stakeholder trading will lead to an increase in the annual net benefit of the basin. The cooperation of all stakeholders can produce the largest overall gain; the government may need to regulate the water market and provide information to guide water trading to achieve optimal allocation in a river basin (Wang et al. 2008). Good quality water at adequate pressure cannot be supplied free of cost round the clock. The consumers need to bear a part of the water cost, hence; water pricing has to be introduced, and this calls for a change in the mindset of the Indian people. Introducing a water pricing structure would be effective in motivating water conservation (Kar D. 2011). The primary responsibility for ensuring equitable and sustainable water resource management rests with the government. Public responsibility includes the task to set and enforce stable and transparent rules that enable all water users to gain equitable access to, and make use of, water. One of the most serious disadvantages of exclusively private allocation is to consider the effect of the transaction on the third party, public, or environmental interests. A private allocation system will impede basin-wide planning and management of public institutions as well as environmental and ecological protection needed to sustain public health. A myriad of potential water allocation alternatives exist in the continuum between these two poles, and a logical choice is a form of public-private allocation that retains the best of both systems and must involve government oversight and controls (Draper 2008). Out of the important problems of water supply is the development of an economic mechanism of chargeable water use, which will dramatically reduce water losses and improve the reliability of water supply (Demin 2005). Models that integrate hydrology with economic, environmental, and institutional aspects into a coherent analytical framework can be useful for managing water resources at the basin level. Incorporating the value of water through economic analyses can provide critical information for decision about the efficient and equitable allocation of water among competitive users, efficient and equitable infrastructure investment in the water sector, and the design of appropriate economic instruments, such as pricing schemes and water trading markets (Cai and Wang 2006, Hernandez et al. 2011, Han et al. 2012). Policy for water pricing, water metering, and water tariffs has been discussed in Chapter 8 of State Water Policy (2010). Water scarcity and ability to pay are the only current variables for calculating water abstraction charges for each province. 1998 Water Law implemented water abstraction charges nationwide in China, and the law was restructured in 2002 to reduce bureaucracy.

2.11.8 Rainwater Harvesting (RWH)

Rainwater is perhaps, the best source of fresh water. It comes only during the monsoon period and, if not conserved this fresh water may not be available for the rest of the year. Benefits of RWH include a rise in the groundwater table, thus improving water quality and yield of aquifers, the salinity of groundwater will reduce augmentation of water supply system and sustainability of drinking water sources. Rainwater harvesting is useful for effective water conservation and management. The US western states could no longer afford to continue “wasting” its waste water. There is a lot of interest among the California, Los Angeles, Colorado, Phoenix, Arizona and some other western cities of USA in making use of their treated wastewater. Reclaimed water is an uninterrupted supply. That is why it has become a powerful incentive in the California area for reclaiming and reusing the wastewater (Kar D. 2011). In Rajasthan, it is made compulsory for the owners of land of size more than 200 sqm by the Government to store the rain water through RWH.

Makropoulos and Butler (2010) advocated the distributed water infrastructure for sustainable communities saying that “Distributed water infrastructure (located at community or household level) is relatively untried and unproven, compared with technologies for managing urban water at higher (e.g. Regional) level. Decentralized options are defined as those being applied at the development level (for example, up to 5000 households). This includes in-house options, water saving devices, conventional, novel technologies. Both local rainwater and local groundwater are collected in this case for both non-potable and potable use. Water is treated at the point of use for potable applications. Bottled water is used to back-up the potable supply when necessary. The rainwater harvesting system is also used for stormwater management through the existence of sufficient storage. It is assumed that all water needs (including potable) are met by rainwater harvesting (and/or local groundwater), with any deficit met by bottled water.

2.11.9 Reuse and Recycle of Waste Water

As cited by Liu et al. (2005) and Saito et al. (2012), we should treat the wastewater generating from apartments and office buildings on the site in a cost effective way, eliminating the need for sewers in urban areas. Makropoulos and Butler (2010) said: "The amount of waste water produced is assumed to be 94% of the water consumed, and energy use is associated with water treatment (assumed to be 700 kWh/ML) and waste water treatment (assumed to be 820 kWh/ML)." Relatively unconventional schemes such as desalination and effluent re-use to meet the temporary seasonal increase in demand (critical periods) are essential for the regional solution in the south east of England (Lany et al. 2008). Shiklomanov et al. (2011) insisted on recycling of water for an effective water management.

2.11.10 Water balance

ET toolbox estimates the losses (Frevert et al. 2006). The purpose of studying the water balance is to determine whether the inputs (rainfall/inflow) balance the outputs (evaporation, outflows and changes in storage) (Yildirim et al. 2010, Baynes et al. 2011). Annual water balance components of the Indus are as follows: the precipitation is 568 mm, and the runoff at the mouth is 98 mm. Therefore, evaporation accounts for 470 mm. The runoff coefficient is 0.17. The potential evaporation in the Indus Delta is very high, of the order of 1750-2000 mm/year. Taking into account that the Indus runoff has abruptly dropped, and the area of the active delta has declined the estimate of the water balance of the Indus Delta needs refinement (Kravtsova et al. 2009). The potential evaporation in the Rajasthan state is also very high, of the order of 1820 mm/year (Bisalpur Report-1991). According to an assessment of Dourte et al. (2012) annually, about 70% of rainfall infiltrates the soil, and about 11% of rainfall infiltration becomes groundwater recharge in the region near Hyderabad. For the purpose of applying hydrological models for water balance analysis and describing hydrological processes, daily rainfall data do not provide sufficient rainfall inputs (Alfa et al. 2011). At present, water used in agriculture accounts for 66.7% of total water use in China, most of which is used for irrigation. It is the biggest factor affecting the basin water cycle (Sang et al. 2010). The WASA model developed mostly in the Brazilian state, describes the water cycle in a river basin, simulating the water balance of soils and water reservoirs, generation of runoff and routing of flow through the river network, in which the reservoirs are located (Krol et al. 2011). Chunale et al. (2014b) found 23.47% of total seasonal rainfall as total runoff after satisfying all losses like canopy interceptions and surface depressions (10.64%), soil ET (19.38%) and percolation to upper GW layer (46.55%) in the Sub-Montane zone of Maharashtra. According to the results of the study conducted by Chunale et al. (2014b) in Maharashtra, the storage capacities of canopy vegetation and surface depression vary from 0.75 to 1.80 mm and 0.85 to 1.90 mm respectively, percolation rates of soil and upper ground water layer from 0.9 to 1.55 mm/hr and 0.80 to 1.39 mm/hr, respectively, and the storage capacity and storage coefficient of upper GW layer vary from 20.00 to 23.90 mm and 2.00 to 2.50 h respectively (Chunale 2014b). Nayak (2014) used Thornthwaite and Mather model to compute the total volumetric runoff through the water balance of the Bina River watershed. Nayak (2014) further explains that hydrological model includes subroutines for the most significant hydrological processes, such as precipitation at different locations, soil moisture dynamics, evapotranspiration, recharge of ground water, runoff generation, and routing in reservoirs and rivers. Most runoff models are based on water balance, using precipitation as a deriving variable and calculating the quantities directed as runoff, R, from the water balance equation.

$$R = P - E - \Delta S \qquad (2.4)$$

Runoff= Precipitation- PET- Various storage terms

2.11.11 Water use efficiency

In Rajasthan, to improve the water use efficiency, various programs have been undertaken like water auditing and benchmarking, repair and rehabilitation of dams and their canals, lining of unlined reaches of canals, formation of water users associations, formation of community participation units, and state partnership program under European Commission for reforms in water sector etc., some of the recommendations have been made by several researchers (Liu et al. 2005, Gurjar 2011). The major share of water use is attributed to irrigation requirements. The basis of agricultural water management involves the replenishment of irrigation water into the root zone of soil that lost due to evapotranspiration. Evapotranspiration includes evaporation from the surface and transpiration of water from the plant stomatal activities (Kumar et al. 2014). A Study done by Han et al. (2012) shows that many opportunities exist to improve water use efficiency, particularly through agricultural irrigation technology and urban water conservation efforts. We need technologies that will enable the maximum efficiency in water consumption in all fields of its use (Danil'Yan et al. 2005). Correct assessment of water losses from canal is vital for proper water management system (Akkuzu 2011)

2.12 Summary

Water is the most critical element to human survival and progress. Water is essential for all economic activities and prosperity of mankind. With the dawn of 21st Century, world stared experiencing the consequences of water scarcity. Draper (2007) stated that in some areas, water scarcity can be attributed primarily to an arid climate and the lack of sufficient rainfall. In other areas, even where sufficient source water is available, water scarcity may still emerge, for a variety of reasons including, many assert misguided government policies, ineffective public management, or inequitable distribution. Water scarcity caused by government inefficiencies, ineffectiveness, neglect or negligence has been described as a "water governance" crisis (UN 2002; World Water Commission 1999; as cited by Draper 2008). To tackle the water scarcity problem and to manage the supply and demand of water, it is essential to take administrative commands based on nationwide interest and the interest of individual branches and republics are of secondary significance (Petrov and Normatov 2010). The reasons for water scarcity are many and vary from one place to other (Carrasco et al. 2012).

Decreasing water levels of the dams, lakes, and reservoirs and increasing water stress is being observed in different parts of the world. Excessive ground water withdrawal during low flow periods for human demands will continue to affect river runoff until the complete filling of the depression cone that has formed due to water withdrawal (Danil'yan et al. 2006). The analysis of rainfall and runoff data revealed that the flow is reduced at Harike. The reasons for this are the over-exploitation of groundwater. All the ecological and economic benefits of this wetland are going to be affected due to the declining trend of flow at Harike (Jain et al. 2008). Yates et al. (2009) inferred that human interventions in the hydrologic cycle have greatly disrupted the natural hydrology. Runoff in major rivers in China has been decreasing in recent decades. The attribution of hydrologic variability to increasing water withdrawal for irrigation, human activity or climate change is a challenging problem and an active research area (Kravtsova et al. 2009, Wang et al. 2011). The decrease in precipitation and rise in temperature may result in runoff reduction (Wang et al. 2011). Water stress in southeastern England is projected to increase over the next 25 years, influenced by factors such as population growth; demographic change; changes in water use; water requirements for environmental protection; and, the potential effects of climate variability and change (Lany et al. 2012). Study results of Hassanzadeh et al. (2012) shows changes in inflows to Urmia lake due to the climate change and overuse of surface water resources is the main factor and accounts for 65% of the effect, constructing four dams is responsible for 25% of the problem, and less precipitation on the lake has 10% effect on decreasing the lake level in the recent years. Study results of Hassanzadeh et al. (2012) shows that precipitation has least effect and climate change and overuse of surface water resources has major effect on inflow to Urmia Lake, while this study reveals that precipitation is the principal component for inflow to the dams of the Rajasthan state.

Various studies revealed different factors to be responsible for declining trend of inflow and resulting water stress. Excessive ground water withdrawal is observed as main factor by many researchers. Some researchers found climate change and human activities (anthropogenic activities) along with population growth as main factors responsible for decreasing runoff. Most of the researchers have not carried out analysis for all the climatic factors and also not conducted the sensitivity analysis to prioritize the factors. This study reveals that rainfall, anthropogenic activities, ground water level, climatic factors (such as mean of relative humidity, wind speed, and daily max. temp.), and population growth are major factors responsible for less water inflow to the dams of Rajsthan state, specifically to Ramgarh and Bisalpur dam. Sensitivity analysis for identification of principal component has also been carried out for dams of the state as a whole and specifically for Ramgarh and Bisalpur dams.

Rain-fed agriculture is a complex, diverse and a risk prone ecosystem that occupies near about 70% of the total cultivable land (180.5 Mha) in India. Out of this about 20.0 Mha land depend on rainfall for cultivation falls in Rajasthan. As the rainfall in the state is erratic and uneven, with an average annual rainfall of 531 mm, state need to use efficient methods of irrigation like drip, sprinkler, greenhouses, and shed net systems, which is also recommended by several researchers (Liu et al. 2005). Influence of excess groundwater withdrawal on inflow to the reservoirs has also been explained by Liu et al. (2005) and Danil'yan et al. (2006). Jain et al. (2008) showed that wetland area of Harike has reduced approximately 30% over the last 13 years. It was also explained that during last five-decade percentage groundwater utilization has almost doubled and the surface water utilization has increased many fold. There are arguments that extensive rice and wheat growth has encouraged the people to extract more and more groundwater causing the decline in the water table. Danil'yan et al. (2005) concluded that the problem of water deficiency is shown to be insoluble without the development of intensive water use, conservation, and protection. Iglesias et al. (2007) and Tarun (2007) also emphasized that water saving is the key strategy for overall reduction of societal vulnerability to drought. Jain et al. (2008) concluded that all the ecological and economic benefits of Harike wetland are going to be affected due to the declining trend of flow. The impact of population density on the water resources have been illustrated by many researchers. With the high population density and its rapid growth in the Central Asia, this has already resulted in a deficiency in water resources in the region. In the future, this deficiency can acquire even more acute and crisis forms. Various measures have been proposed for solving this problem, including the diversion of Siberian River's runoff into Central Asia or serious evolutionary changes of the type of water consumption, implying a change to a new national economic strategy and social policy (Petrov and Normatov 2010). Hassanzadeh et al. (2012) also found some similar results in declining the Urmia Lake's level. He also cited that with the increasing population, farmlands would increase in the future. Unfortunately new dams would be constructed in this region. It is necessary to construct hydrometric stations in near the lake to understand the exact hydrological behavior. Hassanzadeh et al. (2012) concluded in their study that managing water supply and irrigation, introducing water market, strict water rights, modifying the farming, public awareness to conserve water and averting new dams construction in the basin, can help the lake to keep its current level, furthermore, conveying water from other basins to satisfy the agricultural demands in this region could be a proper alternative. The declining water table reduces runoff due to baseflow and hence the inflow to a wetland. Population growth and demographic and land use changes also creating water scarcity in the southeast of England (Lany et al. 2012). The terrain of the study area is flat and with the increased agricultural and developmental activities it is becoming flatter. The flat topography favours for more infiltration opportunity time leading to considerable entry from runoff water below the soil surface (Parmar et al. 2014).

The increase in population density of the state is leading to increase in abstractions in the catchment area of existing dams. These types of abstractions may be in the form of infrastructural development (residential, institutional, industrial, road network etc.), agricultural development (net crop area, area sown more than once), water harvesting structures (WHS, check dams, subsurface barrier, up steam dam development, field confinement, field dams, soil conservation structures etc.), forest development measures (contour vegetation hedging (CVH), Ditch Cum Bund (DCB) etc. (Appendix-10b and 11 a to f). Various hydrological methods can be employed to simulate the inflow to the dams. Various management techniques should be employed to cope up with water scarcity situations. Stringent policies may be implemented to safeguard the catchment area of natural streams (Appendix-11) and to manage the demand and supply of this scarce resource.

The work on rainfall-runoff modeling has been done all around the world a lot. Decreasing water levels in the reservoirs has been studied in many parts of the world by various scientists. Scientific research for temporal variation of inflow to the dams of Rajasthan state specifically for Ramgarh & Bisalpur dams have not been undertaken. Determination of critical year along with principal component responsible for temporal variation of inflow has not been determined scientifically earlier. This study encompasses towards testing the temporal variation of inflow, determination of critical year, and identification of principal components responsible for less water inflow to the dams of the state and specifically to the Ramgarh and Bisalpur dams. Sequential Cluster Analysis found to be very good approach for determination of critical year, understood through this literature, will help in determination of critical year. Cosine Amplitude Method of sensitivity analysis is also very helpful method for determination of principal component responsible for temporal variation of inflow to the dams. The steps taken forward all over the globe for water resources planning and management have been discussed in detail. This may help in finding some of the effective solutions for the problem of less water inflow to the dams of the state and to combat with the resulting water crisis.

3 MATERIALS AND METHODS

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CHAPTER-3

MATERIALS AND METHODS

3.1 Introduction

It is essential to analyze the different types of data regarding changes in rainfall, climatic factors, land use land cover, and water inflow to existing dams because there are many factors affecting the decline in water levels in the dams. Different types of data were obtained from various sources. There data were used and analyzed using several techniques in this study. The basic data used in this study includes: (i) rainfall data (source: Water Resources Department, Rajasthan); (ii) data of water inflow to the dams (source: Water Resources Department, Rajasthan); (iii) other climate data e.g. temperature, wind speed, relative humidity fraction, solar radiation (source: globalweather.swat.tamu.edu); (iv) land use land cover data (source: basic statistics & agricultural statistics published by Directorate of Economics and Statistics, bhuvan.nrsc.gov.in of National Remote Sensing Center, glfc.com, envfor.nic.in of Ministry of Environment and Forest, and iscgm.org of International Steering Committee for Global Mapping); (v) population data (source: basic statistics published by Department of Economics and Statistics), (vi) ground water level data (source: ground water department) and (vii) field studies and results of other relevant studies.

3.2 Materials: Data Collection

For any hydrological analysis, it is necessary to obtain the real-time data of rainfall, inflow, land use land cover (LULC), and other anthropogenic changes. Various types of data have been collected from various departments of Government of Rajasthan by personal visit, purchase, and Right to Information Act-2005. Data related to rainfall and inflows have been collected from the Water Resources Department (WRD). LULC data has been collected from the various publications viz. Some facts about Rajasthan, Basic Statistics of Rajasthan, Statistical Abstract of Rajasthan, Statistical Outlines of various districts of Rajasthan, Agricultural Statistics of Rajasthan, website of National Remote Sensing Centre of Government of India (http://bhuvan.nrsc.gov.in) and other related websites. The consistency of data is maintained to get the reliability.

3.2.1 Inflow Data

Real-time inflow data have been collected from the Water Resources Department (WRD) of Government of Rajasthan. There are 693 dams under the jurisdiction of WRD. There are 460 dams in the state, which are having the capacity more than 4.5 MCM. Out of these 460 dams, there are 115 major and medium dams in 11 river basins, inflow data of which are used for testing the hypothesis. For health performance study of the dams, inflow data of 32 dams of Tonk district selected through area sampling has been used in this study. Detail of basin wise dams in Rajasthan state is shown in Fig. 1.2. Surface water infrastructure of the state is shown in Table 3.1.

Table 3.1 Surface water infrastructure of the state

S.N.	Name of basin	No. of dams
1	Total no. of water bodies in the Rajasthan State	72569
2	Small+ Minor+ Medium+ Major Dams	3302
3	Minor+ Medium+ Major Dams	693
4	Medium+ Major Dams	115
5	Major Dams	22

Inflow data of dams of Rajasthan State has been collected from 1990 to 2013 as per availability of continuous data. For special reference to Bisalpur dam, the simulation period was set from 1979, when the measurement of inflow to Bisalpur dam site was started, to 2013, when the measured inflow to the dam is available. Annual mean inflow to Bisalpur dam is 1170 MCM; however, the minimum inflow decreased to 17 MCM during the year 2002. For special reference to Ramgarh dam, the simulation period was set from 1983, when the measurement of inflow to dam site is available, to 2010, when the measured inflow to the dam significantly changed. Until 2010, the mean annual inflow to Ramgarh dam was approximately 13.81 MCM; however, the minimum inflow decreased to 0.0 MCM during 2009. From 2011 and onward, the inflow to the dam remained to zero even after above average rainfall. Although this decrease represents a change in the hydrologic properties of the catchment area, the exact cause is unclear. Therefore, the chosen simulation period was considered reasonable to evaluate the temporal variation of inflow.

3.2.2 Rainfall Data

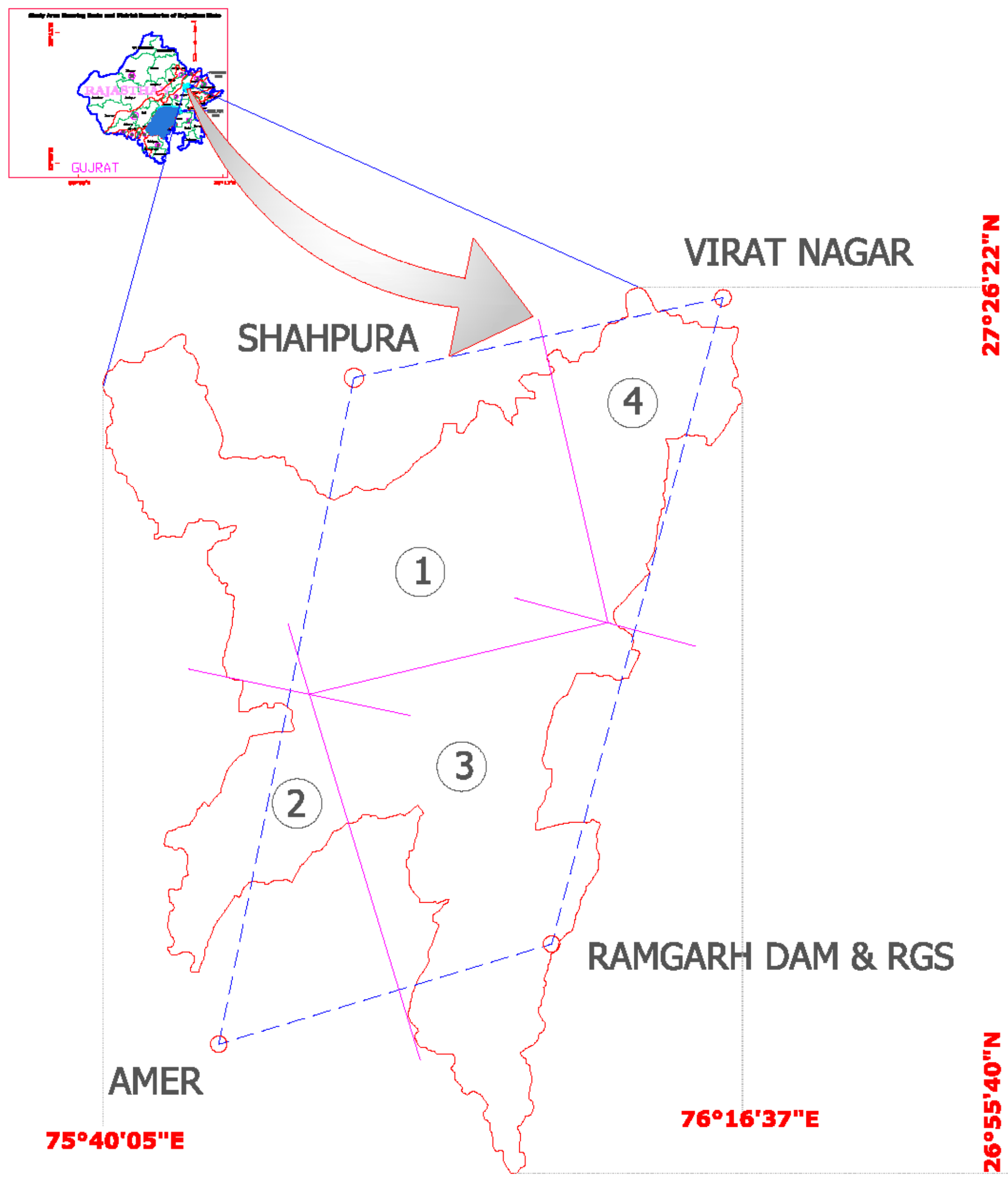
For analysis of the state, daily precipitation data was obtained for 544 Rain Gauge Stations (RGS), spread all over the state, from the Water Resources Department for 113 years (1901-2013). Rainfall data for 34 stations are shown in Appendix 2.

For analysis of the Ramgarh dam, daily precipitation data was obtained for 4 Rain Gauge Stations (RGS), spread within and around the catchment area, from the Water Resources Department for 32 years (1983-2014). Annual weighted rainfall is computed using the Thiessen weighting technique as depicted in Fig 3.1. Computation of influence factor for the 4 RGS is shown in Table 3.2. Average rainfall during the simulation period (1983-2014) in the catchment area of Ramgarh dam was 551mm.

Table 3.2 Computation of influence factor: Ramgarh

S.N.	Name of RGS	Area Influenced, A_i (km^2)	IF
1	Shahpura	408	0.49
2	Amer	67	0.08
3	Jamwa Ramgarh	250	0.30
4	Virat Nagar	107	0.13

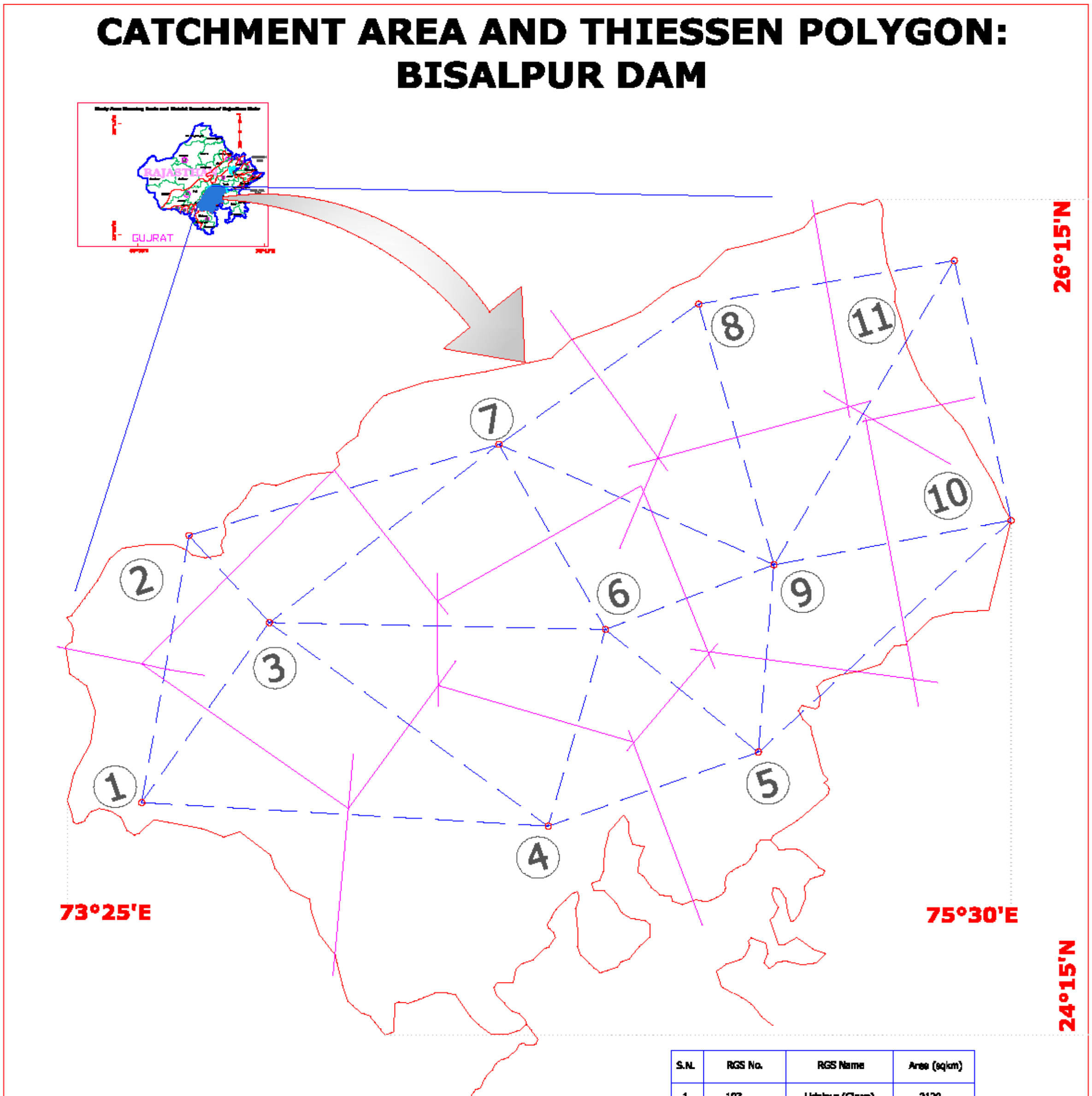
CATCHMENT AREA AND THIESSEN POLYGON: RAMGARH DAM



LEGEND		
S.NO.	DESCRIPTION	SYMBOL
1	CATCHMENT BOUNDARY	
2	THIESSEN P. BOUNDARY	
3	RGS CONNECTION	
4	RGS LOCATION NODE	
5	RGS NUMBER	①

S.N.	RGS No.	RGS Name	Area (%)
1	1	Shahpura	49%
2	2	Amer	08%
3	3	Jamwa Ramgarh	30%
4	4	Virat Nagar	13%
		Total=	100%

Fig. 3.1 Thiessen polygon for Ramgarh dam catchment



LEGEND		
S.NO.	DESCRIPTION	SYMBOL
1	CATCHMENT BOUNDARY	
2	THIESSEN P. BOUNDARY	
3	RGS CONNECTION	
4	RGS LOCATION NODE	
5	RGS NUMBER	1

S.N.	RGS No.	RGS Name	Area (sqkm)
1	103	Udaipur (Girwa)	2129
2	384	Kumbalgarh	1128
3	81	Rajasmand	3340
4	88	Chittorgarh	4777
5	68	Mandalgarh	1898
6	111	Bhilwara	2790
7	134	Jawaja	3076
8	136	Masuda	2347
9	150	Shahpura	3195
10	128	Nasirda	1350
11	154	Arain	1005
		Total=	27035

Fig. 3.2 Thiessen polygon for Bisalpur dam catchment

For analysis of the Bisalpur dam, daily precipitation data was obtained for 11 Rain Gauge Stations (RGS), spread within the catchment area, from the Water Resources Department for 35 years (1979-2013). Annual weighted rainfall is computed using the Thiessen weighting technique as depicted in Fig 3.2. Average rainfall during the simulation period in the catchment area of Bisalpur dam was 573 mm.

3.2.3 Climate Data

Five climatic parameters, namely maximum and minimum temperature (^oC), relative humidity (fraction), wind speed (m/sec), solar radiation (MJ/m^2) were obtained on the daily basis for four stations of Ramgarh catchment and 36 stations of Bisalpur catchment from the SWAT website (http://swat.tamu.edu). For Ramgarh dam catchment, mean minimum and maximum temperature, wind speed, relative humidity, and solar radiation during the period (1983-2010) were 33.55^0C, 17.46^0C, 2.62 m/s, 0.40, and 18.53 MJ/m2, respectively (Appendix-3). For Bisalpur dam catchment, mean minimum and maximum temperature, wind speed, relative humidity, and solar radiation during the period (1979-2013) were 33.67^0C, 18.95^0C, 2.9 m/s, 0.39, and 19.26 MJ/m2, respectively (Appendix-4).

3.2.4 LULC Data

Land use/land cover data has been extracted from district wise, year wise various publications issued by **Directorate of Economics and Statistics**, Rajasthan. For Rajasthan State, the LULC (1957-2012) is shown in Table 3.3 and Table 3.4 is showing specific areas of barren, culturable waste and fallow land having the contributing effect to runoff, and agriculture, forest, residential areas, roads, mining, etc. having the reducing effect on runoff.

Table 3.3 Land utilization of the Rajasthan state (000 ha)

Year	Forest	Area put to non-Ag. uses	Barren & Un-culturable land	Other uncultivated lands			Fallow land		Net area sown	Total cropped area	Area sown more than once
		Resi. roads, mining, etc.		Pasture & Grazing land	Miss. trees crops & grooves	Culturable waste	Other than current fallow<5yr	Current fallow (this yr.)			
1	2	3	4	5	6	7	8	9	10	11	12
1957	1438	1090	4912	1380	46	7326	3311	2248	12425	13711	1286
1958	1159	1125	4911	1397	21	7313	3758	2320	12103	12944	841
1959	1146	1168	4896	1526	23	7063	3639	2066	12588	13728	1140
1960	777	1341	4892	1641	13	6848	3380	1735	13215	14466	1251
1961	814	1095	5153	1684	16	6841	3104	2022	13112	14013	901
1962	879	1090	5223	1735	14	6684	2829	1797	13743	15045	1302
1963	852	1142	5220	1770	12	6488	2779	1902	13821	14833	1012
1964	958	1141	5121	1752	10	6689	2802	2036	13497	14464	967
1965	1057	1164	4988	1784	14	6470	2556	1537	14453	15502	1049
1966	1128	1149	4886	1812	22	6476	2289	2129	14132	14972	840
1967	1146	1166	4844	1810	13	6421	2114	1913	14597	15446	849
1968	1163	1163	4828	1817	13	6235	2007	1706	15097	16657	1560
1969	1236	1171	4760	1828	14	6293	2316	3114	13311	14257	946
1970	1342	1173	4709	1835	11	6378	3008	2556	13095	14267	1172
1971	1355	1162	4716	1807	9	6112	2326	1443	15179	16729	1550
1972	1401	1346	4705	1805	9	6112	1884	1762	15263	16773	1510
1973	1437	1376	4720	1799	8	5881	2033	2168	14859	16097	1238
1974	1549	1386	4568	1808	8	5636	1884	1461	15966	17885	1919
1975	1640	1407	4479	1823	9	5705	2030	3218	13958	15711	1753
1976	1874	1427	3132	1803	11	6647	2251	1933	15105	17163	2058
1977	1986	1454	3044	1814	13	6606	2223	1992	15060	16898	1838
1978	1967	1461	3006	1825	9	6604	2192	1991	15168	16923	1755
1979	2023	1469	2959	1833	10	6881	2118	1936	15470	17495	2025
1980	2069	1509	2931	1841	9	6406	2275	2988	14207	16371	2164
1981	2087	1507	2916	1833	24	6415	2089	2085	15267	17349	2082
1982	2077	1511	2959	1836	32	6206	2063	1969	15577	18596	3019
1983	2150	1510	2891	1835	50	6195	1920	2020	15659	18394	2735
1984	2162	1519	2879	1845	82	5740	1854	1915	16234	18877	2643
1985	2193	1500	2867	1851	29	6054	2024	2505	15215	17286	2071
1986	2227	1521	2816	1840	34	5988	2228	2016	15563	18137	2573
1987	2247	1658	2800	1824	26	5754	2237	2256	15429	17640	2211
1988	2272	1603	2868	1817	32	5985	3006	5139	11514	13308	1794
1989	2307	1656	2801	1799	26	5717	2287	1526	16123	18838	2715
1990	2324	1624	2819	1802	23	5628	2082	2340	15606	17903	2297
1991	2353	1490	2789	1912	22	5566	1927	1814	16377	19379	3002
1992	2369	1638	2754	1787	19	5567	2174	2458	15489	18093	2603

1993	2394	1647	2727	1770	17	5351	1864	1539	16938	20167	3228
1994	2425	1661	2684	1763	15	5282	1984	2194	16231	19254	3022
1995	2450	1667	2670	1751	17	5165	1832	1670	17021	20380	3359
1996	2458	1679	2656	1745	15	5103	1972	2035	16575	19672	3097
1997	2476	1685	2647	1735	14	5043	2020	1826	16789	20693	3903
1998	2528	1698	2621	1722	14	5017	1988	1596	17074	22325	5250
1999	2556	1705	2602	1717	14	5069	2287	2237	16073	21401	5327
2000	2580	1725	2580	1714	14	4987	2511	2637	15509	19286	3777
2001	2606	1739	2566	1707	13	4907	2444	2415	15864	19230	3365
2002	2645	1751	2520	1698	13	4730	2321	1819	16765	20798	4033
2003	2651	1764	2514	1703	12	4866	3259	6688	10807	13217	2410
2004	2660	1760	2498	1708	14	4546	2407	1275	17394	21664	4269
2005	2660	1775	2490	1708	13	4602	2162	2302	16548	21062	4513
2006	2675	1823	2439	1708	21	4590	2264	1910	16836	21699	4863
2007	2698	1835	2427	1706	20	4611	2265	1939	16764	21534	4770
2008	2713	1903	2361	1702	19	4474	2186	1752	17158	22153	4995
2009	2728	1970	2295	1699	18	4336	2108	1565	17551	22771	5220
2010	2742	1889	2379	1694	21	4233	1726	1235	18349	26002	7653
2012	2747	1884	2387	1694	21	4169	1855	1475	18034	24504	6471

(**Source:** Table 1 of 50 years Agricultural Statistics of Rajasthan 1956-57 to 2005-06-May 2008; Table 13.3 of Statistical Abstract-2012 published by Directorate of Economics and Statistics, Rajasthan; and Rajasthan Agricultural statistics at a glance for the year 2012-13-October 2014 published by Commissionerate of Agriculture, Rajasthan)

Barren, culturable waste and fallow land give smooth surface without obstruction, thereby having the contributing effect on runoff. Area put to non-agricultural uses viz. forest+pasture+tree crops and the net area sown increases the surface roughness, thereby having the reducing effect on runoff. Levels of roads and highways are kept above the natural ground level and are formed by digging soil along the roads, highways, and other nearby borrow areas, which obstruct the natural surface runoff. Rainwater harvesting in the residential areas, poor drainage system for storm water, and other constructional activities increases the surface roughness, thereby area put to non-agricultural uses is considered as having the reducing effect on runoff. Accordingly, year wise bifurcation of the geographical area of the state has been done in two categories viz. an area having the contributing effect on surface runoff and area having reducing effect on surface runoff.

Table 3.4 Trend of contributing and reducing effect of land use of Rajasthan State on runoff (000 sqkm)

Year	Contributing effect				Reducing effect			
	Barren	Culturable Waste	Fallow	Total	Non-Ag. Uses	Forest+ pasture+ tree crops	Net area sown	Total
1	2	3	4	5	6	7	8	9
1957	49.12	73.26	55.59	177.9	10.90	28.64	124.25	163.79
1958	49.11	73.13	60.78	183.0	11.25	25.77	121.03	158.05
1959	48.96	70.63	57.05	176.6	11.68	26.95	125.88	164.51
1960	48.92	68.48	51.15	168.5	13.41	24.31	132.15	169.87
1961	51.53	68.41	51.26	171.2	10.95	25.14	131.12	167.21
1962	52.23	66.84	46.26	165.3	10.90	26.28	137.43	174.61
1963	52.20	64.88	46.81	163.8	11.42	26.34	138.21	175.97
1964	51.21	66.89	48.38	166.4	11.41	27.20	134.97	173.58
1965	49.88	64.70	40.93	155.5	11.64	28.55	144.53	184.72
1966	48.86	64.76	44.18	157.8	11.49	29.62	141.32	182.43
1967	48.44	64.21	40.27	152.9	11.66	29.69	145.97	187.32
1968	48.28	62.35	37.13	147.7	11.63	29.93	150.97	192.53
1969	47.60	62.93	54.3	164.8	11.71	30.78	133.11	175.60
1970	47.09	63.78	55.64	166.5	11.73	31.88	130.95	174.56
1971	47.16	61.12	37.69	145.9	11.62	31.71	151.79	195.12
1972	47.05	61.12	36.46	144.6	13.46	32.15	152.63	198.24
1973	47.20	58.81	42.01	148.0	13.76	32.44	148.59	194.79
1974	45.68	56.36	33.45	135.4	13.86	33.65	159.66	207.17
1975	44.79	57.05	52.48	154.3	14.07	34.72	139.58	188.37
1976	31.32	66.47	41.84	139.6	14.27	36.88	151.05	202.20
1977	30.44	66.06	42.15	138.6	14.54	38.13	150.60	203.27
1978	30.06	66.04	41.83	137.9	14.61	38.01	151.68	204.30
1979	29.59	68.81	40.54	138.9	14.69	38.66	154.70	208.05
1980	29.31	64.06	52.63	146.0	15.09	39.19	142.07	196.35
1981	29.16	64.15	41.74	135.0	15.07	39.44	152.67	207.18
1982	29.59	62.06	40.32	131.9	15.11	39.45	155.77	210.33
1983	28.91	61.95	39.4	130.2	15.10	40.35	156.59	212.04
1984	28.79	57.40	37.69	123.8	15.19	40.89	162.34	218.42
1985	28.67	60.54	45.29	134.5	15.00	40.73	152.15	207.88
1986	28.16	59.88	42.44	130.4	15.21	41.01	155.63	211.85
1987	28.00	57.54	44.93	130.4	16.58	40.97	154.29	211.84
1988	28.68	59.85	81.45	169.9	16.03	41.21	115.14	172.38
1989	28.01	57.17	38.13	123.3	16.56	41.32	161.23	219.11
1990	28.19	56.28	44.22	128.6	16.24	41.49	156.06	213.79
1991	27.89	55.66	37.41	120.9	14.90	42.87	163.77	221.55
1992	27.54	55.67	46.32	129.5	16.38	41.75	154.89	213.02
1993	27.27	53.51	34.03	114.8	16.47	41.81	169.38	227.66
1994	26.84	52.82	41.78	121.4	16.61	42.03	162.31	220.95
1995	26.70	51.65	35.02	113.3	16.67	42.18	170.21	229.06
1996	26.56	51.03	40.07	117.6	16.79	42.18	165.75	224.72
1997	26.47	50.43	38.46	115.3	16.85	42.25	167.89	226.99
1998	26.21	50.17	35.84	112.2	16.98	42.64	170.74	230.36
1999	26.02	50.69	45.24	121.9	17.05	42.87	160.73	220.65

2000	25.80	49.87	51.48	127.1	17.25	43.08	155.09	215.42
2001	25.66	49.07	48.59	123.3	17.39	43.26	158.64	219.29
2002	25.20	47.30	41.4	113.9	17.51	43.56	167.65	228.72
2003	25.14	48.66	99.47	173.2	17.64	43.66	108.07	169.37
2004	24.98	45.46	36.82	107.2	17.60	43.82	173.94	235.36
2005	24.90	46.02	44.64	115.5	17.75	43.81	165.48	227.04
2006	24.39	45.90	41.736	112.0	18.23	44.04	168.36	230.63
2007	24.27	46.11	42.044	112.4	18.35	44.23	167.64	230.22
2008	23.61	44.74	39.387	107.7	19.03	44.34	171.58	234.94
2009	22.95	43.36	36.730	103.0	19.70	44.44	175.51	239.66
2010	23.79	42.33	29.61	95.73	18.89	44.57	183.49	246.95
2012	23.87	41.69	33.3	98.86	18.84	44.62	180.34	243.80

Due to regular increase in the population of the state, fields are being regularly subdivided resulting in regularly reducing the value of average field size. Accordingly, changes in number and area of operational holdings and the average size of the field in the state is shown in Table 3.5.

Table 3.5 Variation of operational land holdings in the state

Year	**Average**	**Marginal <1.0 ha**		**Small 1 to 2 ha**		**Semi-medium 2 to 4 ha**		**Medium 4 to 10 ha**		**Large > 10.0 ha**		**Total**	
	Size (ha)	**Numbers (millions)**	**Area (mh)**	**Numbers (millions)**	**Area (mh)**	**Numbers (millions)**	**Area (mh)**	**Numbers (millions)**	**Area (mh)**	**Numbers (millions)**	**Area (mh)**	**Numbers (millions)**	**Area (mh)**
1970	5.46	0.94	0.46	0.69	1.00	0.77	2.24	0.80	5.02	0.52	11.62	3.73	20.34
1975	4.65	1.32	0.58	0.80	1.15	0.87	2.48	0.87	5.49	0.51	10.59	4.37	20.30
1980	4.44	1.32	0.63	0.88	1.27	0.92	2.62	0.89	5.52	0.41	9.88	4.49	19.93
1985	4.34	1.36	0.64	0.92	1.33	0.98	2.79	0.99	6.15	0.50	9.68	4.74	20.59
1990	4.11	1.52	0.73	1.02	1.47	1.06	3.02	1.02	6.33	0.49	9.42	5.11	20.97
1995	3.96	1.61	0.78	1.09	1.57	1.12	3.19	1.06	6.62	0.49	9.10	5.36	21.25
2000	3.65	1.85	0.89	1.21	1.74	1.20	3.42	1.10	6.81	0.46	8.39	5.82	21.25
2005	3.38	2.07	1.02	1.32	1.90	1.26	3.57	1.10	6.80	0.43	7.66	6.19	20.94

For Ramgarh dam, the land use of the catchment area is shown in Table 3.6. It consists of 17.25% barren, culturable waste and fallow land having contributing effect to runoff, and 82.75% agriculture, forest, residential areas, roads, mining, etc. having reducing effect to the runoff in the year 2010.

Table 3.6 Land utilization of the Ramgarh dam catchment (%)

Year	Contributing effect				Reducing effect			
	Barren	Culturable waste	Fallow	Total	Non-Ag. uses	Forest +pasture +tree crops	Net area sown	Total
1978	14.09	2.86	12.65	29.60	4.09	18.66	47.65	70.40
1980	13.82	2.83	11.55	28.20	4.01	19.79	48.00	71.80
1983	16.45	3.77	10.16	30.37	4.01	21.16	44.46	69.63
1985	15.38	4.09	7.56	27.03	4.19	21.42	47.35	72.97
2003	8.64	2.64	14.57	25.84	4.85	27.83	41.48	74.16
2005	4.93	3.30	13.98	22.20	7.11	14.43	56.25	77.80
2010	5.38	3.44	8.44	17.25	7.35	14.22	61.17	82.75

(**Source:** Table 4.5 of Statistical outlines of Jaipur District of various years and Statistical Abstract published by Directorate of Economics and Statistics, Rajasthan)

For Bisalpur dam, the land use of the catchment area is shown in Table 3.7, consisting of 30.97% barren, culturable waste and fallow land having contributing effect to runoff, and 69.03% agriculture, forest, residential areas, roads, mining, etc. having the reducing effect on the runoff in the year 2012.

Table 3.7 Land Utilization of the Bisalpur Dam Catchment (%)

Year	Contributing effect				Reducing effect			
	Barren	Culturable Waste	Fallow	Total	Non-Ag. Uses	Forest+ pasture+ tree crops	Net area sown	Total
1978	16.03	21.41	8.15	45.59	5.43	17.91	31.07	54.41
1980	15.94	21.52	8.44	45.90	5.53	18.09	30.48	54.10
1985	14.49	19.66	7.66	41.80	5.84	18.50	33.85	58.20
1992	14.51	16.86	8.07	39.45	4.99	19.27	36.30	60.55
1995	12.88	16.14	7.93	36.94	5.28	20.21	37.57	63.06
2000	12.06	15.61	10.76	38.43	5.60	21.06	34.91	61.57
2003	11.87	15.04	12.08	38.99	5.71	21.30	34.01	61.01
2006	11.37	12.59	6.63	30.58	5.76	21.98	41.68	69.42
2008	11.22	12.64	7.44	31.30	5.78	22.02	40.89	68.70
2010	12.10	12.68	9.12	33.90	6.13	20.71	39.26	66.10
2012	12.15	11.50	7.32	30.97	6.08	20.78	42.17	69.03

(**Source:** Table 4.5 of the statistical outline of Ajmer, Bhilwara, Chittorgarh and Jaipur Districts; Table 13.3 of Statistical Abstract-2001, 2003, 2010, and 2012 published by Directorate of Economics and Statistics, Rajasthan; and Rajasthan Agricultural statistics at a glance for the year 2012-13-October 2014 published by Commissionerate of Agriculture, Rajasthan)

3.2.5 Ground Water Levels

Pre and Post monsoon groundwater levels below ground levels of the year 1984 to 2013 (30 years) of 9628 gauge sites of the state have been obtained from Senior Hydro-Geologist (D.S.P.C.), Ground Water Department, Jodhpur vide his letter no. 52 dated 23.04.2015, under Right to Information Act-2005. Data was also obtained from Senior Hydro-Geologist (Survey and Investigation), Ground Water Department, Jaipur vide his letter no. F./SHG/Estt./GWD/Jaipur/2015/2846 dated 17.03.2015. It is not possible to attach the data of 9628 gauge sites of the last 30 years. However, year wise average pre and post monsoon water levels of the state are shown in Table 3.8, and average pre and post-monsoon groundwater levels below the ground level of districts and basins are shown in Appendix 2(b).

Table 3.8 Year wise average depth to water table below ground level of the state

S.N.	Year	Pre-monsoon Avg. GWL BGL (m)	Post-monsoon Avg. GWL BGL (m)	Difference of Avg. GWL BGL (m)
1	1984	18.0	17.3	0.68
2	1985	19.1	17.5	1.59
3	1986	19.6	19.1	0.54
4	1987	20.1	19.9	0.21
5	1988	21.9	19.4	2.42
6	1989	21.0	19.1	1.90
7	1990	21.6	18.5	3.07
8	1991	20.3	18.6	1.67
9	1992	20.9	17.7	3.20
10	1993	19.9	18.4	1.46
11	1994	20.8	17.4	3.39
12	1995	19.9	17.5	2.44
13	1996	19.6	19.5	0.05
14	1997	18.8	16.5	2.27
15	1998	18.6	17.3	1.33
16	1999	19.7	18.4	1.25
17	2000	20.0	19.1	0.89
18	2001	21.3	18.3	3.00
19	2002	21.2	21.3	-0.03
20	2003	23.5	19.3	4.18
21	2004	22.5	19.8	2.69
22	2005	22.1	19.5	2.61
23	2006	22.9	19.2	3.61
24	2007	21.9	20.2	1.71
25	2008	22.9	21.3	1.64

26	2009	23.4	21.9	1.51
27	2010	24.6	20.1	4.48
28	2011	23.0	18.8	4.20
29	2012	22.1	18.6	3.49
30	2013	21.8	20.2	1.64
	Min.	18.0	16.5	-0.03
	Max.	24.6	21.9	4.50

The groundwater table of the state is showing an improvement after the year 2010. During the year 2002, post monsoon water table decreased due to scanty rainfall leading to more withdrawal than recharge even during the monsoon period.

3.2.6 Population Data

Population data of the state have been obtained from Department of Economics and Statistics. The decadal population of the country, state, and Jaipur district has been shown in Table 3.9.

Table 3.9 Population data

Year	India		Rajasthan State			Jaipur District		
	Millions	% Decadal increase	Millions	% Share in country	% Decadal increase	Millions	% Share in state	% Decadal increase
1901	238.4		10.3	4.3				
1911	252.1	5.7	11.0	4.4	6.8			
1921	251.3	-0.3	10.3	4.1	-6.4			
1931	279.0	11.0	11.7	4.2	13.6			
1941	318.7	14.2	13.9	4.4	18.8			
1951	361.1	13.3	16.0	4.4	15.1			
1961	439.2	21.6	20.2	4.6	26.3			
1971	548.6	24.9	25.8	4.7	27.7	2.5	9.6	
1981	683.3	24.6	34.3	5.0	32.9	3.4	10.0	37.9
1991	846.4	23.9	44.0	5.2	28.3	4.7	10.7	38.0
2001	1028.7	21.5	56.5	5.5	28.4	5.3	9.3	11.2
2011	1210.2	17.6	68.6	5.7	21.4	6.6	9.7	26.3
2021	1394.0	15.2	82.6	6.2	20.4	8.0	9.7	21.1

(Source: Population facts and figures-Rajasthan June 2008; Table 1.32 of Some facts about Rajasthan-September 2012; Statistical Abstracts; and Basic Statistics of Rajasthan published by Directorate of Economics and Statistics, Rajasthan)

3.3 Methodology

To test the temporal variation of inflow to the dams of Rajasthan state, t-test and Chi-Square test has been applied. Detailed computations have been done for Exceedance Probability, which is mentioned as Dependability as per prevailing nomenclature in Government of Rajasthan. This can also be termed as reliability. Performance measures and performance statistics have been applied. Time series analysis and sequential cluster analysis has been done to determine the critical year, which divides two consecutive nonoverlapping epochs- pre-disturbance and post-disturbance (Wang et al. 2001). Regression analysis and Cosine Amplitude Method (CAM) of sensitivity analysis have been used to find out the most effective input parameters on the output parameters (Sayadi et al. 2013). Trend analysis and regression analysis can be used to find the various correlations (Kumar et al. 2014, Parmar et al. 2014). These techniques have been used in this study.

3.3.1 Sampling

Cluster sampling method has been used to take the sample for this study. Further special analyses have been done for Ramgarh and Bisalpur dams. The major and medium dams are situated in eleven river basins. Therefore, the test has been applied for these eleven river basins only out of total fifteen river basins in the state. Four river basins do not have any major or medium dam within their catchment area. By the storage capacity of the basins, weights have been considered to arrive at weighted dependability. The Government of Rajasthan (Water Resources Department 2002, State Water Resources Planning Department 2011) has declared expected dependability as 50% for minor dams and 75% for medium and major dams. Observed dependabilities have been computed for each of 115 selected dams. Furthermore, area-sampling method has been used to select 33 dams of the Tonk District to conduct performance analysis.

3.3.2 Inflow Trend Analysis

Rainfall and water inflow series are plotted to see the temporal variation of rainfall and inflow to the dams or reservoirs (Yildirim *et al.* 2011). The results of these series reveal the trend of inflow and precipitation based on real time data. Dependability is the exceedance probability, which ensures the certain percentage of time when inflow will exceed the desired quantum of water (Liu et al. 2005, Mantel et al. 2010, Chang et al. 2011; Kim et al. 2012). It can be computed as shown below:

$$D_n = \left(\frac{n}{m+1}\right) \times 100 \tag{3.1}$$

Where Dn= dependability, n= number of years when inflow exceeds the design capacity of the dam, m= total number of years of observation. Daily precipitation data are analyzed to obtain average annual rainfall, average monthly rainfall, and average daily rainfall in rainy days etc. (Erturk et al. 2014)

3.3.3 Formulation and Testing of Hypothesis

Change in water inflow can be tested by the formation of the null hypothesis and testing the same. In this study, null hypotheses claiming no change in expected dependability are formed and tested with the Chi-Square test.

$$\chi^2 = \sum_{i=1}^{n} (O_i - E_i)^2 / E_i \tag{3.2}$$

Where χ^2= computed Chi-Square value, O_i= observed weighted dependability, E_i= expected weighted dependability and n= total number of years i.e. sample size. To test the hypothesis computed Chi-Square value is compared with the tabulated Chi-Square value. After testing the hypothesis, it can be inferred whether there is a change in expected dependability and inflow to the dams or not.

In case n<30, the t-test is applied to check whether the inflow is equal to certain acceptable value. The t-value is computed as

$$t = \frac{\bar{x} - \mu}{\sigma} \text{ ; Where } \sigma = \frac{S}{\sqrt{n}} \text{; where } S = \sqrt{\frac{\sum_{i=1}^{n} (x - \bar{x})^2}{n-1}} \tag{3.3}$$

Where t = computed t-value, $\sigma =$ S.E.= standard error of population, S= standard error of sample, and n= total number of years i.e. sample size, $\bar{x}$ = sample mean value. This computed t-value is compared with the critical t-value obtained from standard t-distribution table. In case n>30, Z-test has been applied.

3.3.4 Performance Measures and Performance Statistics

Hashimoto et al. (1982) and Loucks and van Beek (2005) as cited by Solis et al. (2011) used performance criteria to characterize the hydrologic scenario viz. reliability, vulnerability, and resilience. Reliability is the frequency with which a water demand is satisfied over the simulation period, which can be described as below:

$$Reliability\,(\%) = \frac{n}{m} \times 100 \tag{3.4}$$

Where, m= simulation period and n= frequency with which a water demand is satisfied.
Vulnerability is the magnitude of water delivery deficits over the period of Simulation as a percentage of the demand (average deficit over the period of simulation as percent of total demand), which can be described as below:

$$Vulnerability\,(\%) = \frac{\text{Average Deficit}}{\text{Demand}} \times 100 \tag{3.5}$$

Resilience is the probability that a deficit period will be followed by a successful period during the simulation period, which can be described as below:

$$Resilience\,(\%) = \frac{n'}{m'} \times 100 \tag{3.6}$$

Where n'= number of years when deficit period is followed by a successful period and m'= total number of deficit years.
Sustainability index can be used to summarize the three performance criteria discussed above. The geometric average of reliability, resilience, and vulnerability is termed as sustainability index, which can be described as below:

$$Sust = \left[Rel \times Res \times \left(1 - Vul\right)\right]^{\frac{1}{3}} \tag{3.7}$$

Maximum deficit (%) is also calculated for the simulation period and the year corresponding to the maximum deficit is determined. The performance indices were also used by Hashimoto et al. (1982) and Loucks (1997) as cited by Carrasco et al. (2012).
Theoretical inflow has been computed by employing Thiessen polygon and Strange's Table techniques (Subramanya 2013, Reddy n.d., Sharma and Sharma, Punmia, Satyanarayana Murty 2006, Water Resources Department 2002, 2011). Comparison of theoretical and observed inflow is based on the Nash-Sutcliffe Efficiency- Ens (Nash and

Sutcliffe 1970; Hayashi *et al.* 2008; Sang *et al.* 2010; Pundik *et al.* 2014). Some other statistical parameters are also employed for judging the performance of simulation method.

$$SSE = \sum_{i=1}^{N} (O_i - S_i)^2 \tag{3.8}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (O_i - S_i)^2} \tag{3.9}$$

$$MAPE(\%) = \frac{1}{N} \sum_{i=1}^{N} \frac{|O_i - S_i|}{O_i} \times 100 \tag{3.10}$$

$$MAE = \frac{1}{N} \sum_{i=1}^{N} \frac{|O_i - S_i|}{O_i} \tag{3.11}$$

$$R = \left(\frac{\sum_{i=1}^{N} \left((O_i - \overline{O})(S_i - \overline{S}) \right)}{\sqrt{\sum_{i=1}^{N} (O_i - \overline{O})^2 \sum_{i=1}^{N} (S_i - \overline{S})^2}} \right) \tag{3.12}$$

$$NSE = 1 - \frac{\sum_{i=1}^{N} (O_i - S_i)^2}{\sum_{i=1}^{N} (O_i - \overline{O})^2} \tag{3.13}$$

$$RSR = \frac{RMSE}{\sqrt{\frac{1}{N} \sum_{i=1}^{N} (O_i - \overline{O})^2}} \tag{3.14}$$

$$NMBE(\%) = \frac{1/N \sum_{i=1}^{N} (S_i - O_i)}{1/N \sum_{i=1}^{N} O_i} \times 100 \tag{3.15}$$

Where O_i and S_i denote the observed values and simulated values; $\overline{O}$ and $\overline{S}$ represent the mean observed and mean simulated values respectively. N= total number of data; SSE= sum of square error; RMSE= root mean square error; MAPE= mean absolute percentage error; MAE= mean absolute error; R= Karl Pearson's correlation coefficient; NSE= Nash-Sutcliffe Efficiency; RSR= RMSE to observation's standard deviation ratio; NMBE= normalized mean bias error.

3.3.5 Determination of Critical Year

Time Series Analysis has been carried out to find out the possible critical years (Bolgov et al. 2012, Dourte et al. 2012). Further, the critical year has been determined by Sequential Cluster Analysis. The critical year divides two consecutive nonoverlapping epochs- pre-disturbance and post-disturbance. The minimum sum of squared deviations for the hydrological series before and after the possible critical years gives the unique critical year (Wang *et al.* 2001).

$$V_n = \sum_{i=1}^{n} (O_i - \overline{O_n})^2; \qquad V_{N-n} = \sum_{i=n+1}^{N} (O_i - \overline{O_{N-n}})^2 \tag{3.16}$$

Where O_i = observation of i^{th} year; $\overline{O_n}$ = mean of first 'n' observations; $\overline{O_{N-n}}$ = mean of (n+1) to N^{th} observation; V_n= squared deviation for the hydrological series before the possible critical year; V_{N-n}= squared deviation for the hydrological series after the possible critical year.

3.3.6 Various Factors, their Trend Analysis, and Correlation Matrix

Graph of various factors has been plotted against the time scale. The trend analysis gives us an idea about the direction and rate of change of various factors, which may influence the inflow to the dams (Yates *et al.* 2009, Kravtsova *et al.* 2009, Khaustov and Redina 2010). A correlation matrix (N x N) has been prepared to identify the mutual correlation of each of the parameters and correlation of each parameter with the inflow (output).

3.3.7 Regression Analysis and Determination of Principal Components

Various trends can be plotted for rainfall pattern, climatic factors, GWL BGL, population density etc. with actual inflow. LULC trends and correlations can also be plotted to assess the effect of anthropogenic changes over catchment areas (Liu et al. 2005, Danil'yan 2005; Danil'Yan *et al.* 2006, Draper and Kundele 2007, Shah and Kuma 2008, Mantel *et al.* 2010, Shiklomanov *et al.* 2011, Lemeshko 2011, Yildirim *et al.* 2011, Chang *et al.*

2011, Wang *et al.* 2011, Handhong *et al.* 2012, Kumar et al. 2014). The correlation coefficient (r) was used to measure the degree of fitness of the relationship between model parameters and basin properties to find out which basin property is most closely related to the model parameter (Piman and Babel 2012, Parmar et al. 2014).

Regression analysis is performed between independent (x) and dependent variables (y). The Karl Pearson's correlation coefficient (r) is computed as

$$r = \frac{\sum_{i=1}^{n}\left(x_{i}-\bar{x}\right)\times\left(y_i-\bar{y}\right)}{\sqrt{\sum\left(x_i-\bar{x}\right)^2}\times\sqrt{\sum\left(y_i-\bar{y}\right)^2}} \tag{3.17}$$

The strength of relationship is tested by applying t-test with the help of computed r-value. The Hypothesis is formed as

H_0: r=0

H_1: $r \neq 0$ for a two-tailed test or it may be framed for a one-tailed test.

$$t_r = \frac{r}{\sqrt{\frac{\left(1-r^2\right)}{n-2}}} \tag{3.18}$$

Where t_r= computed value of't'; r = correlation coefficient as computed in equation 3.17; n= number of observations. Computed value of t_r is compared with the tabulated value of t (t_c) to test the hypothesis.

3.3.8 Cosine Amplitude Method of Sensitivity Analysis and Determination of Principal Components

Sensitivity analysis using Cosine Amplitude Method (CAM) is used for finding the relative importance of the factors responsible for the observed output. This technique was employed to find out the most effective input parameters on the output parameters. (Sayadi *et al.* 2013). Firstly, data are normalized by employing the formula

$$x_n = \frac{\left(x_i - x_{\min}\right)}{\left(x_{\max} - x_{\min}\right)} \tag{3.19}$$

Where x_n= normalized value of i^{th} observation; x_i= value of i^{th} observation; x_{min}= minimum value in all observations; x_{max}= maximum value in all observations.

The strength of this relation (R_i) is calculated by

$$R_i = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{\left(\sum_{i=1}^{n} x_i^2 \sum y_i^2\right)}} \tag{3.20}$$

Where x_i= value of normalized i^{th} observation of the input parameter; y_i= value of normalized i^{th} observation of the output parameter.

Many researchers used various methods of sensitivity analysis for varied purposes, noticeable of them are Cosine Amplitude Method (CAM), Principal Component Analysis, MLR, Profile Method, Partial Derivative (PaD) Method, Perturb Method, Weights and Improved Weights Method etc (Jain et al. 2008, Wang et al. 2008, Sang et al. 2010, Karamouz et al. 2010, Carrasco et al. 2012)

3.3.9 Multiple Linear Regressions (MLR) for generation of Inflow Equation

Multiple linear regression analysis has been done using the Excel software employing add-ins of the analysis tool pack, which provides data analysis tools for statistical and engineering analysis. The results of MLR have been correlated with observed values to assess the significance of (R) correlation coefficient; t-test has been applied. Runoff equation using multiple linear regressions was used by Jain et al. (2008) to compute runoff using rainfall and ground water table data.

$$Inflow = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \beta_3 * x_3 + \beta_4 * x_4 + \beta_5 * x_5 + \beta_6 * x_6 \tag{3.21}$$

3.3.10 Regression Analysis and Determination of Factors Responsible for Principal Components

Regression analyses have been conducted to find out the factors, which may be considered responsible for principal components.

3.4 Methodology Flow Chart

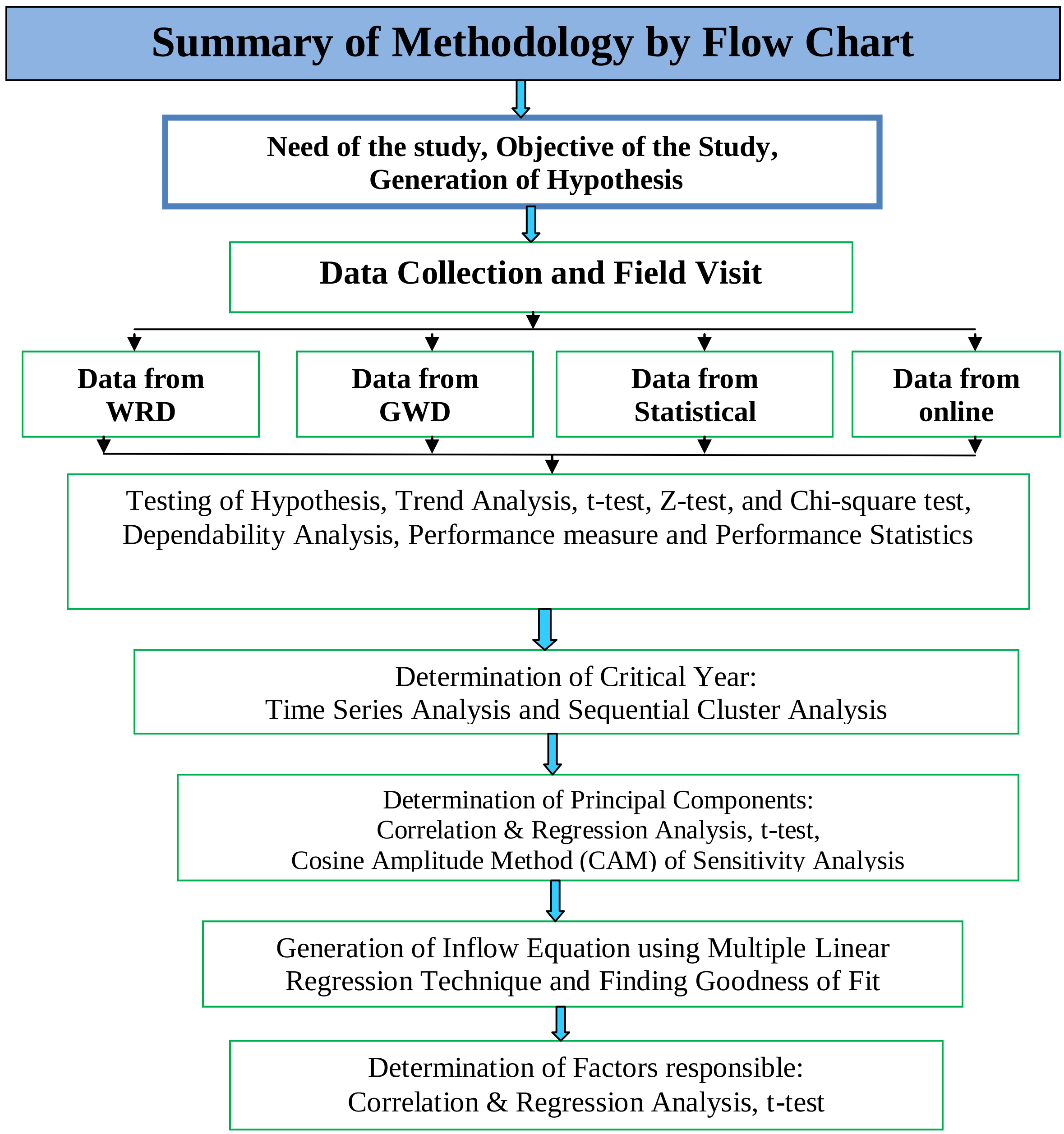


Fig. 3.3 Methodology Flow Chart

3.5 Underlying Assumptions

Following assumptions are made for the present study, which is described below:

- Regular data of reasonable nos. of gauge discharge sites are not recorded by Water Resources Department of the state. Therefore, theoretical inflows have been computed based on Strange's table, which assumes the whole catchment of the dam as uniform and accordingly some constant is assumed.
- Monsoon rainfall during 15 June to 30 September is considered as annual rainfall, as approx. 90% of the annual rainfall occurs during monsoon season.
- Inflow data recorded during monsoon period is assumed as annual inflow.
- Some data, which are not available, have been interpolated.
- There are thousands of water bodies in the state. To study the temporal variation of inflow to the dams of the Rajasthan state, only medium and major dams have been considered. These dams have large amount of storage capacity. Important drinking water supply schemes in the state are mainly dependent on these dams. Therefore, it is assumed that medium and major dams represent the whole state.
- Mean of climatic data of all stations within the catchment has been used, assuming the uniform climatic conditions.
- Even though residential areas, roads, pavements are smooth surface, but for surface runoff it is assumed rough/obstructed catchment due to poor drainage conditions and resulting water accumulation at various points leading to reducing effect on surface runoff.
- It is assumed that small land holdings increase the roughness the catchment due to increased network of boundaries.
- Forest, pasture, and tree crops increase the soil moisture and infiltration. It is assumed that these land uses also increase the surface roughness, which leads to less surface runoff.
- Agricultural activities loose the upper crust of the catchment. Therefore, it is assumed that these land use have reducing effect on the surface runoff.
- Barren, culturable waste and fallow land provide smooth surface. Therefore, it is assumed that these land uses have contributing effect on surface runoff.

4 TEMPORAL VARIATION OF INFLOW TO THE DAMS OF RAJASTHAN STATE

4.1 Formulation and Testing of Hypothesis

4.2 Performance Study and Performance Statistics

4.3 Determination of Critical Year

- 4.3.1 Determination of Possible Critical Years: Time Series Analysis
- 4.3.2 Determination of Critical Year: Sequential Cluster Analysis

4.4 Various Parameters and their Trends

- 4.4.1 Rainfall and other Climatic Parameters
- 4.4.2 Land Use Land Cover Changes
- 4.4.3 Ground Water Levels
- 4.4.4 Population Growth
- 4.4.5 Various Parameters, Trend Lines and their Rate of Changes
- 4.4.6 Correlation Matrix

4.5 Determination of Principal Components

- 4.5.1 Regression Analysis
- 4.5.2 Cosine Amplitude Method

4.6 MLR for Generation of Inflow Equation

4.7 Regression Analysis and Determination of Factors Responsible for Principal Components

CHAPTER-4

TEMPORAL VARIATION OF INFLOW TO THE DAMS OF RAJASTHAN STATE

Rajasthan is a semi-arid state where, only 25% of time three months in a year, rainfall takes place which is also erratic and spatial in nature. There are average 35 rainy days in a year. Therefore, water availability in surface water reservoirs plays an important role in state water resources planning and management. Conjunctive use of surface and groundwater becomes essential when critical (very small) total runoff values are maintained over several successive years, which is also termed as critical N-year groups (Bolgov et al. 2012). This type of situation arises in many dams of the state, which is also reflected in the inflow data of Ramgarh and Bisalpur dams.

Temporal variation of inflow to the dams of Rajasthan State has been shown in Fig. 4.1. Year wise inflow data have been shown in Table 4.1. It is evident that the water inflow trend to the dams is declining. Inflow to the dams was around 74% during 1990-1997 which has reduced to around 60% during 1998-2013. The average inflow by last 24 years data (1990-2013) is 65%. Fig. 4.1 shows that there was a slight improvement in inflow during 2010-2013. The percent inflow was nearly constant around 62-78% during first time segment (1990-1997), it was very less during second time segment (1998-2005), while it is improving during third time segment (2006-2013) primarily because of more than average rainfall. It can be observed from Fig. 4.1(b) that inflow during third-time segment is near to second time segment during low annual rainfall, and it is touching to the first-time segment during high annual rainfall.

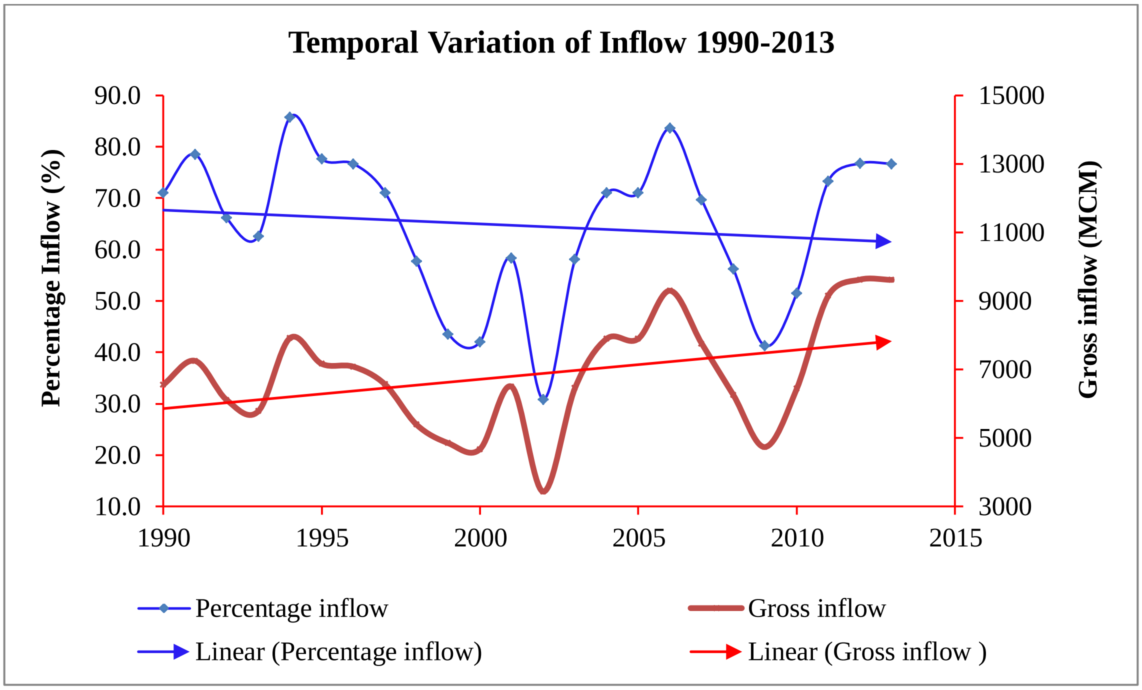
Total storage capacity of the state increases with the construction of new storage reservoirs in the state. Total utilizable water availability in the state is 16050 MCM (Table 1.1 Column 3). The storage capacity of new dams is designed as per the hydrological computations, which is considered as expected inflow to the dam, without intercepting the inflow to the existing dams (Table 4.1 Column 2). Sustainability of the projects are considered when they perform as per design dependability. Total inflow to the dams of the state in the year 1992 was 6109 MCM out of total expected inflow of

9233 MCM, yielding 66.2% inflow, while it was 6433 MCM against total expected inflow of 12486 MCM in the year 2010, yielding only 51.5 % inflow. This infers that there was lesser inflow to the dams of the state in the year 2010 than the year 1992 even after getting a more total inflow of water. Therefore, percentage inflow is considered for analysis of inflow to the dams of Rajasthan state.

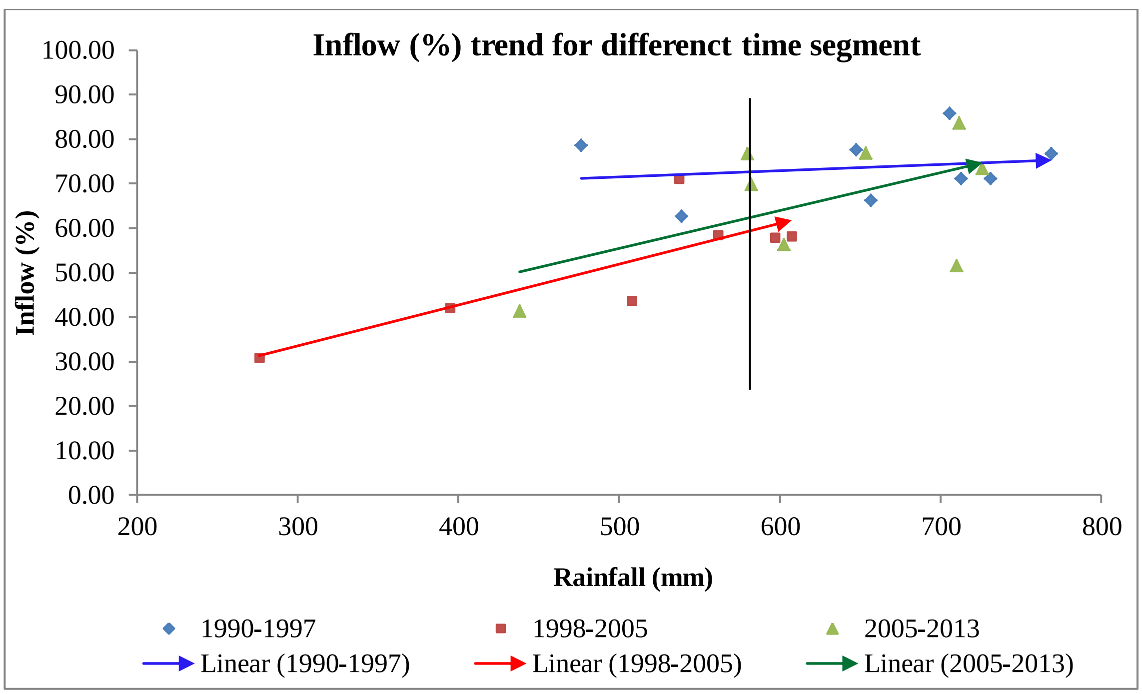
Inflow (%) with respect to dependability is plotted as shown in Fig 4.2. 1998-2003 and 2008-2010 may be considered as the critical N-years groups when inflow was below 60% of the capacity. The graph shows that there was only 30.9% inflow (which is 100% reliable) during 2002 (which was the year of the maximum deficit). Dependability, reliability and exceedance probability are considered similar in a broad sense. 100% reliability is considered for drinking water projects (IS 5477 Part-3:2002).

Table 4.1 Year wise inflow (%) to the dams of Rajasthan state

S.N.	Year	Total gross storage (MCM)	Total inflow (MCM)	Inflow (%)	Inflow in descending order	D_n
1	1990	9233	6556	71.0	85.8	4.0
2	1991	9233	7251	78.5	83.6	8.0
3	1992	9233	6109	66.2	78.5	12.0
4	1993	9233	5780	62.6	77.6	16.0
5	1994	9233	7919	85.8	76.78	20.0
6	1995	9233	7165	77.6	76.71	24.0
7	1996	9233	7082	76.7	76.7	28.0
8	1997	9233	6564	71.1	73.35	32.0
9	1998	9321	5386	57.8	71.1	36.0
10	1999	11121	4847	43.6	71.0	40.0
11	2000	11121	4674	42.0	71.0	44.0
12	2001	11121	6495	58.4	71.0	48.0
13	2002	11121	3433	30.9	69.7	52.0
14	2003	11121	6459	58.1	66.2	56.0
15	2004	11121	7897	71.0	62.6	60.0
16	2005	11124	7898	71.0	58.4	64.0
17	2006	11124	9298	83.6	58.1	68.0
18	2007	11124	7756	69.7	57.8	72.0
19	2008	11124	6252	56.2	56.2	76.0
20	2009	11475	4735	41.3	51.5	80.0
21	2010	12486	6433	51.5	43.6	84.0
22	2011	12486	9158	73.3	42.0	88.0
23	2012	12535	9624	76.8	41.3	92.0
24	2013	12535	9615	76.7	30.9	96.0
			Average=	65.0		



(a) Water inflow trend



(b) Water inflow trends for different time segments

Fig. 4.1 Temporal variations of water inflow to the dams of Rajasthan state

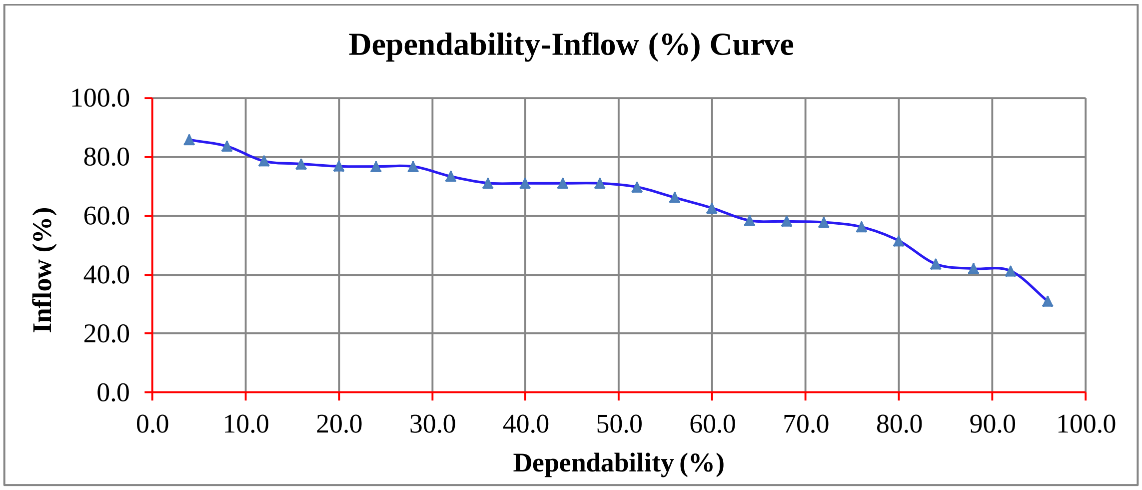


Fig. 4.2 Variations of inflow with dependability in the dams of Rajasthan state

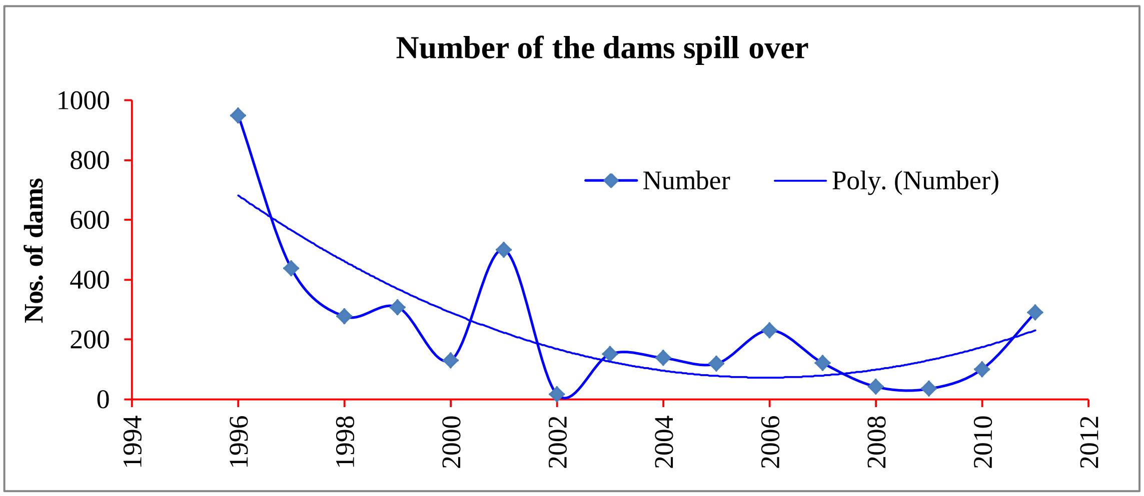


Fig. 4.3 Number of dams spillover in the state

The number of dams spillover reduced after the year 2001 as shown in Fig. 4.3, which shows a reduced inflow to the dams of Rajasthan State.

4.1 Formulation and Testing of hypothesis

(1) T-test: T-test can be applied to check the sample mean for size of the sample n<30. In this case, we want to check the average inflow and sample size is n=24 (<30), therefore t-test has been applied.

H_o (Null Hypothesis): $\mu = 75$

H_1 (Alternate Hypothesis): $\mu < 75$

$\bar{x} = 65$; S= 14.58; SE= 2.98; t= 3.36

t_c for 23 degree of freedom (n-1) for left tail test at 5% significance level= 1.714

$t>t_c$; therefore null hypothesis is rejected and alternate hypothesis is accepted, i.e. dams are getting less than the desired 75% inflow of water.

(2) Chi-square-test: Chi-square test can be applied to test, whether there is any effect of any change on expected result. Therefore, Chi-square test has been applied to test whether there is any effect of time series (A=10 year/B=20 year) on the dependability of dams of the state or not.

Table 4.2 Testing of hypothesis (Basin wise): Chi-square test

S.N.	Name of Basin	Capacity of the Basin (MCM)	E_i %	O_i %	O_i %	Chi^2	Chi^2
				(A)	(B)	(A)	(B)
1.	Banas	2243	11.94	6.25	4.16	2.71	5.08
2.	Shekhawati	9	0.05	0.00	0.00	0.04	0.05
3.	Ruparail	27	0.14	0.01	0.00	0.12	0.14
4.	Banganga	148	0.79	0.12	0.00	0.57	0.79
5.	Gambhir	147	0.78	0.21	0.05	0.42	0.69
6.	Parbati	16	0.08	0.02	0.00	0.05	0.08
7.	Sabi	24	0.13	0.00	0.00	0.13	0.13
8.	Chambal	3414	18.17	10.91	9.77	2.91	3.89
9.	Mahi	2791	14.86	14.42	9.30	0.01	2.08
10.	Luni	533	2.84	1.27	0.67	0.86	1.65
11.	West Banas	39	0.21	0.14	0.08	0.02	0.08
	Total	9391	50.00	33.36	24.02	7.84	14.66

Chi-square value for 11 numbers of basins, d_1=10 (11-1); d_2= (2-1) and $d=d_1xd_2$=10 degree of freedom, at the 5% level of significance is 18.307. The computed value is 22.5 (7.84+14.66), which is more than the critical value, this infers that there is a change in the expected dependability with time series. **Observed dependability of the state surface water resources has reduced to 33.36% for 20 years data series and 24.02% for 10 years data series against expected dependability 50%. This shows a sign of temporal variation of inflow to the dams of Rajasthan State.**

4.2 Performance Study and Performance Statistics

On the basis of year wise inflow data (Table 4.1) hydrological performance of the dams is measured as below. The historical minimum value of the inflow was observed in the year 2002.

Reliability: 29.17%

Resilience: 23.53%

Vulnerability: 15.52%

Maximum deficit: 44.13% (2002)

Sustainability: 38.70%

32 dams, comprising minor, medium and major dams, of Tonk District have been selected through area sampling method. Actual inflow (at 50% dependability) as percentage of design capacity is categorized on interval scale and health status of the dam has been assessed (Table 4.3). Only 17 dams are performing safe; 6 dams are put in critical scale; and 9 dams are under hyper-critical scale. In brief, it can be said that 17 dams (around 50% dams) are getting water more than 75% of their design capacity in Tonk district. Theoretical values have been computed and compared with observed values. Performance statistics of the computed values shows that the theoretical values are not in correlation with the actual observed values. Therefore, it is inferred that the Strange's table method of computation of theoretical yield should not be used for inflow assessment of the dams (Table 4.4).

Table 4.3 Performance study of the dams of Tonk district

S. N.	Name of Dam	Type of Dam	Design Parameters		Present Theoretical Yield based on Rainfall(MCM) data of last 30 years				Yield based on Actual Storage(MCM)				Mean Rainfall (based on last 30 years)	D_n for design capacity	Actual yield (50% dep.) in % of design capacity col. 10/4	Health Status of Dam Safe/ Semi Critical/Critical/ Hyper Critical
			Capacity (MCM)	Mean Rainfall (mm)	50% Dep.	75% Dep.	90% Dep.	Mean	50% Dep.	75% Dep.	90% Dep.	Mean				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Bisalpur #	Major	938.83	588	607.0	338.0	243.3	708.6	726.1	174.6	106	977.6	520	40.91	77.34%	Safe
2	Galwa	Major	48.74	724	20.36	16.00	4.37	25.54	32.85	16.31	10.5	30.73	507	25.00	67.4%	Critical
3	Tordi Sagar	Major	47.14	686	15.17	4.53	2.73	45.98	10.11	2.85	1.15	17.32	403	16.67	21.45%	Hyper Critical
4	Mashi	Medium	48.15	483	59.80	30.56	7.96	91.01	22.59	13.42	0.00	26.81	461	29.17	46.91%	Hyper Critical
5	Chandsen	Medium	14.70	569	0.96	0.45	0.18	2.22	3.61	1.73	0.42	5.46	371	12.50	24.57%	Hyper Critical
6	Moti Sagar	Medium	12.89	635	4.87	1.85	0.95	6.15	11.03	6.11	3.20	9.34	453	41.67	85.60%	Safe
7	Dakhiya	Minor	8.58	584	1.83	0.69	0.36	2.31	3.51	0.70	0.00	3.91	453	17.65	40.92%	Hyper Critical
8	Kirawal Sagar	Minor	6.51	569	1.96	0.92	0.37	4.56	2.11	0.84	0.51	2.79	371	16.67	32.43%	Hyper Critical
9	Shahodra	Minor	6.51	569	8.07	3.29	0.70	8.98	5.41	1.00	0.00	4.00	460	25.00	83.04%	Safe
10	Shyodanpura	Minor	6.29	864	1.50	0.72	0.34	3.65	4.87	2.97	0.70	4.43	466	29.17	77.48%	Safe
11	Chandlai	Minor	4.53	610	3.68	1.86	1.10	4.29	2.55	0.23	0.01	2.14	594	12.50	56.25%	Critical
12	Doulat Sagar	Minor	4.50	559	2.39	1.10	0.38	2.86	2.15	1.22	0.09	2.41	499	14.29	47.80%	Hyper Critical
13	Bidoli	Minor	4.11	635	3.68	1.86	1.10	4.29	3.68	3.32	1.84	3.67	565	25.00	89.62%	Safe
14	Panwad Sagar	Minor	4.06	584	0.23	0.13	0.03	0.39	2.55	0.73	0.38	2.49	368	38.89	62.76%	Critical
15	Thanwla	Minor	3.41	584	0.48	0.26	0.07	0.80	1.93	18.07	0.27	1.97	367	27.27	56.55%	Critical
16	Ghareda Sagar	Minor	2.88	508	2.38	1.38	0.60	2.70	2.38	1.33	0.93	2.16	641	31.58	82.51%	Safe
17	Ramsagar L. Harisingh	Minor	2.86	569	0.33	0.11	0.03	0.69	2.07	1.20	0.65	1.98	331	40.00	72.28%	Critical
18	Soonthra	Minor	2.78	711	1.45	0.59	0.15	1.94	2.27	1.92	0.89	2.21	514	16.67	81.63%	Safe
19	Kumhariya	Minor	2.69	304*	0.23	0.09	0.01	0.37	2.52	2.00	1.23	2.29	304	30.77	93.68%	Safe
20	Thikariya	Minor	3.68	306*	0.33	0.14	0.02	0.52	3.71	3.12	2.12	3.32	306	70.59	100.77%	Safe
21	Ramsagar G.	Minor	2.46	508	0.43	0.15	0.03	0.90	0.51	0.29	0.12	0.91	331	20.00	20.69%	Hyper Critical
22	Halolaw K.	Minor	2.10	508	2.38	1.38	0.60	2.70	2.10	0.95	0.40	1.65	403	57.14	100%	**Safe**
23	Matholao	Minor	2.03	719	0.92	0.45	0.20	1.23	0.33	0.10	0.04	0.58	565	0.00	16.05%	Hyper Critical
24	Mohamadgarh	Minor	1.95	940	0.53	0.22	0.06	0.71	1.87	0.96	0.41	1.47	514	46.15	95.65%	Safe
25	Dhibru Sagar	Minor	1.79	660	0.76	0.23	0.14	2.31	1.53	1.50	0.28	1.45	403	28.57	85.47%	Safe
26	Bhanpura	Minor	1.76	514*	0.85	0.35	0.09	1.14	1.54	0.79	0.20	1.31	514	33.33	87.90%	Safe

27	Bhavalpur Kerwaliya	Minor	1.74	402*	0.36	0.11	0.06	0.52	1.54	1.09	0.48	1.45	403	25.00	88.53%	Safe
28	Mansagar Arnia	Minor	1.64	584	0.35	0.19	0.05	0.59	1.64	1.30	0.18	1.34	367	64.71	100%	**Safe**
29	Nasirda	Minor	1.61	584	0.23	0.13	0.03	0.39	1.36	0.92	0.25	1.22	367	44.44	84.57%	Safe
30	Duni Sagar	Minor	1.42	584	0.68	0.41	0.34	0.74	0.65	0.48	0.06	0.77	576	20.00	46.00%	Hyper Critical
31	Sangrampura Newariya	Minor	1.36	584	0.18	0.08	0.02	0.23	0.77	0.40	0.19	0.75	368	18.75	56.46%	Critical
32	Dudi Sagar	Minor	0.42	711	0.53	0.22	0.06	0.71	0.33	0.18	0.08	0.30	514	50.00	78.00%	Safe

Safe: Actual yield (50% dep.) in % of design capacity: 75-100%= 17 dams

Critical: Actual yield (50% dep.) in % of design capacity: 50-74%= 6 dams

Hyper Critical: Actual yield (50% dep.) in % of design capacity: <50%= 9 dams

15 dams out of 32 dams of Tonk district fall under critical and hyper critical stage as per above mentioned interval scale. We can say that around 50% of the dams may be considered safe, which are receiving more than 75% of their design capacity at 50% dependability. Average observed rainfall in the district is less than the average design rainfall, which is one of the reasons for less inflow.

Data are normalized with respect to design capacity of dams. RMSE and MAPE values are higher and R-values are very low (<0.2), showing no correlation between computed and theoretical values (Table 4.4). Computed t-values are less than critical t-value at 5% level of significance (2.07) i.e. accept null hypothesis (H_0: R=0). NSE values are negative, showing that average of the observed value is better predictor than the theoretical value. Simulation results are not in correlation with the observed values.

Table 4.4 Performance statistics for the dams of Tonk district

Dependability	RMSE	MAPE (%)	R	T-Value	NSE
50%	0.47	57.93	0.15	0.83	-2.40
75%	0.36	95.13	0.07	0.38	-1.13
90%	0.18	370.40	0.04	0.22	-0.64
Mean	0.49	63.66	0.03	0.16	-6.36

4.3 Determination of Critical Year

Critical year separates the pre-disturbance and post-disturbance two non-overlapping epochs. Determination of critical year is an essential requirement for investigation of inflow behaviour of the dams.

4.3.1 Determination of Possible Critical Years: Time Series Analysis

In the first step of determination of critical year, possible critical years are identified. Possible critical years have been identified with the help of time series analysis by trend elimination using least square method as shown in Table 4.5.

The trend equation U = a + bt has been derived as

Inflow = (64.77) + (-0.27) x Time

Where U= Inflow, a = 64.77, b = -0.27 and t= time

Table 4.5 Time series analysis: Dams of Rajasthan state (Trend elimination using least square method)

Year	Inflow, U (%)	t	tUi	t*t	Trend	Elimination of trend	Possible critical years
1990	71.01	-11	-781.11	121	67.72	3.28	
1991	78.53	-10	-785.3	100	67.45	11.07	
1992	66.16	-9	-595.44	81	67.18	-1.02	***
1993	62.6	-8	-500.8	64	66.91	-4.31	
1994	85.76	-7	-600.32	49	66.65	19.1	***
1995	77.6	-6	-465.6	36	66.38	11.21	
1996	76.7	-5	-383.5	25	66.11	10.58	
1997	71.09	-4	-284.36	16	65.84	5.24	
1998	57.78	-3	-173.34	9	65.57	-7.79	
1999	43.58	-2	-87.16	4	65.3	-21.72	
2000	42.03	-1	-42.03	1	65.04	-23.01	
2001	58.4	0	0	0	64.77	-6.37	***
2002	30.87	1	30.87	1	64.50	-33.63	
2003	58.08	2	116.16	4	64.23	-6.15	***
2004	71.01	3	213.03	9	63.96	7.04	
2005	71	4	284	16	63.69	7.3	
2006	83.58	5	417.9	25	63.43	20.14	
2007	69.72	6	418.32	36	63.16	6.55	***
2008	56.2	7	393.4	49	62.89	-6.69	
2009	41.27	8	330.16	64	62.62	-21.35	
2010	51.52	9	463.68	81	62.35	-10.83	***
2011	73.35	10	733.5	100	62.09	11.25	
2012	76.78	11	844.58	121	61.82	14.95	
2013	76.71	12	920.52	144	61.55	15.15	
Sum	1551.33	12	467.16	1156	1551.33		

Exceptional periods are marked ***, which are considered as possible critical years, when drastic changes were observed. In this analysis year 1992, 1994, 2001, 2003, 2007, and 2010 are identified as possible years (Table 4.5).

4.3.2 Determination of Critical Years: Sequential Cluster Analysis

It is essential to determine the critical year, which divides two consecutive non-overlapping epochs, pre-disturbance and post-disturbance. The final critical year can be obtained by applying Sequential Cluster Analysis on the possible critical years which have been identified in Table 4.5. The minimum sum of squared deviations for the hydrological series before and after the possible critical years, gives the unique critical year (Table 4.6). The method of computation has been described in section 3.3.5.

Table 4.6 Sequential cluster analysis: Dams of Rajasthan state

S.N.	Year	Inflow (%)	Sequential Cluster Analysis					
			1992	1994	2001	2003	2007	2010
1	1990	71.0	0.8	3.2	26.1	65.7	32.6	62.5
2	1991	78.5	44.0	32.9	159.6	244.4	175.1	238.2
3	1992	66.2	32.9	44.1	0.1	10.6	0.7	9.4
4	1993	62.6	1.0	104.0	10.9	0.1	7.3	0.2
5	1994	85.8	491.1	168.0	394.5	522.7	418.7	513.6
6	1995	77.6	195.9	227.9	136.8	216.0	151.2	210.1
7	1996	76.7	171.5	201.6	116.6	190.4	129.9	184.9
8	1997	71.1	56.1	73.8	26.9	67.1	33.5	63.9
9	1998	57.8	33.9	22.3	66.0	26.2	56.6	28.3
10	1999	43.6	400.8	357.9	498.1	373.2	471.7	381.0
11	2000	42.0	465.4	419.1	569.9	435.7	541.6	444.1
12	2001	58.4	27.0	16.8	56.2	20.2	47.6	22.1
13	2002	30.9	1071	1000.3	1051.5	1025.8	1185.3	1038.6
14	2003	58.1	30.5	19.6	27.3	23.3	52.2	25.2
15	2004	71.0	54.9	72.4	59.4	15.3	32.6	62.6
16	2005	71.0	54.7	72.2	59.3	15.2	32.5	62.4
17	2006	83.6	399.4	444.5	411.4	271.7	334.3	419.6
18	2007	69.7	37.5	52.1	41.2	6.9	50.7	43.8
19	2008	56.2	54.7	39.7	50.4	118.7	40.9	47.6
20	2009	41.3	498.8	450.9	485.5	667.4	455.2	476.7
21	2010	51.5	145.9	120.6	138.8	242.7	122.8	134.1
22	2011	73.3	95.0	117.6	100.9	39.0	115.5	5.1
23	2012	76.8	173.6	203.8	181.6	93.6	201.0	1.4
24	2013	76.7	171.7	201.8	179.7	92.3	199.0	1.2
		Sum	4708	**4467**	4849	4784	4888	4477

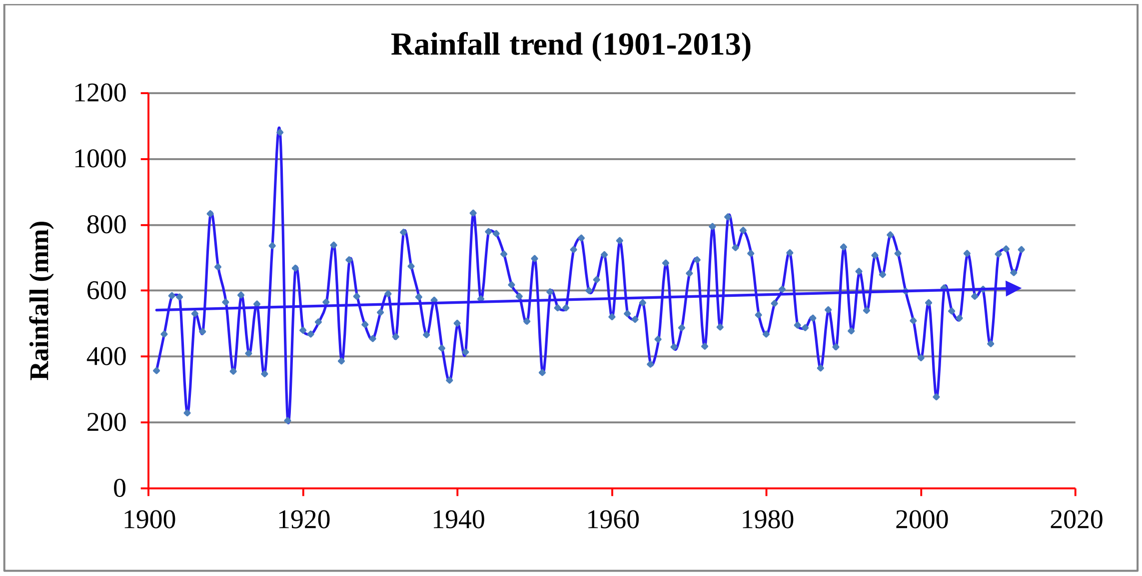
The minimum sum of squared deviations is correspond to the year 1994. Therefore, the year 1994 is considered as the critical year for the hydrological behavior of the dams of Rajasthan state. This shows that, some disturbances have taken place after 1994 which is attributed to low inflow to the dams. Determination of critical year will help in policy formulation for an effective water resources planning and management of the state.

4.4 Various Parameters and their Trends

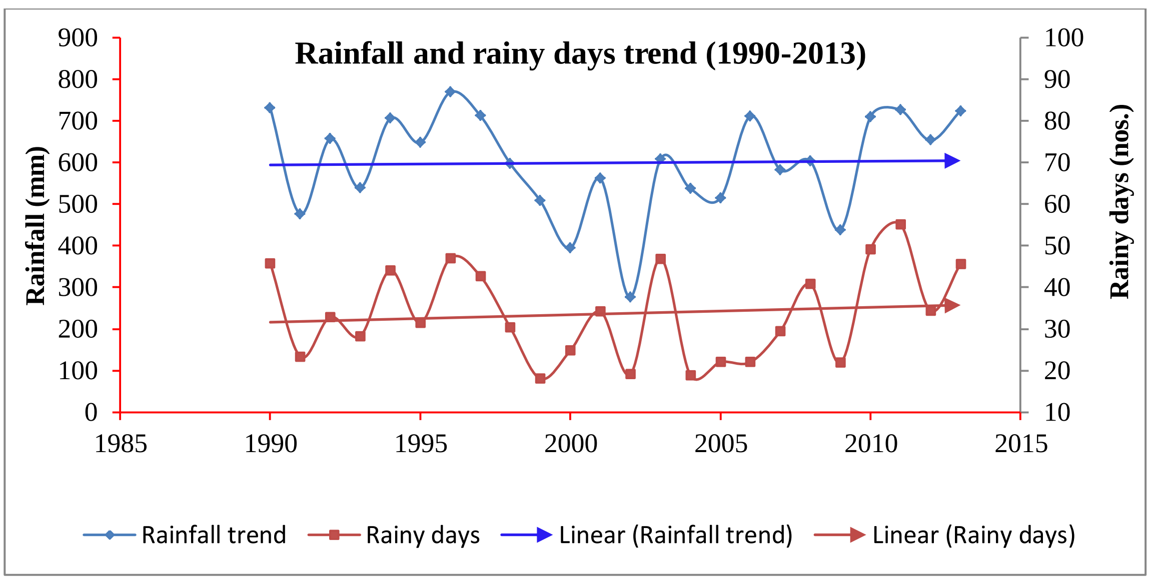
The declining trend of inflow to the dams of Rajasthan State has been tested. The critical year of initiation of post-disturbance epoch is determined as 1994. Climate change and global warming are posing a serious threat to the water resource availability. Climatic parameters such as average daily minimum and maximum temperature, precipitation, wind speed, relative humidity and solar radiation are studied and graphs are plotted to determine the variation of these parameters with time (Fig. 4.4 and 4.5). Various parameters which are considered responsible for surface runoff are to be analyzed and discussed. Trends of various factors are plotted and shown in fig 4.4 to 4.11.

4.4.1 Rainfall and Other Climatic Parameters

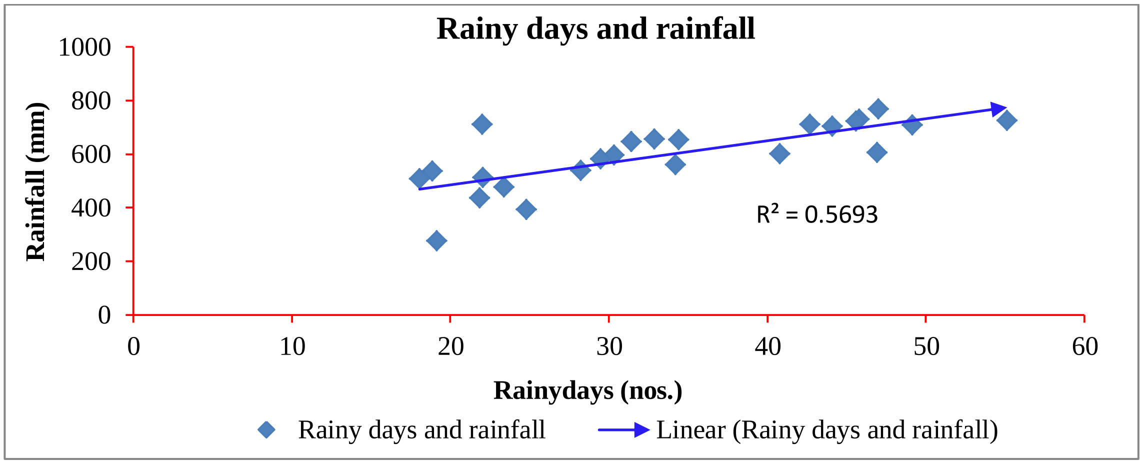
Accurate and correct rainfall characterization is an important tool for water related system design and management. Although the spatial distribution of the change in precipitation character is uncertain, it would mean greater risk of both dry spells and floods for some region even though annual precipitation totals may increase slightly (Dourte et al. 2012). Temporal variation of average annual precipitation of the state for long time series (1901-2013) is on slightly increasing trend (Fig. 4.4 a). The trend of rainy days for simulation period (1990-2013) is also slightly increasing and plotted along with the rainfall trend in Fig. 4.4 (b). It infers that rainy days and annual rainfall has a positive and good correlation which is shown in Fig. 4.4 (c). For a constant amount of annual rainfall (e.g. 700-715mm), inflow has a negative correlation with rainy days (Fig. 4.4 d). This infers that the annual rainfall spreads over more rainy days and gives lesser inflow and more infiltration. Temporal distribution of monthly rainfall shows that rainy season remains during only four months in a year i.e. June to September (Fig. 4.4 e). There is a spatial distribution of average annual rainfall over the state ranging from 190mm in Jaisalmer to 1000mm in Banswara (Fig. 4.4 f) therefore, it becomes essential to judiciously plan and manage the available water resources within the state. Rainfall distribution is following the Gaussian distribution. Highest frequency of annual rainfall of the state ranges between 500-600mm as shown in Fig. 4.5 (g). For constant amount of annual rainfall (e.g. 700-715mm), inflow decreases with increase of rainydays.



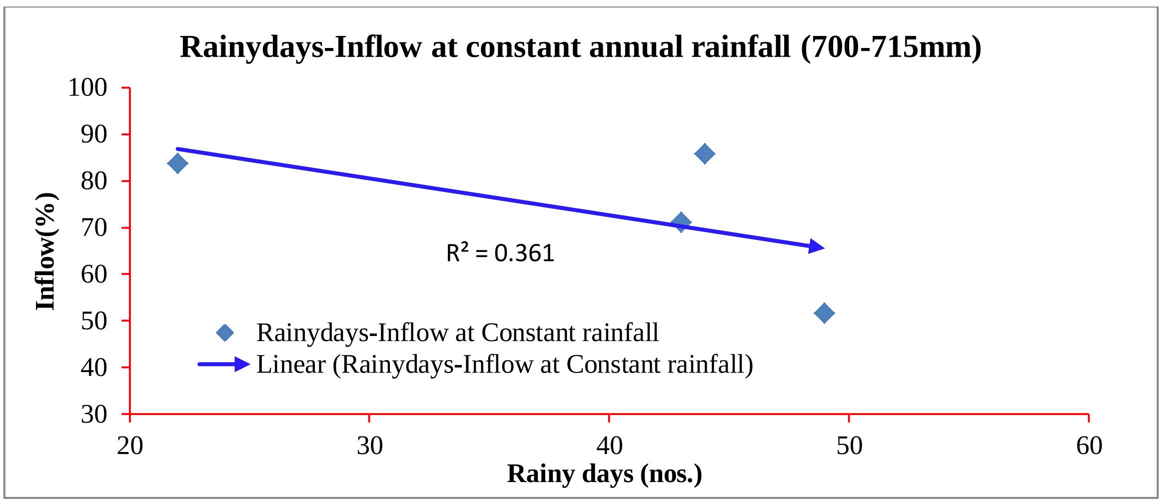
(a) Rainfall trend (1901-2013)



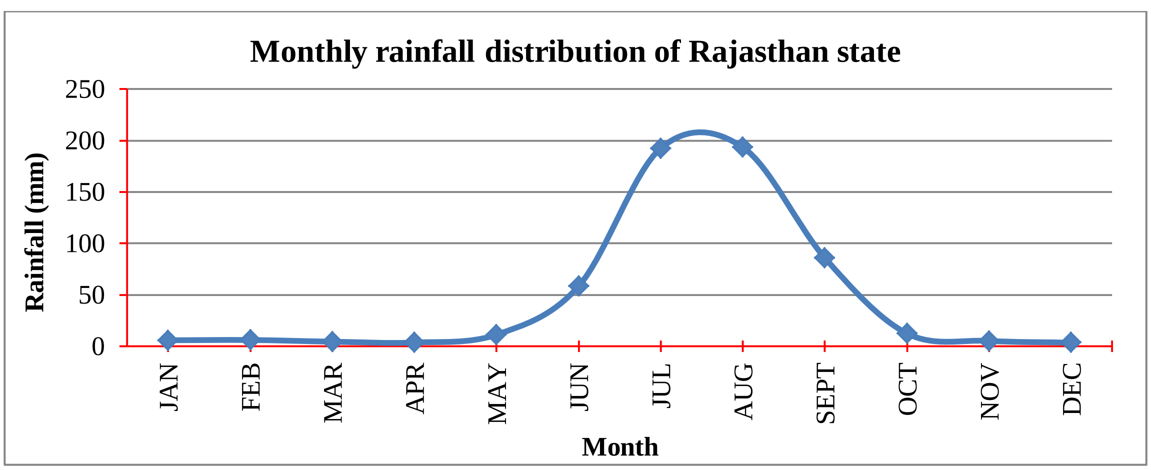
(b) Rainfall and rainy days trend (1990-2013)



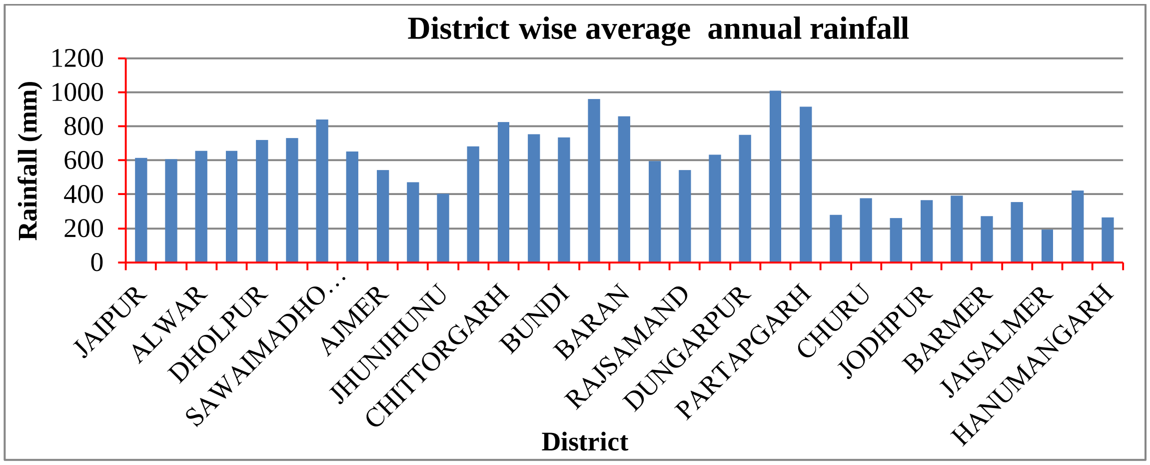
(c) Rainy days and rainfall



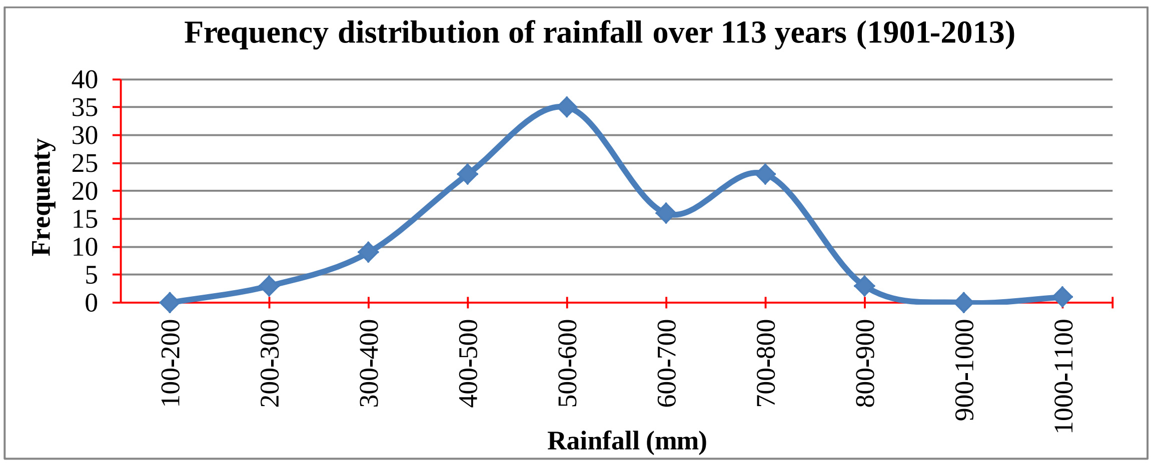
(d) Rainy days and inflow at constant rainfall



(e) Monthly rainfall distribution



(f) District wise average annual rainfall



(g) Frequency distribution of rainfall

Fig. 4.4 Rainfall trend and its distribution (Rajasthan)

The Rainfall trend of the state varies significantly over the years and during the year, showing the temporal variation of rainfall. It also varies significantly between various districts, showing the spatial variation of rainfall (Fig. 4.4). We proposed one way ANOVA to study the impact of districts and year on the annual rainfall. Table (a) shows that impact of year on annual rainfall was highly significant (p value <0.01), calculated value of $F= 7.705 > F$ (tabulated) at df= 111, 3341 at 1% level of significance. Table (b) shows that impact of districts on annual rainfall was also significant (p value < 0.01) and calculated value of $F=95.136 > F$ (tabulated) at df= 32, 3420 at 1% level of significance.

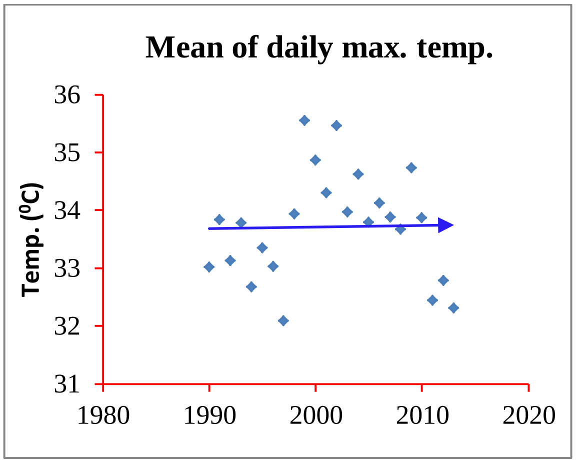
Table (a) One way ANOVA using year as factor

	Sum of Squares	**df**	**Mean square**	**F**	**Significance**
Between Groups	68690485	111	618833.198	7.705	0.000
Within Groups	2.68E+08	3341	80314.481		
Total	3.37E+08	3452			

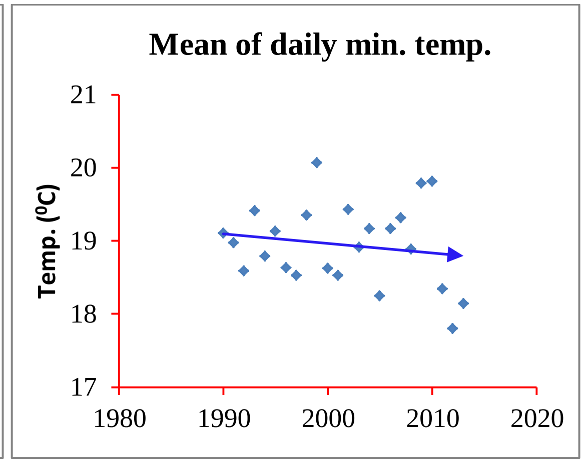
Table (b) One way ANOVA using district as factor

	Sum of Squares	**df**	**Mean square**	**F**	**Significance**
Between Groups	1.59E+08	32	4959945.535	95.136	0.000
Within Groups	1.78E+08	3420	52135.353		
Total	3.37E+08	3452			

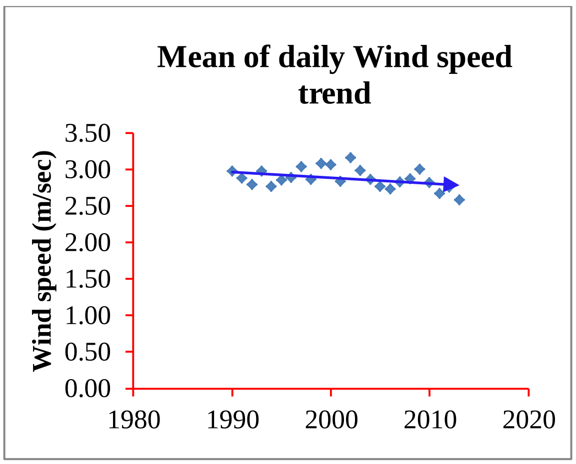
The impact of global climate change is making the precipitation of rainfall pattern quite uncertain (Kar 2011). Climate change challenges existing water resources management practices by adding uncertainty (Draper and Kundell 2007). Intergovernmental Panel on Climate Change (IPCC 2001) as described by Iglesias et al. 2007 states that climate change projections derived from global climate models driven by socio-economic scenario results in an increase in temperature of 1.5 to 3.6^{o}C and a precipitation decrease of about 10 to 20% by 2050. This may lead to increased likelihood of droughts and variability of precipitation in time-space, and intensity. That would directly influence water resources availability. As described above the importance of climatic parameters; trends of daily max. and min. temperature, wind speed, relative humidity and solar radiation have been plotted in Fig. 4.5.



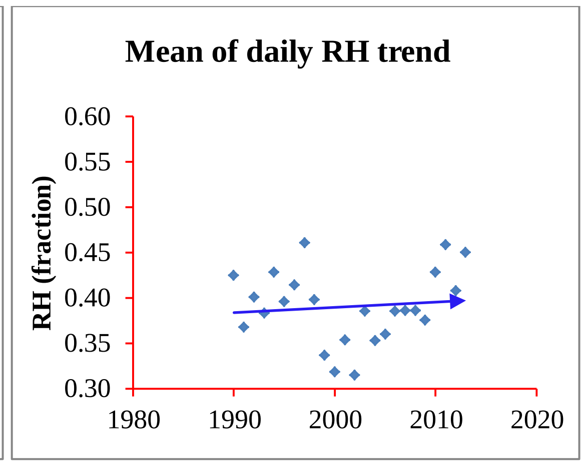
(a) Mean daily max. temp.



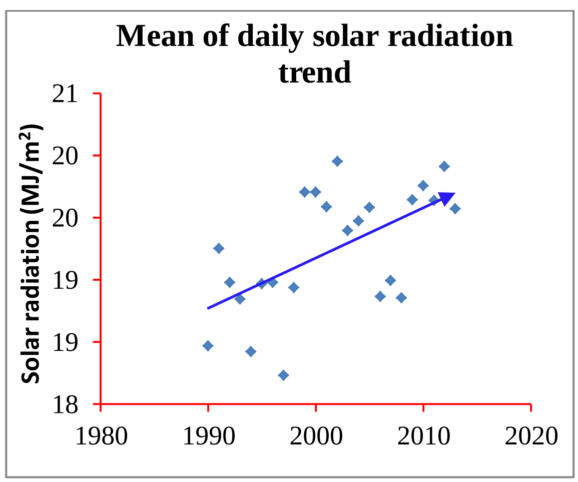
(b) Mean of daily min. temp.



(c) Wind speed



(d) Relative Humidity



(e) Solar radiation

Fig. 4.5 Trends of other climatic factors (Rajasthan)

There is an increasing trend of the mean of daily maximum temperature, daily relative humidity, and daily solar radiation while a slightly decreasing trend of the mean of daily minimum temperature and daily wind speed. Increased daily maximum temperature and solar radiation cause evaporation of soil moisture thereby may cause increased infiltration and reduced inflow. Trends and rate of changes of various climatic parameters are listed in Table 4.8.

4.4.2 Land Use Land Cover Changes

Land use data from 1957-2013 have been plotted in Fig. 4.6. A comparison has been made in Fig. 4.6 and 4.7 that contributing area is decreasing while crop area is increasing. This infers that the increasing crop area results in decreasing contributing area for runoff, thereby less water inflow to the dams. Land holding data have been presented for the available duration. Data of all the factors related to the study of the state are presented from 1990 to 2013 as per the availability of the data of all the factors.

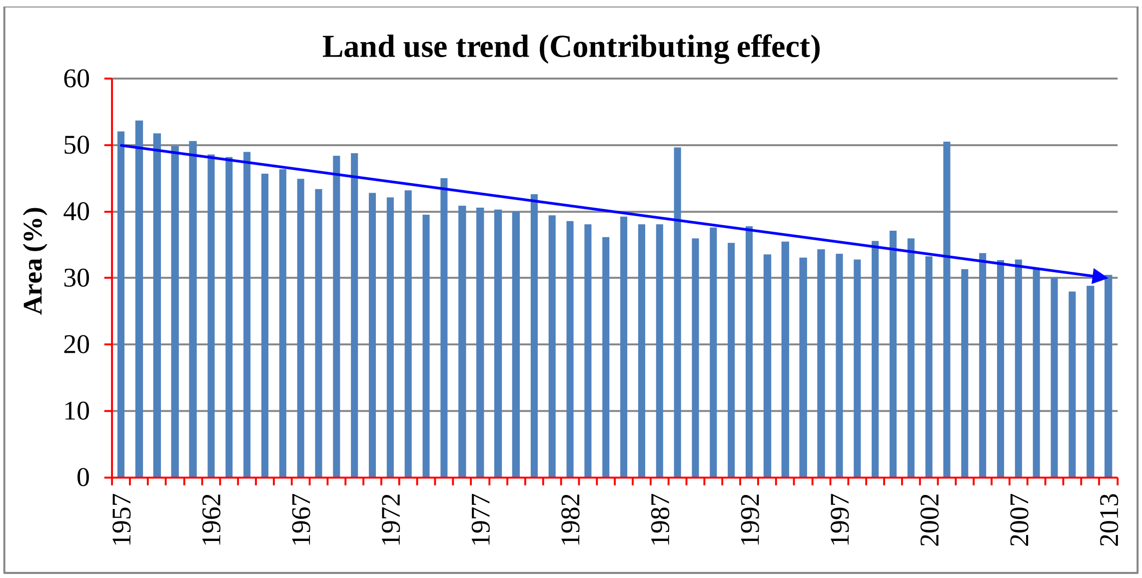
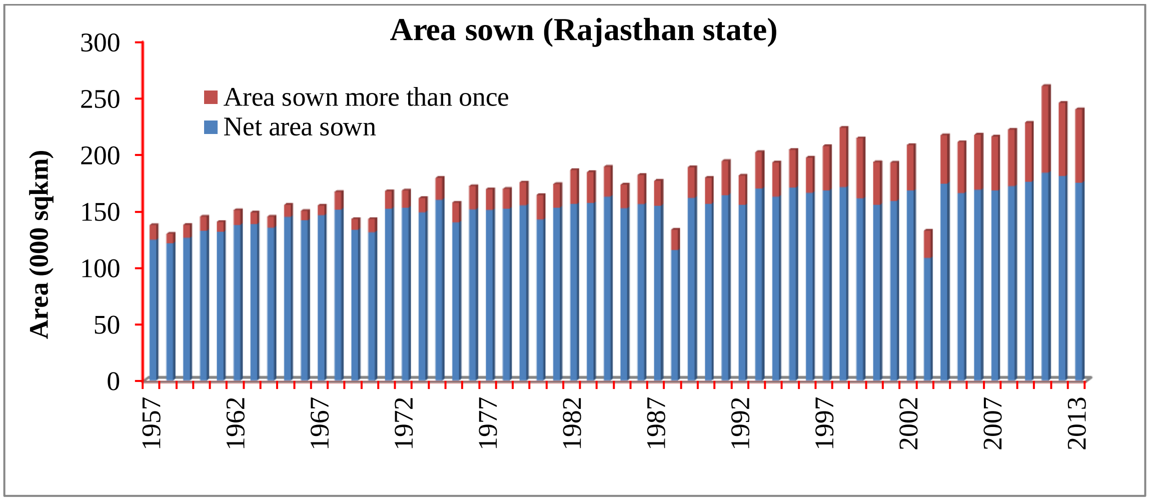
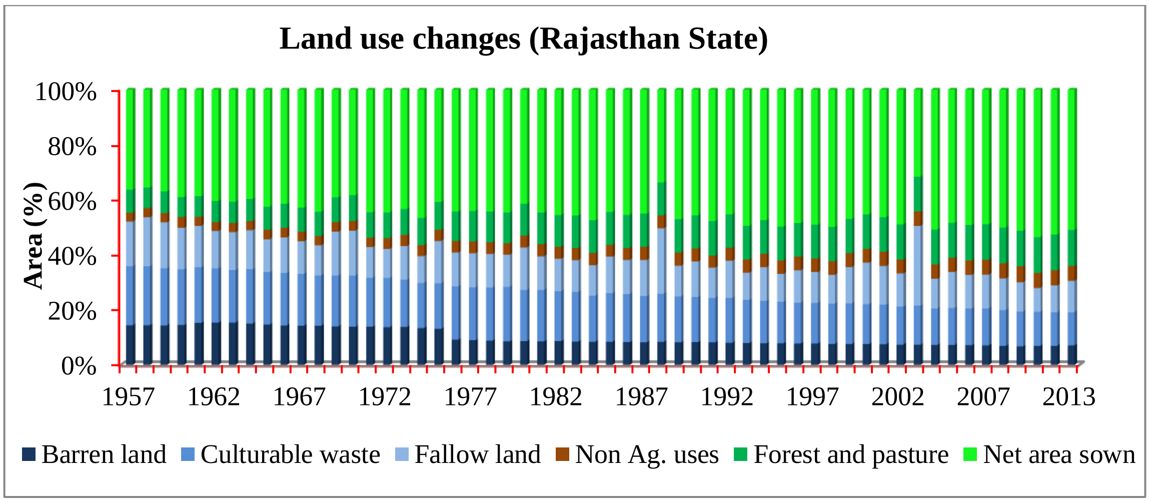


Fig. 4.6 Land use (Contributing effect): Rajasthan

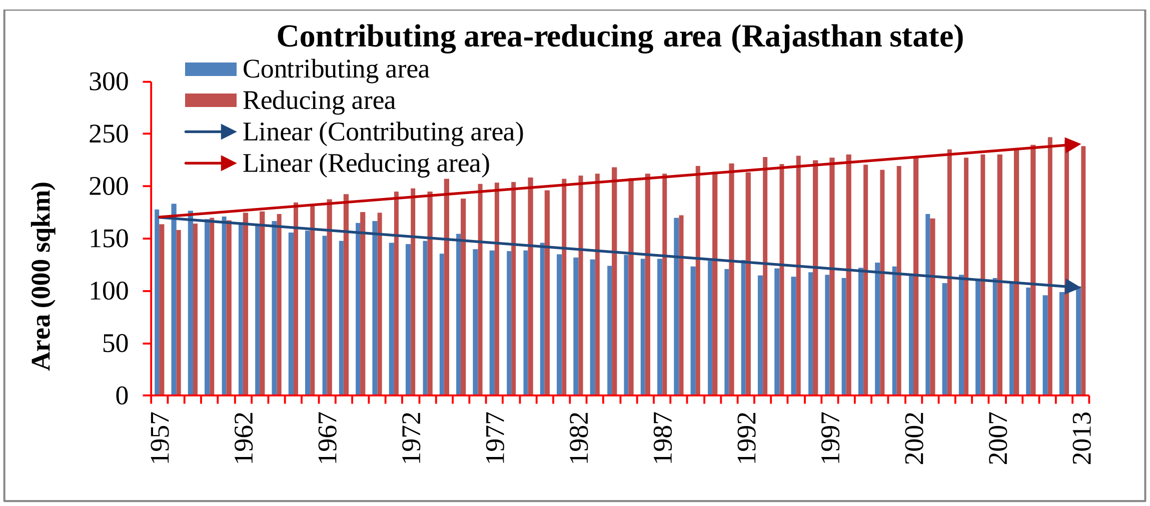
The mean of daily data has been analyzed for the sake of getting the trends of climatic parameters and further correlating them with the inflow. A detailed analysis of land use changes has been presented for Rajasthan state for the data available from the year 1957 onwards (Fig. 4.7).


Area sown (Rajasthan state)
Area sown more than once
Net area sown
Area (000 sqkm)
300
250
200
150
100
50
0
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2013

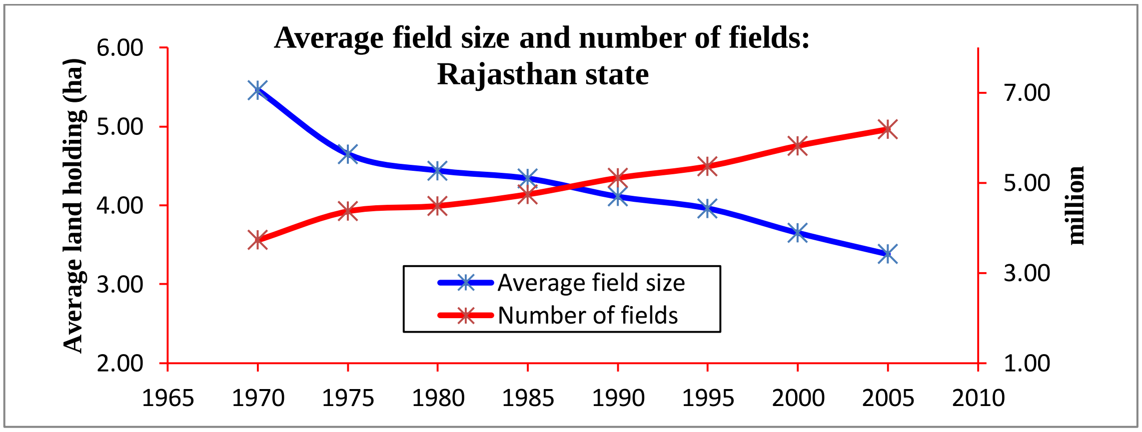
(a)


Land use changes (Rajasthan State)
Area (%)
100%
80%
60%
40%
20%
0%
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2013
Barren land
Culturable waste
Fallow land
Non Ag. uses
Forest and pasture
Net area sown

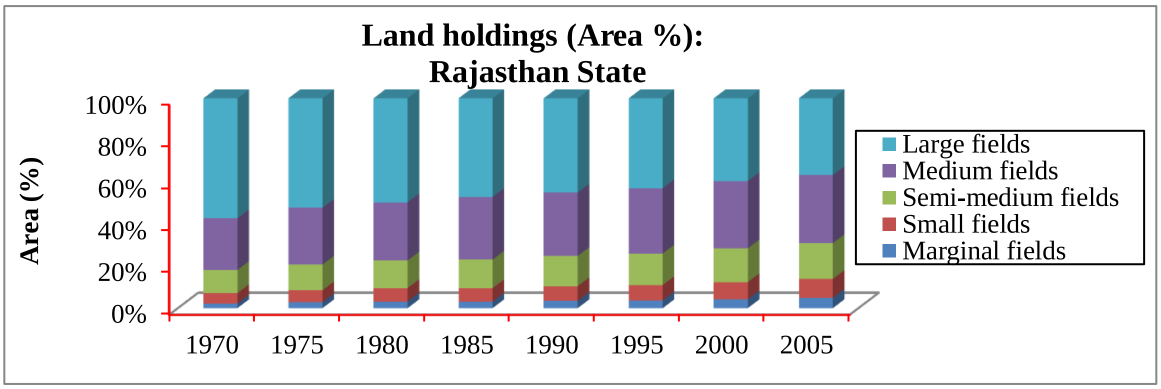
(b)


Contributing area-reducing area (Rajasthan state)
Contributing area
Reducing area
Linear (Contributing area)
Linear (Reducing area)
Area (000 sqkm)
300
250
200
150
100
50
0
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2013

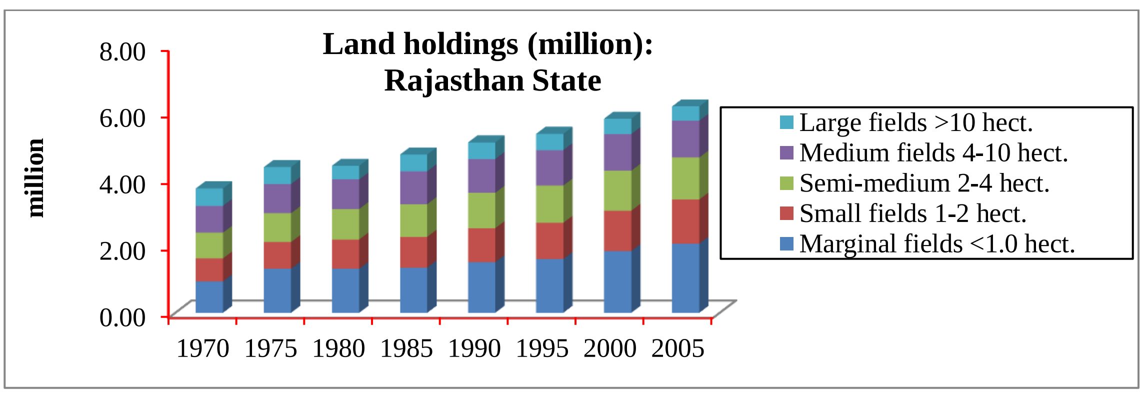
(c)



(d)



(e)



(f)

Fig. 4.7 Land use changes (1957-2013): Rajasthan

Agricultural area is increasing with time and population. It has increased from 124, 000 sqkm to 180,000 sqkm from 1957 to 2013. The area sown more than once is also increasing; it has increased from around 10,000 sqkm to 65,000 sqkm (Fig. 4.7 a). Irrigation area increased from around 20,000 sqkm to 63,000 sqkm from 1968 to 2006.

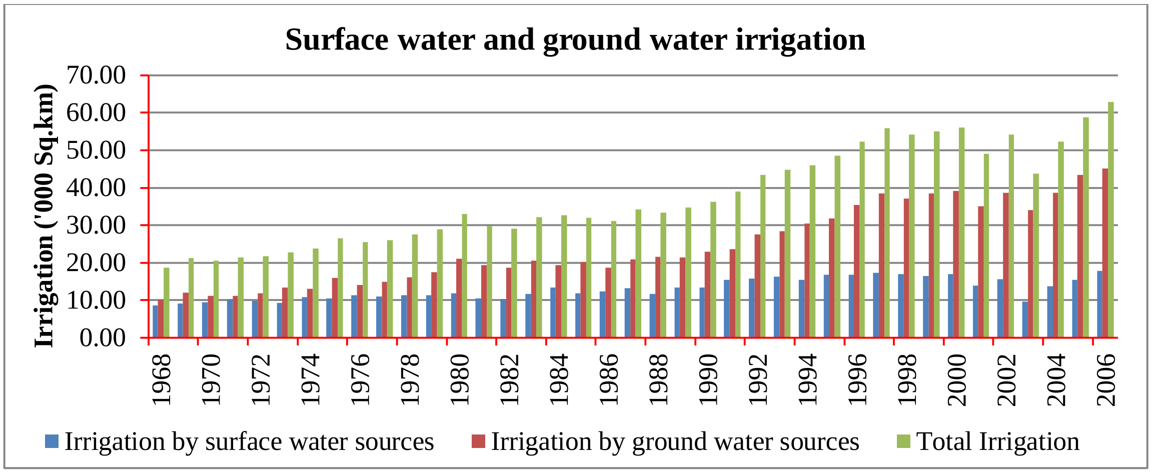
The contribution of groundwater irrigation to the total irrigated area was around 10,000 sqkm in 1968 and 45,000 sqkm in 2006 (Fig. 4.8 a). With the development of electrical facilities, irrigation from tube wells increased from 120 sqkm in 1968 to 19,000 sqkm in 2006 (Fig. 4.8 b). Due to this tremendous increase in agricultural areas, land use pattern changed at a very fast pace. The increase in groundwater irrigation facilities resulted in lowering of water table and increase in dark zones within the state.

Land utilization of the state is plotted in graphs as shown in Fig. 4.6 & 4.7 shows that the land utilizations which are having reducing effect on the surface runoff viz. agricultural, forest and infrastructural uses are increasing and the land utilization which is having a contributing effect on the surface runoff viz. barren land, culturable waste, and fallow land are decreasing with the passage of time (Fig. 4.7 b). The area which is having contributing effect on surface runoff has decreased to half of the area which was available in 1957 (Fig. 4.7 c). These types of land use changes, viz. agricultural, forest and infrastructural uses of land increase the surface roughness, are not favorable to the surface runoff. The total cropped area has increased from 137 (000 sqkm) to 245 (000 sqkm) during 1957 to 2012. The double crop area has increased from 12.86 (000 sqkm) to 64.71 (000 sqkm) during this period.

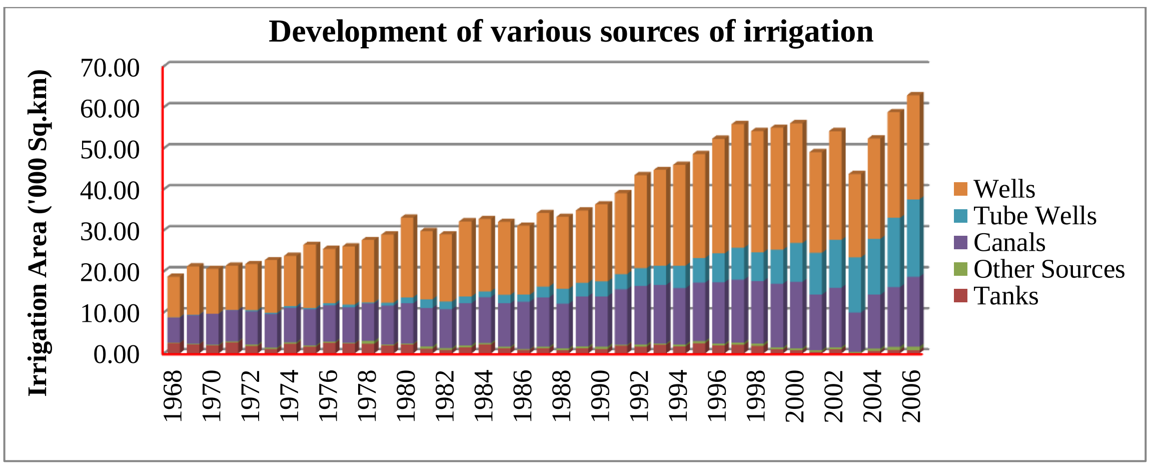
Due to continuous partitions of the fields, the average size of the field is decreasing, and the total number of fields is increasing with time. The average size of the land holding has decreased from 5.46 ha to 3.38 ha from 1970 to 2005, and a total number of fields has increased from 3.7 million to 6.2 million during this period (Fig. 4.7 d). The percentage area of large fields is decreasing while under marginal, small and semi-medium category it is increasing. Accordingly the number of land holdings under marginal, small and semi-medium category is increasing (Fig. 4.7 e,f). This reflects that total number of fields are increasing because of partitions of large fields, thereby more length of periphery boundaries increasing the surface roughness and decreasing the resultant runoff to the reservoir.

4.4.3 Groundwater Level Changes

Agricultural area of the state is increasing due to increase in irrigation facilities. Irrigation by ground water sources increased at a fast pace than surface water sources (Fig. 4.8 a). Underground water sources such as wells and tube wells increased due to the development of digging and boring system along with rapid electrification (Fig. 4.8 b), resulting in overexploitation of ground water.



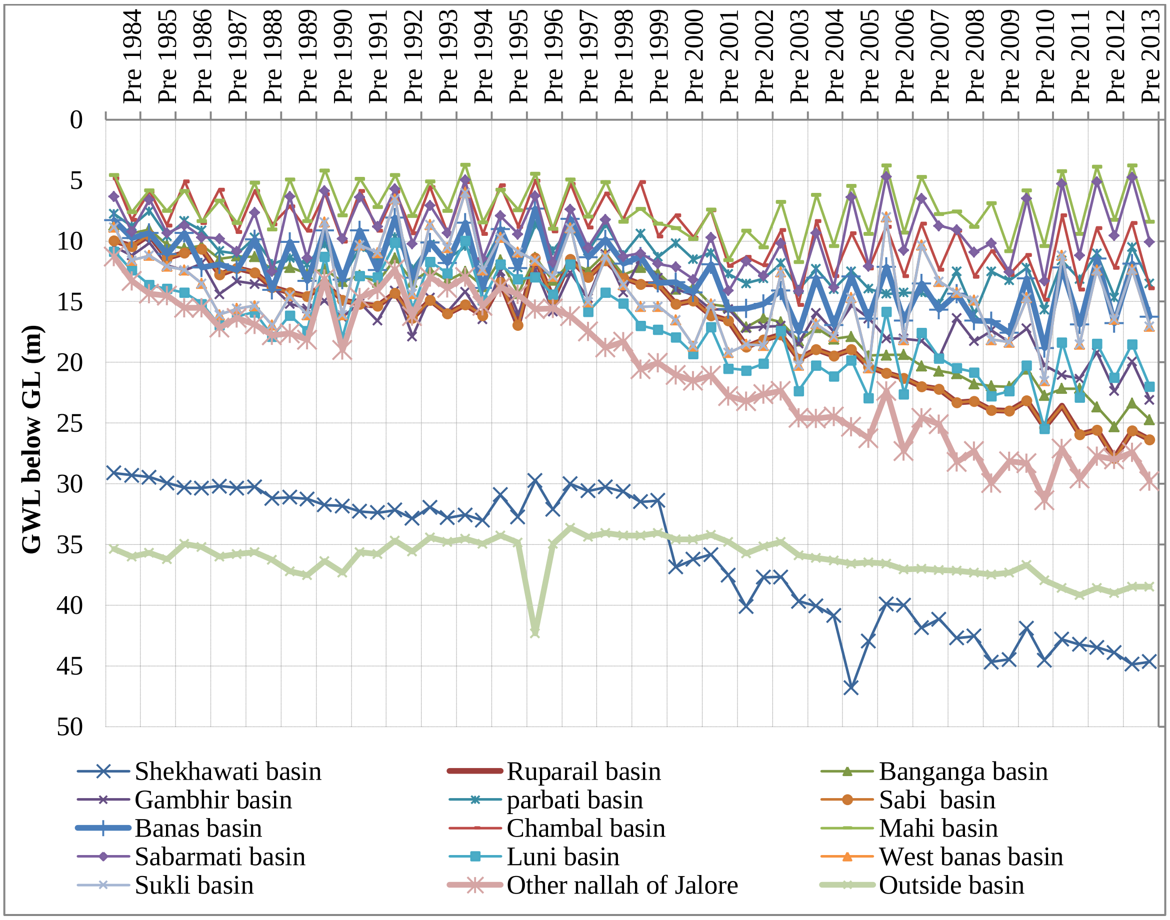
(a) Sources of irrigation



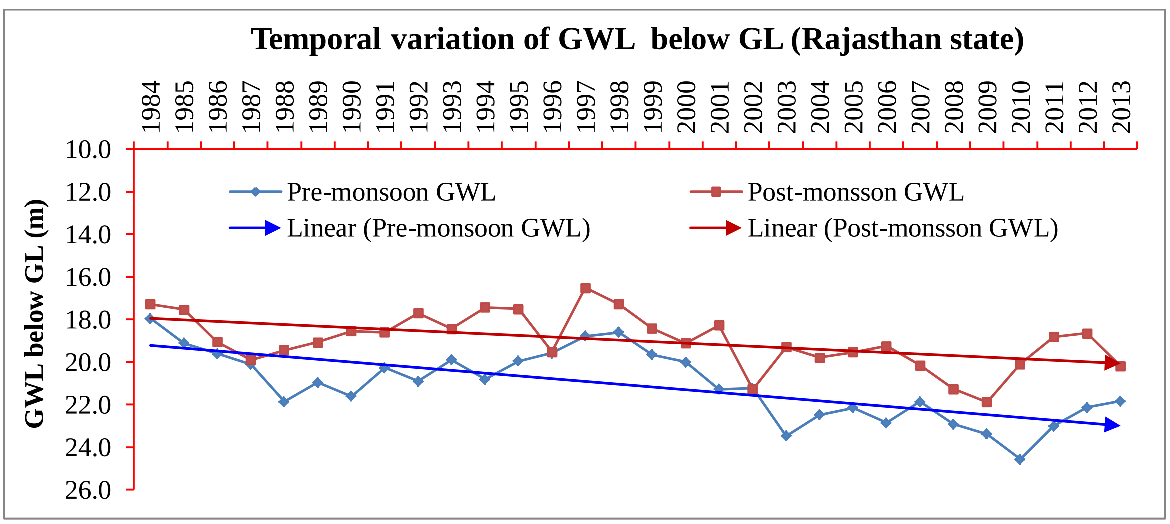
(b) Various sources of irrigation

Fig. 4.8 Development of agricultural and irrigation facilities in Rajasthan

Over-exploitation of groundwater has resulted in lowering of ground water level below ground level. Fluctuations of basin wise ground water level below ground level are shown in Fig. 4.9 (a). Groundwater level changes in the state are shown in Fig. 4.9 (b).



(b) Basin wise GWL below GL



(b) Rajasthan

Fig. 4.9 Groundwater level changes: Rajasthan

Basin wise fluctuations of ground water level below ground level shows that Shekhawati basin is adversely affected by ground water withdrawal and showing the deepest ground water level below ground level. A major part of Sikar and Jhunjhunu districts lie in the Shekhawati basin. Water inflows to the dams of these districts are also negligible. Looking to these adverse situations, it is planned to provide water for drinking, irrigation and other necessary requirements from Yamuna water through the transboundary management of surplus water through an interstate agreement between Rajasthan and Haryana. Sikar district has also been covered in Model District Irrigation Plan under Pradhan Mantri Krishi Sinchai Yojna (PMKSY). In the first phase, water is to be received through Yamuna water agreement and in successive phases it is to be received from Sharda-Yamuna Link. Major parts of Barmer, Churu, Ganganagar, Hanumangarh, Jaisalmer, Jodhpur and Nagaur districts are falling under Outside Basin. Though groundwater level below ground level in this basin is very low but it is not going further low at accelerating rate as part of the basin is under Gang Canal and Indira Gandhi Canal system.

Development of lift facilities through pump sets resulted in a tremendous increase in irrigation from groundwater using wells and tube wells (Fig. 4.8 b). Overexploitation of groundwater has resulted in only 25 blocks out of total 243 in the safe category in the year 2011, which were 135 in the year 1998 (Table 4.7, Fig. 4.10). Tara Nagar of Churu district and Khajuwala of Bikaner district have been declared as total saline blocks; therefore, they have not been assessed by Central Ground Water Board (CGWB 2014). Declining water table reduces runoff due to base flow and hence the inflow to the wetland (Jain et al. 2008). Over exploitation of surface water results in many rivers dying, and outflow amount decreasing drastically, and overexploitation of groundwater has also induced the groundwater level to go down continuously and form several underground funnels. Over-exploitation of water has greatly changed the transfers among precipitation, surface water, soil water, and groundwater. As is seen in Hai He basin, the river is dying, and funneled groundwater is increasing, and this once natural water cycle has evolved into a semiartificial water cycle (Sang et al. 2010). Losses due to evaporation and water withdrawal reduce the runoff towards the mouth by a factor 2.3. The runoff changes as large as these are due to the increasing water withdrawal for irrigation (Kravtsova et al.

2009). **It has been observed during the last five decade that, percentage groundwater utilizations have almost doubled, and the surface water utilization has increased manifold, causing a decline in the water table. The declining water table reduces runoff due to baseflow and hence the inflow to the wetland (Jain et al. 2008)**. In Rajasthan state also, over-exploitation of water has greatly changed the transfers among precipitation, surface water, soil water, and groundwater. The rivers are dying and funneled ground water is increasing leading to the diminishing base flow and decreasing surface runoff.

Table 4.7 Scenario of Groundwater Development: Rajasthan

Year	Over-exploited blocks (>100%)	Critical blocks (90%-100%)	Semi-critical blocks (70%-90%)	Safe blocks (<70%)
1998	41	26	34	135
2004	102	82	27	25
2009	166	25	16	31
2011	172	24	20	25

Graphical presentation of Table 4.7 is shown in Fig. 4.10 in the form of stacked bar chart. This shows that about 70% of the blocks of the state are over-exploited while safe blocks are only around 10%.

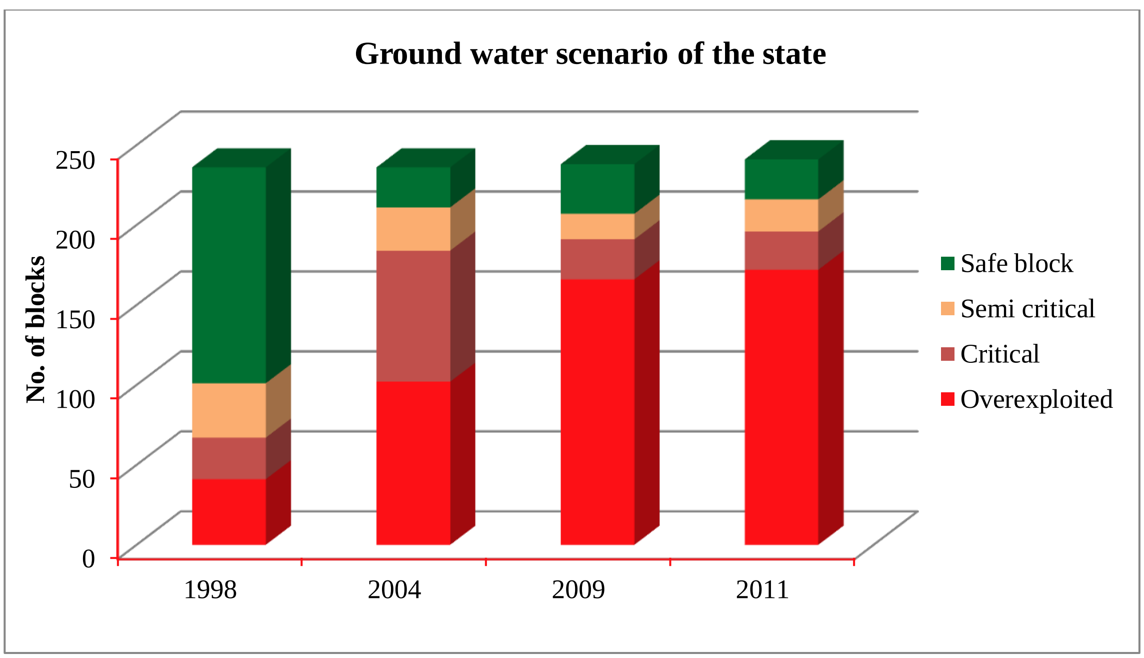
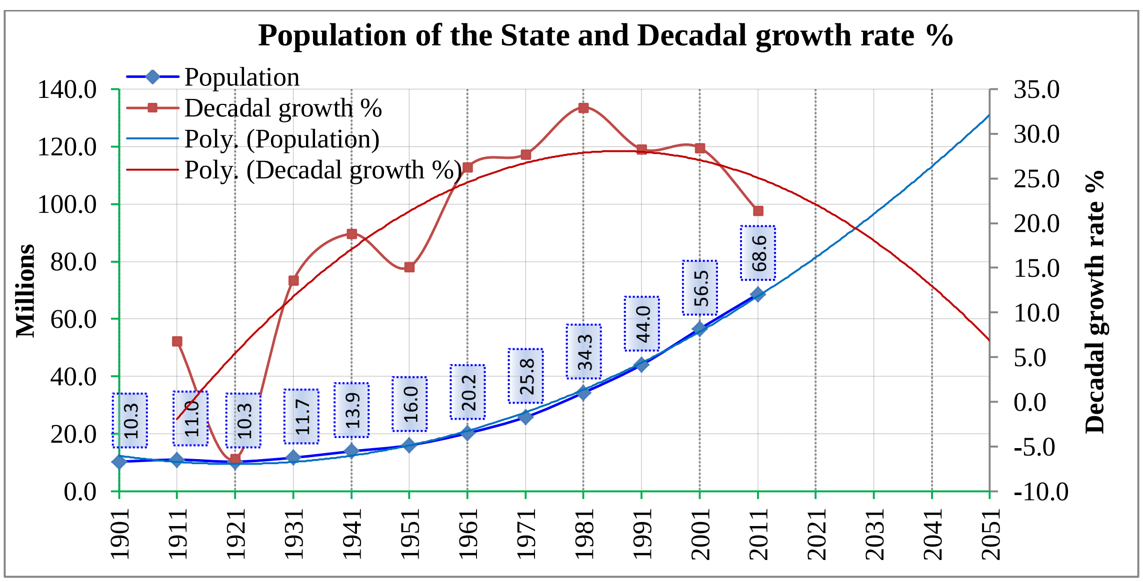


Fig. 4.10 Scenario of groundwater development: Rajasthan

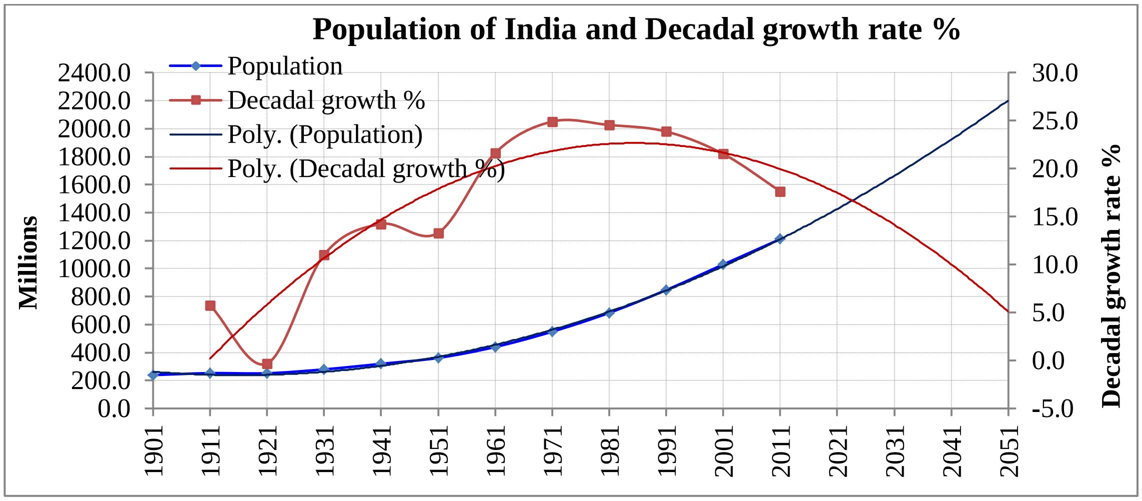
Grond water development <70% may be considered as safe, 70% to 90% may be considered as semi-critical, 90% to 100% may be considered as critical, and >100% is considered as overexploited. Groundwater development is regularly increasing due to less water availability in surface water resources. Districtwise groundwater development is shown in appendix-10. Only 3 districts in safe, 2 districts in semi-critical, 2 districts in critical and rest 27 districts lies under overexploited categories out of a total of 33 districts in the state. In whole, the complete state may be considered as overexploited. Overall stage of groundwater development of the state is around 137% (CGWB 2014).

4.4.4 Population Growth and Trends

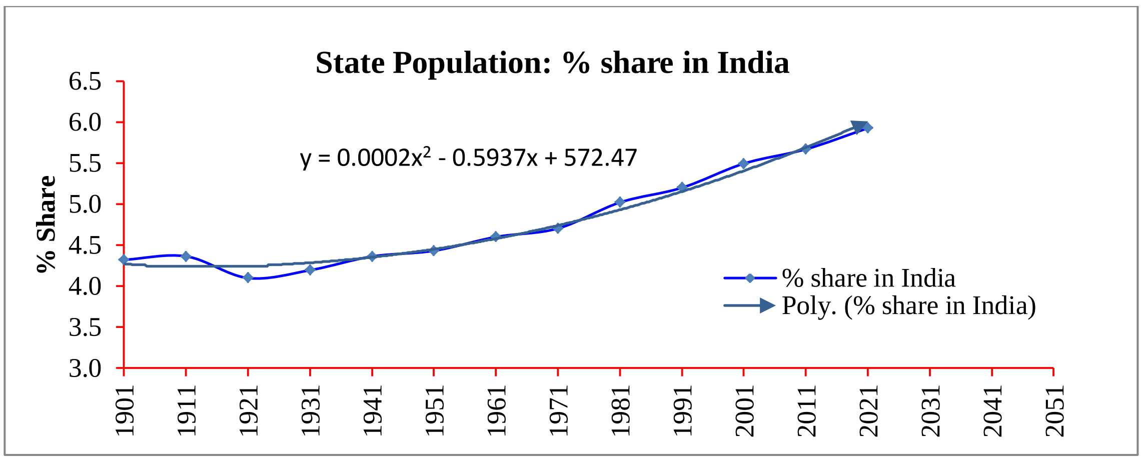
Land use and cultivation area are influenced by the population growth. The state population is regularly increasing. However it is a good sign that decadal growth rate of population is on decreasing trend after the year 1981 (Fig. 4.11 a). Country population and its decadal growth rate are also on the same trend (Fig. 4.11 b). The percentage share of the state population in country population is on increasing trend (Fig. 4.11 c).



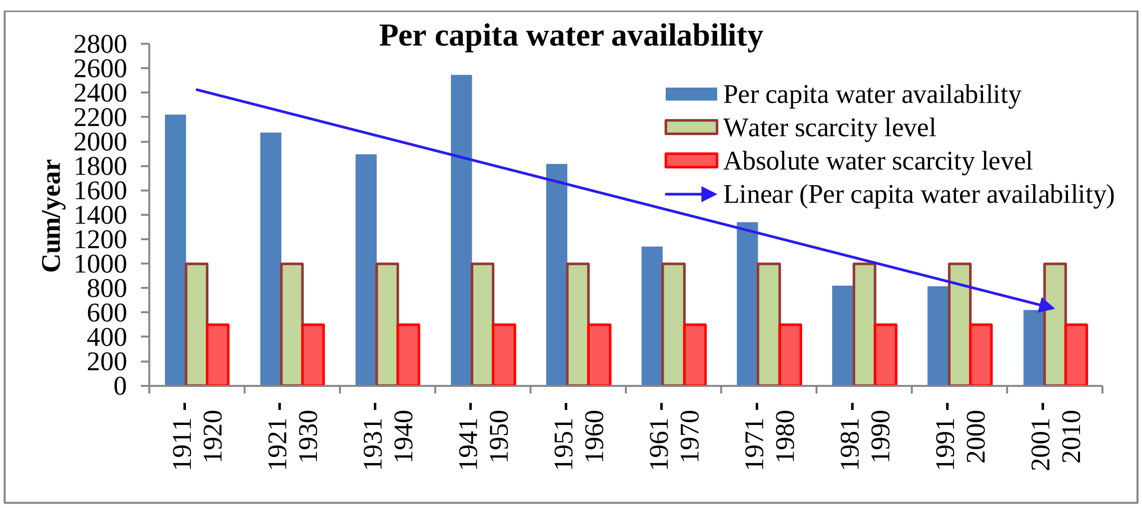
(a) State population and its growth



(b) Country population and its growth



(c) State population share with India



(d) Per capita water availability in the state

Fig. 4.11 Population and its growth: Rajasthan

Fig. 4.11 ('c) shows that the impact of population growth on natural resources will be more severe than the average condition of the country. This impact on water resources availability will be more severe in future because per capita water availability in the state has gone down below the level of water scarcity (1000 cum per capita per year) and it is touching to the level of absolute water scarcity (500 cum per capita per year) (Fig. 4.11 d). There is an alarm to adopt most efficient practices of water resources planning and management in the state. Han et al. (2012) also mention that available water resources per capita are decreasing in river basins around the world.

4.4.5 Various Factors, Trend Lines and their Rate of Changes

Trend lines showed in Fig. 4.4 to 4.11give an idea about the various factors, whether they are on increasing or decreasing trend and at what rate. The results are summarized in Table 4.8.

Table 4.8 Various factors, trend lines and their rate of change

S.N.	**Factor**	**Trend**	**Rate of Change**
1	Rainfall 1901-2013 (mm)	Increasing	10 mm in 25 yrs.
2	Rainfall 1990-2013 (mm)	Increasing	10mm in 22 yrs.
3	Rainy days/ year 1990-2013 (nos.)	Increasing	1 day in 6 yrs.
4	Mean of daily max. temp. (^{0}C)	Increasing	1 deg. in 500 yrs.
5	Mean of daily min. temp. (^{0}C)	Decreasing	1 deg. in 77 yrs.
6	Mean of daily wind speed (m/sec)	Decreasing	1 m/sec in 143 yrs.
7	Mean of daily RH (fraction)	Constant	NA
8	Mean of daily solar radiation (MJ/m^2)	Increasing	1MJ/m^2 in 40 yrs.
9	Land use (Contributing effect) (%)	Decreasing	1% in 3 yrs.
10	Cultivation area (%)	Increasing	1.37% in 2 yrs.
11	Groundwater level below ground level (m)	Increasing	1m in 6 yrs.
12	State population (million)	Increasing	80 million in 2021
13	State population decadal growth	Decreasing	15-20% in 2021
14	Country population	Increasing	1400 million in 2021
15	Country population decadal growth	Decreasing	15% in 2021
16	State population share with country	Increasing	6.2% in 2021

Rainfall and rainy days during 1990-2013 are on increasing trends (Fig. 4.4 b). Rainy days have positive correlations with annual rainfall and inflow if plotted independently (Fig. 4.4 c and 4.12 b). A graph between rainy days and inflow for the nearly constant amount of annual rainfall (700-710mm) has been plotted in Fig. 4.4 (d). This shows a decreasing trend of inflow with increasing rainy days for a constant rainfall. This infers that precipitations are shifting towards fewer common higher intensity storms and more light and moderate events resulting in lesser runoff. **This pattern shows that nearly constant amount of monsoon rainfall is spreading over the longer time duration than earlier, which may result in reduced percentage inflow.**

Land use having a contributing effect is on decreasing trend. Cultivation area, state population, state population share with the country, and groundwater level below ground level is on increasing trend. A stable tendency towards a decrease in water resources can be seen in recent decades, which is largely due to the intense economic activities on watersheds (Shiklomanov et al. 2011). Irrigation systems, three dams and seven ponds built recent decades for agricultural irrigation and domestic use made the major impact on lowering the lake levels because they derive water from the river for human use upstream of the lake's catchments. Population growth, rising water consumption for agricultural and domestic purposes and building dams has led to lake levels declining. The change of lake levels might depend more on anthropogenic factors than on climate factors (Yildirim et al. 2011).

4.4.6 Correlation Matrix: Rajasthan

A 14x14 correlation matrix has been developed. Mutual correlations of most of the factors are insignificant, being quite low. But, some factors have significant mutual correlations. Significant correlations at 2-tailed test at 1% and 5% level of significance has been shown by * and **. However, the matrix has been derived to show the mutual correlations of all the factors with each other (Table 4.9), for the sake of mutual dependence. This matrix can be utilized for determining the sensitivity of each parameter with other remaining parameters.

Table 4.9 Correlation Matrix: Rajasthan

Correlations

		YEAR	INFLOW	LULC	POPDEN	WTRTBL	RAINFALL	RDAYS	MAXTMP	MINTMP	WINDSPD	RELHUM	SOLAR	NA	ASMO
YEAR	Pearson Correlation	1.000	-.130	-.480*	.999**	.915**	-.059	.114	.020	-.165	-.404	.125	.584**	.366	.824**
	Sig. (2-tailed)	.	.545	.018	.000	.000	.786	.596	.926	.442	.050	.559	.003	.079	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
INFLOW	Pearson Correlation	-.130	1.000	-.097	-.108	-.264	.685**	.326	-.738**	-.518**	-.696**	.577**	-.502*	.129	-.106
	Sig. (2-tailed)	.545	.	.651	.614	.213	.000	.120	.000	.009	.000	.003	.013	.547	.621
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
LULC	Pearson Correlation	-.480*	-.097	1.000	-.493*	-.385	-.049	.048	.157	.013	.388	-.242	-.193	-.991**	-.734**
	Sig. (2-tailed)	.018	.651	.	.014	.063	.819	.823	.464	.952	.061	.255	.367	.000	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
POPDEN	Pearson Correlation	.999**	-.108	-.493*	1.000	.906**	-.040	.132	-.009	-.176	-.424*	.154	.571**	.380	.830**
	Sig. (2-tailed)	.000	.614	.014	.	.000	.854	.539	.968	.411	.039	.473	.004	.067	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
WTRTBL	Pearson Correlation	.915**	-.264	-.385	.906**	1.000	-.250	-.003	.178	-.180	-.244	-.082	.701**	.281	.751**
	Sig. (2-tailed)	.000	.213	.063	.000	.	.239	.990	.406	.401	.252	.704	.000	.184	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
RAINFALL	Pearson Correlation	-.059	.685**	-.049	-.040	-.250	1.000	.715**	-.746**	-.272	-.511*	.800**	-.549**	.071	.060
	Sig. (2-tailed)	.786	.000	.819	.854	.239	.	.000	.000	.199	.011	.000	.005	.742	.781
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
RDAYS	Pearson Correlation	.114	.326	.048	.132	-.003	.715**	1.000	-.742**	-.375	-.370	.810**	-.274	-.060	.139
	Sig. (2-tailed)	.596	.120	.823	.539	.990	.000	.	.000	.071	.075	.000	.196	.782	.518
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
MAXTMP	Pearson Correlation	.020	-.738**	.157	-.009	.178	-.746**	-.742**	1.000	.650**	.591**	-.900**	.498*	-.177	-.059
	Sig. (2-tailed)	.926	.000	.464	.968	.406	.000	.000	.	.001	.002	.000	.013	.408	.783
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
MINTMP	Pearson Correlation	-.165	-.518**	.013	-.176	-.180	-.272	-.375	.650**	1.000	.521**	-.336	-.001	-.001	.001
	Sig. (2-tailed)	.442	.009	.952	.411	.401	.199	.071	.001	.	.009	.108	.996	.996	.996
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
WINDSPD	Pearson Correlation	-.404	-.696**	.388	-.424*	-.244	-.511*	-.370	.591**	.521**	1.000	-.545**	.011	-.358	-.419*
	Sig. (2-tailed)	.050	.000	.061	.039	.252	.011	.075	.002	.009	.	.006	.959	.086	.041
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
RELHUM	Pearson Correlation	.125	.577**	-.242	.154	-.082	.800**	.810**	-.900**	-.336	-.545**	1.000	-.444*	.245	.286
	Sig. (2-tailed)	.559	.003	.255	.473	.704	.000	.000	.000	.108	.006	.	.030	.249	.176
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
SOLAR	Pearson Correlation	.584**	-.502*	-.193	.571**	.701**	-.549**	-.274	.498*	-.001	.011	-.444*	1.000	.124	.503*
	Sig. (2-tailed)	.003	.013	.367	.004	.000	.005	.196	.013	.996	.959	.030	.	.562	.012
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
NA	Pearson Correlation	.366	.129	-.991**	.380	.281	.071	-.060	-.177	-.001	-.358	.245	.124	1.000	.665**
	Sig. (2-tailed)	.079	.547	.000	.067	.184	.742	.782	.408	.996	.086	.249	.562	.	.000
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
ASMO	Pearson Correlation	.824**	-.106	-.734**	.830**	.751**	.060	.139	-.059	.001	-.419*	.286	.503*	.665**	1.000
	Sig. (2-tailed)	.000	.621	.000	.000	.000	.781	.518	.783	.996	.041	.176	.012	.000	.
	N	24	24	24	24	24	24	24	24	24	24	24	24	24	24

*. Correlation is significant at the 0.05 level (2-tailed).

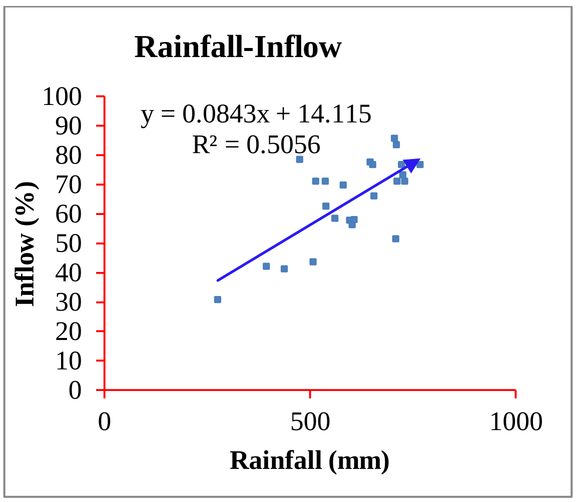
**. Correlation is significant at the 0.01 level (2-tailed).

4.5 Determination of Principal Components

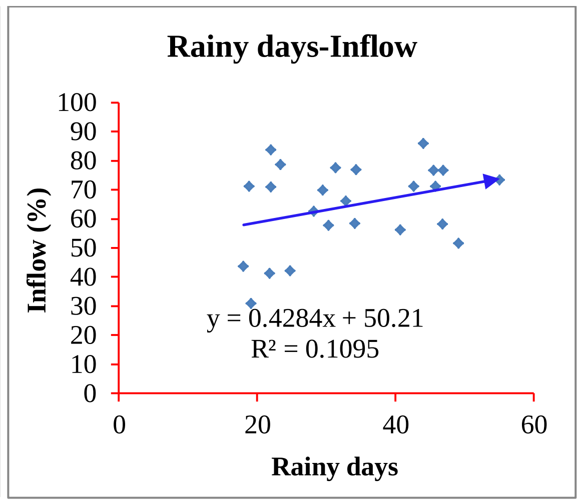
Correlations of various components with inflow have been established after drawing the trend line and regression equation.

4.5.1 Regression Analysis

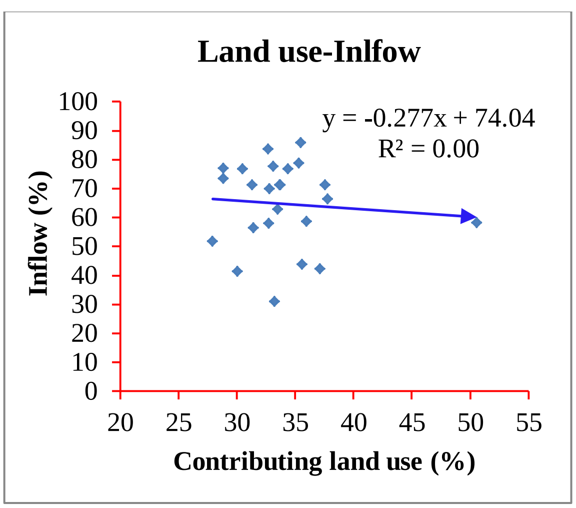
To reduce the dimensionality of the proposed equation, linear regression analyses of inflow (%) with various factors have been carried out independently, as shown in fig 4.12 and summarized in Table 4.10.



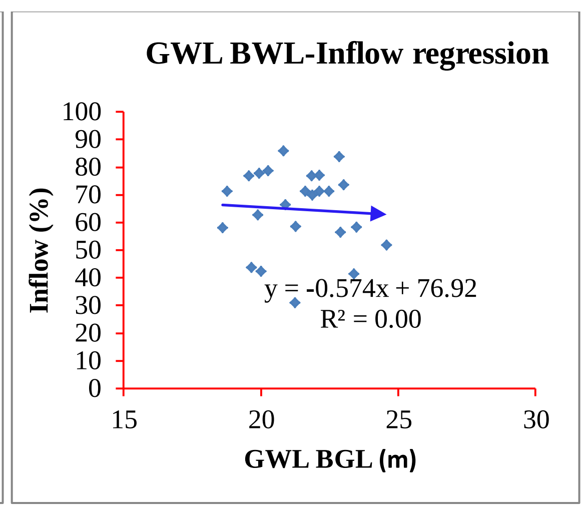
(a) Rainfall



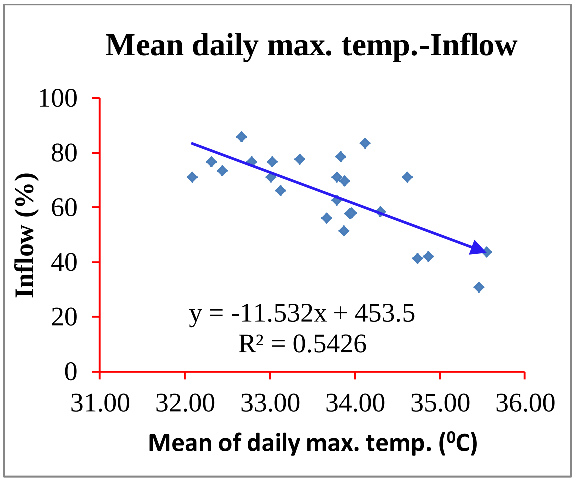
(b) Rainy days



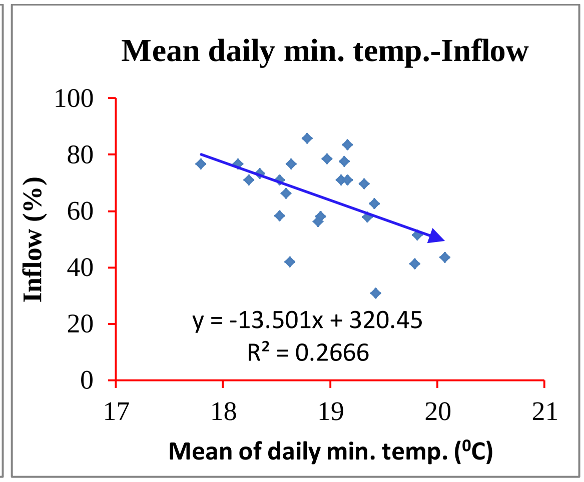
(c) Land use



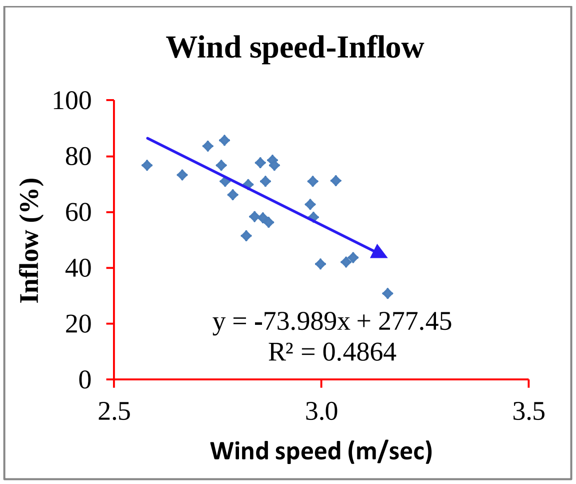
(d) GWL Below GL



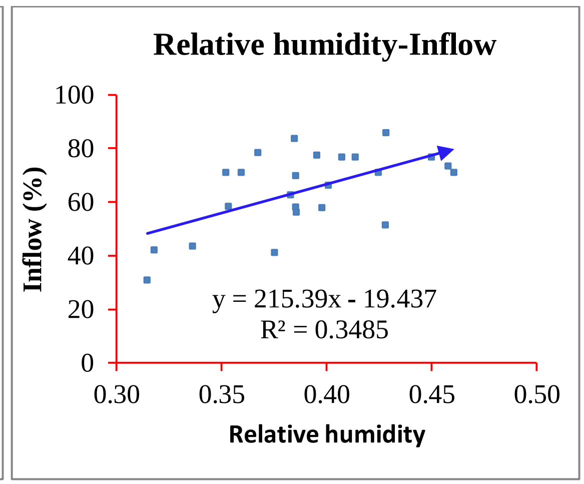
(e) Mean daily max. Temp.



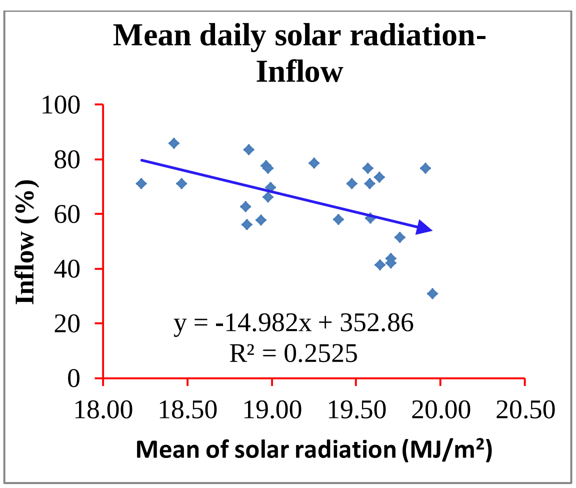
(f)Mean daily min. temp.



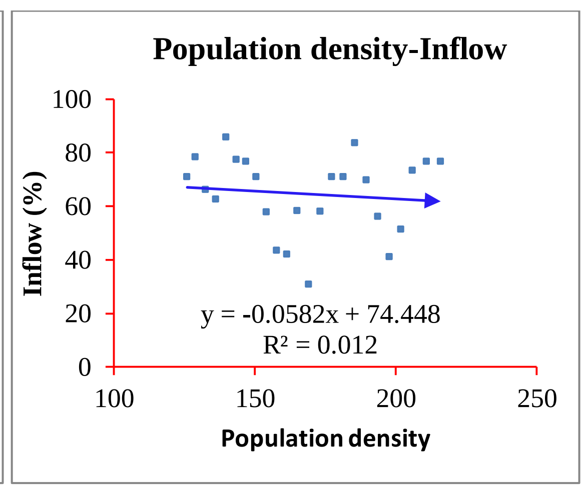
(g) Wind speed



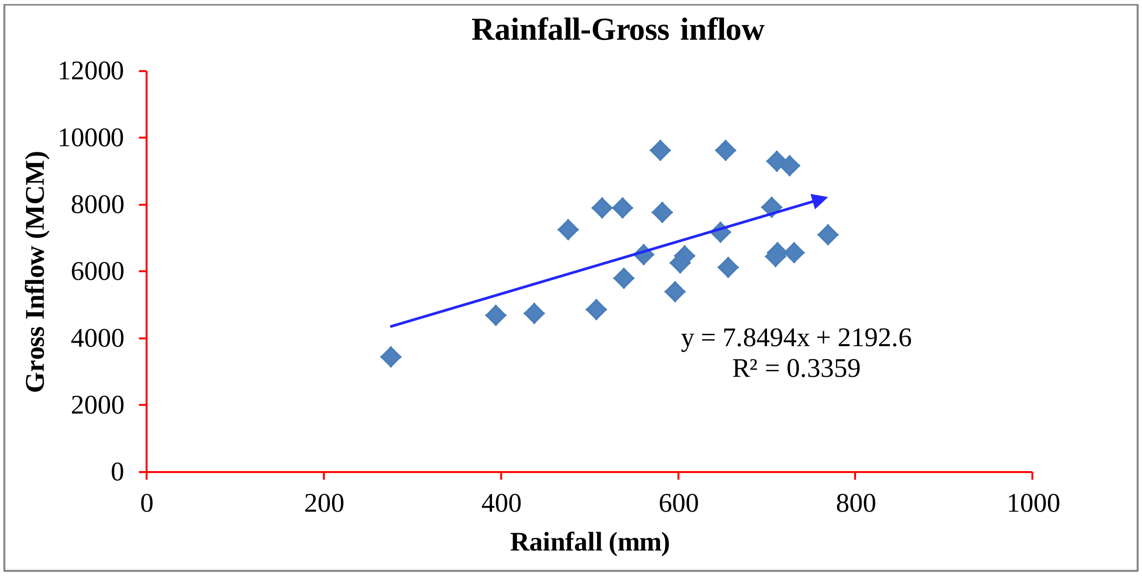
(h) Relative humidity



(i) Solar radiation



(j) Population density



(k) Gross inflow-rainfall

Fig. 4.12 Cross plots: Between inflows and independent variables: Rajasthan

Several cross plots showing the relationship between independent variables and inflows have been generated to develop empirical relations for the indirect estimation of the output. These relations are obtained using statistical methods such as regression analysis. However, although empirical equations are cost- effective and not too time-consuming, they include uncertainties relating to the limited data available (Majdi et al. 2010). To determine the parameters affecting the inflow more than others, several cross plots showing the relationship between independent variables and inflows (%) have been generated for a total of 24 datasets (Fig. 4.12 a to J and Table 4.10). A regression plot between gross inflow and rainfall has been developed in Fig. 4.12 (k) which shows a highly significant correlation with t-value of 3.33 but less than the t-value of inflow (%) and rainfall.

Table 4.10 Correlation and regression of inflow (%) with various factors: Rajasthan

S. N.	Factor	Regression equation	Type of correlation	Coefficient of correlation (R)	t-value	Strength of correlation
1	Rainfall (mm)	y = 0.084x + 14.11	Positive	0.71	4.74	**HS**
2	Rainy days (nos.)	y = 0.428x + 50.21	Positive	0.33	1.64	NS
3	Land use (Cont. effect)	NS	-	0.08	0.39	NS
4	GWL BGL (m)	NS	-	0.05	0.26	NS
5	Population density	NS	-	0.11	0.52	NS
6	Mean of daily max. temp. (^{0}C)	y = -11.53x + 453.5	Negative	0.74	5.1	**HS**
7	Mean of daily min. temp. (^{0}C)	y = -13.50x + 320.4	Negative	0.52	2.82	S
8	Mean of daily wind speed (m/sec)	y = -73.98x + 277.4	Negative	0.70	4.56	**HS**
9	Mean of daily RH (fraction)	y = 215.3x - 19.43	Positive	0.59	3.43	**HS**
10	Mean of daily solar radiation	y = -14.98x + 352.8	Negative	0.50	2.72	S

Here, NS=Not Significant, S= Significant, HS= Highly Significant

Here no. of years (n)=24<30, therefore, to determine correlations of inflows (%) with the variables independently, t-tests have been applied. Here df=n-2=22, and corresponding critical value of t_c=2.074 and 2.819 at 5% and 1% level of significance. Jain et al. (2008) developed a regression equation showing the relationship of runoff with rainfall and depth to water table. For Rajasthan state as a whole, applying linear regression on the available 24 years datasets, we find that rainy days and GWL BGL have weak correlations with runoff. Land use and population density do not have any correlation with inflow. Regression analysis of land use (contributing area) is showing a negative correlation with inflow with R=0.08 and t-value=0.39 against the critical value of t_c=2.074 and 2.819 at 5% and 1% level of significance. Rainfall and other climate parameters have moderate to strong correlations with inflow. This shows that land use have no correlation with the inflows to the dams of the state as a whole and rainfall is having the strong effect on the inflows i.e. inflows was less than the average values when the rainfalls were lesser than the average rainfalls even if the contributing areas of land use were more than the average value desired, as observed in years 1999, 2000, 2001, and 2002. Inflows during the years 2011, 2012, and 2013 improved even after the lesser contributing area than the average because of more than average rainfall during these years. This concludes that rainfall and other climatic factors are principal components for the inflow to the dams of the state i.e. rainfall, mean daily max. temp., wind speed, and relative humidity are considered as principal components.

4.5.2 Cosine Amplitude Method

Cosine Amplitude Method of sensitivity analysis is employed to find out the principal components and their relative importance. By relative influence value (R_{ij}) computed by CAM (Appendix-8), the relative importance of the four factors is mentioned as below:

(1) Rainfall= 0.96

(2) Mean of daily Relative humidity= 0.92

(3) Mean of daily wind speed= 0.73

(4) Mean of daily max. temp.= 0.66

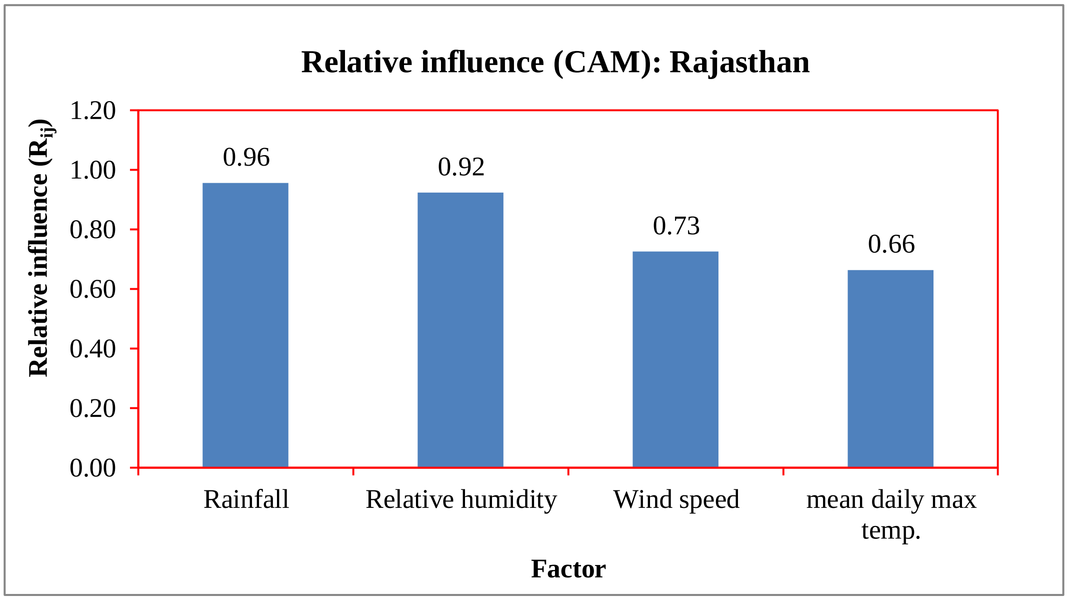


Fig. 4.13 Relative Importance of the factors responsible for inflow (Rajasthan): CAM

Rainfall is the principal factor governing the inflow to the dams of the state as a whole. Other climatic parameters like relative humidity, wind speed and mean of daily max temperature also influence the inflow. Percentage effect of each factor on inflow can be determined by the ratio $\frac{R_{ij}}{\sum R_{ij}}$;

Sensitivity analysis shows less water inflow to the dams of the Rajasthan state due to the precipitation is the main factor having 30% of the effect; relative humidity is responsible for 28% of the effect, wind speed 22% of the effect, and mean daily max. temp. has 20% effect on the inflow.

5 TEMPORAL VARIATION OF INFLOW TO THE RAMGARH DAM

5.1 Formulation and Testing of Hypothesis

5.2 Performance Study and Performance Statistics

5.3 Determination of Critical Year

- 5.3.1 Determination of Possible Critical Years: Time Series Analysis
- 5.3.2 Determination of Critical Year: Sequential Cluster Analysis

5.4 Various Parameters and Their Trends

- 5.4.1 Rainfall and other Climatic Parameters
- 5.4.2 Land Use Land Cover Changes
- 5.4.3 Ground Water Levels
- 5.4.4 Population Growth
- 5.4.5 Various Parameters, Trend Lines and their Rate of Changes
- 5.4.6 Correlation Matrix

5.5 Determination of Principal Components

- 5.5.1 Regression Analysis
- 5.5.2 Cosine Amplitude Method

5.6 MLR for Generation of Inflow Equation

5.7 Regression Analysis and Determination of Factors Responsible for Principal Components

CHAPTER-5

TEMPORAL VARIATION OF INFLOW TO THE RAMGARH DAM

Year wise inflow data of Ramgarh dam have been shown in Table 5.1. Temporal variation of inflow to the Ramgarh dam has been shown in Fig. 5.1 It is evident that the water inflow trend to the dam has tremendously declined. Inflow to the dam was satisfactory up to 1996-1997 which has reduced to around nil inflow during 2009-2014. The average inflow by last 32 years data (1983-2014) is 12.08 MCM against the design capacity of 75 MCM. During the last 32 years, Ramgarh dam never received water equal to or more than its design capacity. Therefore, performance dependability of the dam may be considered as zero. However, if we compute the yield at different dependability's, the dam yields only 4.67 MCM and 0.87 MCM at 50% and 75% dependability's respectively. Dependability of the dam at design capacity (75 MCM) is nil. The theoretical yield has been computed using Strange's Table considering the catchment as 'bad.' Theoretical yield, actual inflow, and weighted rainfall have been plotted against the successive years.

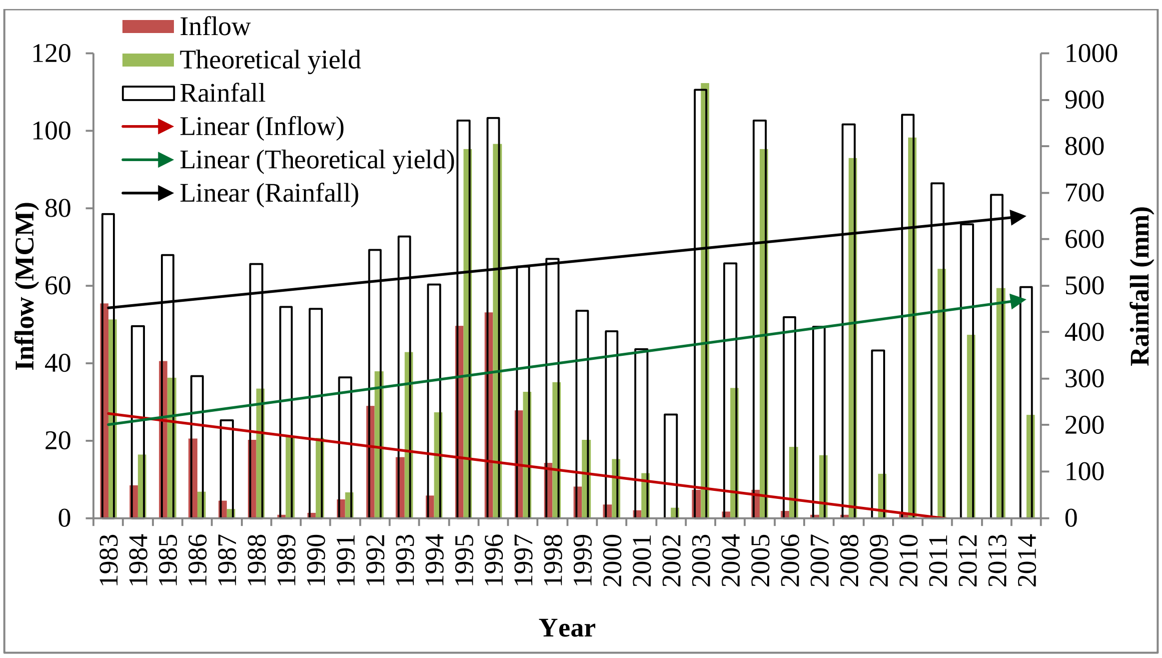


Fig. 5.1 Temporal variation of water inflow to the Ramgarh dam

Theoretical inflows have been computed to compare the actual inflows with the anticipated inflows as per rainfall and to check whether the method of computation prevailing in the department holds good or not (section 5.2).

Table 5.1 Year wise inflow to the Ramgarh dam

S.N.	Year	Rainfall (mm)	Theoretical yield (MCM)	Observed Inflow (MCM)	Observed Inflow in Descending Order	D_n
1	1983	654	51.37	55.46	55.46	3.0
2	1984	413	16.39	08.37	53.09	6.1
3	1985	566	36.22	40.46	49.66	9.1
4	1986	305	06.83	20.55	40.46	12.1
5	1987	210	02.29	04.55	28.99	15.2
6	1988	547	33.47	20.25	27.78	18.2
7	1989	454	21.14	00.91	20.55	21.2
8	1990	451	20.74	01.39	20.25	24.2
9	1991	302	06.67	04.79	15.72	27.3
10	1992	577	37.91	28.99	14.23	30.3
11	1993	606	42.93	15.72	08.37	33.3
12	1994	502	27.30	05.88	08.07	36.4
13	1995	856	95.23	49.66	07.34	39.4
14	1996	862	96.59	53.09	07.31	42.4
15	1997	541	32.64	27.78	05.88	45.5
16	1998	558	35.02	14.23	04.79	48.5
17	1999	446	20.17	08.07	04.55	51.5
18	2000	402	15.30	03.53	03.53	54.5
19	2001	364	11.65	01.93	01.93	57.6
20	2002	223	02.72	00.05	01.86	60.6
21	2003	922	112.33	07.34	01.71	63.6
22	2004	547	33.54	01.71	01.39	66.7
23	2005	856	95.24	07.31	01.07	69.7
24	2006	432	18.44	01.86	0.91	72.7
25	2007	412	16.24	0.86	0.86	75.8
16	2008	847	92.95	0.77	0.77	78.8
27	2009	361	11.41	0.00	0.05	81.8
28	2010	868	98.21	1.07	**0.00**	**84.8**
29	2011	721	64.33	0.00	0.00	87.9
30	2012	632	47.40	0.00	0.00	90.9
31	2013	696	59.37	0.00	0.00	93.9
32	2014	497	26.60	0.00	0.00	97.0
Average=			40.27	12.08		

Graph of three-time segments 1983-1990, 1991-2000 and 2001-2014 (Fig. 5.2) shows a tremendous reduction of inflow at the same quantum of monsoon rainfall. The figure can also be used to predict the maximum probable inflow for a certain amount of monsoon rainfall using trend line of 2001-2014.

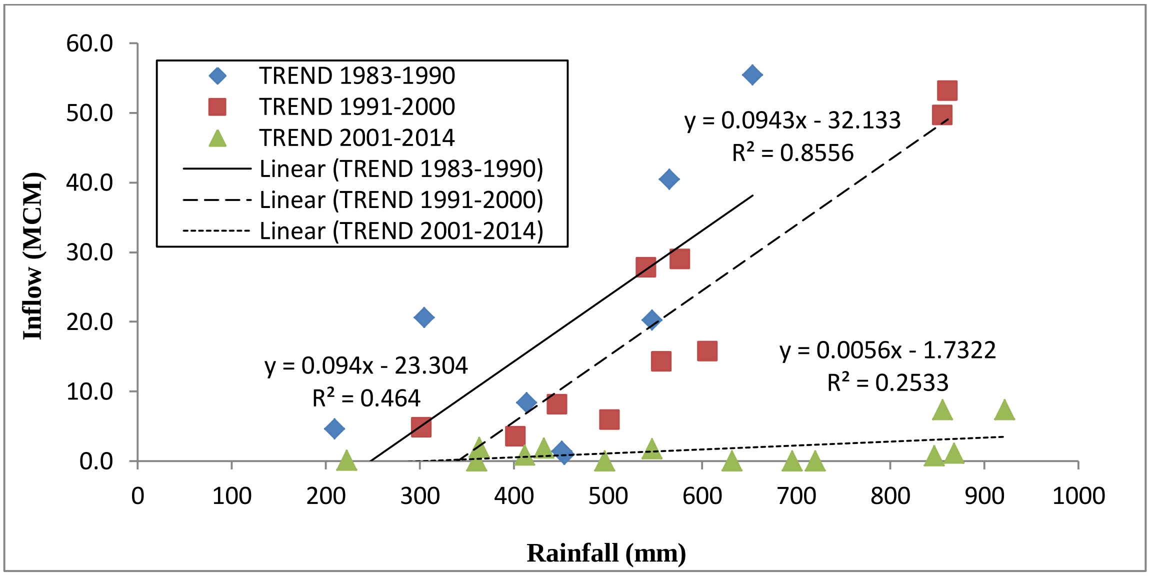


Fig. 5.2 Water Inflow trend for different time segments: Ramgarh dam

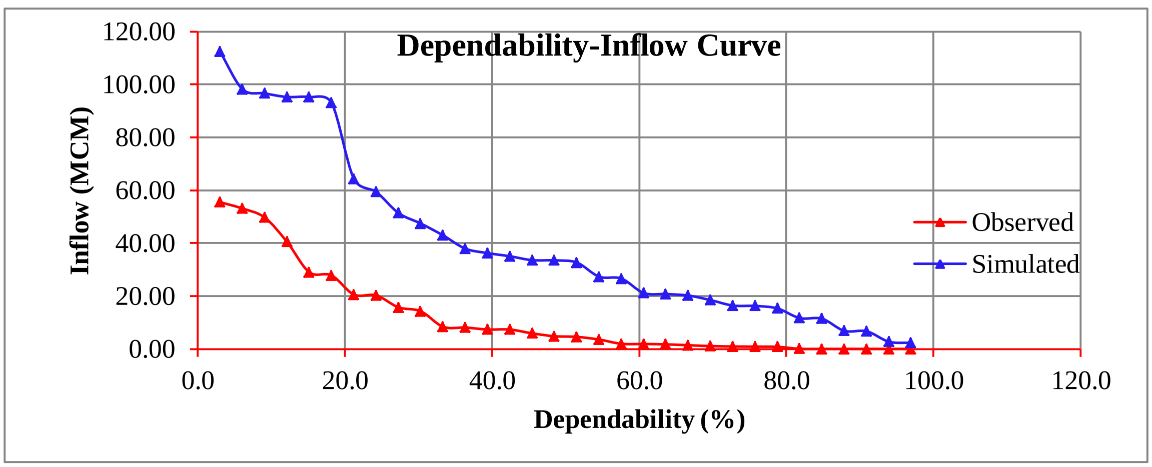


Fig. 5.3 Variations of inflow with dependability in Ramgarh dam

Inflows on dependability are plotted as shown in Fig. 5.3. The Graph shows that there was 0.00 MCM inflow at 84.80% reliability. As per code provisions, inflow at 100% reliability is considered for drinking water projects (IS 5477 Part-3:2002).

5.1 Formulation and Testing of hypothesis

Here, a total number of years are 32 i.e. n>30; therefore, Z-test has been applied.

Z-Test: **H_o (Null Hypothesis)**: $\mu = 75$ MCM

H_1 (Alternate Hypothesis): $\mu \neq 75$ MCM

Here n=32 (>30), therefore z-test has been applied.

$\bar{x} = 12.08$; S= 16.63; SE= 2.94;

z= 21.40;

Standard z value at 5% significance level= 1.96

$z > z_{std}$; therefore null hypothesis is rejected and alternate hypothesis is accepted, i.e. Ramgarh dam is not getting the desired 75 MCM inflow of water. Trend of inflows infers that the dam is getting less than the desired inflow.

5.2 Performance Study and Performance Statistics

On the basis of year wise inflow data (Table 5.1) hydrological performance of the dams is measured as below:

Reliability:	0.00%
Resilience:	0.00%
Vulnerability:	83.89%
Maximum deficit:	100% (2009,2011,2012,2013,2014)
Sustainability:	0.00%

Results of performance analysis show that Ramgarh dam is highly vulnerable. As per Danilyan et al. 2006, one of the major features of small rivers is a close correlation between their runoff formation and watershed landscape, a property which makes them heavily vulnerable when subject to intense economic development. Ploughing up of floodplain lands, as well as other types of land treatment, leads, as a rule, to a decrease in the annual and springtime runoff. The decrease in water flow disturbs the natural regime, reduce the depth and rate of water flows, and causes the transformation of river channels into chains of isolated pools and often a complete degradation of small rivers, the same case exists in the Ramgarh dam catchment. The state of an ecological catastrophe, i.e., the situation in which exogenous and endogenous processes of natural or anthropogenic origin destroy the structural and functional organization of the system; the result of this process is the death of the water body; no return of the system to the original state is possible either in a normal way or through forced recultivation (Danil'Yan et al. 2006). Theoretical values have been computed using the Thiessen polygon and Strange's Table considering 'bad' catchment and compared with the observed values. Statistical parameters for measuring the performance of computation method of theoretical yield has been shown in Table 5.2.

Table 5.2 Performance Statistics: Ramgarh dam

Statistical Parameter	MAE	MAPE (%)	R	R^2	t_{30}	NSE	RMSE	RSR	NMBE
Value	29.74	961280.41	0.30	0.09	1.72	-5.57	42.02	2.56	234.20
Optimal value	Lower value	Lower value	Unity	Unity	2.04	Unity	Lower value	Zero	Lower value

The value of the coefficient of correlation is 0.30, the corresponding t-value is 1.72, which is less than the critical value of t_c = 2.042, at (32-2) =30 degree of freedom at the 5% level of significance. This shows that there is no correlation between the observed and computed values. Nash Sutcliff Efficiency (NSE) is a negative value, which shows that the average of the observed values is a better indicator than the computed value. Different inflow means can be computed for different rainfall events, and that may be utilized for future prediction of inflow. RSR is also far beyond the optimal value. MAE, MAPE, RMSE, and NMBE are very high. Therefore, it can be concluded that the method of computation of theoretical values of inflows is not an acceptable method in this case. During the last 32 years, Ramgarh dam never received water equal to or more than its design capacity. Therefore, the performance dependability (reliability) of the dam may be considered as zero. The dam yields only 4.88 MCM and 0.69 MCM at 50% and 75% dependability respectively. Inflow to the Ramgarh dam was never remained above the theoretical yield except the year 1986. Inflow always remained below the theoretical yield after the year 1991, and it slashed after the year 2000 and touched to nearby zero level. The rainfall trend over the catchment is increasing while the water inflow trend in the Ramgarh dam has steeply declined as shown in Fig.5.1. The phenomenon was well explained by Danil'Yan et al. (2006), the large variations in the hydrological regime are typical of small rivers in urban territory because of radical changes in landscape due to urbanization; many small rivers in such territory disappeared, therefore, the most important problem in urban areas in the protection and rehabilitation of small river resources rather than runoff withdrawal. Ramgarh dam is also situated on small river Banganga, and the catchment of Ramgarh dam comes under the jurisdiction of Jaipur Development Authority, i.e. in urban territory.

5.3 Determination of Critical Year

After testing the hypothesis and getting the inference that water inflow to the Ramgarh dam has declined, it is essential to find out the critical year which divides the pre and post-disturbance epochs. The sequential cluster analysis gives us the critical year out of the possible years, which divides the pre and post-disturbance epochs.

5.3.1 Determination of Possible Critical Years: Time Series Analysis

Time Series Analysis and Sequential Cluster Analysis have been carried out for determination of critical year. Time series analysis gives us an idea about the possible critical years where trends are broken, and abrupt changes have taken place. The results of the time series analysis are as shown in Table 5.3.

Table 5.3 Time series analysis: Ramgarh dam (Trend elimination using least square method)

S. N.	Year	Inflow, MCM	t	t*I	t*t	Trend	Elimination of Trend	Possible critical year
1	1983	55.45	-15	-831.8	225	26.95	28.49	
2	1984	8.38	-14	-117.3	196	25.99	-17.61	***
3	1985	40.47	-13	-526.1	169	25.03	15.43	
4	1986	20.56	-12	-246.7	144	24.07	-3.51	
5	1987	4.56	-11	-50.16	121	23.11	-18.55	
6	1988	20.25	-10	-202.5	100	22.15	-1.9	
7	1989	0.91	-9	-8.19	81	21.19	-20.28	
8	1990	1.39	-8	-11.12	64	20.23	-18.84	
9	1991	4.79	-7	-33.53	49	19.27	-14.48	
10	1992	29	-6	-174	36	18.31	10.68	***
11	1993	15.72	-5	-78.6	25	17.36	-1.64	
12	1994	5.89	-4	-23.56	16	16.4	-10.51	
13	1995	49.67	-3	-149	9	15.44	34.22	***
14	1996	53.1	-2	-106.2	4	14.48	38.61	***
15	1997	27.78	-1	-27.78	1	13.52	14.25	
16	1998	14.22	0	0	0	12.56	1.65	***
17	1999	8.07	1	8.07	1	11.6	-3.53	
18	2000	3.54	2	7.08	4	10.64	-7.1	
19	2001	1.93	3	5.79	9	9.68	-7.75	
20	2002	0.06	4	0.24	16	8.72	-8.66	
21	2003	7.34	5	36.7	25	7.76	-0.42	

22	2004	1.73	6	10.38	36	6.8	-5.07	
23	2005	7.31	7	51.17	49	5.84	1.46	***
24	2006	1.87	8	14.96	64	4.88	-3.01	
25	2007	0.85	9	7.65	81	3.92	-3.07	
26	2008	0.76	10	7.6	100	2.96	-2.2	
27	2009	0	11	0	121	2	-2	
28	2010	1.08	12	12.96	144	1.05	0.02	
29	2011	0	13	0	169	0.09	-0.09	
30	2012	0	14	0	196	-0.86	0.86	
31	2013	0	15	0	225	-1.82	1.82	
32	2014	0	16	0	256	-2.78	2.78	
	Sum	386.68	16	-2424	2736	386.68		

The Trend equation U = a + bt has been derived as

Inflow = 12.56 + -0.96 x Time

Where a = 12.56 and b = -0.96 (Fig. 5.4)

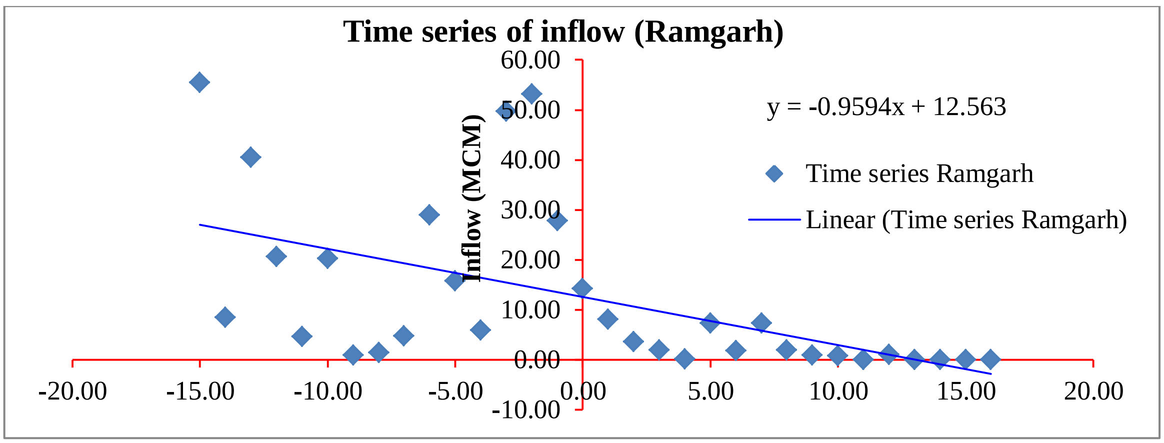


Fig. 5.4 Time series inflow of Ramgarh dam

Exceptional periods are (possible critical years) marked as *** where there is a drastic change. In this analysis year 1984,1992, 1995, 1996, 1998, and 2005 are identified as possible critical years It can be attributed to climatic or anthropogenic changes.

5.3.2 Determination of Critical Year: Sequential Cluster Analysis

The final critical year can be obtained by applying Sequential Cluster Analysis on the possible critical years which have been identified in Table 5.3. The minimum sum of squared deviations for the hydrological series before and after the possible critical years gives the unique critical year (Table 5.4).

Table 5.4. Sequential cluster analysis: Ramgarh dam

S. N.	Year	Actual Inflow (MCM)	Possible Critical Year					
			1984	**1992**	**1995**	**1996**	**1998**	**2005**
1	1983	55.45	553.7	1359.5	1273.2	1109.0	1118.3	1508.7
2	1984	8.38	**554.0**	104.0	129.7	189.5	185.7	67.7
3	1985	40.47	882.7	479.2	428.5	335.6	340.8	569.3
4	1986	20.56	96.1	3.9	0.6	2.5	2.1	15.6
5	1987	4.56	38.4	196.6	231.4	309.4	304.5	145.2
6	1988	20.25	90.0	2.8	0.2	3.6	3.1	13.2
7	1989	0.91	97.1	312.4	355.8	451.3	445.4	246.6
8	1990	1.39	87.8	295.6	337.9	431.1	425.3	231.7
9	1991	4.79	35.7	190.3	224.5	301.5	296.7	139.8
10	1992	29.00	332.7	**108.6**	85.2	46.9	48.9	153.5
11	1993	15.72	24.6	43.4	16.4	41.4	39.6	0.8
12	1994	5.89	23.7	10.5	192.6	264.4	259.8	114.9
13	1995	49.67	1514.3	1643.8	**894.3**	757.6	765.3	1093.2
14	1996	53.10	1792.8	1933.5	2141.9	**958.0**	966.7	1331.6
15	1997	27.78	289.8	347.9	439.4	553.8	33.3	124.8
16	1998	14.22	12.0	25.9	54.7	99.3	**60.7**	5.7
17	1999	8.07	7.2	1.1	1.6	14.6	34.9	72.9
18	2000	3.54	52.1	31.2	10.8	0.5	1.9	170.8
19	2001	1.93	78.0	51.9	24.0	5.4	0.1	215.6
20	2002	0.06	114.6	82.3	45.7	17.6	4.4	274.0
21	2003	7.34	11.7	3.2	0.3	9.5	26.8	86.0
22	2004	1.73	81.6	54.8	25.9	6.4	0.2	221.5
23	2005	7.31	11.9	3.3	0.2	9.3	26.5	**86.6**
24	2006	1.87	79.0	52.7	24.5	5.7	0.1	1.8
25	2007	0.85	98.2	68.6	35.6	11.6	1.7	0.1
26	2008	0.76	99.9	70.0	36.7	12.1	1.9	0.1
27	2009	0.00	115.8	83.4	46.5	18.1	4.7	0.3
28	2010	1.08	93.8	64.9	33.0	10.1	1.2	0.3
29	2011	0.00	115.8	83.4	46.5	18.1	4.7	0.3
30	2012	0.00	115.8	83.4	46.5	18.1	4.7	0.3
31	2013	0.00	115.8	83.4	46.5	18.1	4.7	0.3
32	2014	0.00	115.8	83.4	46.5	18.1	4.7	0.3
	Mean	O_n=	31.92	18.58	19.77	22.15	22.01	16.61
	Mean	O_{N-n}=	10.76	09.13	06.82	04.25	2.16	0.51
	Sum	$V_n + V_{N-n=}$	7732	7959	7277	6048	**5419**	6894

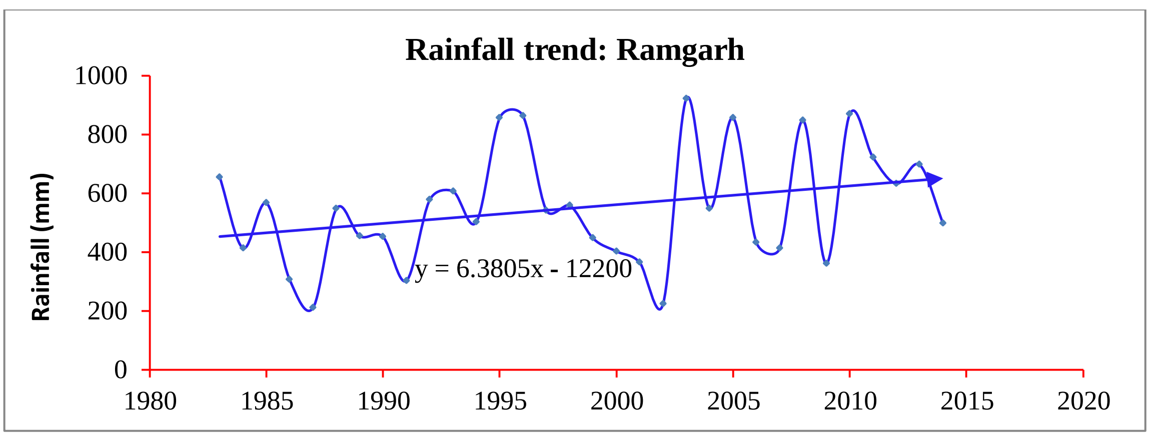
From section 5.1 it is evident that there is a declining trend of water inflow to the Ramgarh dam. It is very essential to determine the critical year, which divides two consecutive non-overlapping epochs- pre-disturbance and post-disturbance. Determination of critical year will help in policy formulation for an effective water resources planning and management of the area. The year 1998 is considered as the critical year for the hydrological behavior of the Ramgarh dam. This shows that some disturbances have taken place after 1998 which is attributed to the low inflow to the dam.

5.4 Various Parameters and Their Trends

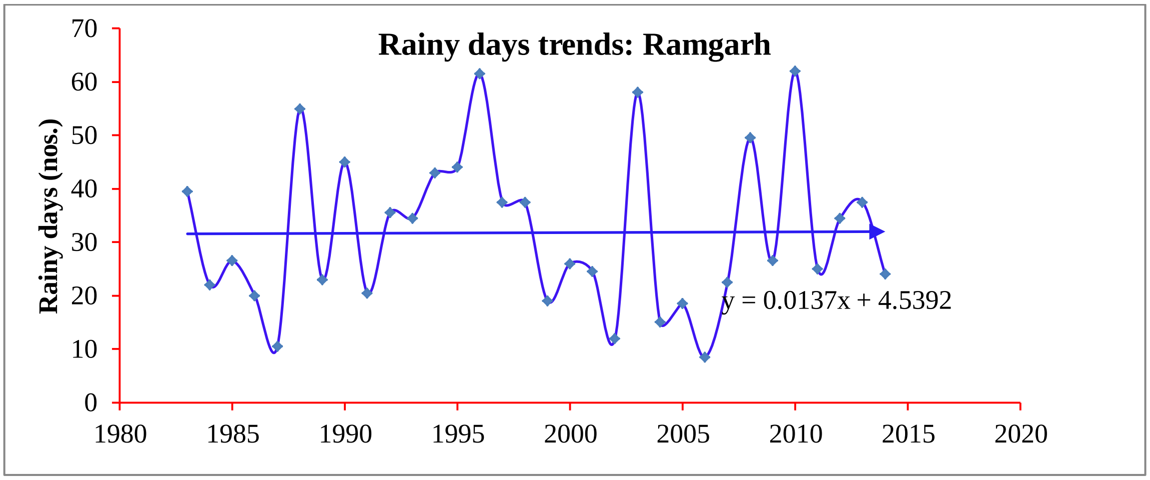
The declining trend of inflow to the Ramgarh dam has been tested. The year of initiation of post-disturbance epoch is determined as 1998. The various factors which are considered responsible for surface runoff are analyzed and discussed. Trends of various factors are plotted and shown in Fig 5.5 to 5.8. Climatic parameters such as average daily minimum and maximum temperature, precipitation, wind speed, relative humidity and solar radiation are studied, and graphs are plotted to determine the variation of these parameters with time.

5.4.1 Rainfall and Other Climatic Factors

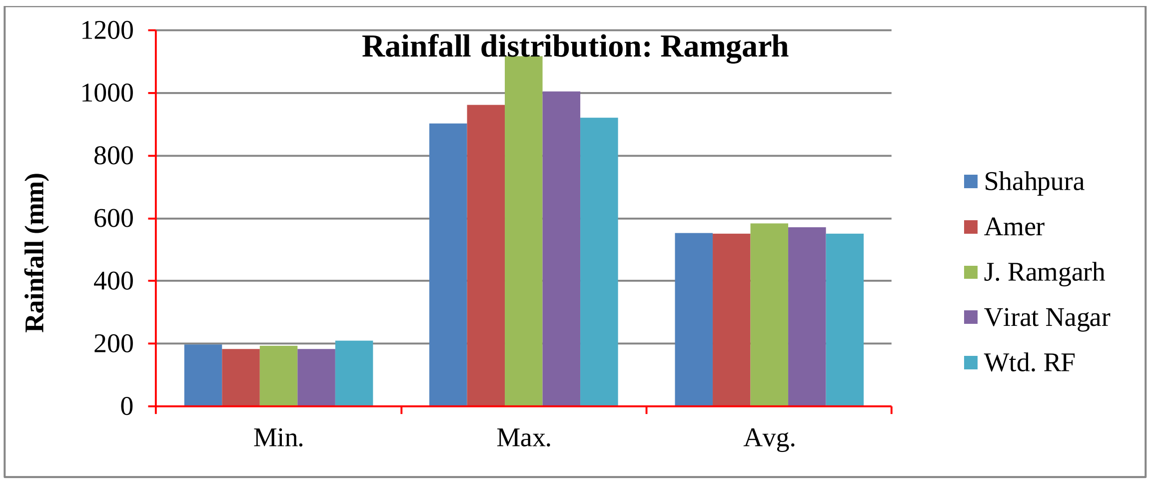
Year wise rainfall has been computed using the Thiessen polygon technique and the graph has been plotted (Fig. 5.5 a). Variation of rainy days during monsoon period has been shown in Fig. 5.5 (b). Minimum, maximum and average of rainfall of four rain gauge stations within/around the Ramgarh catchment during the analysis period is shown in Fig. 5.5 (c).



(a) Rainfall trend (1983-2014)



(b) Rainy days trend (1983-2014)



(c) Rainfall pattern over different RGS

Fig. 5.5 Rainfall trend: Ramgarh

The rainfall trend over the catchment area of Ramgarh dam varies significantly over the years, showing the temporal variation of rainfall. But it does not vary significantly within various RGS. To test the variances along the time scale and along the RGS, F-test is applied. Computed F value is 156.26 which is more than the critical value of F_c=8.62 (32-1=31 and 4-1=3 degree of freedoms). This shows that there exist significant variances.

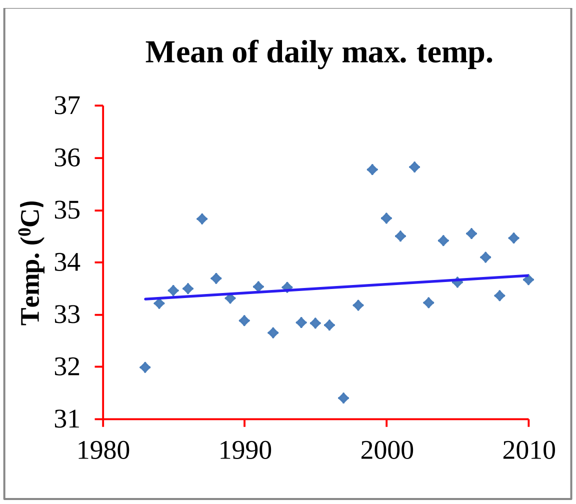
Minimum and maximum weighted annual rainfall is 209.7 mm (1987) and 921.9 mm (2003) with an average value of 551 mm. This shows that there exists temporal variation of rainfall over the catchment. The pattern of rainfall intensity over the catchment can be seen from Table 5.5. There is no much variation of rainfall intensities over the catchment.

Table 5.5 Number of events for different rainfall intensities at four RGS

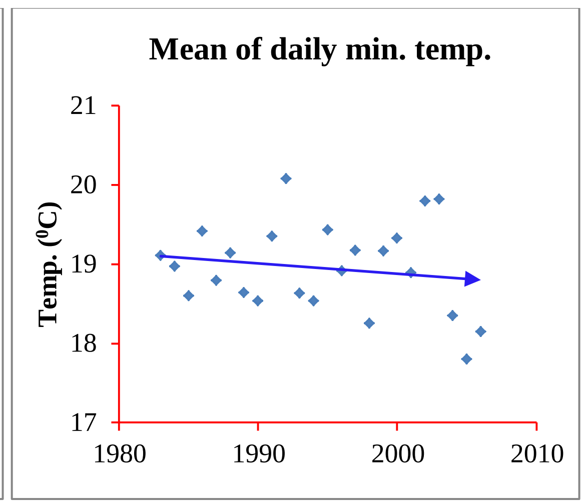
Year	No. of days (>20 mm/day)				No. of days (>50 mm/day)				No. of days (>100 mm/day)				No. of days (>150 mm/day)			
	SH	AM	JR	VN	SH	AM	JR	VN	SH	AM	JR	VN	SH	AM	JR	VN
1983		10	10	8		6	4	3		0	1	0		0	0	0
1984		7	6			2	1			0	0			0	0	
1985		11	10	9		4	2	3		1	1	0		0	0	0
1986		6	4	6		1	2	0		0	0	0		0	0	0
1987		6	2	2		1	1	0		0	0	0		0	0	0
1988		8	9	10		0	0	4		0	0	1		0	0	0
1989		7	8	7		5	1	2		2	0	0		0	0	0
1990		13	7	6		1	0	0		0	0	0		0	0	0
1991	2	8	9	5	0	2	2	0	0	0	0	0	0	0	0	0
1992	6	12	12	10	3	5	4	3	0	1	0	1	0	0	0	1
1993	9	11	7	13	5	5	2	2	0	1	0	0	0	1	0	0
1994	7	14	7	8	1	3	1	1	0	0	0	0	0	0	0	0
1995	17	13	13	19	4	6	4	2	0	1	2	0	0	1	0	0
1996	10	16	17	13	4	5	7	4	1	0	2	1	0	0	0	0
1997	8	9	10	12	3	3	1	2	0	0	0	0	0	0	0	0
1998	7	11	12	10	2	5	2	2	0	0	0	0	0	0	0	0
1999	8	4	8	10	2	3	4	2	0	0	0	0	0	0	0	0
2000	8	3	8	9	0	0	2	1	0	0	0	0	0	0	0	0
2001	5	6	4	8	1	0	0	2	0	0	0	0	0	0	0	0
2002	4	3	6	3	2	1	0	0	0	0	0	0	0	0	0	0
2003	11	8	15	16	7	2	6	6	1	1	0	1	0	0	0	0
2004	11	10	12	4	1	2	4	1	0	0	1	0	0	0	0	0
2005	12	7	12	14	5	3	6	7	2	0	2	1	1	0	1	1
2006	4	3	6	6	2	1	3	2	1	0	1	0	1	0	0	0
2007	7	5	9	0	2	2	0	0	0	1	0	0	0	0	0	0
2008	13	6	15	12	4	1	7	4	1	0	3	1	0	0	0	0
2009	4	0	8	3	2	0	3	1	0	0	0	0	0	0	0	0
2010	12	9	14	13	5	2	3	4	1	1	1	1	1	0	0	0
2011	14	7	11	12	5	1	0	6	0	0	0	0	0	0	0	0
2012	4	9	6	7	2	1	2	2	2	1	1	1	0	0	0	0

Here, abbreviations SH refers to Shahpura RGS, AM refers to Amer RGS; JR refers to Jamwa Ramgarh RGS, and VN refers to Virat Nagar RGS.

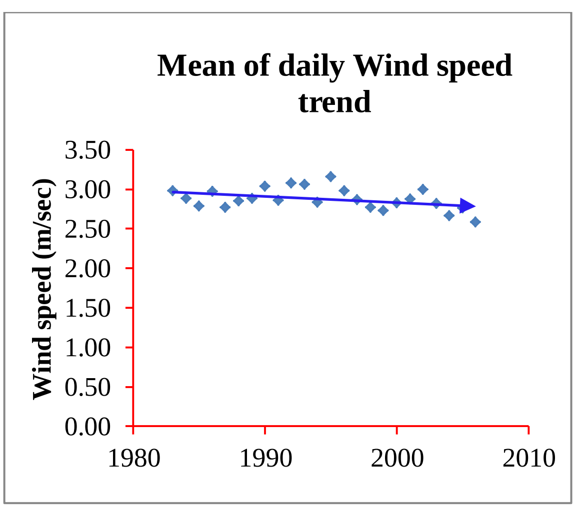
Four numbers RGS are situated nearby catchment area of Ramgarh dam. Weighted monsoon rainfall has been computed using the Thiessen polygon method. The pattern of distribution of rainfall intensity over the catchment has also been analyzed and found no major variation over the years. During 2003 and 2005, even after fairly widespread and heavy to very heavy rainfall events, the inflow to the dam was only around 7.3 MCM, which is around 10% of the design capacity of the dam. During the year 2010 and 2011, the rainfall pattern was same, but the inflow to the dam remained on zero level. Changes in land use, construction of small structures like check dams; anicuts, field bunding, etc. also cause a reduction in inflow to the dam (Technical Committee report 2013, SRSAC report, Appendix- 10b). Therefore, we can say that even after widespread and more than normal rainfall, the water inflow to the Ramgarh dam has diminished to zero level. Trends of other climatic parameters are shown in Fig. 5.6.



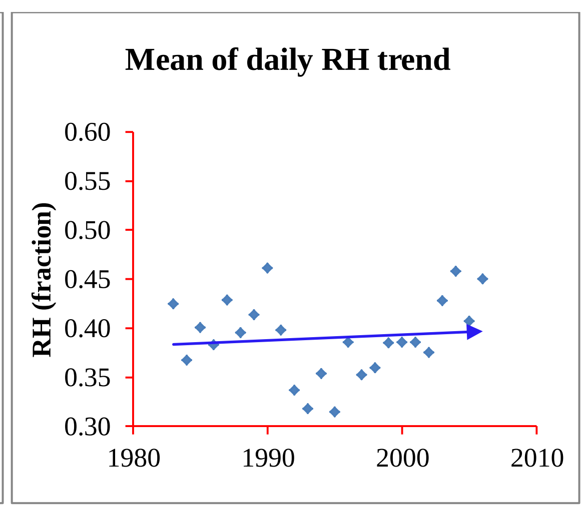
(a) Mean daily max. temp.



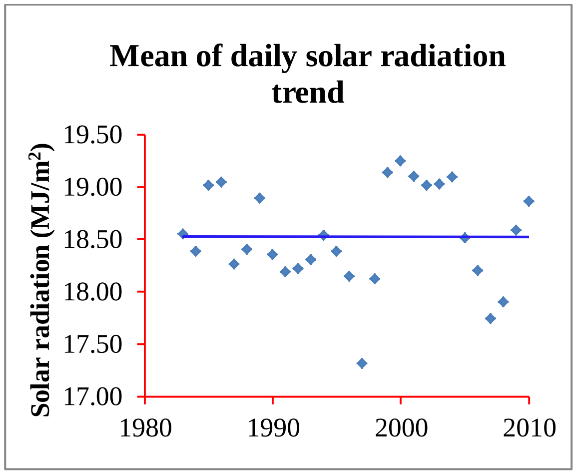
(b) Mean of daily min. temp.



(c) Wind speed



(d) Relative Humidity

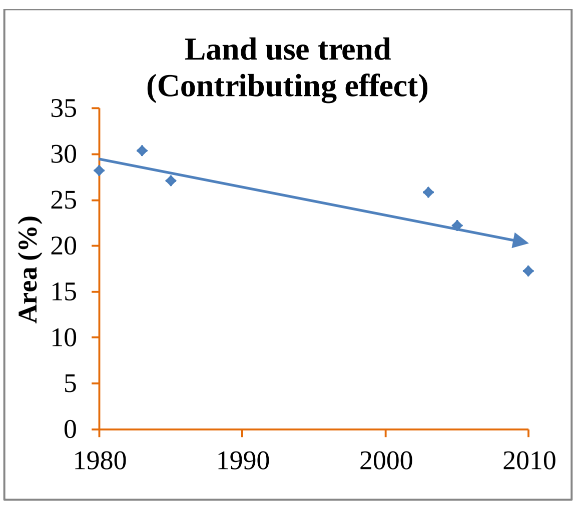


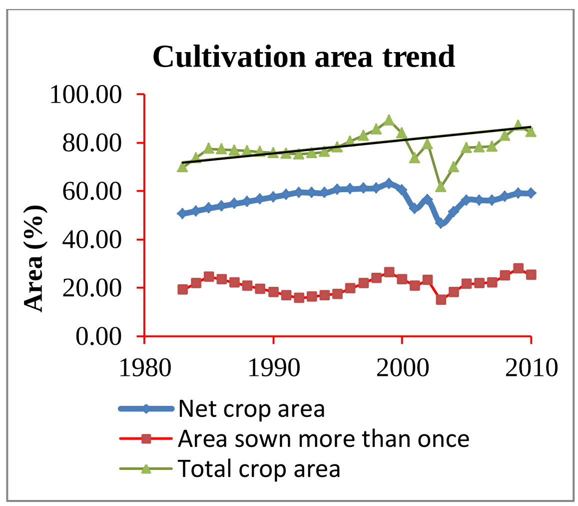
(e) Solar radiation

Fig. 5.6 Trends of other climatic factors: Ramgarh

5.4.2 Land Use Land Cover Changes

Due to anthropogenic reasons land use and land cover is also changing with time. Land use has been divided in two category viz. land use having a contributing effect and reducing effect. One of the major land use is increasing in the cultivated area. Land use trend (Contributing area) and Cultivation area trend are shown in Fig. 5.7.

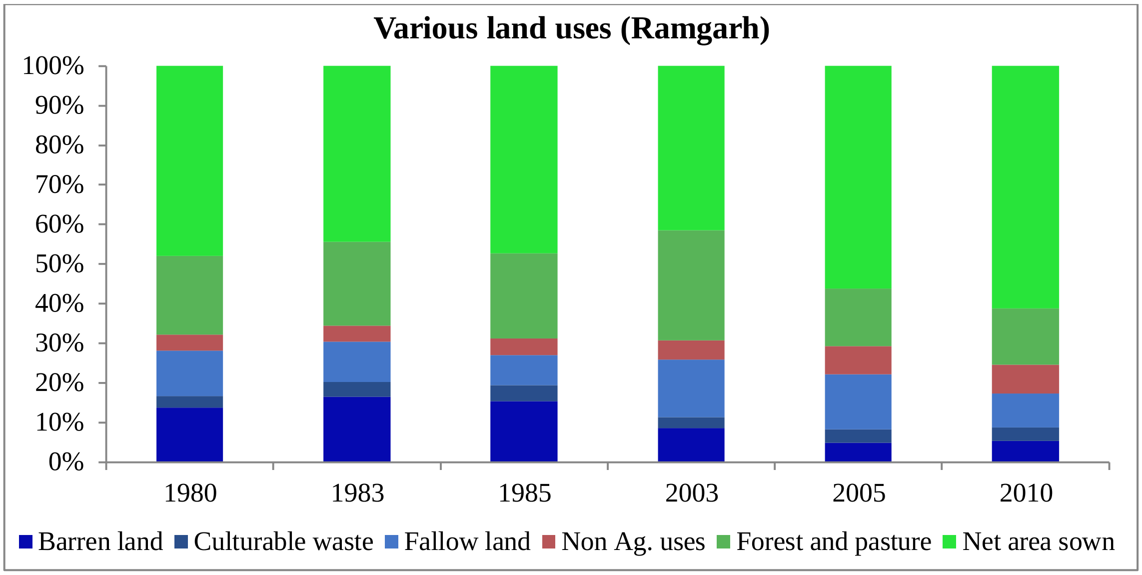




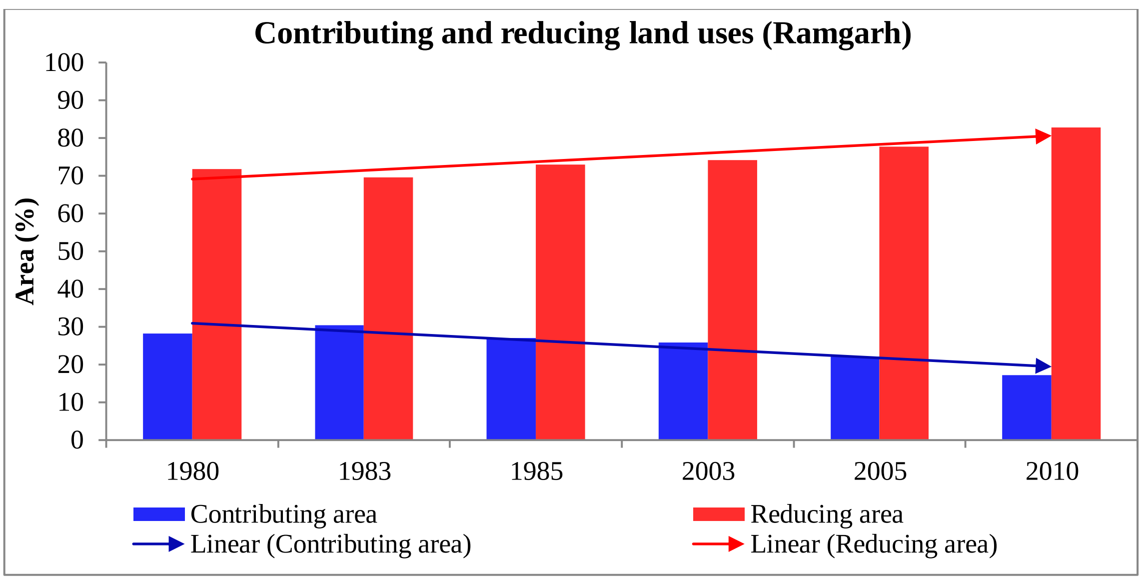
(a) Contributing Land use (c) Cultivation area

Fig. 5.7 Land use (Contributing effect) and cultivation area trend: Ramgarh

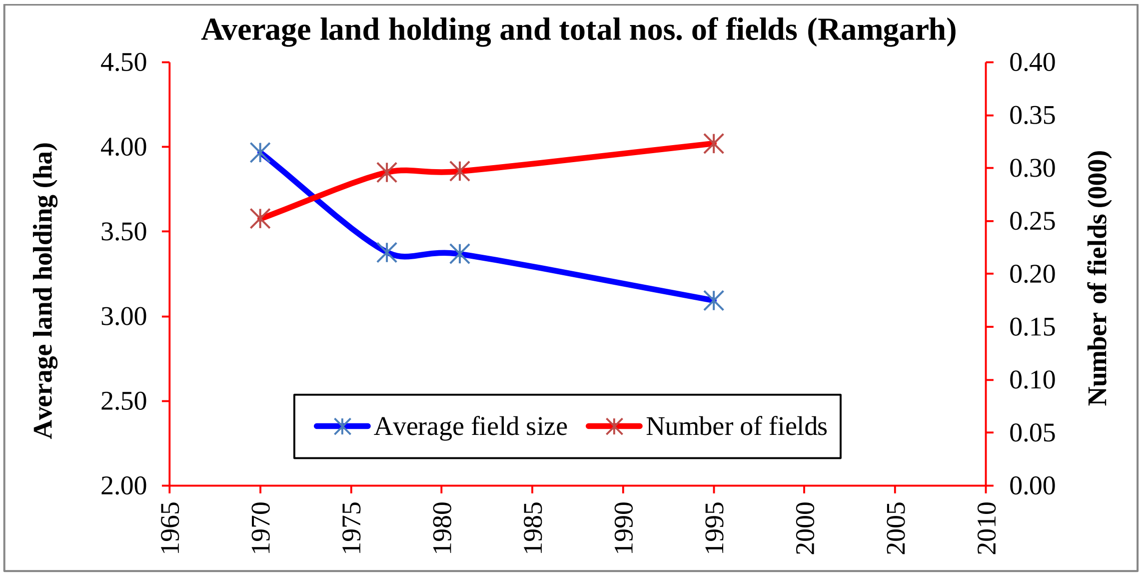
Various types of the land use trend are shown in Fig. 5.8. These figures show that land use having reducing effect, area sown are on an increasing trend. Average land holding is decreasing, and a total number of fields are increasing. This type of pattern of land use increases the surface roughness and decreases the runoff.



(a) Various land uses



(b) Comparison of Contributing and Reducing land use changes



('c) Average land holding and total nos. of fields

Fig. 5.8 Land use changes: Ramgarh

Construction of small storage structures like check dams, anicuts, johads, earthen bunds, field bundings etc. are also causing a reduction in inflow to the dam. As mentioned in a report of a technical committee (2013), in Ramgarh catchment area 430 water bodies with a total storage capacity of 12.62 MCM exist as detailed below:

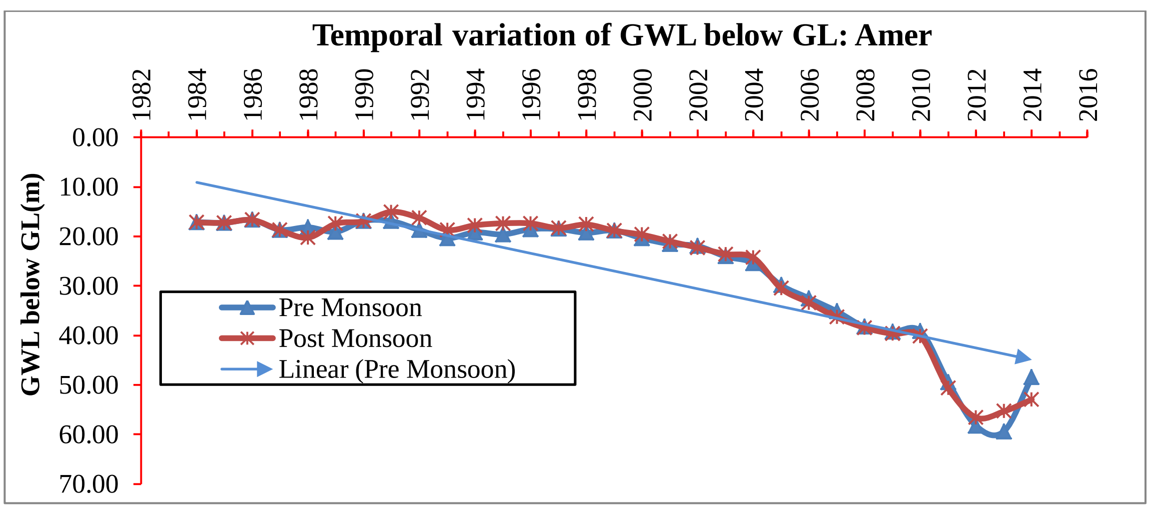
4 minor irrigation projects with a capacity	2.37 MCM
322 village tanks with a capacity	8.26 MCM
104 anicuts with a capacity	1.99 MCM

Similarly, Watershed & Soil Conservation Department constructed 342 water bodies consisting of anicuts, WHS, etc. storing 1.07 MCM of water. Besides this, contour bunding has also been done in about 67.80 sqkm with an average height of 0.3m. This contour bunding stores about 1.52 MCM of water in a single spell of rainfall. So activities of Watershed & Soil Conservation Department store about 2.59 MCM of runoff. So the total interception in the yield is about 15.21 MCM. These types of activities intercept the catchment area of Ramgarh dam and also increases the surface roughness, thereby causes a reduction in inflow to the dam.

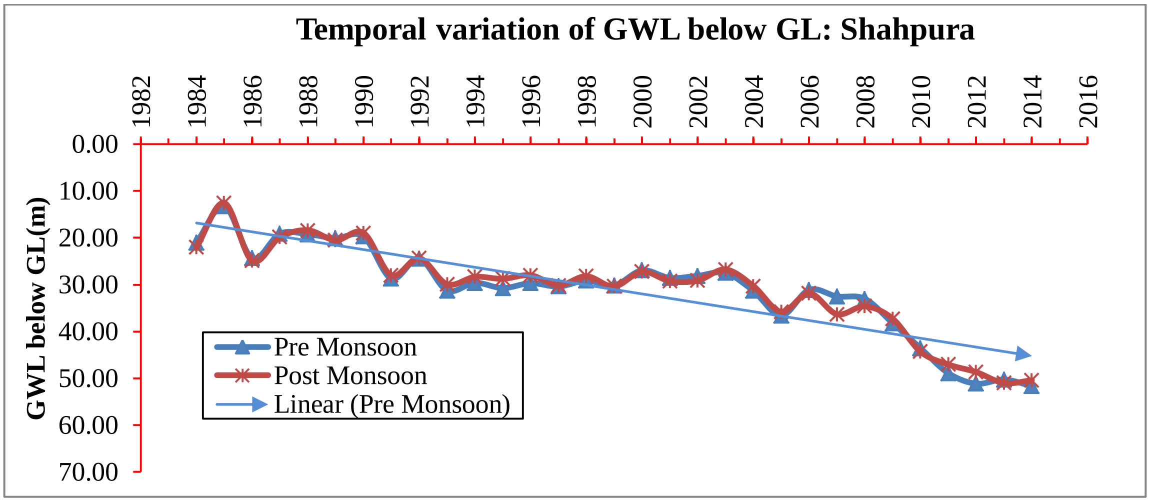
A field visit was also conducted on 29.01.2016 to 02.02.2016 to identify abstractions in the catchment area of existing dams of capacity 45.0 mcft and found 104 number of such small storage structures of capacity 45.203 mcft (Appendix 10b), which also have resulted in the nil inflow to the dams. Literature regarding the effect of this type of land use change and an interception on inflow has been discussed in detail in section 2.6 and 2.11.3.

5.4.3 Groundwater Level Changes

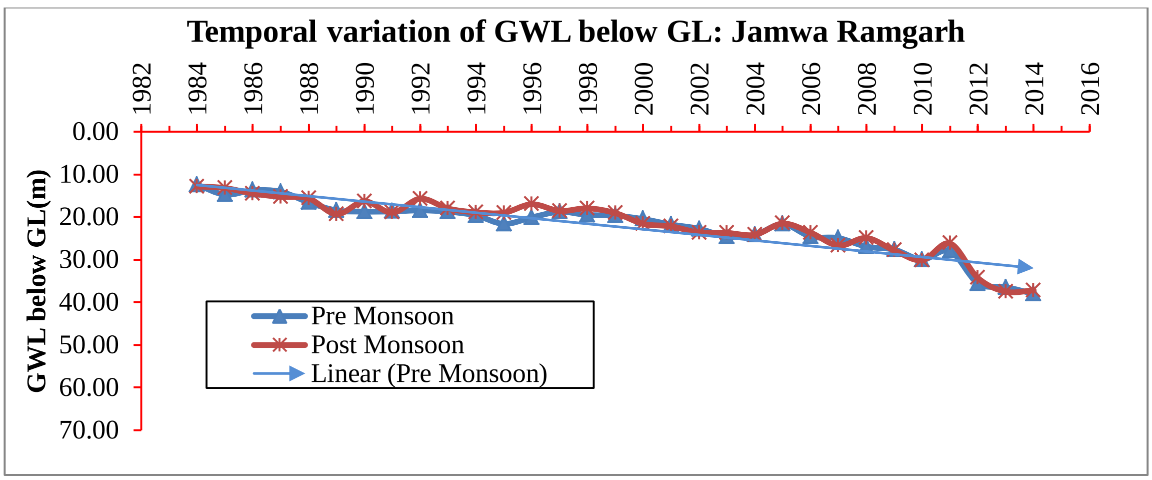
Net area sown within the catchment area of Ramgarh dam has increased from 50.66% to 62.75% from the year 1983 to 2014 and area sown more than once has increased from 19.22% to 35.43% during this period. A major part of this cultivation is done through tube wells. Total annual draft within the catchment is 97.91 MCM through groundwater pumping (Technical Committee report 2013) which is more than the capacity of Ramgarh dam and also more than the replenishable ground water recharge. Gross ground water draft for only irrigation in Jaipur is to the tune of 1081.11 MCM against the total annual replenishable ground water recharge of 712.38 MCM (CGWB 2014). This infers that the increasing cultivation area is lowering the groundwater Table. Year wise changes in pre-monsoon and post-monsoon groundwater level below ground level in four blocks of Ramgarh dam catchment along with the mean groundwater level are shown in Fig. 5.9.



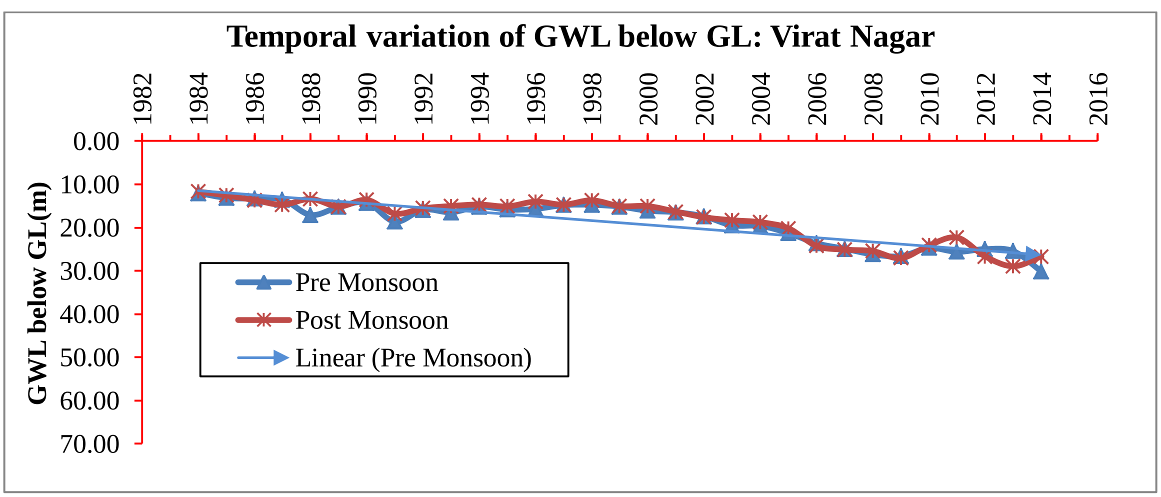
(a) GWL below GL: Amer



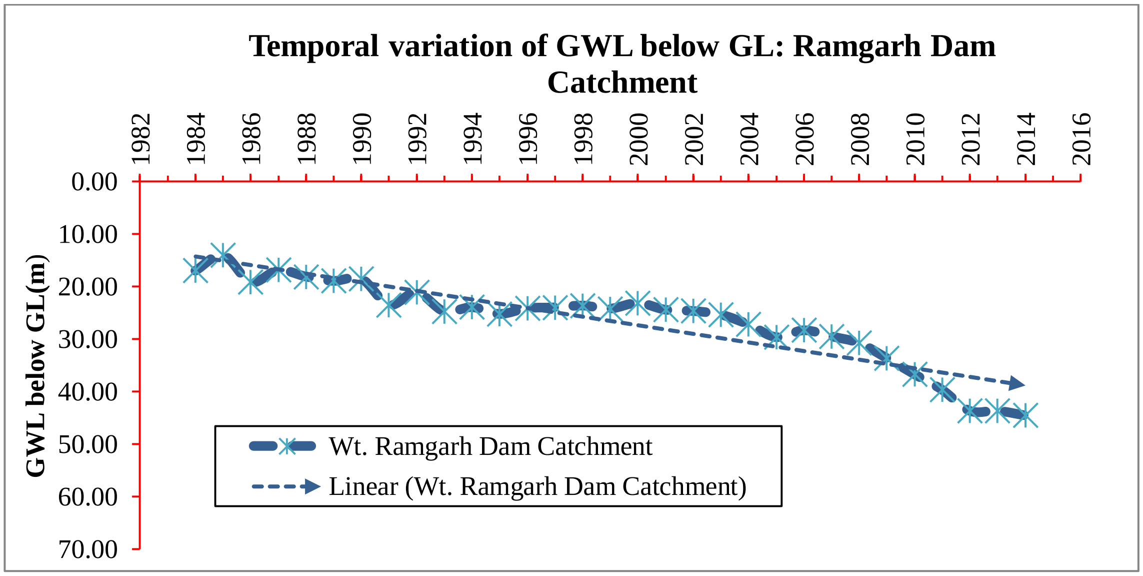
(b) GWL below GL: Shahpura



(c) GWL below GL: Jamwa Ramgarh



(d) GWL below GL: Virat Nagar



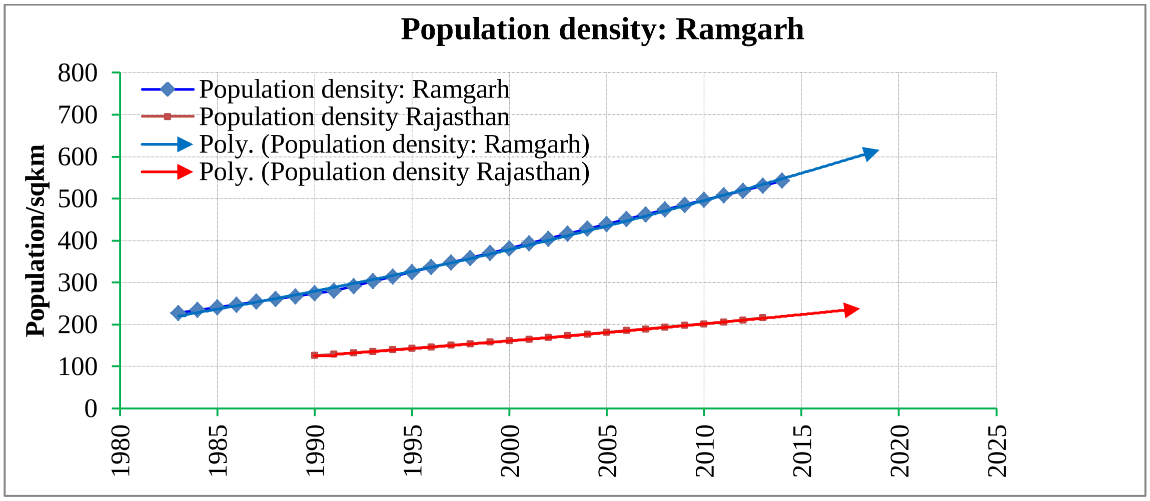
(e) Pre-monsoon and Post-monsoon GWL below GL: Ramgarh

Fig. 5.9 Pre-monsoon and Post-monsoon GWL below GL: Ramgarh

Pre-monsoon GWL of the catchment area of Ramgarh dam has decreased from average level of 16.0m to 43.0m during the observation period, which depicts a lowering trend of GWL at the rate of 82 cm per year. The rise of underground water level before and after the monsoon period ranges from approximately 0.0m to 2.0m, with an average rise of 0.36m. Development of lift facilities through pump sets has resulted in a tremendous increase in irrigation by underground water using wells and tube wells. Overexploitation of underground water has resulted in no block in the safe category in the year 2014. Rivers are around 10-20m deep in different stretches. Lowering of groundwater level below ground level is leading to the diminishing subsurface flow and decreasing contribution to the surface runoff.

5.4.4 Population Growth

Annual monsoon rainfall, rainy days, land use, cultivation area and climatic parameters, GWL below GL, which influence the runoff, have been plotted to show the trend over time. Land use and cultivation area are influenced by the population growth, which is plotted in the graph and shown in Fig.5.10.



(a) Population density: Ramgarh and Rajasthan

Fig. 5.10 Population density and its growth: Ramgarh

Population growth of Jaipur district is much more than the state. Population density of the Ramgarh dam catchment may be considered as that of Jaipur city as catchment area being near to the city area.

5.4.5 Various Parameters, Trend Lines and their Rate of Changes

Trend lines plotted in section 5.4 give an idea about the various factors, whether they are on increasing or decreasing trend and at what rate. The results are summarized in Table 5.6.

Table 5.6 Factors and their trends: Ramgarh

S.N.	Factor	Trend	Rate of Change
1	Rainfall 1983-2014 (mm)	Increasing	10 mm in 2 yrs.
4	Rainy days in a year (nos.)	Increasing	1 day in 77 yrs.
5	Mean of daily max. temp. (^{0}C)	Increasing	1 deg. in 60 yrs.
6	Mean of daily min. temp. (^{0}C)	Decreasing	1 deg. in 77 yrs.
7	Mean of daily wind speed (m/sec)	Decreasing	1 m/sec in 143 yrs.
8	Mean of daily RH (fraction)	Constant	NA
9	Mean of daily solar radiation (MJ/m^2)	Constant	NA
10	Land use (Contributing effect) (%)	Decreasing	1% in 2.5 yrs.
11	Cultivation area (%)	Increasing	3.69% in 2 yrs.
12	Groundwater level below GL(m)	Increasing	0.82m in 1 yrs.
13	Population density	Increasing	720 in 2021
14	State population density	Increasing	254 in 2021

Rainfall and rainy days trends over the catchment area of Ramgarh dam are increasing. Groundwater level below ground level and population density are on steep increasing trend. Land use having contributing effect is on decreasing trend.

5.4.6 Correlation Matrix

A 14x14 correlation matrix has been developed. Mutual correlations of most of the factors are insignificant, being quite low. But, some factors have significant mutual correlations. Significant correlations at 2-tailed test at 1% and 5% level of significance has been shown by * and **. However, the matrix has been derived to show the mutual correlations of all the factors with each other (Table 5.7), for the sake of mutual dependence. This matrix can be utilized for determining the sensitivity of each parameter with other remaining parameters.

Table 5.7 Correlation Matrix: Ramgarh

Correlations

		YEAR	INFLOW	LULC	POPDEN	WTRTBL	RAINFALL	RDAYS	MAXTMP	MINTMP	WINDSPD	RELHUM	SOLAR	NA	ASMO
YEAR	Pearson Correlation	1.000	-.541**	-.889**	.997**	.923**	.303	-.012	.157	.359*	-.256	-.017	-.004	.384*	.619**
	Sig. (2-tailed)	.	.001	.000	.000	.000	.092	.948	.389	.043	.158	.927	.981	.030	.000
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
INFLOW	Pearson Correlation	-.541**	1.000	.508**	-.536**	-.465**	.327	.375*	-.461**	-.178	-.121	.471**	-.166	-.075	-.350*
	Sig. (2-tailed)	.001	.	.003	.002	.007	.067	.035	.008	.330	.509	.006	.364	.683	.049
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
LULC	Pearson Correlation	-.889**	.508**	1.000	-.906**	-.954**	-.257	.019	.011	-.373*	.132	-.061	.082	-.433*	-.800**
	Sig. (2-tailed)	.000	.003	.	.000	.000	.156	.918	.951	.035	.471	.738	.655	.013	.000
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
POPDEN	Pearson Correlation	.997**	-.536**	-.906**	1.000	.929**	.303	-.024	.149	.351*	-.249	-.020	.006	.352*	.656**
	Sig. (2-tailed)	.000	.002	.000	.	.000	.092	.897	.415	.049	.169	.915	.972	.048	.000
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
WTRTBL	Pearson Correlation	.923**	-.465**	-.954**	.929**	1.000	.320	.027	-.038	.344	-.203	.089	-.047	.496**	.746**
	Sig. (2-tailed)	.000	.007	.000	.000	.	.074	.884	.838	.054	.265	.628	.797	.004	.000
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
RAINFALL	Pearson Correlation	.303	.327	-.257	.303	.320	1.000	.685**	-.463**	.189	-.409*	.575**	-.060	.056	.013
	Sig. (2-tailed)	.092	.067	.156	.092	.074	.	.000	.008	.299	.020	.001	.743	.759	.944
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
RDAYS	Pearson Correlation	-.012	.375*	.019	-.024	.027	.685**	1.000	-.490**	.245	-.325	.748**	-.164	.078	-.165
	Sig. (2-tailed)	.948	.035	.918	.897	.884	.000	.	.004	.176	.069	.000	.371	.672	.367
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
MAXTMP	Pearson Correlation	.157	-.461**	.011	.149	-.038	-.463**	-.490**	1.000	.138	.289	-.856**	.531**	-.092	.060
	Sig. (2-tailed)	.389	.008	.951	.415	.838	.008	.004	.	.453	.108	.000	.002	.615	.744
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
MINTMP	Pearson Correlation	.359*	-.178	-.373*	.351*	.344	.189	.245	.138	1.000	-.061	.156	-.132	.340	.195
	Sig. (2-tailed)	.043	.330	.035	.049	.054	.299	.176	.453	.	.741	.393	.472	.057	.286
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
WINDSPD	Pearson Correlation	-.256	-.121	.132	-.249	-.203	-.409*	-.325	.289	-.061	1.000	-.440*	.278	.131	.210
	Sig. (2-tailed)	.158	.509	.471	.169	.265	.020	.069	.108	.741	.	.012	.123	.473	.248
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
RELHUM	Pearson Correlation	-.017	.471**	-.061	-.020	.089	.575**	.748**	-.856**	.156	-.440*	1.000	-.513**	.160	-.098
	Sig. (2-tailed)	.927	.006	.738	.915	.628	.001	.000	.000	.393	.012	.	.003	.382	.592
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
SOLAR	Pearson Correlation	-.004	-.166	.082	.006	-.047	-.060	-.164	.531**	-.132	.278	-.513**	1.000	-.303	.076
	Sig. (2-tailed)	.981	.364	.655	.972	.797	.743	.371	.002	.472	.123	.003	.	.092	.679
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
NA	Pearson Correlation	.384*	-.075	-.433*	.352*	.496**	.056	.078	-.092	.340	.131	.160	-.303	1.000	.462**
	Sig. (2-tailed)	.030	.683	.013	.048	.004	.759	.672	.615	.057	.473	.382	.092	.	.008
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32
ASMO	Pearson Correlation	.619**	-.350*	-.800**	.656**	.746**	.013	-.165	.060	.195	.210	-.098	.076	.462**	1.000
	Sig. (2-tailed)	.000	.049	.000	.000	.000	.944	.367	.744	.286	.248	.592	.679	.008	.
	N	32	32	32	32	32	32	32	32	32	32	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

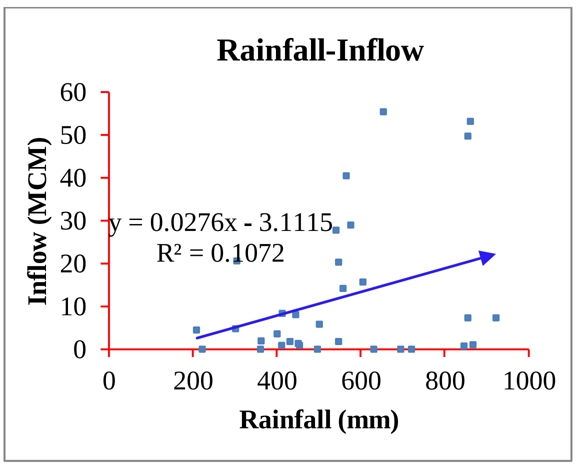
*. Correlation is significant at the 0.05 level (2-tailed).

5.5 Determination of Principal Components

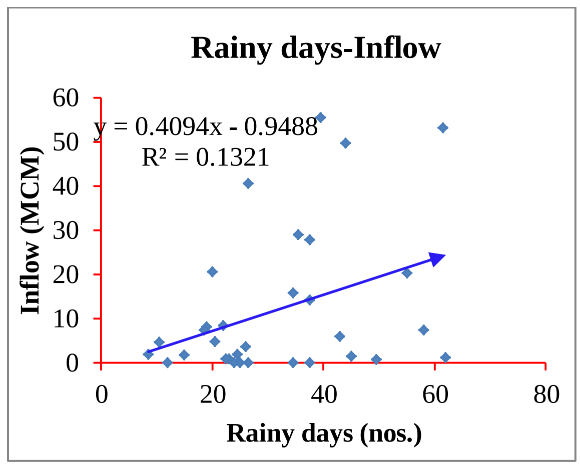
In section 5.4 trend lines and directions of various parameters which influence runoff have been shown. Now it is essential to determine the principal components out of the various components discussed earlier so that the same may be considered for further planning and analysis.

5.5.1 Regression Analysis

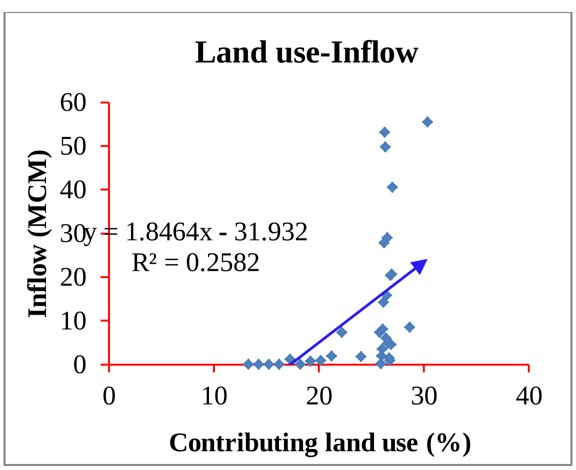
Regression lines of various parameters (predictors) with inflow (dependent variable) have been plotted as shown in Fig. 5.11. Coefficients of determinations have also been mentioned on graphs. By coefficient of correlations and corresponding t-values compared with critical t-values at 5% and 1% level of significance, we can determine the significance level of the parameters for inflow to the dam.



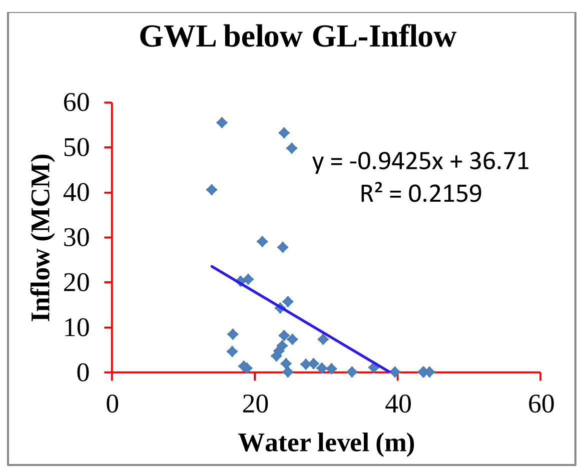
(a) Rainfall



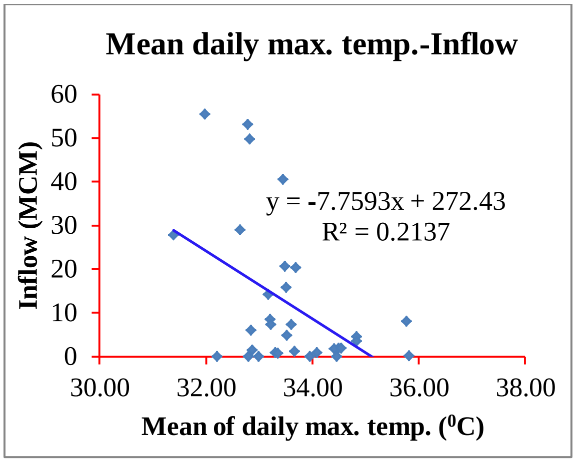
(b) Rainy days



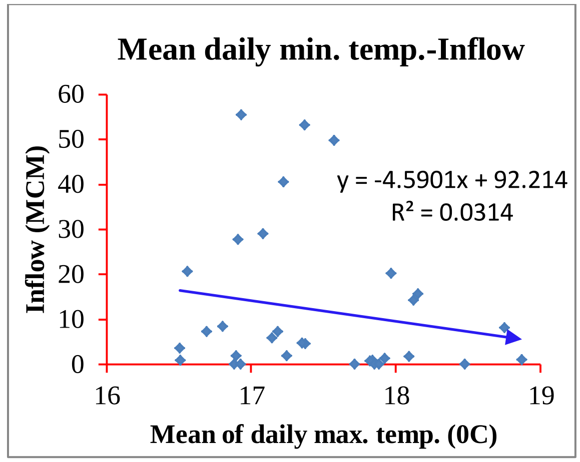
(c) Land use



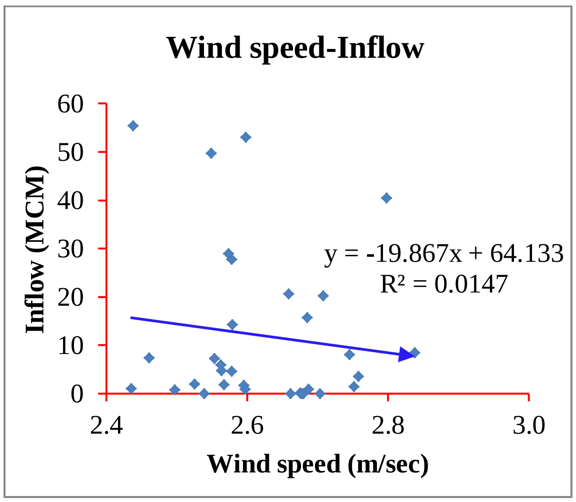
(d) GWL below GL



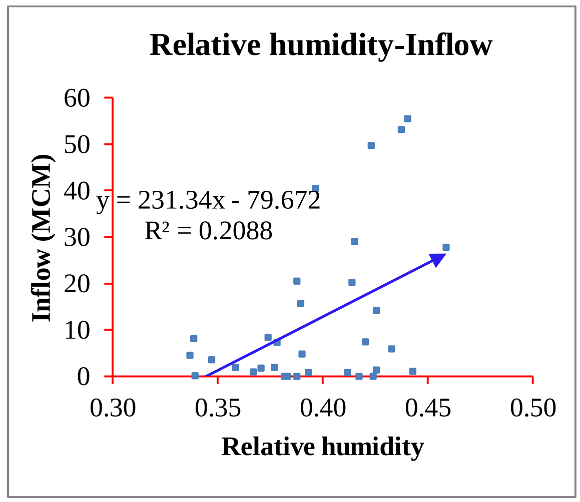
(e) Mean daily max. Temp.



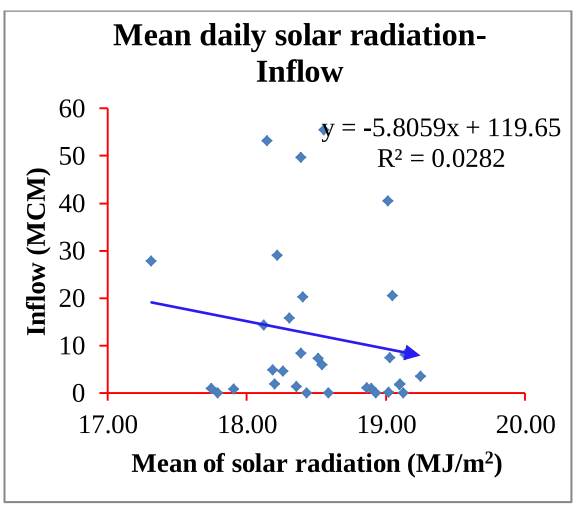
(f) Mean daily min. temp.



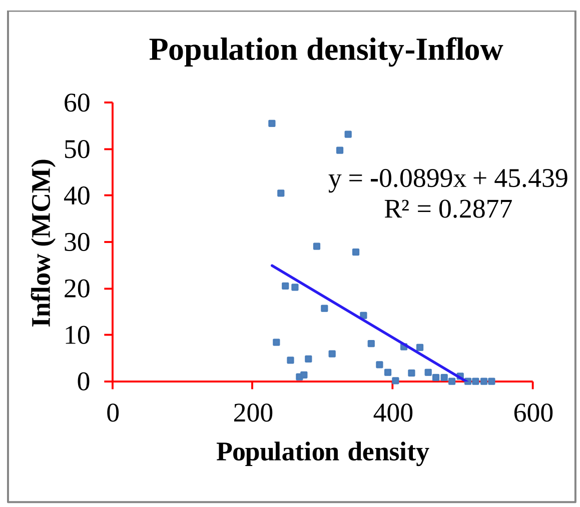
(g) Wind speed



(h) Relative humidity



(i) Solar radiation



(j) Population density

Fig. 5.11 Cross plots: Between inflow and independent variables: Ramgarh

Regression analysis of inflow with various factors independently, as shown in Fig. 5.11 is summarized in Table 5.8. Several cross plots showing the relationship between independent variables and inflow may be generated to develop empirical relations for the indirect estimation of the output. These relations are obtained using statistical methods such as regression analysis. However, although empirical equations are cost- effective and not too time-consuming, they include uncertainties relating to the limited data available (Majdi et al. 2010). To determine the parameters affecting inflow, several cross plots showing the relationship between independent variables and inflow have been generated from a total of 32 data (Fig. 5.11 and Table 5.8).

Table 5.8 Correlation and regression of inflow with various parameters: Ramgarh

S.N.	Factor	Regression equation	Type of correlation	Coefficient of correlation (R)	t-value	Significance
1	Rainfall	y = 0.027x -3.111	Positive	0.30	1.72	NS
2	Rainy days	y = 0.409x -0.948	Positive	0.36	2.14	S
3	Land use (Cont. effect)	y = 1.846x -31.93	Positive	0.51	3.23	HS
4	GWL below GL	y = -0.942x + 36.31	Negative	0.46	2.87	HS
5	Population density	y = -0.089x + 45.43	Negative	0.54	3.48	HS
6	Mean of daily max. temp. (^{0}C)	y = -7.759x + 272.4	Negative	0.46	2.86	HS
7	Mean of daily min. temp. (^{0}C)	y = -4.59x + 92.21	Negative	0.18	0.99	NS
8	Mean of daily wind speed (m/sec)	y = -19.86x + 64.13	Negative	0.12	0.67	NS
9	Mean of daily RH (fraction)	y = 231.3x –79.67	Positive	0.46	2.81	HS
10	Mean of daily solar radiation (MJ/m^2)	y = -5.805x + 119.6	Negative	0.17	0.93	NS

Here, NS=Not Significant, S= Significant, HS= Highly Significant

The critical value of t for n=32-2=30 degree of freedom at 5% level of significance is 2.042 and 1% level of significance is 2.75. Rainfall and rainy days are having a weak correlation with the inflow, mean of daily max. temp. and mean of daily relative humidity has moderate correlations and highly significant while other climatic factors like mean daily min. temp., wind speed, and solar radiation are having no correlation with inflow. Principal components derived out are population density, land use, GWL, and mean of daily max. temp.. These are having a moderate correlation with inflow and t-values are higher than the critical t_c value. This concludes that population density, land use, GWL, mean of daily max. temp., and mean of daily relative humidity are principal components for the inflow to the Ramgarh dam. The effect of land use changes, increase in agricultural land irrigation, mining activities and uncontrollable water withdrawal on the hydrological regime of small rivers is also well explained by Danil'Yan et al. (2006).

5.5.2 Cosine Amplitude Method

Cosine Amplitude Method of sensitivity analysis is employed to find out the principal components and their relative influence so that the MLR can be further simplified as per availability of data. Rainfall is also included in CAM being an important parameter for the runoff. By relative influence value (R_{ij}) computed by CAM (Annexure 8b), the relative importance of the five factors is mentioned as below and shown in Fig. 5.12.

(1) LULC (Contributing area %)= 0.71

(2) Rainfall= 0.65

(3) Mean of daily max. temp.= 0.39

(4) GWL below GL= 0.29

(5) Population density= 0.25

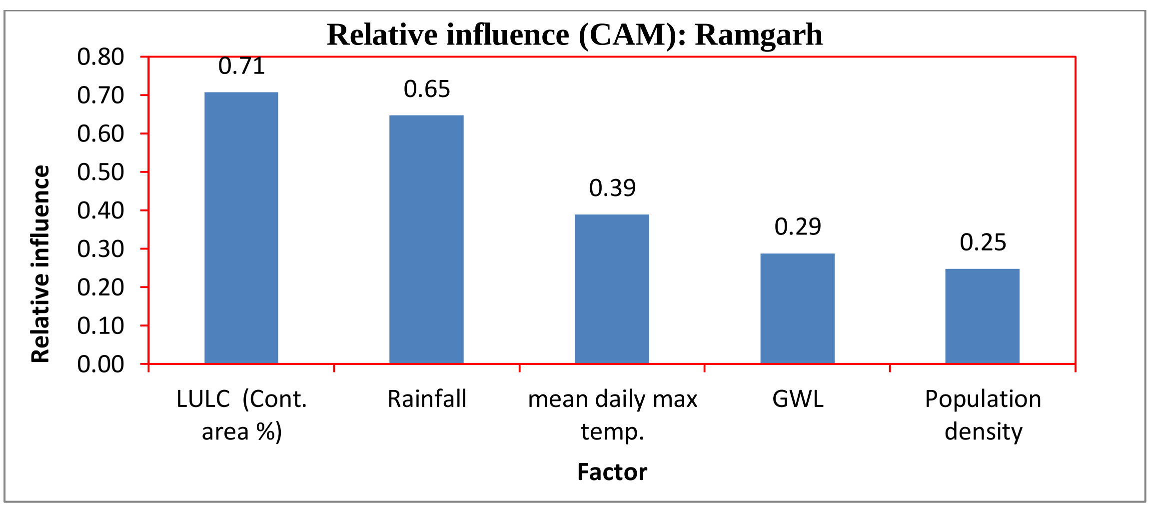


Fig. 5.12 Relative influences of the factors responsible for inflow: CAM for Ramgarh

From the analyses, it is found that LULC, rainfall, mean daily max. temp., GWL, and population density are the principal components for inflow to the Ramgarh dam.

Sensitivity analysis shows less water inflow to the Ramgarh dam due to the LULC is the main factor having 31% of the effect; rainfall is responsible for 28% of the effect, mean of daily max. temp. is having 22% of the effect, GWL below GL is having 13% of the effect and population density has 11% effect on the inflow. Rainfall is not determined as significant component as per regression analysis conducted independently while it is determined as principal component influencing next to the LULC.

5.6 MLR for Generation of Inflow Equation

The inflow equation for Ramgarh dam may be formed with the help of Multiple Linear Regression (MLR) considering the six principal components as derived in Section 5.4 and 5.5. The summary output of MLR is shown in Table 5.9.

Table 5.9 MLR summary output: Inflow to the Ramgarh dam

Regression Statistics	
Multiple R	0.77
R Square	0.60
Adjusted R Square	0.50
Standard Error	11.78
Observations	32.00

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*
Regression	6	5104.09	850.68	6.13	0.00
Residual	25	3467.58	138.70		
Total	31	8571.68			

	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	-77.86	207.22	-0.38	-504.64	348.92
Rainfall	0.03	0.01	2.10	0.00	0.06
LULC (Cont. effect %)	1.22	1.60	0.76	-2.08	4.52
GWL (water Table)	0.46	1.08	0.42	-1.77	2.69
Mean of daily max. temp.	0.38	4.80	0.08	-9.49	10.26
Relative Humidity	135.52	136.53	0.99	-145.68	416.72
Population density	-0.09	0.07	-1.26	-0.25	0.06

Using the computed coefficients, inflow equation is developed as shown below:

$$Inflow = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \beta_3 * x_3 + \beta_4 * x_4 + \beta_5 * x_5 + \beta_6 * x_6 \qquad (5.1)$$

Where values of the coefficients are -77.86, 0.03, 1.22, 0.46, 0.38, 135.52, -0.09 and predictors are rainfall, LULC (Contributing effect), GWL below GL, Mean of daily max. temp, relative humidity, and population density respectively, and a minimum value of computed inflow is set to zero. The correlation coefficient (multiple R) for the above relationship is 0.77.

From the developed equation, the inflow has been computed, and a graph is plotted between inflow and computed inflow along with the goodness of fit as shown in Fig.5.13. Between the two values coefficient of correlation (R) is 0.80 and the corresponding t-value is 7.27, which is more than the critical value at 1% level of significance, which infers that the inflow values computed from the developed equation are highly significant.

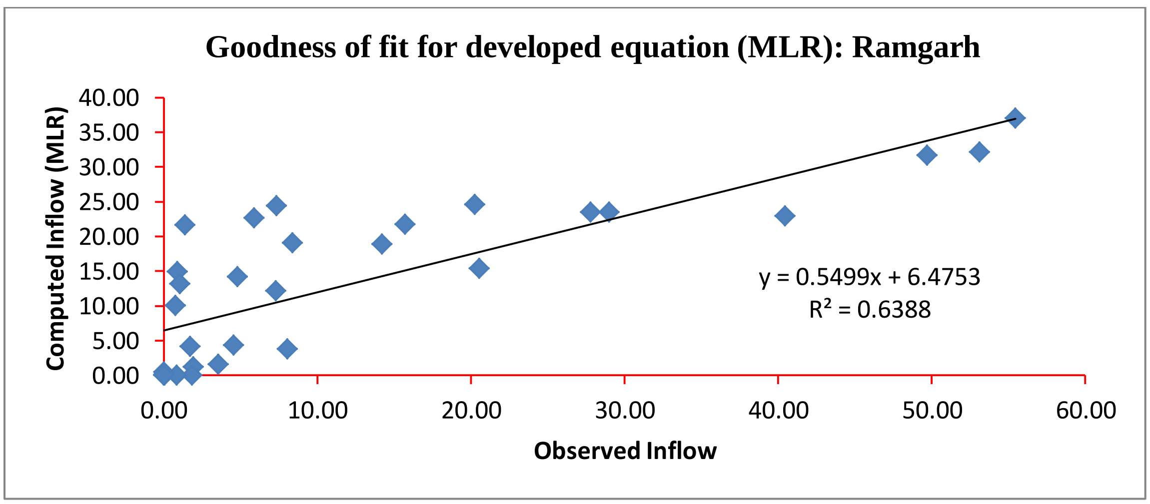


Fig. 5.13 Goodness of fit for the developed equation (MLR): Ramgarh

5.7 Factors Responsible for Principal Components

As far as changes in land use are concerned, agricultural area (Total crop area) is increasing with time and population. It has increased from 563 sqkm to 819 sqkm from 1970 to 2012. The area sown more than once is also increasing; it has increased from around 70 sqkm to 311 sqkm. Effect of land use changes in absorption of most intense storms was also inferred by Hakkim et al. (2014) for Western Ghats of Kerala. Due to a tremendous increase in agricultural areas, land use pattern has changed at a very fast pace. The increase in groundwater irrigation facilities resulted in lowering of the water Table and increase in dark zones within the catchment area of Ramgarh dam. Agricultural activities, land area sown, forest area, land area put to nonagricultural uses are increasing at a very fast pace. Land utilization of the state is plotted in graphs as shown in Fig. 5.7 and 5.8 show that land utilization which is having a reducing effect on the surface runoff viz. agricultural, forest and infrastructural uses are increasing and the land utilization which is having a contributing effect on the surface runoff viz. barren land, culturable waste, and fallow land are decreasing with the passage of time. These types of land use changes, increase the surface roughness, are not favorable to the surface runoff. Due to continuous partitions of the fields, the average size of the field is decreasing, and the number of total fields is increasing with time. The average size of the field has decreased from 3.97 ha to 2.4 ha from 1970 to 2015. Increased agricultural plough activities before the rainy season and decreased average field sizes increase the infiltration rates with the potential to absorb even most intense storms, results in very less surface runoff, making excess infiltration flow or Hortonian Overland Flow a rare phenomenon in the observed watersheds. Groundwater Table (average 44.5 m below the ground surface) of the area has declined far below the level of the coarse-grained soil. Therefore, neither it is contributing effectively to the groundwater, nor the subsurface flow.

6 TEMPORAL VARIATION OF INFLOW TO THE BISALPUR DAM

6.1 Formulation and Testing of Hypothesis

6.2 Performance Study and Performance Statistics

6.3 Determination of Critical Year

- 6.3.1 Determination of Possible Critical Years: Time Series Analysis
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6.4 Various Parameters and Their Trends

- 6.4.1 Rainfall and other Climatic Parameters
- 6.4.2 Land Use Land Cover Changes
- 6.4.3 Ground Water Levels
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- 6.4.5 Various Parameters, Trend Lines and their Rate of Changes
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6.5 Determination of Principal Components

- 6.5.1 Regression Analysis
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6.6 MLR for Generation of Inflow Equation

6.7 Regression Analysis and Determination of Factors Responsible for Principal Components

CHAPTER-6

TEMPORAL VARIATION OF INFLOW TO THE BISALPUR DAM

Year wise inflow data of Bisalpur dam have been shown in Table 6.1. Temporal variation of inflow to the Bisalpur dam has been shown in Fig. 6.1 It is evident that the water inflow trend to the dam is declining. The average inflow on the basis of last 35 years data series (1979-2013), 18 years data series (1996-2013), and 13 year data series (2001-2013) is 1170 MCM, 684 MCM, and 609 MCM against the design capacity of 1095 MCM. During last 35 year, Bisalpur Dam received a minimum inflow of 17 MCM in the year 2002. The dam received 13 times water equal to or more than its design capacity, therefore the performance dependability of the dam may be considered as 36.45%. However, if we compute the yield at different dependability's, the dam yields only 804 MCM, 314 MCM, and 122 MCM at 50%, 75%, and 90% dependability's respectively. Theoretical yield has been computed using Strange's Table considering the catchment as 'average'. Theoretical yield, actual inflow and weighted rainfall have been plotted against the successive years.

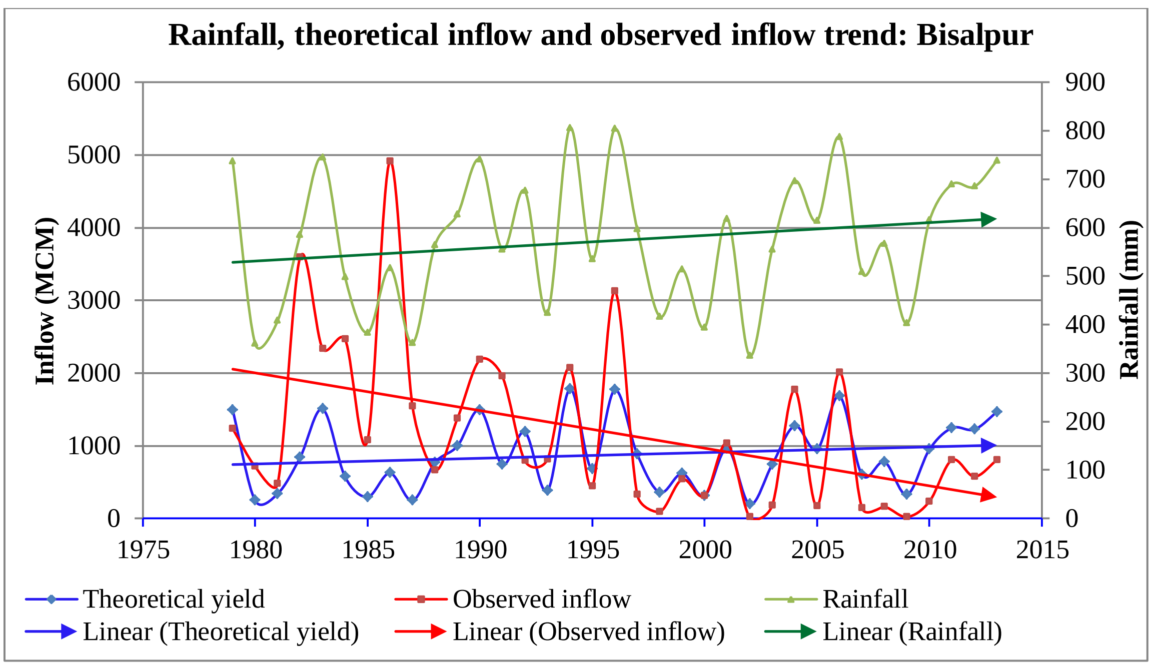


Fig. 6.1 Temporal variations of rainfall, theoretical yield, and observed inflow to the Bisalpur dam

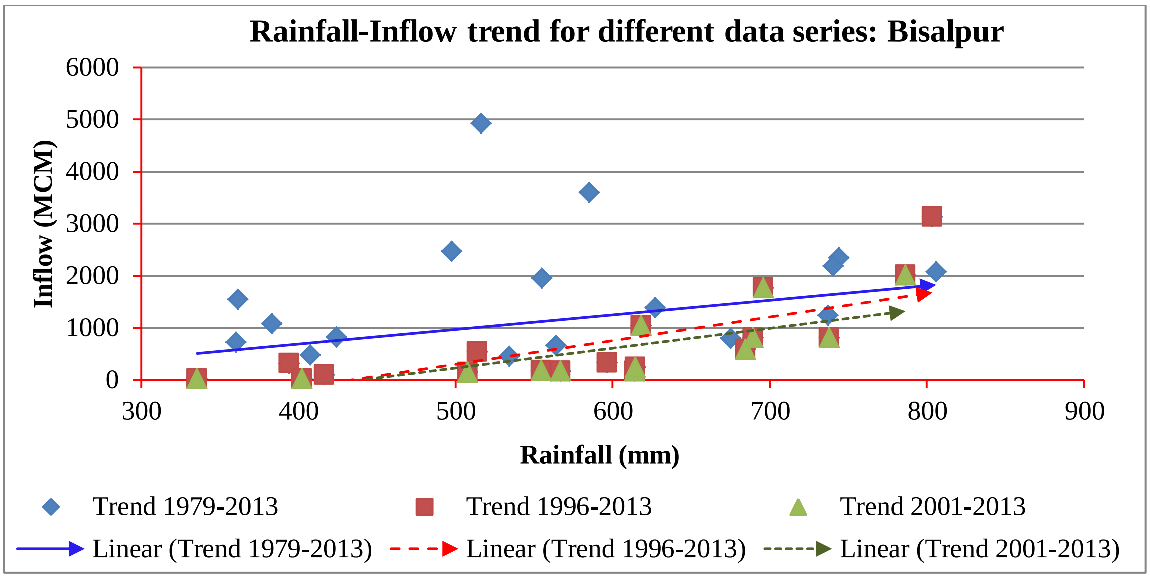
Table 6.1 Year wise inflow to the Bisalpur dam

S.N.	Year	Theoretical Yield (MCM)	Observed Inflow (MCM)	35 yr data series (1979-2013)		18 Yr data series (1996-2013)		13 Yr data series (2001-2013)	
				Inflow in Descending order (MCM)	Dn	Inflow in Descending order (MCM)	Dn	Inflow in Descending order (MCM)	Dn
1	1979	1490	1234	4915	2.8				
2	1980	245	712	3592	5.6				
3	1981	339	477	3122	8.3				
4	1982	839	3592	2464	11.1				
5	1983	1504	2334	2334	13.9				
6	1984	572	2464	2183	16.7				
7	1985	295	1076	2071	19.4				
8	1986	624	4915	2012	22.2				
9	1987	246	1542	1952	25.0				
10	1988	770	661	1767	27.8				
11	1989	997	1376	1542	30.6				
12	1990	1492	2183	1376	33.3				
13	1991	742	1952	1234	36.1				
14	1992	1186	791	1076	38.9				
15	1993	376	811	1035	41.7				
16	1994	1779	2071	811	44.4				
17	1995	678	443	804	47.2				
18	1996	1767	3122	804	50.0	3122	5.26		
19	1997	883	324	791	52.8	2012	10.53		
20	1998	358	90	712	55.6	1767	15.79		
21	1999	617	537	661	58.3	1035	21.05		
22	2000	313	314	576	61.1	804	26.32		
23	2001	963	1035	537	63.9	804	31.58	2012	7.14

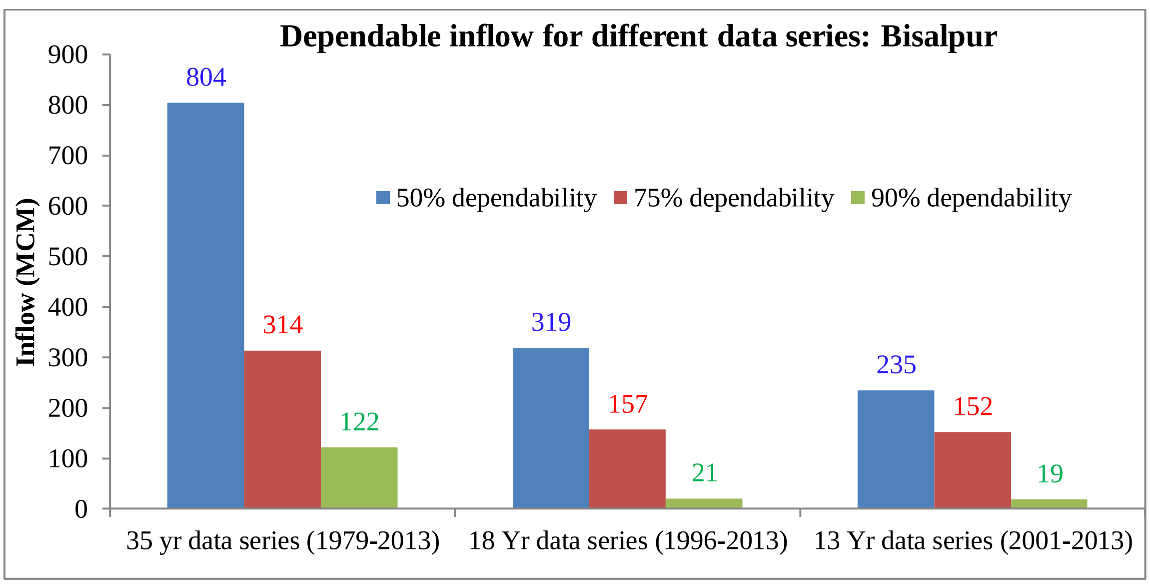
24	2002	195	17	477	66.7	576	36.84	1767	14.29
25	2003	741	177	443	69.4	537	42.11	1035	21.43
26	2004	1272	1767	324	72.2	324	47.37	804	28.57
27	2005	948	169	314	75.0	314	52.63	804	35.71
28	2006	1683	2012	235	77.8	235	57.89	576	42.86
29	2007	600	143	177	80.6	177	63.16	235	50.00
30	2008	778	161	169	83.3	169	68.42	177	57.14
31	2009	328	21	161	86.1	161	73.68	169	64.29
32	2010	950	235	143	88.9	143	78.95	161	71.43
33	2011	1244	804	90	91.7	90	84.21	143	78.57
34	2012	1224	576	21	94.4	21	89.47	21	85.71
35	2013	1465	804	17	97.2	17	94.74	17	92.86
Inflow	Average	=		1170.00	MCM	684.00	MCM	609.00	MCM
Inflow at	50%	Dn =		803.88	MCM	318.89	MCM	234.67	MCM
Inflow at	75%	Dn =		313.79	MCM	156.75	MCM	152.08	MCM
Inflow at	90%	Dn =		121.67	MCM	20.81	MCM	18.69	MCM

Rainfall-Inflow trends for different data series are shown in Fig. 6.2 (a). Inflow trend at different dependability's for 35, 18, and 13-year data series is shown in Fig. 6.2 (b). Inflow is showing a declining trend for all three dependability's with longer to shorter data series.

Graph of three-time segments 1979-2013, 1996-2013 and 2001-2013 (Fig. 6.2) shows a reduction of inflow at the same quantum of monsoon rainfall. The figure can also be used to predict the maximum probable inflow for a certain amount of monsoon rainfall using trend line of 2001-2013.



(a) Rainfall-Inflow trend for different data series



(b) Inflow at different dependability for different data series

Fig. 6.2 Water Inflow trend for different time segment: Bisalpur

6.1 Formulation and Testing of hypothesis

(1) Z Test for 35 years data series (1979-2013)**:**

H_o (Null Hypothesis): $\mu = 1095$ MCM

H_1 (Alternate Hypothesis): $\mu > 1095$ MCM

For n=35 (>30), z-test has been applied.

$\bar{x} = 1170$; S= 1130.22; SE= 191.04;

Z= 0.39;

Critical z value at 5% significance level= 1.96 (two tail) and 1.645 (one tail)

$Z<z_c$; therefore null hypothesis is accepted, i.e. Bisalpur dam is getting the desired 1095 MCM inflow of water.

(1I) T-Test for 18 years data series (1996-2013)**:**

H_o (Null Hypothesis): $\mu = 1095$ MCM

H_1 (Alternate Hypothesis): $\mu < 1095$ MCM

For n=18 (<30), t-test has been applied.

$\bar{x} = 684$; S= 835.33; SE= 196.89;

t= -2.09;

Critical t value at 5% significance level= 1.74 (one tail) at df= 18-1= 17

$t>t_c$; therefore null hypothesis is rejected and alternate hypothesis is accepted, i.e. Bisalpur dam is receiving less than the desired 1095 MCM inflow of water.

(1II) T-Test for 13 year data series (2001-2013)**:**

H_o (Null Hypothesis): $\mu = 1095$ MCM

H_1 (Alternate Hypothesis): $\mu < 1095$ MCM

For n=13 (<30), test has been applied.

$\bar{x} = 609$; S= 658.48; SE= 182.63;

t= -2.66;

Critical t value at 5% significance level= 1.782 (one tail) at df= 13-1= 12

$t>t_c$; therefore null hypothesis is rejected and alternate hypothesis is accepted, i.e. Bisalpur dam is receiving less than the desired 1095 MCM inflow of water.

Hypotheses tested on three data series shows that water inflow in Bisalpur dam is on decreasing trend

6.2 Performance Study and Performance Statistics

By year wise inflow data (Table 6.1) hydrological performance of the dam regarding reliability, resilience, vulnerability, maximum deficit and sustainability can be determined for different data series, which is as shown below:

	35 years data series (1979-2013)	**18 Year data series** (1996-2013)	**13 Year data series** (2001-2013)
Reliability:	37.14%	16.67%	15.38%
Resilience:	31.82%	13.33%	18.18%
Vulnerability:	35.78%	55.90%	55.52%
Maximum Deficit(2002):	98.45%	98.45%	98.45%
Sustainability	42.34%	21.40%	23.17%

Inflow on dependability is plotted as shown in Fig. 6.3. The graph shows that there was 17 MCM inflow at 97.20% reliability. As per code provisions, inflow at 100% reliability is considered for drinking water projects (IS 5477 Part-3:2002). Danil'Yan et al. (2006) recommends guarantee of 95% occurrence for water supply. The dam was designed for 1095 MCM at 75% dependability, but it is yielding only 314 MCM as per 35 years data series. For 13 year or 18-year data series, it is yielding only half of this i.e. around 152 MCM at 75 % dependability.

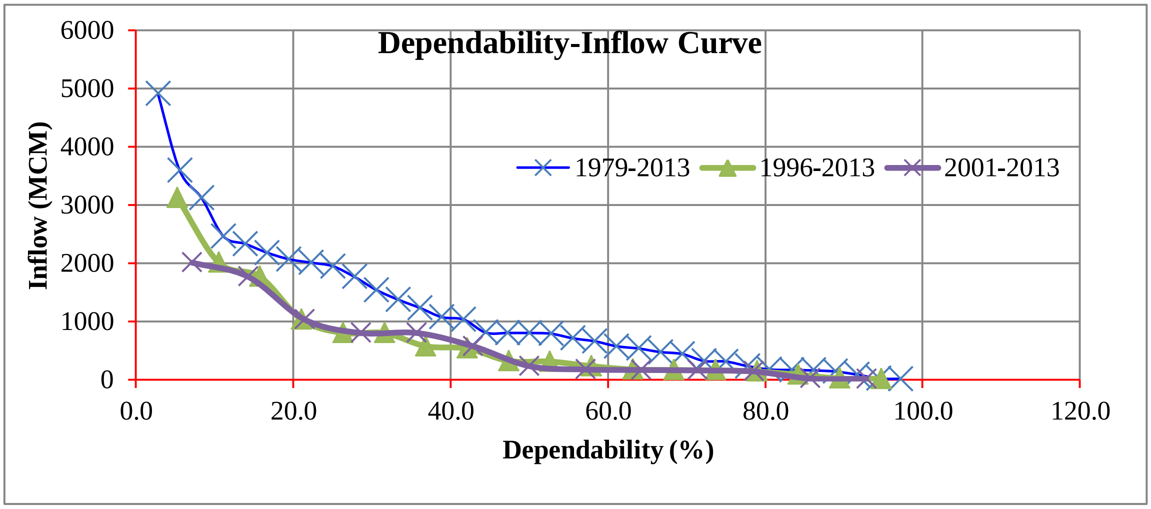


Fig. 6.3 Variations of inflow with dependability in Bisalpur Dam

Theoretical inflow computed by annual rainfall, and catchment area has been compared with observed values. The performance of method of computing theoretical inflow is shown in Table 6.2.

Table 6.2 Performance Statistics: Bisalpur dam

Statistical Parameter	MAE	MAPE (%)	R	R^2	t_{33}	NSE	RMSE	RSR	NMBE
Value	713.57	170.51	0.36	0.13	2.22	0.05	1085.38	0.97	-25.49
Optimal value	Lower value	Lower value	Unity	Unity	2.034	Unity	Lower value	Zero	Lower Value

The value of the coefficient of correlation is 0.36, the corresponding t-value is 2.22, which is more than the critical value of t_c = 2.034, at (35-2) =33 degree of freedom at 5% level of significance. This shows that there is a marginal correlation between the observed and computed values. Nash-Sutcliff Efficiency (NSE) is a low positive value, which also shows a marginal correlation. RSR is far beyond the optimal value. MAE, MAPE, and NMBE are very high. Therefore, it can be concluded that the method of computation of theoretical values of inflow is not an accepTable method in this case.

6.3 Determination of Critical Year

Performance dependability of Bisalpur dam is only 36.45%, and water inflow trend to the Bisalpur dam is declining. Therefore, it is essential to find out the critical year. Time Series Analysis and Sequential Cluster Analysis have been carried out for the purpose. Time series analysis gives us an idea about the possible critical years where trends are broken, and abrupt changes have taken place. The Sequential cluster analysis gives us the critical year out of the possible critical years, which divides the pre and post-disturbance epochs.

6.3.1 Determination of Possible Critical Years: Time Series Analysis

To determine the critical year using sequential cluster analysis, we need to determine possible critical years. Possible critical years have been identified with the help of time series analysis by trend elimination using least square method. The results of the time series analysis are as shown in Table 6.3. Time series of inflow for Bisalpur dam has been shown in Fig. 6.4.

Table 6.3. Time series analysis: Bisalpur Dam (Trend elimination using least square method)

S. N.	Year	Inflow	t	t*I	t*t	Trend	Elimination of Trend	Possible critical year
		MCM						
1	1979	1233.93	-17	-20977	289	2050	-816.18	
2	1980	712.26	-16	-11396	256	1998	-1286.06	
3	1981	476.64	-15	-7150	225	1947	-1469.9	
4	1982	3592.47	-14	-50295	196	1895	1697.71	***
5	1983	2333.9	-13	-30341	169	1843	490.92	
6	1984	2464.46	-12	-29574	144	1791	673.27	
7	1985	1075.62	-11	-11832	121	1739	-663.78	
8	1986	4914.76	-10	-49148	100	1688	3227.14	***
9	1987	1542.34	-9	-13881	81	1636	-93.49	
10	1988	661.29	-8	-5290	64	1584	-922.75	
11	1989	1375.81	-7	-9631	49	1532	-156.45	
12	1990	2182.95	-6	-13098	36	1480	702.47	
13	1991	1951.57	-5	-9758	25	1429	522.87	
14	1992	791.28	-4	-3165	16	1377	-585.63	
15	1993	810.82	-3	-2432	9	1325	-514.3	
16	1994	2070.8	-2	-4142	4	1273	797.45	
17	1995	442.93	-1	-442.9	1	1222	-778.62	
18	1996	3122.34	0	0	0	1170	1952.56	***
19	1997	323.99	1	323.99	1	1118	-793.99	
20	1998	90.06	2	180.12	4	1066	-976.14	
21	1999	537.24	3	1611.7	9	1014	-477.17	
22	2000	313.79	4	1255.2	16	962.6	-648.84	
23	2001	1034.55	5	5172.8	25	910.8	123.7	
24	2002	16.99	6	101.94	36	859.1	-842.07	
25	2003	176.72	7	1237	49	807.3	-630.55	
26	2004	1767.49	8	14140	64	755.5	1011.99	***
27	2005	168.51	9	1516.6	81	703.7	-535.19	
28	2006	2011.89	10	20119	100	651.9	1359.96	***
29	2007	142.74	11	1570.1	121	600.1	-457.39	
30	2008	161.43	12	1937.2	144	548.4	-386.92	
31	2009	21.23	13	275.99	169	496.6	-475.33	
32	2010	234.67	14	3285.4	196	444.8	-210.11	
33	2011	804.29	15	12064	225	393	411.29	
34	2012	576.32	16	9221.1	256	341.2	235.1	
35	2013	803.88	17	13666	289	289.4	514.45	
	Sum	40942	0	-184872	3570	40942		

The Trend equation $U = a + bt$ has been derived as

Inflow = (1169.77) + (-51.78) x Time

Where $a = 1169.77$ and $b = -51.78$

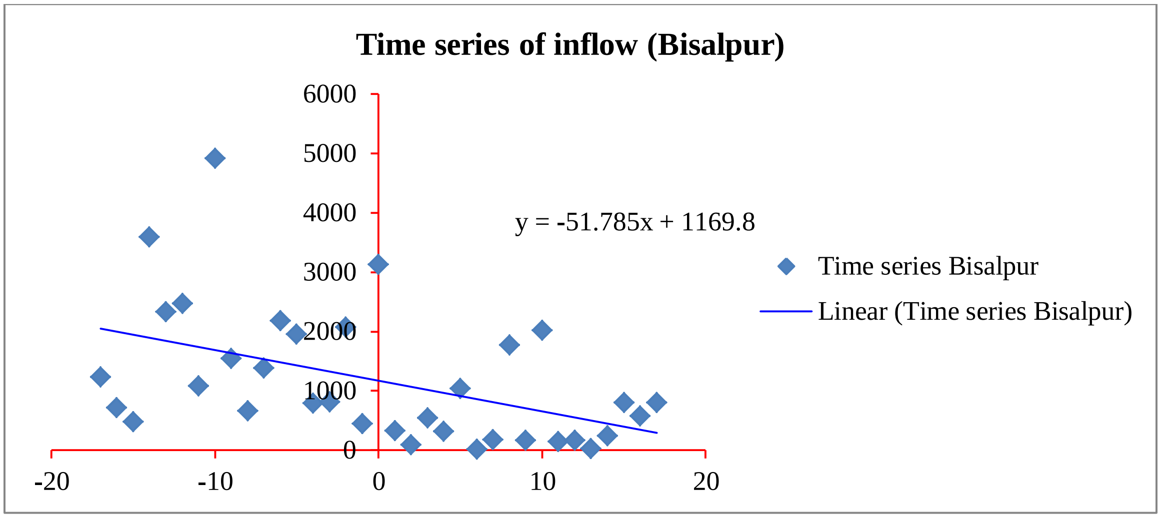


Fig. 6.4 Time series inflow of Bisalpur dam

Exceptional periods are (possible critical years) marked as *** where there are changes that can be attributed to climatic or anthropogenic changes.

6.3.2 Determination of Critical Year: Sequential Cluster Analysis

A critical year for the possible critical years is determined using sequential cluster analysis as shown in Table 6.4. From section 6.1 it is evident that there is a declining trend of water inflow to the Bisalpur Dam. It is essential to determine the critical year, which divides two consecutive non-overlapping epochs- pre-disturbance and post-disturbance. Determination of critical year will help in policy formulation for an effective water resources planning and management of the area. Sequential Cluster Analysis has been employed to determine the critical year.

Table 6.4. Sequential cluster analysis: Bisalpur Dam

S. N.	Year	Actual Inflow (MCM)	Possible Critical Year					
			1982	1986	**1996**	2001	2004	2006
1	1979	1234	72939	751814	280976	61045	22823	16919
2	1980	712	626848	1928591	1106151	590957	452575	424761
3	1981	477	1055478	2638560	1657307	1008748	825126	787416
4	1982	3592	4361693	2224473	3343291	4458292	4872909	4966064
5	1983	2334	1471126	54242	324786	727438	900411	940706
6	1984	2464	1804878	132101	490641	967189	1165229	1211007
7	1985	1076	2060	1051412	473873	164336	95718	83165
8	1986	4915	14392577	7917217	9927257	11790674	12459171	12607861
9	1987	1542	177527	420344	49133	3763	24756	31805
10	1988	661	211337	54156	1215979	671931	523762	493807
11	1989	1376	64930	232145	150688	11064	84	140
12	1990	2183	1127740	1661395	175520	492735	636726	670681
13	1991	1952	689850	1118458	35183	221438	321004	345241
14	1992	791	108717	10552	946190	475717	352507	328011
15	1993	811	96213	6919	908555	449143	329684	306010
16	1994	2071	902123	1384862	94127	347866	470324	499568
17	1995	443	459773	203461	1745215	1077581	887488	848363
18	1996	3122	4005382	4965521	1845101	2694013	3018367	3091777
19	1997	324	635229	324914	46661	1338678	1125747	1081626
20	1998	90	1062838	646320	202446	1934716	1676871	1622924
21	1999	537	340774	127277	8	890680	718694	683529
22	2000	314	651585	336641	51170	1362374	1147486	1102937
23	2001	1035	7473	19755	244581	199317	122814	108537
24	2002	17	1218833	769142	273537	310258	1871445	1814430
25	2003	177	891664	514490	131972	157831	1459939	1409633
26	2004	1767	417947	762981	1506727	1424414	146297	162803
27	2005	169	907242	526339	138007	164424	143257	1429202
28	2006	2012	793693	1249688	2166474	2067541	2145916	419767
29	2007	143	957001	564398	157819	185989	163430	62133
30	2008	161	920780	536663	143317	170216	148666	53164
31	2009	21	1209494	761727	269122	305555	276434	137470
32	2010	235	785581	434716	93226	115145	97550	24753
33	2011	804	100305	8048	69849	53033	66198	169983
34	2012	576	72939	751814	280976	61045	22823	16919
35	2013	804	626848	1928591	1106151	590957	452575	424761
	Mean	O_n=	1504	2101	1764	1481	1385	1364
	Mean	O_{N-n}=	1121	894	540	574	547	392
	Sum	V_n+ $V_{N-n=}$	42531629	34339324	**30264890**	36894099	38669410	37936191

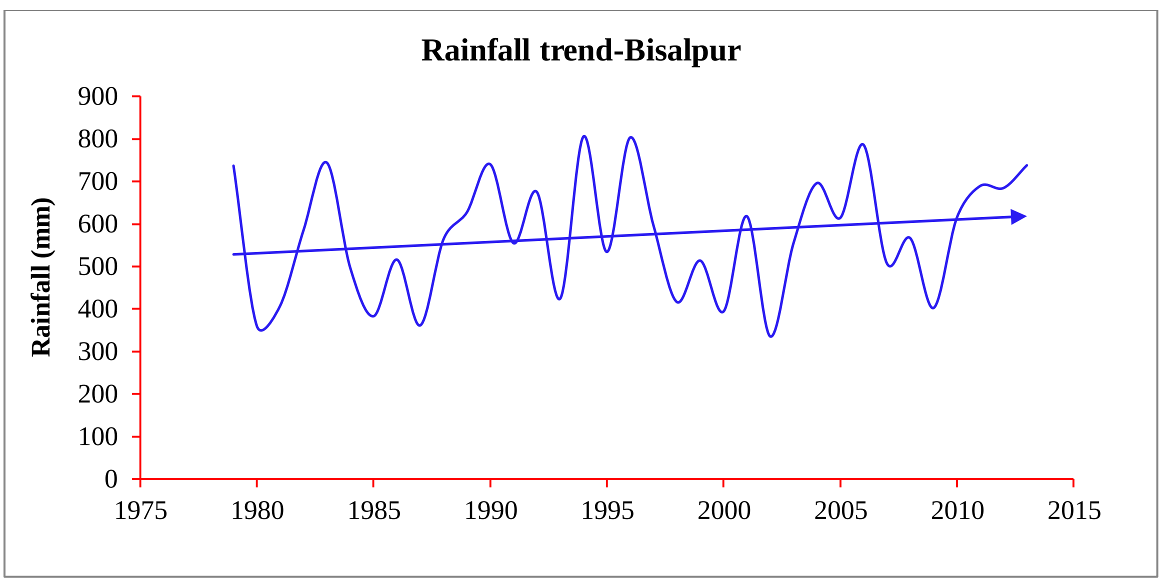
The minimum sum of squared deviations of hydrological series before and after the possible critical year is corresponding to the year 1996 as shown in Table 6.4. Therefore, the year 1996 is considered as the critical year for the hydrological behavior of the Bisalpur Dam. This shows that some disturbances have taken place after 1996 which is attributed to the low inflow to the dam.

6.4 Various Parameters and Their Trends

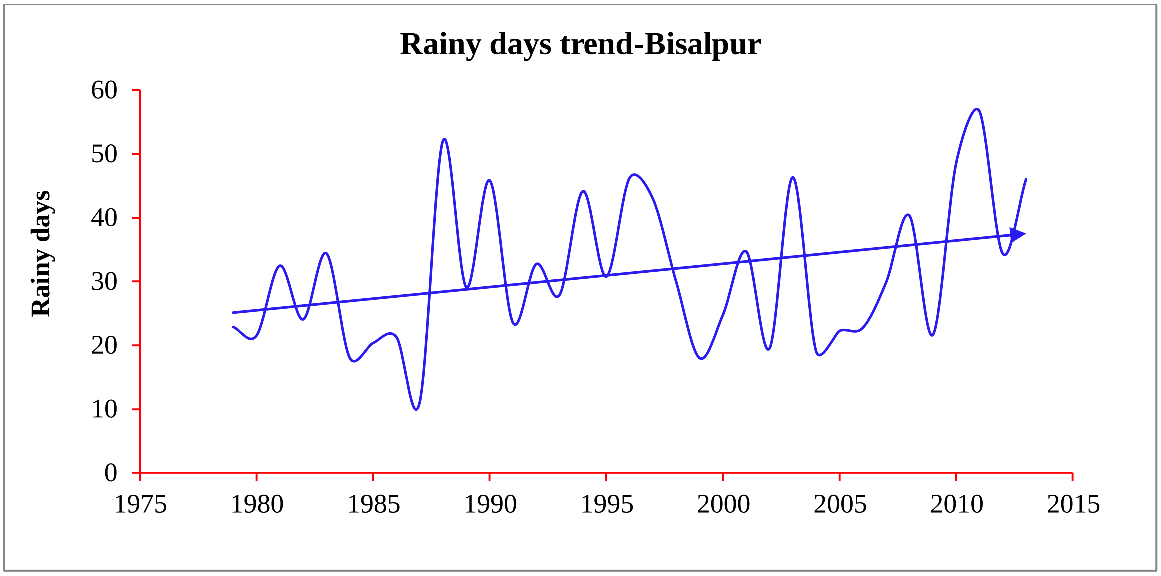
The declining trend of inflow to the Bisalpur dam has been observed. The critical year of initiation of post-disturbance epoch is determined as 1996. The various factors which are considered responsible for surface runoff are analyzed and discussed. Trends of various factors are plotted and shown in Fig. 6.5 to 6.10. Climatic parameters such as average daily minimum and maximum temperature, precipitation, wind speed, relative humidity and solar radiation are studied, and graphs are plotted to determine the variation of these parameters with time.

6.4.1 Rainfall and Other Climatic Factors

Eleven numbers RGS are situated within and nearby catchment area of Bisalpur dam. Year wise rainfall has been computed using the Thiessen polygon technique and the graph has been plotted (Fig. 6.5 a). Variation of rainy days during monsoon period has been shown in Fig. 6.5 (b).



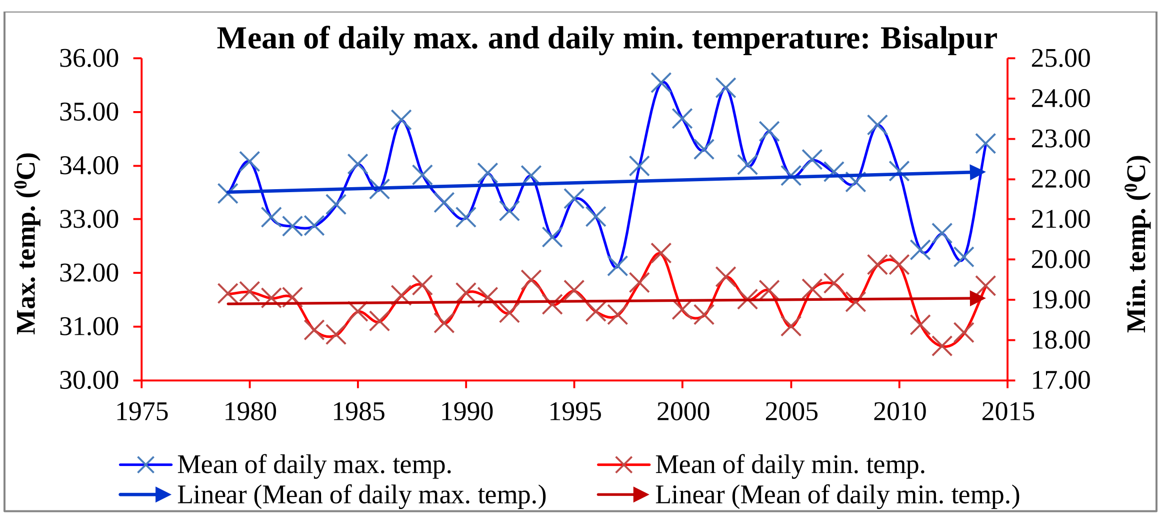
(a) Rainfall trend (1979-2013)



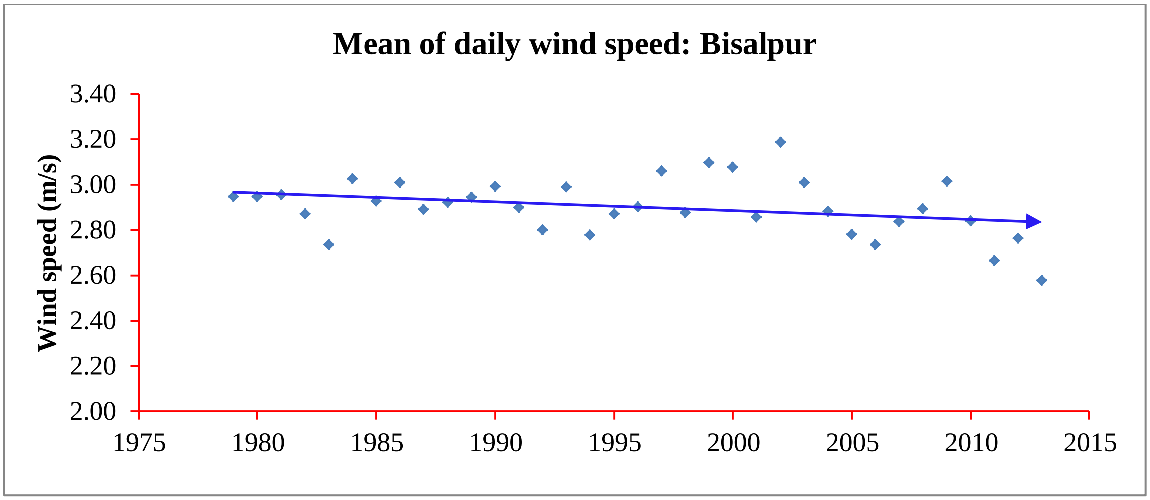
(b) Rainy days trend (1979-2013)

Fig. 6.5 Rainfall trend: Bisalpur

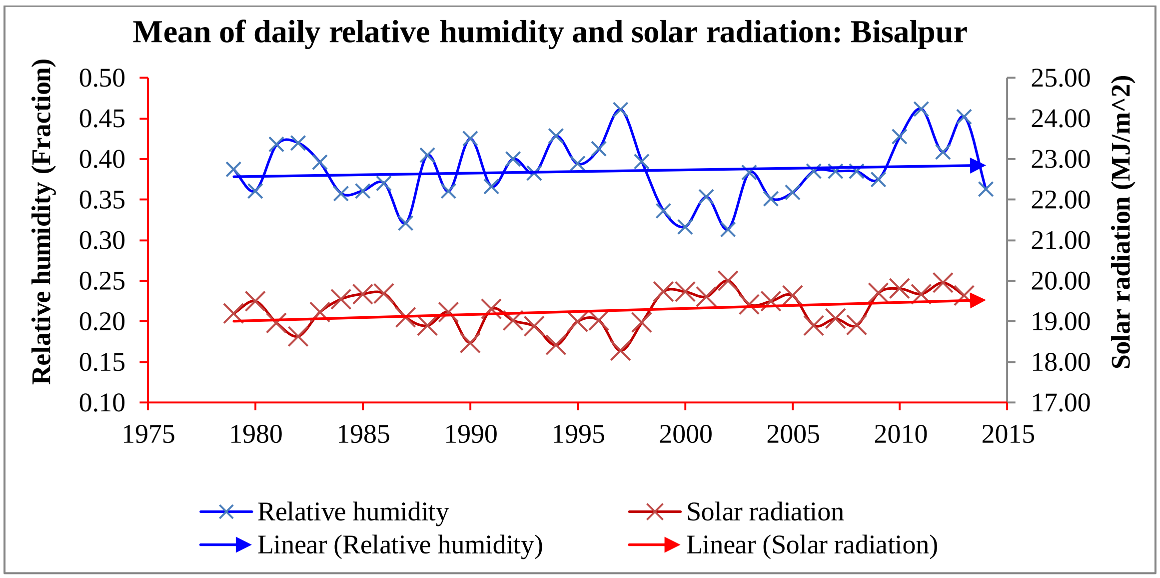
The rainfall trend over the catchment area of Bisalpur Dam varies significantly over the years, showing the temporal variation of rainfall and the trend of variation is increasing. Minimum and maximum weighted annual rainfall is 336 mm (2002) and 806 mm (1994) with an average value of 573 mm. This shows that there exists temporal variation of rainfall over the catchment. During 2005, 2010, and 2013, even after more than average rainfall, the inflow to the dam was less than design capacity. Trends of other climatic parameters are shown in Fig. 6.6.



(a) Mean of daily maximum and daily minimum temperature



(b) Mean of daily wind speed



(c) Mean of daily relative humidity and solar radiation

Fig. 6.6 Trends of other climatic factors: Bisalpur

There is an increasing trend of mean of daily maximum and minimum temperature, daily relative humidity and daily solar radiation while a slightly decreasing trend of mean of daily wind speed. These trends are shown in Table 4.8.

6.4.2 Land Use Land Cover Changes

Due to anthropogenic reasons, land use land cover is changing with time. Land use has been divided in two category viz. land use having a contributing effect and reducing effect. One of the major land use is increasing cultivated area. Land use trend (Contributing area) is shown in Fig. 6.7. Various types of land use trends are shown in Fig. 6.8. These figures show that land use having reducing effect viz. area sown, area sown more than once are on an increasing trend.

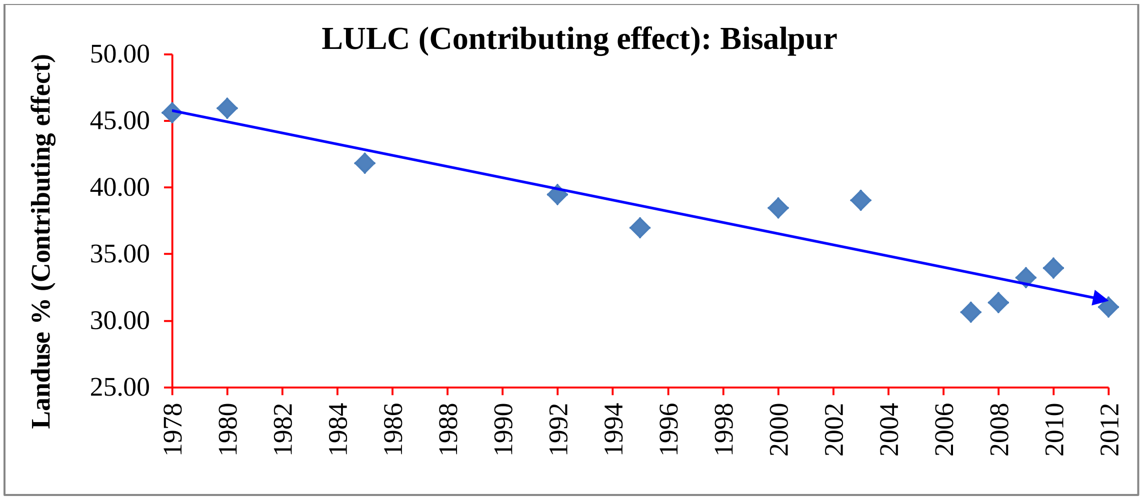
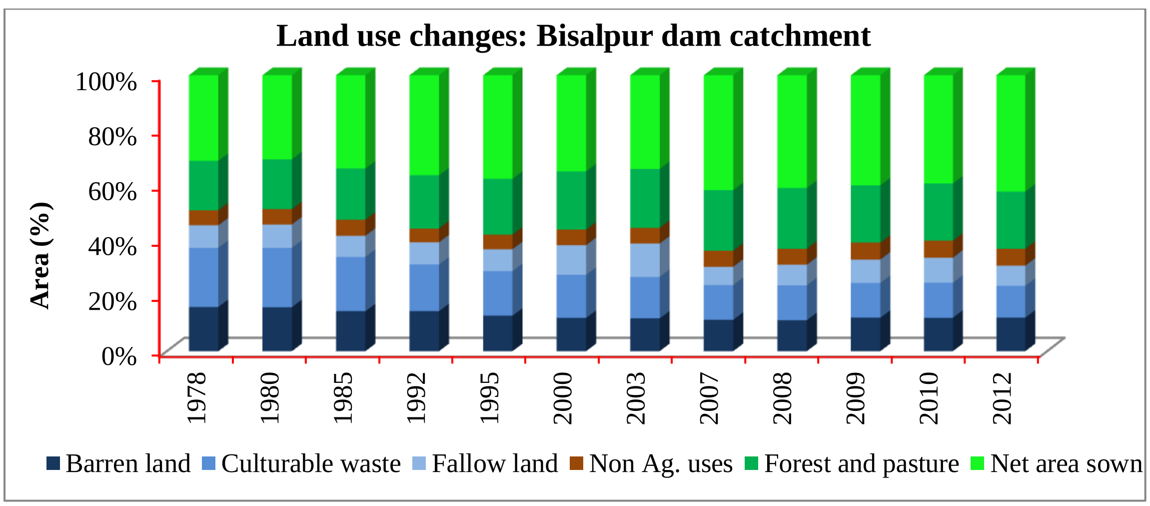


Fig. 6.7 Land use (Contributing effect): Bisalpur



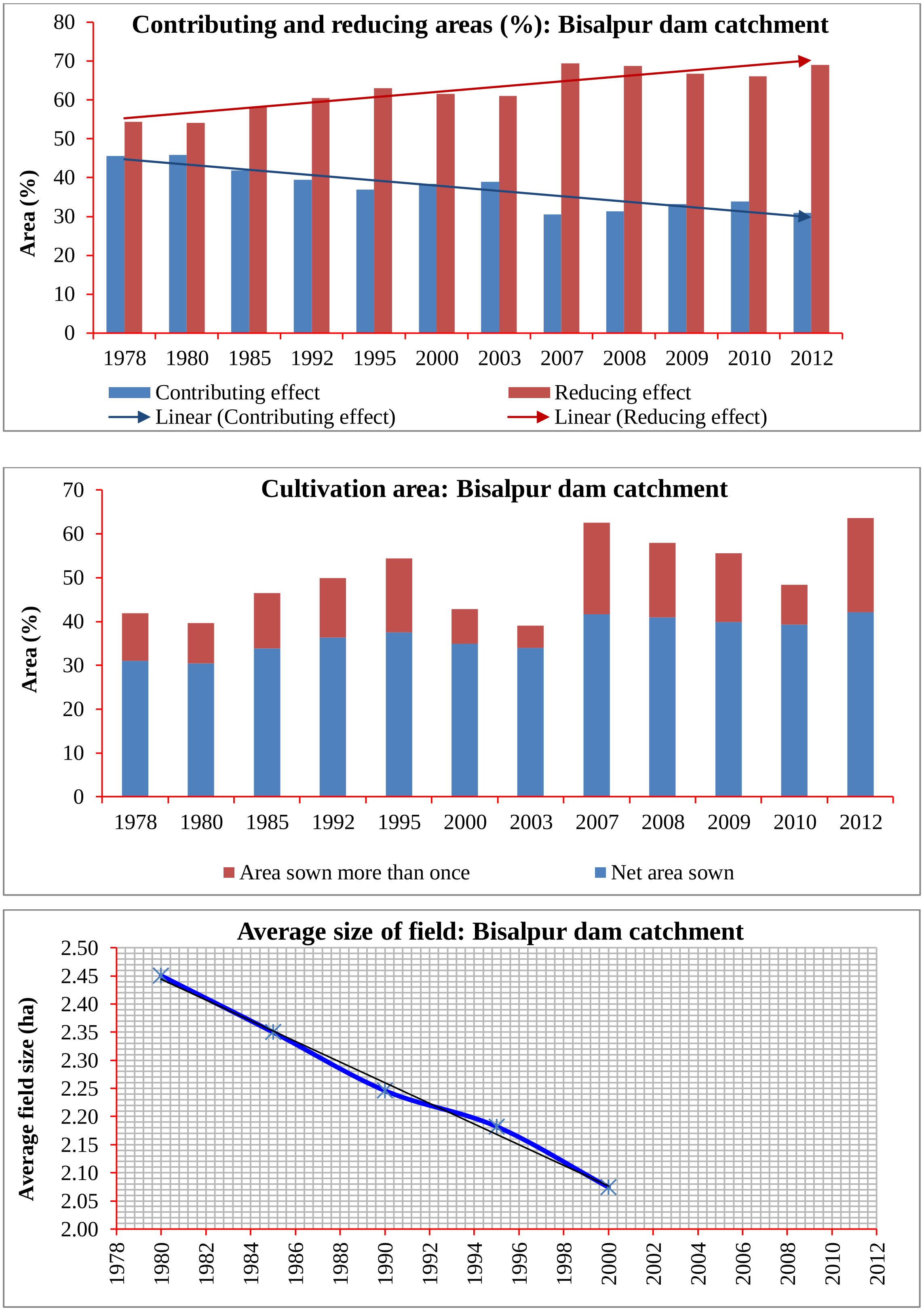


Fig. 6.8 Land use changes: Bisalpur

Agricultural area is increasing with time and population. It has increased from 5,691 sqkm to 6,916 sqkm from 1978 to 2012. The area sown more than once is also increasing; it has increased from around 1,973 sqkm to 3,520 sqkm. Due to this increase in agricultural areas, land use pattern changed at a very fast pace.

Due to continuous partitions of the fields, the average size of the field is decreasing, and the total number of fields is increasing with time. The average size of the land holding has decreased from 2.45 ha to 2.07 ha from 1980 to 2000. This reflects that total number of fields are increasing because of partitions of large fields, thereby more length of periphery boundaries increasing the surface roughness and decreasing the resultant runoff to the reservoir.

6.4.3 Groundwater Level Changes

Year wise changes in pre monsoon and post monsoon groundwater level below ground level in the catchment area of Bisalpur dam are shown in Fig. 6.9. Average river bed level below ground level within the catchment area was measured at some random places and found in between 12-15m. After the year 1996 the pre-monsoon ground water level went down the average river bed level, and post monsoon water levels were also deeper than the average river bed level in some years. No recorded data is available to mention the contribution of groundwater to rivers. The local enquiry was conducted by the old people of the area, and they told that earlier to 1995-1996, some deep rivers of the catchment flowed during the post-monsoon period also. However, according to the literature reviewed earlier, the declining water table reduces runoff due to baseflow and hence the inflow to the wetland (Jain et al. 2008).

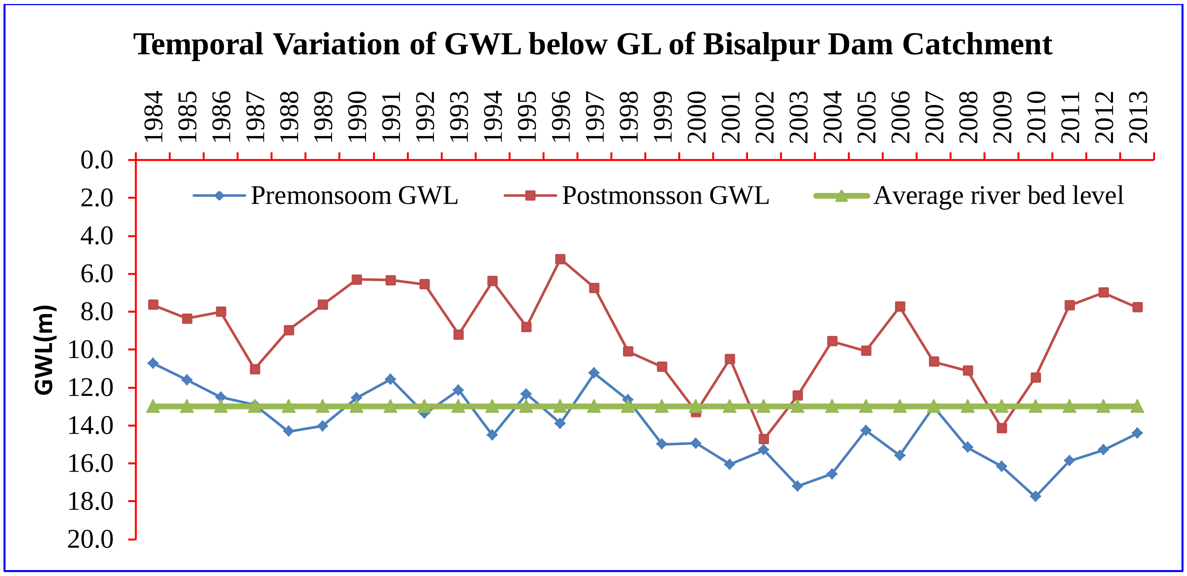


Fig. 6.9 Pre-monsoon and Post-monsoon GWL below GL: Bisalpur

Pre-monsoon GWL below ground level of the catchment area of Bisalpur Dam has increased from an average level of 10.0m to 17.0m during the observation period, which depicts a lowering trend of GWL at the rate of 15 cm per year. The rise of underground water level before and after the monsoon period ranges from approximately 0.5m to 8.0m, with an average rise of 4.9m. Development of lift facilities through pump sets has resulted in a tremendous increase in irrigation from underground water using wells and tube wells.

6.4.4 Population Growth

Land use and cultivation area are influenced by the population growth, which is plotted in the graph and shown in Fig 6.10. As the population increases, cultivation and other anthropogenic disturbances increases and fallow land decrease, therefore, reducing the surface runoff.

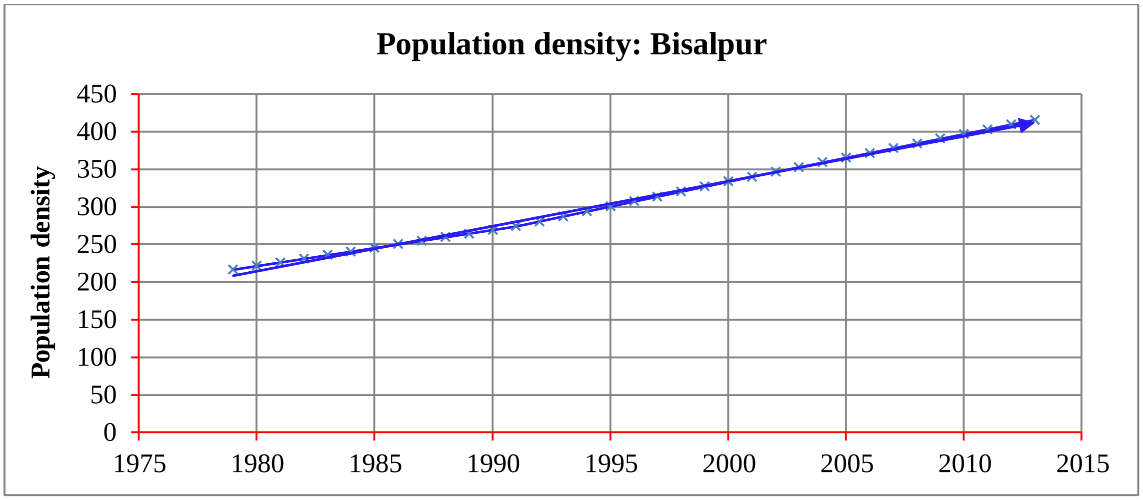


Fig. 6.10 Population density and its growth: Bisalpur

Population growth in the catchment area of Bisalpur dam has been derived by applying weights to the corresponding districts density. Population density has an excellent negative correlation with LULC (contributing effect) at 1% level of significance (Table 6.6)

6.4.5 Various Parameters, Trend Lines and their Rate of Changes

Trend lines plotted in section 6.4 give an idea about the various factors, whether they are in increasing or decreasing trend and at what rate. The results are summarized in Table 6.5.

Table 6.5 Factors and their trends: Bisalpur

S.N.	Factor	Trend	Rate of Change
1	Rainfall 1979-2013 (mm)	Increasing	5 mm in 2 yrs.
2	Rainy days in a year (nos.)	Increasing	1 day in 3 yrs.
3	Mean of daily max. temp. (^{0}C)	Increasing	1 deg. in 100 yrs.
4	Mean of daily min. temp. (^{0}C)	Increasing	1 deg. in 250 yrs.
5	Mean of daily wind speed (m/sec)	Decreasing	1 m/sec in 300 yrs.
6	Mean of daily RH (fraction)	Constant	NA
7	Mean of daily solar radiation (MJ/m^2)	Decreasing	1MJ/m2 in yrs.
8	Land use (Contributing effect) (%)	Decreasing	1% in 2.5 yrs.
9	Cultivation area (%)	Increasing	1% in 2 yrs.
10	Groundwater level below GL(m)	Increasing	0.15m in 1 yrs.
11	Population density	Increasing	450 in 2021
12	State population density	Increasing	254 in 2021

Rainfall and rainy days trends over the catchment area of Bisalpur dam are increasing. Groundwater levels below GL and population density are on increasing trend.

6.4.6 Correlation Matrix: Bisalpur

A 14x14 correlation matrix has been developed. Mutual correlations of most of the factors are insignificant, being quite low. But, some factors have significant mutual correlations. Significant correlations at 2-tailed test at 1% and 5% level of significance has been shown by * and **. However, the matrix has been derived to show the mutual correlations of all the factors with each other (Table 6.6), for the sake of mutual dependence. This matrix can be utilized for determining the sensitivity of each parameter with other remaining parameters.

Table 6.6 Correlation Matrix : Bisalpur dam

Correlations

		YEAR	INFLOW	LULC	POPDEN	WTRTBL	RAINFALL	RDAYS	MAXTMP	MINTMP	WINDSPD	RELHUM	SOLAR	NA	ASMO
YEAR	Pearson Correlation	1.000	-.469**	-.943**	.998**	.810**	.195	.327	.100	.048	-.319	.142	.342*	.816**	.265
	Sig. (2-tailed)	.	.004	.000	.000	.000	.262	.055	.566	.783	.062	.417	.045	.000	.124
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
INFLOW	Pearson Correlation	-.469**	1.000	.362*	-.473**	-.337*	.345*	-.147	-.270	-.300	-.059	.063	-.194	-.308	.024
	Sig. (2-tailed)	.004	.	.033	.004	.048	.042	.398	.116	.080	.738	.721	.264	.071	.893
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
LULC	Pearson Correlation	-.943**	.362*	1.000	-.938**	-.669**	-.282	-.305	.034	.017	.451**	-.231	-.182	-.907**	-.528**
	Sig. (2-tailed)	.000	.033	.	.000	.000	.100	.075	.847	.921	.007	.182	.296	.000	.001
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
POPDEN	Pearson Correlation	.998**	-.473**	-.938**	1.000	.804**	.192	.320	.097	.043	-.330	.148	.361*	.803**	.255
	Sig. (2-tailed)	.000	.004	.000	.	.000	.268	.061	.580	.808	.053	.397	.033	.000	.140
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
WTRTBL	Pearson Correlation	.810**	-.337*	-.669**	.804**	1.000	.190	.306	.341*	.187	-.132	-.092	.407*	.575**	-.056
	Sig. (2-tailed)	.000	.048	.000	.000	.	.275	.074	.045	.283	.449	.598	.015	.000	.750
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
RAINFALL	Pearson Correlation	.195	.345*	-.282	.192	.190	1.000	.506**	-.573**	-.359*	-.593**	.560**	-.281	.252	.273
	Sig. (2-tailed)	.262	.042	.100	.268	.275	.	.002	.000	.034	.000	.000	.102	.144	.112
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
RDAYS	Pearson Correlation	.327	-.147	-.305	.320	.306	.506**	1.000	-.588**	-.170	-.377*	.750**	-.278	.319	.144
	Sig. (2-tailed)	.055	.398	.075	.061	.074	.002	.	.000	.329	.025	.000	.106	.062	.409
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
MAXTMP	Pearson Correlation	.100	-.270	.034	.097	.341*	-.573**	-.588**	1.000	.626**	.528**	-.853**	.450**	-.077	-.386*
	Sig. (2-tailed)	.566	.116	.847	.580	.045	.000	.000	.	.000	.001	.000	.007	.661	.022
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
MINTMP	Pearson Correlation	.048	-.300	.017	.043	.187	-.359*	-.170	.626**	1.000	.418*	-.223	-.093	.027	-.175
	Sig. (2-tailed)	.783	.080	.921	.808	.283	.034	.329	.000	.	.013	.197	.594	.878	.315
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
WINDSPD	Pearson Correlation	-.319	-.059	.451**	-.330	-.132	-.593**	-.377*	.528**	.418*	1.000	-.538**	.054	-.370*	-.428*
	Sig. (2-tailed)	.062	.738	.007	.053	.449	.000	.025	.001	.013	.	.001	.760	.029	.010
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
RELHUM	Pearson Correlation	.142	.063	-.231	.148	-.092	.560**	.750**	-.853**	-.223	-.538**	1.000	-.456**	.253	.355*
	Sig. (2-tailed)	.417	.721	.182	.397	.598	.000	.000	.000	.197	.001	.	.006	.143	.036
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
SOLAR	Pearson Correlation	.342*	-.194	-.182	.361*	.407*	-.281	-.278	.450**	-.093	.054	-.456**	1.000	.056	-.276
	Sig. (2-tailed)	.045	.264	.296	.033	.015	.102	.106	.007	.594	.760	.006	.	.749	.108
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
NA	Pearson Correlation	.816**	-.308	-.907**	.803**	.575**	.252	.319	-.077	.027	-.370*	.253	.056	1.000	.714**
	Sig. (2-tailed)	.000	.071	.000	.000	.000	.144	.062	.661	.878	.029	.143	.749	.	.000
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35
ASMO	Pearson Correlation	.265	.024	-.528**	.255	-.056	.273	.144	-.386*	-.175	-.428*	.355*	-.276	.714**	1.000
	Sig. (2-tailed)	.124	.893	.001	.140	.750	.112	.409	.022	.315	.010	.036	.108	.000	.
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

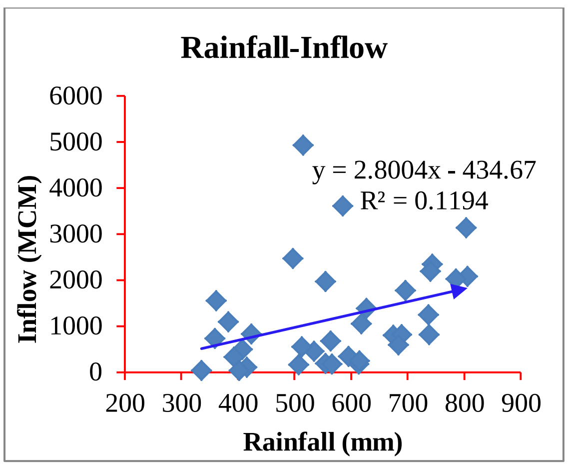
*. Correlation is significant at the 0.05 level (2-tailed).

6.5 Determination of Principal Components

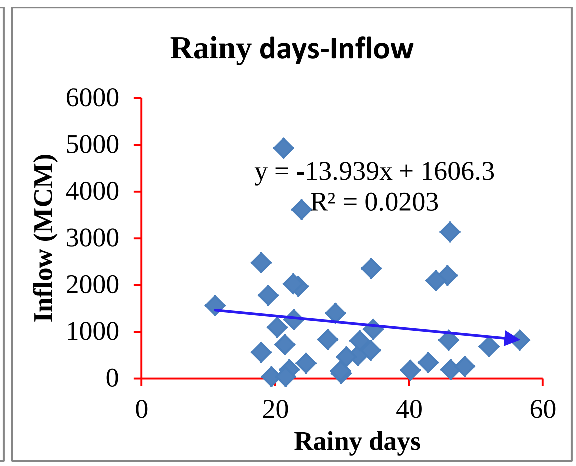
In section 6.4, trend lines and directions of various parameters which influence to runoff have been shown. Now it is essential to determine the principal components out of the various components discussed earlier so that the same may be considered for further planning and analysis.

6.5.1 Regression Analysis

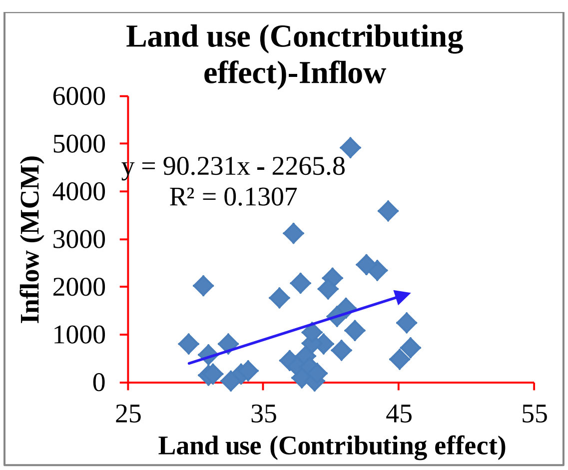
Regression lines of various parameters (predictors) with inflow (dependent variable) have been plotted as shown in Fig. 6.11. Coefficients of determination have also been mentioned on graphs. By coefficient of correlations and corresponding t-values compared with critical t-values at 5% and 1% level of significance, we can determine the significance level of the parameters for inflow to the dam.



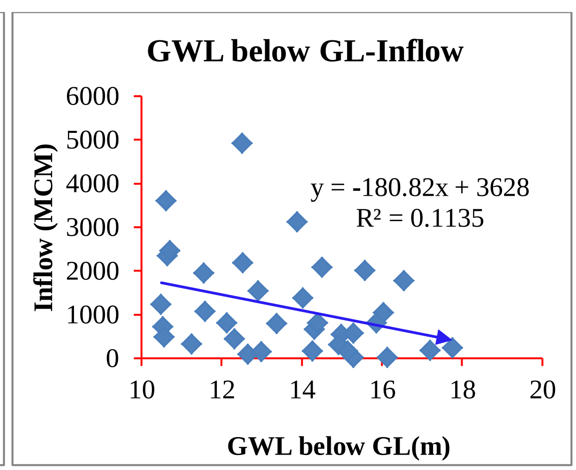
(a) Rainfall



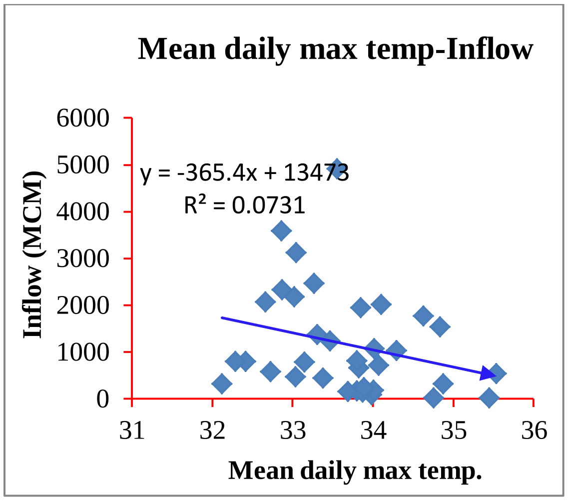
(b) Rainy days



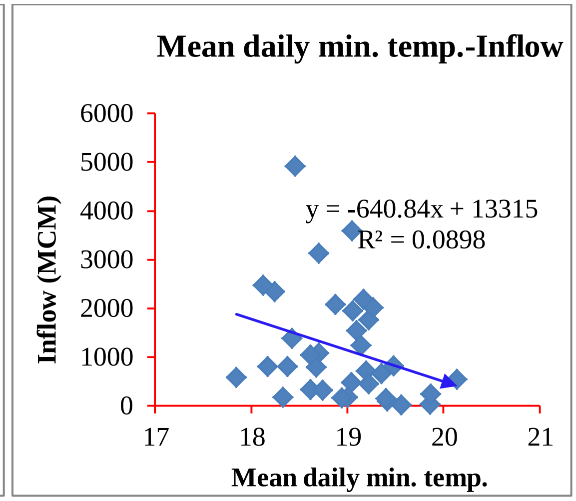
(c) Land use



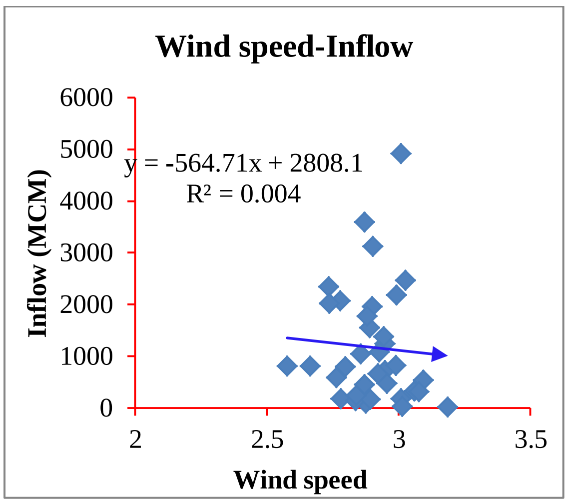
(d) GWL below GL



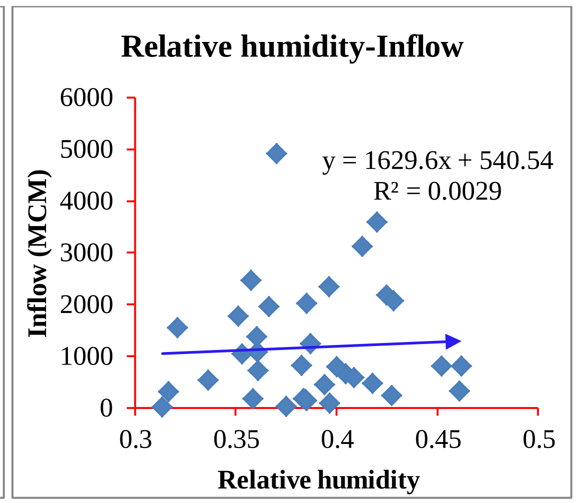
(e) Mean daily max. Temp.



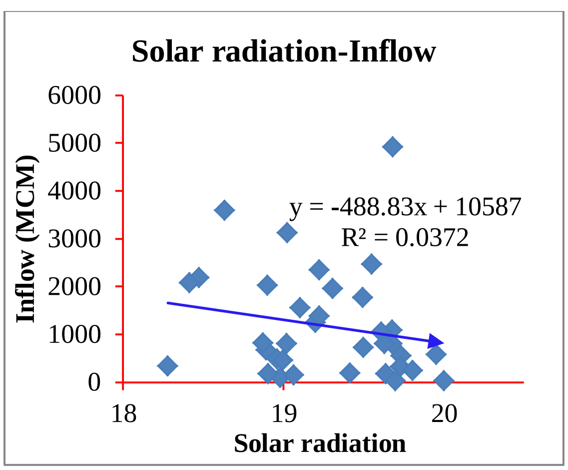
(f)Mean daily min. temp.



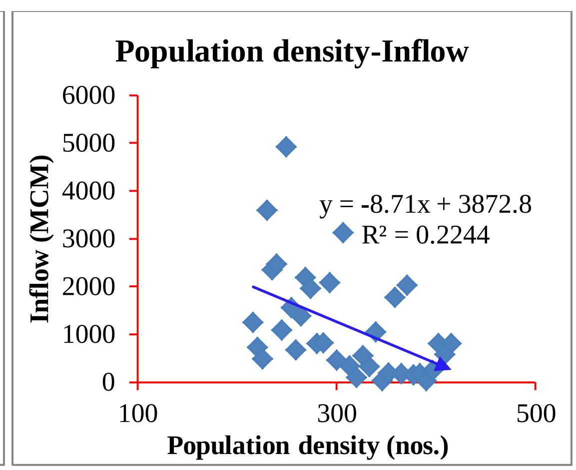
(g) Wind speed



(h) Relative humidity



(i)Solar radiation



(j) Population density

Fig. 6.11 Cross plots: Between inflow and independent variables:Bisalpur

Regression analysis of inflow with various factors independently, as shown in Fig 6.11 is summarized in Table 6.7. Several cross plots showing the relationship between independent variables and inflow may be generated to develop empirical relations for the indirect estimation of the output. These relations are obtained using statistical methods such as regression analysis. However, although empirical equations are cost- effective and not too time-consuming, they include uncertainties relating to the limited data available (Majdi et al. 2010). To determine the parameters affecting inflow more than others, several cross plots showing the relationship between independent variables and inflow have been generated from a total of 35 data (Fig. 6.11 and Table 6.7).

Table 6.7 Correlation and regression of inflow with various parameters: Bisalpur

S.N.	Factor	Regression equation	Type of correlation	Coefficient of correlation (R)	t-value	Significance
1	Rainfall	y = 2.80x -434.6	Positive	0.34	2.11	S
2	Rainy days	y = -13.93x+1606	Negative	0.14	0.82	NS
3	Land use (Cont. effect)	y = 90.23x -2265	Positive	0.36	2.22	S
4	GWL below GL	y = -180.8x + 3628	Negative	0.34	2.05	S
5	Population density	y = -8.71x + 3872	Negative	0.47	3.09	HS
6	Mean of daily max. temp. (^{0}C)	y = -365.4x + 13473	Negative	0.27	1.61	NS
7	Mean of daily min. temp. (^{0}C)	y = -640.8x + 13315	Negative	0.30	1.80	NS
8	Mean of daily wind speed (m/sec)	y = -564.7x + 2808	Negative	0.06	0.36	NS
9	Mean of daily RH (fraction)	y = 1629x –540.5	Positive	0.04	0.26	NS
10	Mean of daily solar radiation (MJ/m^2)	y = -488.8x + 10587	Negative	0.19	1.13	NS

Here, NS=Not Significant, S= Significant, HS= Highly Significant

The critical value of t_c for the n=35-2=33 degree of freedom at the 5% level of significance is 2.034 and 1% level of significance is 2.735. Rainfall, land use (contributing effect), groundwater level are having a significant correlation with the inflow, and population density is highly significant while other climatic factors like mean daily min. temp., wind speed, and solar radiation are having no correlation with inflow. Population density, land use, rainfall, and GWL below GL are having correlations with inflow and t-values are higher than the critical t_c value. This concludes that population density; land use, rainfall, and GWL below GL are principal components for the inflow to the Bisalpur dam.

6.5.2 Cosine Amplitude Method

Cosine Amplitude Method of sensitivity analysis is employed to find out the principal components and their relative influence so that the MLR can be further simplified as per availability of data. By relative influence value (R_{ij}) computed by CAM (Annexure 8c), the relative importance of the four factors is mentioned as below (Fig. 6.12):

(1) LULC (Contributing area %)= 0.75

(2) Rainfall= 0.74

(3) GWL= 0.47

(4) Population density= 0.43

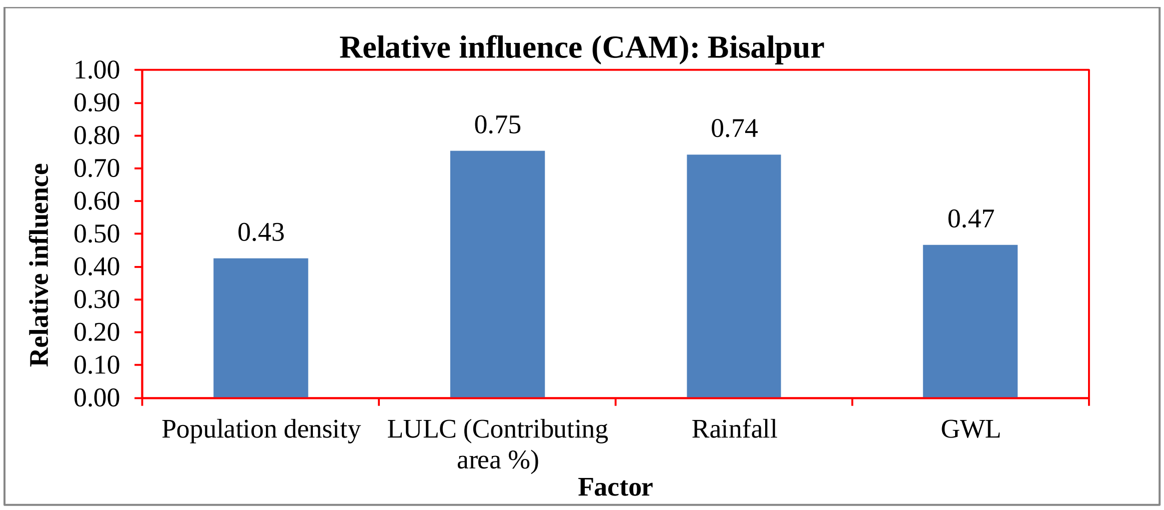


Fig. 6.12 Relative influences of the factors responsible for inflow: CAM for Bisalpur

From the two analyses, it is found that four components viz. LULC, rainfall, GWL below GL, and population density are the principal components for inflow to the Bisalpur dam. Out of these four principal components, LULC and rainfall are most influencing components to the inflow to Bisalpur dam. Sensitivity analysis shows less water inflow to the Bisalpur dam due to the LULC is the main factor having 32% of the effect; rainfall is responsible for 31% of the effect, GWL below GL is having 19% of the effect and population density has 18% effect on the inflow.

6.6 MLR for Generation of Inflow Equation

The inflow equation for Bisalpur dam may be formed with the help of Multiple Linear Regression (MLR) considering the six principal components as derived in Section 6.5.

Table 6.8 MLR summary output: Inflow to the Bisalpur dam

Regression Statistics	
Multiple R	0.67
R Square	0.44
Adjusted R Square	0.37
Standard Error	896.65
Observations	35.00

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	19312407	4828102	6.01	0.001
Residual	30	24119425	803980.8		
Total	34	43431832			

	Coefficients	*Standard Error*	*t Stat.*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	9280.76	6829.89	1.36	0.18	-4667.74	23229.26
LULC (Contributing effect)	-123.43	115.30	-1.07	0.29	-358.90	112.03
Rainfall	3.17	1.21	2.63	0.01	0.71	5.64
Water table	108.26	137.80	0.79	0.44	-173.16	389.69
Population density	-21.59	10.39	-2.08	0.05	-42.80	-0.38

Using the computed coefficients, inflow equation is developed as shown below:

$$Inflow = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \beta_3 * x_3 + \beta_4 * x_4 \quad (6.1)$$

Where values of the coefficients are 9820.76, -123.43, 3.17, 108.26, -21.59 and variables are LULC (Contributing effect), rainfall, GWL below GL and population density respectively, and a minimum value of computed inflow is set to zero. The correlation coefficient (multiple R) for the above relationship is 0.67.

From the developed equation, the inflow has been computed, and a graph is plotted between observed inflow and computed inflow along with the goodness of fit as shown in Fig.6.13. Between the two values, the coefficient of correlation (R) is 0.67, and the corresponding t-value is 5.16, which is more than the critical value at 1% level of significance (2.735), which infers that the inflow values computed from the developed equation are highly significant.

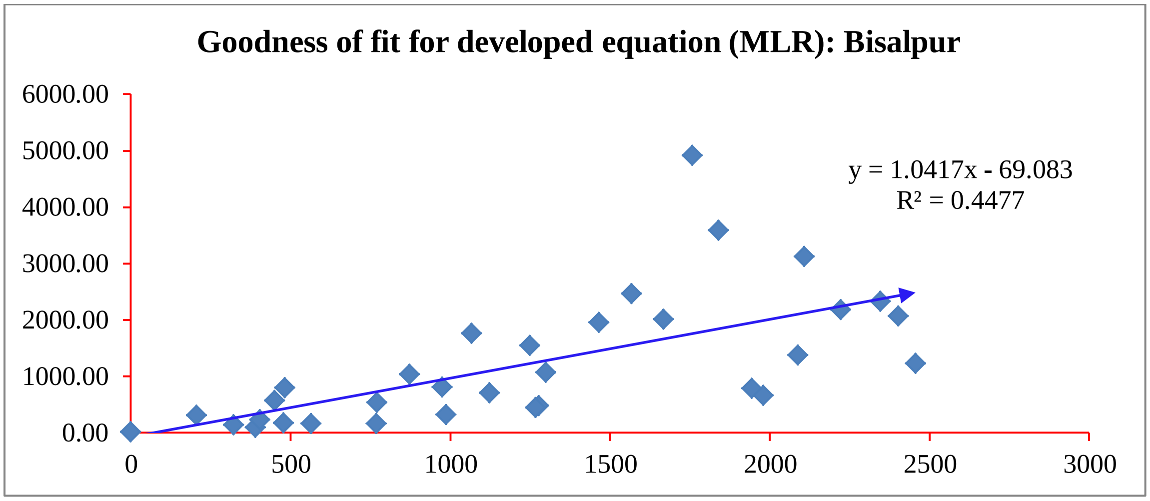


Fig. 6.13 Goodness of fit for the developed equation (MLR)

6.7 Regression Analysis and Determination of Factors Responsible for Principal Components

As far as changes in land use are concerned, agricultural area (Total crop area) is increasing with time and population. It has increased from 7664 sqkm to 10437 sqkm from 1978 to 2012. The area sown more than once is also increasing; it has increased from around 1973 sqkm to 3520 sqkm. Agricultural activities, land area sown, forest area, land area put to non-agricultural uses like habitation, industries, mining, roads, infrastructures, etc. are increasing at a very fast pace. Fig. 6.7 and 6.8 show that land utilizations which are having a reducing effect on the surface runoff are increasing and the land utilizations which are having a contributing effect on the surface runoff viz. barren land, culturable waste, and fallow land are decreasing with the passage of time. Due to continuous partitions of the fields, the average size of the field is decreasing, and the number of total fields is increasing with time. The average size of the field has decreased from 2.45 ha to 2.07 ha from 1980 to 2000. Population density has highly significant correlations with LULC, crop area, GWL below GL, and average field size. T-values for these correlations are 15.48, 7.73, 7.74, and 39.22 which is more than the critical value of t_c=2.735 at df=35-2=33 and 1% level of significance. T-value for correlation of average field size with LULC is 11.67 which is highly significant. In these analyses, it is inferred that inflow to the dam is influenced by the land use (contributing effect) in addition to rainfall, which has a highly significant correlation with population density and average field size.

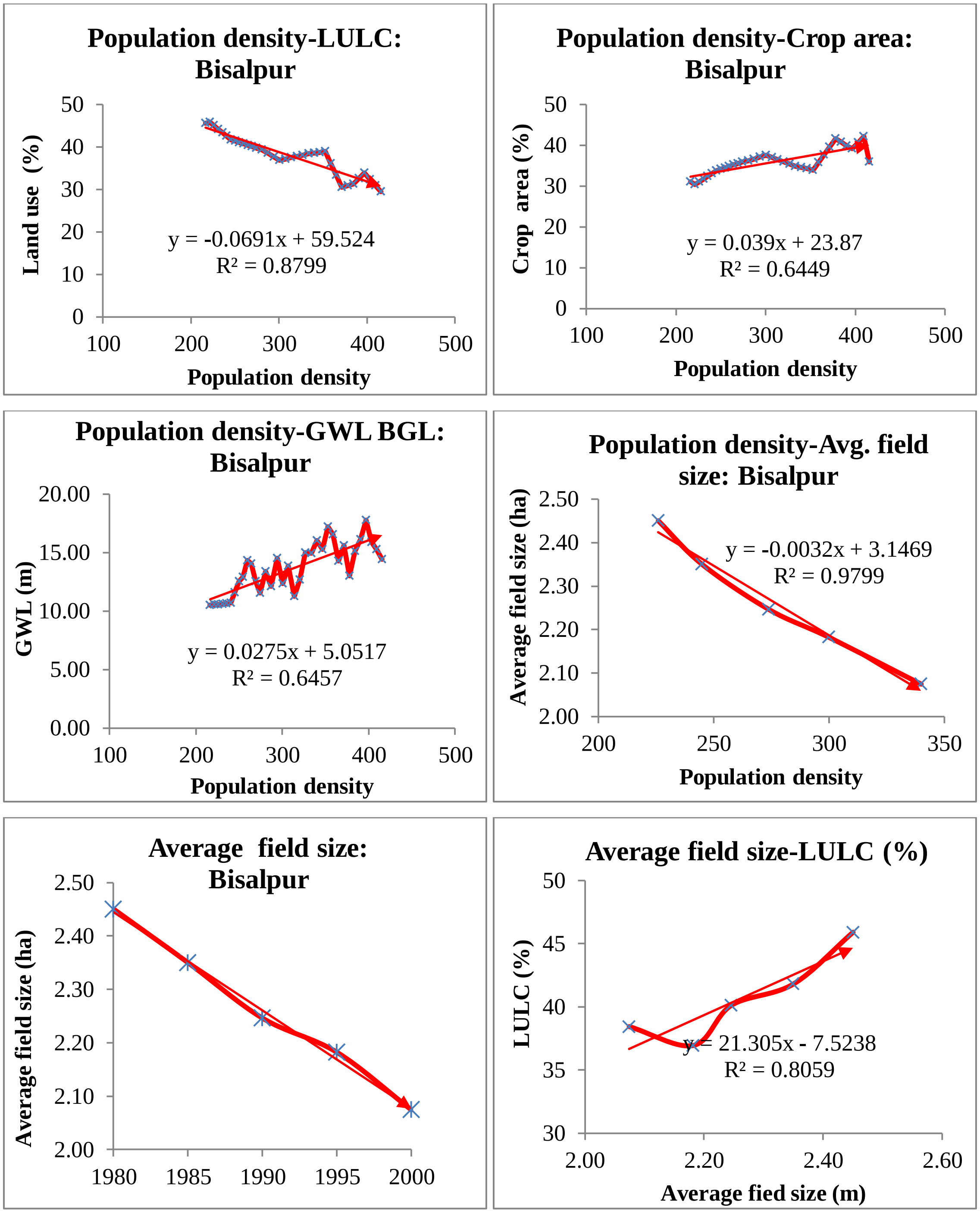


Fig. 6.14 Correlation between factors responsible and principal components

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.2 Recommendations

7.3 Major Contributions of Present Study

7.4 Limitations of Findings

7.5 Scope of Further Research

CHAPTER-7

CONCLUSIONS AND RECOMMENDATIONS

7.1 The following conclusions are drawn based on the studies

I. The temporal variation of water inflow to the dams of Rajasthan State is declining. It has slightly improved since the last couple of years (2010-2013). The inflow trend has diminished in the Ramgarh dam while it is showing a declining trend in the Bisalpur dam.

II. Performance dependability of the state surface water resources has reduced to 33.36% and 24.02% for 20 years data series and 10 year data series against the 50% expected dependability. This shows a sign of temporal variation of inflow to the dams of Rajasthan State. Performance dependability of Ramgarh dam is zero. Performance dependability of Bisalpur dam for 35 yrs, 18 yrs, and 13 yrs data series is 36.45%, 16.23%, and 14.88% respectively. Therefore, the reliability of the state surface water resources is very less and showing the declining trend. Sustainability of the dams of Rajasthan state is 38.7%, and vulnerability is 15.52%. The two parameters for Ramgarh dam are 0% and 83.89%. Sustainability of Bisalpur dam is 42.34%, 21.40% and 23.17% for 35 yrs, 18 yrs, and 13 yrs data series respectively. The vulnerability of Bisalpur dam is 35.78%, 55.90%, and 55.52% for 35 yrs, 18 yrs, and 13 yrs data series respectively.

III. The year 2002 was the year of maximum deficit. In this year, dams of Rajasthan State received only 30.9% water while Bisalpur dam received only 17 MCM of water, which were the lowest inflow to the dams.

IV. Various performance statistical parameters reveal that method of computation of theoretical inflow "Strange's Table Method" proved to be giving the less precise/ erroneous results.

V. Year 1994 is identified as critical year, which divides two consecutive non-overlapping epochs- pre-disturbance and post-disturbance, for the dams of Rajasthan State. Critical years for Ramgarh and Bisalpur dams are 1998 and 1996 respectively.

VI. The results of the ANOVA test reveal that there exists a temporal and spatial distribution of rainfall over the state, which is one of the reasons for temporal variability of inflow to the dams of the state.

VII. Trend analysis reveals that rainfall is showing an increasing trend, in spite of that inflow trend is declining. The numbers of rainy days in monsoon period are increasing. Climate parameters are showing a slight variation. LULC is the principal component responsible for inflow to the Ramgarh and Bisalpur dams while rainfall is the principal component for inflow to the dams of the state as a whole. Decadal population growth rate of the state is more than the country's growth rate.

VIII. Inflow to the dams have negative correlations with GWL below GL, mean of daily maximum temperature, the daily minimum temperature, daily wind speed, daily solar radiation and population density while positive correlations with rainfall, LULC (contributing effect), and mean of daily relative humidity.

IX. Cosine Amplitude Method (CAM) of sensitivity analysis shows that rainfall and other climatic parameters have high relative influence value (R_{ij}) for inflow to the dams of Rajasthan State while land use, GWL below GL, and population density are not principal components. Specifically, inflows to the Ramgarh and Bisalpur dams are highly influenced by LULC, rainfall, GWL and population density.

X. Considering the principal components as a predictor, inflow (dependent variable) equations have been derived using Multiple Linear Regression (MLR) technique. The generated equations give highly significant results of inflows, therefore, could be used for an assessment of inflow patterns to the dams of Rajasthan State and specifically in Ramgarh and Bisalpur dams.

XI. Regression analysis and t-tests infer that besides rainfall, inflows to the dams are also influenced by the land use (contributing effect) and GWL, which have highly significant correlations with population density and average field size. The average size of the field is regularly decreasing with time and increasing population.

7.2 The following recommendations are made based on the studies

Increase in population density is putting stress on quality and quantity (Q & Q) of water and on the other hand it is affecting the land use (contributing effect) pattern and also lowering the GWL below GL of the catchment area of the dams. This situation is leading to the declining trend of inflow to the dams of Rajasthan State.

I. More scientific methods should be used to compute theoretical inflow to the dams instead of using 'Strange's table', which gives less precise/ erroneous results.

II. 1994-1998 are proved to be critical years, which divide the two consecutive non-overlapping epochs- pre-disturbance and post-disturbance. This may be used to analyze the changes occurred leading to declining trend of inflow to the dams. It is recommended to review the policies adopted, LULC; agricultural practices etc. after the respective critical years.

III. Population density is found to be one of the principal component responsible for less water inflow to the Ramgarh and Bisalpur dams. It is recommended to adhere with most efficient use of available water to cater the increasing population and also to plan to stabilize/reduce the decadal growth rate of population. This will lead to stabilization of the average size of the field; increase in LULC (contributing effect), and improvement of GWL below GL. As concluded earlier, these improvements will lead to augmentation of inflow pattern to the dams.

IV. IWRM, INRM, RWH, recycle and reuse of water, micro watershed planning, benchmarking and water auditing, water pricing, water trading, water privatization, interlinking of rivers/ transboundary water sharing, infiltration/ground water recharge, conjunctive use of surface and subsurface water, more crop per drop by adopting sprinkler/drip/shednet irrigation techniques and other suitable water management techniques should be adhered to ensure equitable and sustainable Q & Q of water to all stakeholders including environment and river itself. Policies need to fulfill the slogan 'some, for all, forever. Dedicated pressure irrigation techniques like sprinkler/drip were implemented in Narmada Canal Project (Jalore district) and selected canals of Indira Gandhi Nahar Project (IGNP). This has resulted in 30% saving of water along with around 20% increase in per acre production. Similarly, RWH has been made compulsory for residential houses of the area more than 300 sqm in Jaipur city. These RWH (Tankas) and reuse techniques were being used in western Rajasthan since long back for self-reliance for water. Recycle (Sewerage Treatment Plant-STP) is being made compulsory for new housing and industrial project. In housing effluents, STP recycles around 75-80% water. District wise and village wise IWRM plans have been prepared, and micro-watershed planning is being done in the state. This type of planning is enabling the water administrators to supervise, monitor and plan the available water and demand at micro-watershed level. The project of ATW (Any Time Water) and water cans are ensuring availability of drinking water 24x7 at a very nominal price. These types of case studies are making successful stories of proper allocation and planning of available water and recommended to be encouraged.

V. 5-R principal (refuse, reduce, reuse, recycle, rationing) can help in facing the consequences arising out of water scarcity situations. Resource saving is resource generation. Iglesias et al. (2007) and Liu et al. (2005) emphasized that water saving is the key strategy for overall reduction of societal vulnerability to drought/water scarcity.

7.3 Major Contribution of Present Study

I. The present study attempts to address the existing gap in available scientific literature to describe the temporal variation of inflow to the dams of Rajasthan State.

II. This study is an attempt to draw conclusions regarding the direction and variability of inflow to the dams of Rajasthan State with special reference to Ramgarh and Bisalpur dams.

III. This study attempts to draw a conclusion regarding the correctness of inflow assessment by ‘Strange’s table’ being used as per prevailing practice in the WRD. It is concluded in the study that this method gives less precise/ erroneous results.

IV. Critical years have been determined in this study, which may help in the determination of factors responsible for disturbances, which lead to the declining trend of inflow to the dams.

V. Direction and variability assessment of various parameters viz. Climatic, land use, groundwater and population parameters which influence the inflow to the dams have been made in this study.

VI. Correlation and relative influence of various parameters have been ascertained to find out the principal components responsible for inflow to the dams so that it may help in an efficient planning and management of surface water availability in the state.

VII. Equations for inflow assessment of dams in the state, specifically for Ramgarh and Bisalpur dams have been derived in this study, which may help for reliable assessment of inflows to these dams.

VIII. Ramgarh dam was the source of drinking water supply of Jaipur city and Bisalpur dam is a present source. Inflow to the Ramgarh dam has diminished to zero level, and Bisalpur dam is showing a declining trend even after more than normal rainfall. It is now being planned by the Government of Rajasthan to augment the inflow to Bisalpur dam by the interlinking of rivers Banas (catchment area of Bisalpur dam) and Chambal. Future of drinking water supply in Jaipur 'the capital city of the state' is dependent on surplus water availability in the Chambal River, which is also uncertain looking to the inflow trend in the state. Therefore, this study may help in an optimized and efficient planning and management of storages, distribution and uses of available water and the various factors influencing these aspects.

IX. In the future, the study can also be used by managers as a decision support system (DSS) to manage the inflow to the dams.

7.4 Limitations of Findings

I. Theoretical inflow has been computed using Strange's table due to absence of gauge-discharge data. However it is proved that this method gives less precise/ erroneous results. More scientific method is desired to be used for assessment of theoretical inflow, specifically in Ramgarh dam.

II. LULC is determined as principal component responsible for temporal variation of inflow to the dams. LULC data has been collected from statistical department instead of GIS.

III. Hydrological processes like water balance equations etc. have not been covered in the thesis.

IV. There is little physics or science like soil moisture, evapotranspiration etc.

7.5 Scope of Further Research

I. Further research may be carried out to simulate the actual inflow to the Ramgarh dam as there is further need for the development of water balance equation.

II. A similar study can be undertaken for other major/medium dams so that inflow pattern, critical year, and principal components responsible for less water inflow can be ascertained. This will help in reviewing the impact of policy formed earlier and will also help in policy formation in future.

III. More scientific investigations of the impacts of anthropogenic changes and climate change on inflow to the dams based on focused field study, systematic experimental design, and long term programmes can be undertaken.

IV. Effect of soil moisture and GWL below GL on inflow to the dams can be investigated further.

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APPENDICES

Appendix-1

Detail of 115 major and medium dams of Rajasthan State

S.N.	Name of the Dam	Name of Basin	Name of District	Type of Dam	Capacity (MCM)	Actual D_n based on Inflow (20 years)	Actual D_n based on Inflow (10 years)	IF of the district (20 years)	IF of the district (10 years)
1	Udaisagar	Banas	Udaipur	Medium	31.15	15.0%	9.1%	165.0	100.1
2	Vallabhnagar	Banas	Udaipur	Medium	30.44	9.5%	9.1%	102.1	97.8
3	Bhagolia	Banas	Udaipur	Medium	18.55	4.8%	9.1%	31.2	59.6
4	Badgaon	Banas	Udaipur	Medium	31.49	33.0%	45.0%	367.0	500.4
5	Jaisamand	Mahi	Udaipur	Major	414.90	19.1%	9.1%	2790.8	1333.2
6	Jakham	Mahi	Udaipur	Major	142.03	38.1%	27.3%	1910.7	1367.6
7	Som kagdar	Banas	Udaipur	Medium	36.19	81.0%	72.7%	1035.2	929.4
		Udaipur District(Total)=			**704.76**			6402.0	4388.0
						Wtd.	**D_n (%)=**	**25.7**	**17.6**
8	Rajasmand	Banas	Rajasmand	Major	98.73	0.0%	0.0%	0.0	0.0
9	Nandsamand	Banas	Rajasmand	Medium	21.24	66.7%	45.5%	500.0	340.9
10	Mataji ka khera	Banas	Rajasmand	Medium	11.92	0.0%	0.0%	0.0	0.0
		Rajasmand District(Total)=			**131.89**			500.0	340.9
						Wtd.	**D_n (%)=**	**10.7**	**7.3**
11	Bisalpur	Banas	Tonk	Major	938.83	33.3%	27.3%	11048.9	9040.0
12	Galwa	Banas	Tonk	Major	48.74	28.6%	0.0%	491.7	0.0
13	Tordi sagar	Banas	Tonk	Major	47.15	19.1%	0.0%	317.2	0.0
14	Mashi	Banas	Tonk	Medium	48.15	33.3%	0.0%	566.6	0.0
15	Chandsen	Banas	Tonk	Medium	14.70	14.3%	0.0%	74.2	0.0
16	Galwania	Chambal	Tonk	Medium	12.55	38.1%	27.3%	168.8	120.8
17	Motisagar	Banas	Tonk	Medium	12.89	38.1%	9.1%	173.4	41.4
		Tonk District(Total)=			**1123.00**			12840.7	9202.2
						Wtd.	**D_n (%)=**	**32.4**	**23.2**
18	Meja	Banas	Bhilwara	Major	84.03	9.5%	9.1%	281.9	270.0
19	Matrakundia	Banas	Bhilwara	Medium	50.67	0.0%	0.0%	0.0	0.0
20	Sareri	Banas	Bhilwara	Medium	55.11	4.8%	0.0%	92.6	0.0
21	Arwar	Banas	Bhilwara	Medium	47.81	4.8%	0.0%	80.3	0.0
22	Khari Dam	Banas	Bhilwara	Medium	33.31	14.3%	0.0%	168.1	0.0
23	Naharsagar	Banas	Bhilwara	Medium	24.53	23.8%	9.1%	206.2	78.8
24	Kothari	Banas	Bhilwara	Medium	21.52	28.6%	18.2%	217.1	138.2
25	Jetpura	Banas	Bhilwara	Medium	16.40	57.1%	36.4%	330.8	210.5
26	Umedsagar	Banas	Bhilwara	Medium	17.79	14.3%	0.0%	89.7	0.0
27	Mandal	Banas	Bhilwara	Medium	11.89	14.3%	18.2%	60.0	76.4
28	Chandrabhaga	Banas	Bhilwara	Medium	9.01	0.0%	0.0%	0.0	0.0
29	Jhadol	Banas	Bhilwara	Medium	9.29	19.1%	18.2%	62.5	59.6
		Bhilwara District(Total)=			**381.34**			1589.3	833.5
						Wtd.	**D_n (%)=**	**11.8**	**6.2**

30	Gosunda	Banas	Chittorgarh	Major	0.00	D.N.A.			
31	Bassi	Banas	Chittorgarh	Medium	20.25	57.1%	45.5%	408.6	325.0
32	Bhopal Sagar	Banas	Chittorgarh	Medium	18.55	9.5%	9.1%	62.4	59.6
33	Dhindoli	Banas	Chittorgarh	Medium	7.53	5.9%	0.0%	15.7	0.0
34	Gambhiri	Banas	Chittorgarh	Medium	55.03	33.3%	18.2%	647.6	353.2
35	Murlia	Banas	Chittorgarh	Medium	9.63	14.3%	9.1%	48.6	30.9
36	Orai	Banas	Chittorgarh	Medium	35.29	61.9%	27.3%	771.3	339.8
37	Rana Pratap Sagar	Chambal	Chittorgarh	Major	2899.07	28.6%	27.3%	29246.0	27915.2
38	Wagon	Banas	Chittorgarh	Medium	37.58	28.6%	9.1%	379.1	120.8
		Chhitorgarh District(Total)=			**3082.92**			31579.2	29144.5
						Wtd.	**D_n (%)=**	**29.0**	**26.8**
39	Buchara	Sabi	Jaipur	Medium	16.65	16.7%	0.0%	98.0	0.0
40	Chhittoli	Sabi	Jaipur	Medium	24.38	0.0%	0.0%	0.0	0.0
41	Ramgarh	Banganga	Jaipur	Major	75.05	0.0%	0.0%	0.0	0.0
42	Chhaparwara	Banas	Jaipur	Medium	35.00	4.8%	0.0%	58.8	0.0
43	Kalakh Sagar	Banas	Jaipur	Medium	16.45	0.0%	0.0%	0.0	0.0
44	Kanota	Banas	Jaipur	Medium	14.13	0.0%	0.0%	0.0	0.0
45	Hingoniya	Banas	Jaipur	Medium	7.50	0.0%	0.0%	0.0	0.0
		Jaipur District(Total)=			**189.18**			156.8	0.0
						Wtd.	**D_n (%)=**	**2.3**	**0.0**
46	Narayan Sagar	Banas	Ajmer	Medium	19.97	0.0%	0.0%	0.0	0.0
47	Phool Sagar	Luni	Ajmer	Medium	0.00	D.N.A.		0.0	0.0
48	Lassariya	Banas	Ajmer	Medium	11.50	38.1%	18.2%	154.7	73.8
		Ajmer District(Total)=			**31.46**			154.7	73.8
						Wtd.	**D_n (%)=**	**13.9**	**6.6**
49	Mora Sagar	Banas	Sawai Madhopur	Medium	13.74	9.5%	9.1%	46.2	44.1
50	Dheel	Banas	Sawai Madhopur	Medium	27.75	42.9%	9.1%	420.0	89.2
51	Kalisil	Banas	Sawai Madhopur	Medium	41.77	42.9%	27.3%	632.2	402.2
52	Mansarovar	Chambal	Sawai Madhopur	Medium	15.32	33.3%	18.2%	180.3	98.4
53	Surwal	Banas	Sawai Madhopur	Medium	22.91	14.3%	0.0%	115.6	0.0
		Sawai Madhopur District(Total)=			**121.50**			1394.3	633.9
						Wtd.	**D_n (%)=**	**32.5**	**14.8**
54	Raipur Patan	Shekhawati	**Sikar**	Medium	9.18	4.8%	0.0%	**4.8**	**0.0**
						Wtd.	**D_n (%)=**		
55	Harsora	Sabi	Alwar	Medium	8.81	21.1%	9.1%	65.5	28.3
56	Jaisamand	Ruparail	Alwar	Medium	26.96	4.8%	0.0%	45.3	0.0
57	Tasai	Banganga	Alwar	Medium	0.00	D.N.A.		0.0	0.0
		Alwar District(Total)=			**35.77**			110.8	28.3
						Wtd.	**D_n (%)=**	**8.8**	**2.2**
58	Bharetha	gambhir	Bharatpur	Medium	52.68	19.1%	9.0%	354.3	167.6
59	Sikari Bund	Ruparail	Bharatpur	Major	42.48	D.N.A.		0.0	0.0
60	Ajan Lower	Banganga	Bharatpur	Medium	17.98	19.0%	0.0%	120.9	0.0
61	Bhatawali	Banganga	Bharatpur	Medium	0.00	D.N.A.		0.0	0.0

62	Sarsera	Banganga	Bharatpur	Medium	0.00	D.N.A.		0.0	0.0
63	Baretha	Banganga	Bharatpur	Medium	0.00	D.N.A.		0.0	0.0
		Bharatpur District(Total)=			**113.14**			475.2	167.6
						Wtd.	**D_n (%)=**	**11.9**	**4.2**
64	Morel	Banas	Dausa	Major	76.66	19.1%	0.0%	515.7	0.0
65	Chandrana	Banganga	Dausa	Medium	4.93	14.3%	0.0%	24.9	0.0
66	Kala Kho	Banganga	Dausa	Medium	13.28	33.3%	0.0%	156.3	0.0
67	Rondh	Banganga	Dausa	Medium	0.00	D.N.A.		0.0	0.0
68	Moroli	Banganga	Dausa	Medium	0.00	D.N.A.		0.0	0.0
69	Sainthal Sagar	Banganga	Dausa	Medium	13.71	19.1%	0.0%	92.2	0.0
70	Madho Sagar	Banganga	Dausa	Medium	22.60	0.0%	0.0%	0.0	0.0
		Dausa District(Total)=			**131.18**			789.1	0.0
						Wtd.	**D_n (%)=**	**17.0**	**0.0**
71	Jugger	gambhir	Karauli	Medium	35.00	24.5%	0.0%	302.8	0.0
72	Panchana	gambhir	Karauli	Medium	59.47	0.0%	0.0%	0.0	0.0
		Karauli District(Total)=			**94.48**			302.8	0.0
						Wtd.	**D_n (%)=**	**9.1**	**0.0**
73	Parbati	Parbati	Dholpur	Major	113.85	22.2%	18.2%	893.2	730.8
74	Urmila Sagar	Parbati	Dholpur	Medium	15.75	9.5%	0.0%	52.9	0.0
		Dholpur District(Total)=			**129.60**			946.2	730.8
						Wtd.	**D_n (%)=**	**20.7**	**16.0**
75	Sawan Bhado	Chambal	Kota	Medium	30.02	9.5%	18.2%	100.7	192.7
76	Alnia	Chambal	Kota	Medium	43.73	23.8%	9.1%	367.5	140.5
77	Kota Barrage	Chambal	Kota	Major	0.00	D.N.A.			
78	Takli	Chambal	Kota	Medium	0.00	D.N.A.	Ongoing		
		Dholpur District(Total)=			**73.75**			468.2	333.2
						Wtd.	**D_n (%)=**	**18.0**	**12.8**
79	Jawahar Sagar	Chambal	Bundi	Major	0.00	D.N.A.			
80	Burdha	Chambal	Bundi	Medium	29.00	61.9%	36.4%	633.9	372.3
81	Bhimlet	Chambal	Bundi	Medium	11.70	38.1%	45.5%	157.4	187.7
82	Bundi Ka Gothra	Chambal	Bundi	Medium	18.97	33.3%	18.2%	223.3	121.8
83	Dugari	Chambal	Bundi	Medium	18.10	5.3%	0.0%	33.6	0.0
84	Gudha	Chambal	Bundi	Major	95.58	61.9%	45.5%	2089.1	1533.9
85	Gararda	Chambal	Bundi	Medium	0.00	D.N.A.	Ongoing		
		Bundi District(Total)=			**173.35**			3137.3	2215.8
						Wtd.	**D_n (%)=**	**51.3**	**36.2**
86	Parwan Pickup	Chambal	Baran	Medium	0.00	D.N.A.	Pickup/lift		
87	Parwati Pickup	Chambal	Baran	Medium	0.00	D.N.A.	Pickup/lift		
88	Parwan Lift	Chambal	Baran	Medium	0.00	D.N.A.	Pickup/lift		
89	Gopalpura	Chambal	Baran	Medium	32.65	71.4%	36.4%	823.6	419.2
90	Bilas	Chambal	Baran	Medium	29.17	66.7%	54.5%	686.6	561.8
91	Benthali	Chambal	Baran	Medium	31.58	_	22.2%	0.0	247.8
92	Umedsagar	Chambal	Baran	Medium	18.61	66.7%	36.4%	438.0	238.9
93	Lhasi	Chambal	Baran	Medium	0.00	D.N.A.	Ongoing		
		Baran District(Total)=			**112.01**			1948.2	1467.6

						Wtd.	**D_n (%)=**	**68.6**	**37.1**
94	Chhapi	Chambal	Jhalawar	Medium	82.64	0.0%	0.0%	0.0	0.0
95	Chauli	Chambal	Jhalawar	Medium	53.44	_	14.28%(6 yr)	0.0	269.5
96	Bhimsagar	Chambal	Jhalawar	Medium	76.55	38.1%	18.2%	1029.8	491.4
97	Harishchand Sagar	Chambal	Jhalawar	Medium	0.00	D.N.A.			
98	Piplad	Chambal	Jhalawar	Medium	0.00	D.N.A.	Ongoing		
99	Gagrin	Chambal	Jhalawar	Medium	0.00	D.N.A.	Ongoing		
		Jhalawar District(Total)=			**212.63**			1029.8	760.9
						Wtd.	**D_n (%)=**	**18.3**	**10.1**
100	Mahi	Mahi	**Basnwara**	Major	2061.48	57.1%	36.4%	**0.6**	**0.4**
101	Som Kamla Amba	Mahi	**Dungarpur**	Major	172.81	25.0%	27.3%	**0.3**	**0.3**
102	Sardarsamand	Luni	Pali	Major	88.22	4.8%	0.0%	148.3	0.0
103	Jawai Dam	Luni	Pali	Major	207.45	28.6%	18.2%	2092.8	1331.7
104	Hemawas	Luni	Pali	Medium	62.53	33.3%	9.1%	735.9	200.9
105	Kharda	Luni	Pali	Medium	18.80	28.6%	18.2%	189.7	120.7
106	Giroliya	Luni	Pali	Medium	0.00	D.N.A.		0.0	0.0
107	Raipur Luni	Luni	Pali	Medium	12.55	52.4%	27.3%	232.0	120.8
108	Rajsagar Chopra	Luni	Pali	Medium	7.59	23.5%	0.0%	63.1	0.0
		Pali District(Total)=			**397.14**			3461.8	1774.1
						Wtd.	**D_n (%)=**	**24.7**	**12.7**
109	Jaswant Sagar	Luni	Jodhpur	Medium	52.82	4.8%	9.1%		
		Jodhpur District(Total)=					**D_n (%)=**	**4.8**	**9.1**
110	Bankli	Luni	Jalore	Medium	34.55	33.3%	9.1%		
111	Bandi Sendhara	Luni	Jalore	Medium	0.00	D.N.A.	Ongoing		
112	Chittalwara	Luni	Jalore	Medium	12.23	0.0%	0.0%	0.0	0.0
		Jalore District(Total)=			**46.79**	**Wtd.**		**24.6**	**6.7**
113	Angore	Luni	Sirohi	Medium	14.02	38.1%	36.4%	188.6	180.0
114	Ora	Luni	Sirohi	Medium	22.66	9.5%	0.0%	76.2	0.0
115	West Banas	West Banas	Sirohi	Medium	39.08	33.3%	18.2%	460.0	250.9
		Sirohi District(Total)=			**75.76**			724.7	430.9
						Wtd.	**D_n (%)=**	**18.3**	**16.1**

Appendix-2

113-yea rrainfall data for ANOVA test (A3 Sheet attached)

Appendix-2

YEAR	JAIPUR	DAUSA	ALWAR	BHARATPUR	DHOLPUR	KARAULI	SAWAIMADHOPUR	TONK	AJMER	SIKAR	JHUNJHUNU	BHILWARA	CHITTORGARH	KOTA	BUNDI	JHALAWAR	BARAN	SIROHI	RAJSAMAND	UDAIPUR	DUNGARPUR	BANSWARA	PARTAPGARH	BIKANER	CHURU	GANGANAGAR	JODHPUR	JALORE	BARMER	NAGAUR	JAISALMER	PALI	HANUMANGARH	State Average
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1901	308	379	487	426	808	608	435	309	345	218	93			558	440		1051	140		281	265	589		160			205	27	64	206	93	129		357
1902	475	492	457	743	757	774	715	687	433	223	218			618	473		622	288		548	505	563		148			175	145	155	164	132	322		468
1903	592	550	325	623	714	995	645	485	464	592	409			904	1000		1022	416		676	834	1018		251			513	346	178	461	108	435		583
1904	630	651	1117	958	1073	826	1144	767	427	478	288			673	718		1505	287		484	423	519		215			160	125	166	331	54	301		580
1905	120	135	258	281	341	182	200	169	181	169	211			172	317		251	204		443	524	526		89			89	370	82	80	92	83		227
1906	331	558	736	690	783	450	504	411	491	227	337			923	799		795	595		656	846	1143		397	297		284	420	262	275	316	530	308	529
1907	469	436	598	551	305	455	724	634	355	201	244			448	481		516	646		493	421	781		495	325		307	645	497	443	241	618	329	474
1908	925	656	826	1245	1305	972	958	677	920	598	758			1022	1473		1171	1017		619	590	858		458	769		850	657	673	684	433	805	590	633
1909	659	502	1041	739	567	769	649	916	774	659	616			923	843		920	811		1062	677	1009		554	523		507	419	385	524	218	444	538	672
1910	438	601	774	958	876	892	704	579	437	324	446			783	644		892	567		640	737	1209		335	226		208	348	186	349	108	780	112	565
1911	452	445	880	458	683	618	579	450	218	239	347			435	536		477	172		359	269	455		153	186		147	122	62	221	67	250	230	353
1912	807	621	683	687	850	921	865	837	352	504	531			626	745		689	615		647	659	1047		212	403		451	238	348	398	193	355	395	585
1913	383	309	430	387	495	280	274	218	394	355	354			503	550		503	517		638	1111	1259		180	316		185	318	288	131	128	265	214	408
1914	631	575	529	823	989	584	865	689	500	593	421			649	642		1154	467		620	640	1019		363	280		257	297	225	243	293	283	474	559
1915	364	347	536	468	638	409	396	320	365	293	355			586	476		378	279		432	490	628		167	216		135	107	130	323	103	203	98	347
1916	602	649	951	954	1099	748	1233	729	719	784	532			1119	658		1308	584		785	718	1223		536	348		800	455	279	402	334	735	251	735
1917	1317	1173	1260	1092	1115	1318	1774	1409	1227	810	563			1593	1412		1377	1260		1223	922	1235		771	784		1177	857	597	806	575	645	558	1079
1918	224	212	199	297	293	248	235	210	149	179	129			388	323		447	157		348	349	506		53	77		38	50	29	63	193	79	69	295
1919	681	1024	993	877	753	1110	1341	741	497	410	300			728	840		1049	827		542	883	1292		481	382		311	618	385	237	100	429	292	657
1920	795	462	447	457	421	522	661	741	558	362	469			585	728		809	475		571	873	602		337	273		274	382	262	173	279	359	78	479
1921	550	597	487	602	679	734	752	483	292	226	249			502	579		795	789		657	654	569		424	172		161	315	415	191	67	279	84	408
1922	451	637	579	828	782	729	709	477	338	405	295			674	677		883	614		787	766	889		244	284		237	277	212	314	124	212	175	504
1923	532	761	585	887	898	639	1229	927	338	432	347			1158	605		1085	420		413	420	683		292	445		415	212	101	380	202	289	464	503
1924	1284	1305	1049	1001	1923	1248	1031	1152	901	656	374			1304	1051		1034	452		824	758	936		261	376		533	327	307	198	188	224	127	737
1925	326	337	599	516	559	576	593	469	287	288	433			551	458		654	334		477	694	517		186	461		177	131	52	178	72	237	193	384
1926	829	597	776	1383	749	854	709	752	671	509	523			1050	872		920	944		994	1133	679		391	410	246	545	726	468	305	319	771	338	633
1927	453	549	724	473	659	694	635	697	715	539	306			770	858		888	823		891	842	1006		257	501	188	562	443	335	324	175	503	168	582
1928	425	409	551	543	467	409	638	612	615	363	288			656	722		657	589		649	902	1087		304	339	482	391	335	185	469	100	455	283	495
1929	634	247	279	411	469	547	568	584	722	480	261			453	664		600	618		575	529	736		262	277	165	364	415	460	426	105	477	94	453
1930	577	532	604	496	647	716	974	799	558	504	561			615	376	1186	639	337		674	684	1029		235	423	417	240	284	92	328	71	302	400	533
1931	697	437	765	580	491	521	1053	647	532	419	442			931	740	1024	913	535		766	1060	933		302	309	223	464	504	617	265	275	568	161	590
1932	574	526	441	459	527	647	876	405	373	435	339			634	622	549	907	645		432	378	676		213	317	153	456	379	283	180	171	388	206	459
1933	995	755	1114	937	803	812	1717	1164	897	618	487			761	906	1408	1295	547		927	1028	1452		440	464	200	627	440	284	426	264	353	464	775
1934	718	780	655	821	807	781	1503	600	731	574	480			1294	1017	1029	1107	654		732	757	1050		431	412	165	382	444	214	378	137	422	341	673
1935	735	467	565	834	800	985	1222	819	675	405	379			1020	918	1123	943	489		541	477	651		344	254	209	277	315	214	239	172	306	373	580
1936	565	725	972	550	629	917	1049	379	502	601	308			587	495	628	658	227		300	408	457		484	271	122	299	121	145	340	158	253	206	464
1937	452	336	455	356	533	540	1051	708	635	379	450			947	554	973	850	683		450	1801	1309		313	342	159	300	451	265	335	248	287	288	569
1938	325	335	417	468	689	412	485	374	221	198	269			650	648	753	848	519		551	654	968		121	252	201	261	503	215	166	166	508	220	423
1939	230	208	475	610	639	455	302	265	245	253	180			524	457	718	466	315		448	450	624		91	188	116	200	162	162	112	41	280	223	327
1940	768	494	444	561	672	528	566	490	758	446	355			512	773	1004	703	475		583	502	812		209	277	234	354	246	297	453	290	480	286	499
1941	209	286	444	212	428	340	461	254	335	293	248			382	400	558	417	1020		652	947	1409		161	315	262	221	444	298	151	115	288	324	411
1942	776	561	1021	863	1282	1160	2410	1115	777	864	709	893	1034	1086	1533	1698	1379	545	377	540	737	1015		695	735	276	371	290	325	514	170	396	543	834
1943	526	647	510	406	637	1031	1345	719	571	326	321	662	1080	587	806	1137	755	784	488	662	744	743		205	382	103	637	309	240	278	91	491	144	574
1944	763	694	650	735	695	686	891	514	520	556	396	1103	1534	799	737	1108	1180	1393	650	699	1081	1588		409	389	275	776	818	940	383	578	677	297	779
1945	858	681	581	526	609	816	1780	1508	495	613	436	698	1139	1305	1183	1462	1149	1042	580	590	855	1483		483	382	490	576	668	273	345	165	451	440	771
1946	922	679	633	537	435	820	1376	1303	612	552	435	766	1320	1204	1256	1670	1328	541	553	1139	865	1244		182	479	72	239	321	307	209	193	285	170	710
1947	542	605	664	682	627	937	695	752	482	602	634	695	815	1119	1179	1585	1197	368	744	739	528	641		253	354	122	360	307	277	265	213	474	288	617
1948	658	649	837	871	1177	878	796	778	374	364	372	480	693	1069	712	1530	1200	306	337	490	415	774		121	374	497	388	336	284	87	80	451	220	581
1949	450	563	553	1159	1121	735	766	589	391	310	279	500	551	844	717	701	699	384	307	398	592	921		318	398	140	229	247	242	343	107	264	355	505
1950	709	545	388	686	799	698	1005	936	715	533	484	944	911	879	737	1015	866	885	800	825	1502	1496		478	552	442	286	378	213	430	118	550	468	698
1951	398	358	447	520	529	554	365	331	249	310	184	326	287	333	404	428	467	461	472	454	611	514		220	158	288	216	263	248	140	110	308	170	349
1952	411	557	347	805	999	614	809	614	544	302	210	1046	1062	885	990	1416	777	641	554	746	703	1447		217	215	168	378	584	120	124	152	512	105	505
1953	441	410	529	527	621	485	574	747	524	469	356	655	663	404	653	515	606	668	423	698	1011	1001		182	340	106	369	403	303	806	367	798	844	547
1954	592	509	580	450	970	538	784	735	487	425	478	706	684	713	658	886	557	518	515	1000	748	1203		352	327	231	223	347	111	278	278	398	231	547
1955	860	883	646	700	951	876	1000	685	871	684	735	958	1080	1285	1215	1030	931	549	596	559	714	1156		303	321	176	333	702	371	382	441	693	233	722
1956	1013	632	797	690	799	1083	1494	380	753	690	766	1304	1149	842	851	879	929	856	746	883	884	839		316	1073	416	595	650	496	383	255	535	341	759
1957	935	849	739	893	644	890	1326	987	566	663	559	492	661	869	835	950	1042	421	542	604	489	622	550	178	382	164	276	340	205	287	207	368	213	598
1958	567	557	973	993	1119	918	1003	695	728	339	358	736	741	900	1049	956	569	442	518	734	1021	1191	901	208	326	237	307	425	192	453	226	266	139	632
1959	889	829	586	544	659	773	1303	864	826	464	457	317	1095	868	872	746	981	829	767	856	1046	1970	912	552	320	341	417	635	305	323	232	594	240	708
1960	414	844	886	708	876	499	694	544	353	406	385	432	592	761	487	962	1009	951	415	520	644	694	952	181	327	215	240	342	259	135	134	262	230	520
1961	615	818	876	639	1056	932	1057	1041	606	378	417	832	1083	1130	962	1433	1340	1025	558	652	1003	1186	1241	334	379	243	355	619	536	297	532	388	192	759
1962	542	363	775	469	475	643	683	629	590	515	503	478	631	688	676	901	913	587	406	472	858	1113	1012	292	320	90	280	207	168	327	255	285	144	529
1963	638	335	648	642	754	568	747	498	393	364	348	504	778	748	681	801	638	368	629	829	733	1129	894	87	348	250	250	212	194	139	63	351	311	511
1964	661	530	776	604	641	756	951	562	548	669	548	520	672	456	663	846	605	628	498	578	522	780	474	247	500	309	373	284	284	586	120	464	293	592
1965	203	389	416	565	607	505	319	301	341	219	181	371	390	440	607	705	449	530	343	604	380	561	527	161	185	105	287	350	309	236	91	489	172	376
1966	474	450	471	641	638	481	692	621	460	267	508	747	585	400	757	516	514	502	575	413	400	510	360	358	407	291	383	275	67	148	108	504	293	451
1967	625	802	975	804	1372	815	856	717	518	165	667	838	785	855	846	794	1367	1127	605	817	618	1143	757	317	233	357	611	434	235	352	187	793	180	683
1968	408	381	464	692	643	511	851	444	467	541	307	427	802	605	536	375	689	334	394	582	790	943	585	46	226	79	168	100	37	286	63	158	211	429
1969	478	522	1064	491	636	823	620	622	272	391	439	585	916	918	537	1267	877	451	305	459	454	871	930	114	270	103	104	51	64	183	28	101	100	488
1970	822	573	787	724	819	682	687	656	673	561	474	869	841	671	603	1035	1030	887	687	780	701	954	749	267	499	223	832	475	170	571	232	600	368	652
1971	980	753	808	830	750	1091	1244	959	789	575	535	590	719	1251	1096	1515	1075	713	484	472	697	1049	1220	241	298	121	269	368	157	487	108	438	121	692
1972	351	607	714	577	489	912	561	344	245	200	234	612	613	380	532	788	597	465	280	373	722	677	580	207	191	243	237	453	114	331	68	237	214	431
1973	782	551	629	682	633	818	989	711	837	442	402	1019	1230	828	752	1265	1110	1578	1002	1118	974	1050	1616	197	291	205	652	869	490	882	286	675	298	793
1974	646	605	578	621	641	565	833	620	464	622	287	651	750	633	813	981	908	354	214	442	452	838	953	280	283	109	104	133	50	295	31	172	76	487
1975	982	1363	884	701	541	1326	1090	697	1102	803	586	825	1272	451	775	990	1537	977	755	624	910	1086	1091	336	549	234	709	721	518	1259	409	775	275	823
1976	590	596	813	777	818	838	799	803	985	340	527	944	964	456	983	595	1262	1097	593	693	1040	1326	1357	329	473	659	645	444	510	559	309	368	498	729
1977	1036	1025	914	640	1029	992	874	876	614	1096	807	950	812	1101	768	849	901	808	580	582	1266	1097	1320	358	692	413	389	542	143	503	129	511	283	761
1978	1021	756	716	585	630	855	785	570	573	984	663	766	782	970	808	861	916	724	665	800	1292	1597	1016	340	604	482	365	545	336	450	215	434	314	711
1979	510	503	452	219	382	439	807	606	817	306	226	565	803	784	738	1219	541	604	627	511	743	927	598	222	176	160	527	585	298	276	178	943	102	525
1980	456	809	526	636	578	621	572	476	416	520	324	361	990	385	375	532	682	443	519	475	831	888	973	147	373	194	250	173	89	228	143	260	135	466
1981	1202	1206	532	357	483	683	604	851	516	740	249	469	576	653	469	708	856	350	492	614	769	1383	698	348	288	261	279	268	212	320	231	197	287	559
1982	576	740	476	780	639	954	656	674	484	585	318	938	811	1013	1021	958	1138	306	532	571	983	816	673	337	306	294	451	274	183	511	177	325	324	604
1983	912	1353	868	889	450	1270	643	965	947	717	471	900	797	501	757	802	661	788	809	816	801	795	660	482	424	666	526	886	310	617	287	380	439	714
1984	380	716	552	396	598	462	295	422	656	302	293	634	650	448	948	757	560	425	271	554	878	1721	1008	117	235	451	221	247	248	179	133	268	310	495
1985	694	587	704	683	906	811	580	452	445	370	272	473	552	586	588	1073	600	283	330	640	401	643	758	137	385	387	167	303	249	304	76	251	305	486
1986	532	492	318	377	449	537	678	578	314	372	325	591	780	695	975	1492	1277	311	443	299	507	1265	1020	295	337	216	175	298	98	180	65	253	290	516
1987	399	410	224	394	371	541	430	254	295	195	210	457	683	491	596	927	907	191	380	298	523	973	592	188	254	178	185	149	101	206	39	127	87	364
1988	418	457	677	573	836	661	716	550	439	596	579	684	811	855	549	788	707	333	671	594	708	1025	683	218	633	215	322	318	171	351	228	427	144	541
1989	318	478	331	548	521	484	493	372	421	254	189	799	829	437	492	569	560	456	465	754	657	676	821	234	164	228	303	282	268	270	137	297	78	428
1990	695	499	768	621	868	703	664	610	841	444	381	871	1007	744	651	1037	716	1415	781	856	974	1358	1259	234	368	286	815	1047	748	484	68	1022	120	731
1991	561	700	318	447	357	405	773	435	409	344	337	856	947	729	498	715	1047	207	446	513	549	1203	895	159	395	230	233	164	49	275	130	305	133	476
1992	742	955	675	736	993	1216	807	605	657	464	509	796	620	608	425	836	605	932	679	659	655	1096	675	338	384	354	526	745	413	443	233	688	305	657
1993	493	665	491	558	430	910	713	602	562	296	401	338	529	760	663	1114	631	542	582	467	692	1204	1023	207	511	223	232	395	386	323	371	291	181	539
1994	713	681	509	654	612	722	1130	572	551	461	546	1051	981	919	848	987	990	719	461	764	1240	1675	1445	314	377	341	390	733	608	255	196	650	207	706
1995	755	1021	759	637	1009	1204	1086	903	740	761	591	642	605	829	557	1012	723	523	516	404	496	839	767	329	446	273	374	580	179	515	321	418	338	648
1996	887	690	1445	841	993	986	802	1078	769	970	549	926	1096	781	1241	1282	807	469	618	976	694	1167	1006	297	387	201	521	342	225	914	189	633	395	789
1997	715	632	695	648	916	959	845	675	1076	671	521	782	608	799	899	1247	691	835	446	643	753	1187	811	437	624	568	572	672	365	709	185	808	485	713
1998	696	762	734	952	885	1084	817	628	690	674	444	455	513	519	536	802	645	505	541	678	715	910	913	326	650	286	577	327	325	486	333	255	252	597
1999	437	464	489	786	698	701	662	745	480	415	204	641	1008	569	505	1160	782	341	365	405	386	710	1080	181	228	253	357	326	172	248	372	384	211	508
2000	346	488	432	402	535	582	518	380	326	168	249	452	579	789	621	660	860	363	245	465	387	551	407	147	229	99	262	311	217	361	145	235	121	395
2001	427	506	535	648	409	595	978	674	412	657	397	684	765	1081	824	917	868	571	638	546	791	624	689	208	413	365	527	340	264	305	321	500	264	591
2002	222	309	322	465	454	292	334	221	281	152	123	317	471	463	276	588	254	196	354	352	369	571	565	32	288	98	91	171	126	111	63	90	117	276
2003	511	658	834	901	746	898	888	816	481	584	270	494	818	526	754	938	571	780	483	618	708	1074	879	245	570	420	359	661	475	532	178	337	179	607
2004	807	504	416	635	773	577	985	699	377	272	202	922	877	572	848	956	715	385	462	587	675	1383	1093	96	292	130	182	314	220	273	47	220	241	537
2005	388	634	624	617	712	477	632	393	513	415	307	428	815	647	525	793	898	818	792	719	572	910	709	175	264	110	224	293	92	474	177	417	210	515
2006	335	373	589	374	303	372	661	563	417	452	355	1129	1072	679	707	1615	925	1234	739	926	1611	2591	1415	274	251	233	210	713	759	214	503	433	268	711
2007	521	562	656	539	620	867	1120	545	441	446	442	475	628	801	749	659	690	636	637	499	580	1391	946	362	449	479	205	368	255	444	195	711	388	582
2008	572	810	1024	768	1320	692	962	518	702	565	610	653	1055	712	602	808	665	298	423	757	319	688	799	254	636	292	476	344	207	443	174	296	234	603
2009	306	379	581	643	521	766	426	380	283	124	214	307	677	648	575	870	650	110	447	496	914	963	981	294	165	297	156	199	167	396	91	173	257	438
2010	659	718	857	754	976	1178	1125	1011	653	698	828	637	687	571	662	841	614	431	1039	902	760	636	1005	409	635	366	511	535	434	601	309	465	547	710
2011	660	918	813	743	746	500	946	738	492	516	646	730	818	968	750	1420	1507	751	522	1015	977	1382	1381	356	646	453	314	582	343	230	277	521	297	726
2012	1084	830	1107	832	729	634	793	679	590	810	427	655	838	625	736	645	743	783	599	739	1178	1300	1347	343	430	257	480	196	258	409	219	330	214	653
2013	751	888	739	529	945	658	1165	1173	676	425	305	655	692	1059	644	1448	1652	395	654	764	1316	1105	1315	392	300	209	518	420	363	361	145	589	152	724
Avg	612	697	656	657	719	729	839	652	542	471	402	651	821	754	734	982	858	534	541	635	749	1009	914	280	377	260	364	394	372	354	194	422	256	574
Min	120	135	199	212	293	182	200	169	149	124	93	307	287	172	276	375	251	110	214	299	269	455	360	32	77	72	38	27	29	63	28	79	69	205
Max	1317	1363	1445	1383	1372	1326	2410	1508	1227	1096	828	1304	1534	1593	1533	1698	1652	1578	1039	1223	1801	2591	1616	771	1073	659	1177	1047	940	1259	578	1022	844	1079

Appendix-3 Weather Data of Ramgarh Dam Catchment

Year	Annual mean Max temp.	Annual mean min. temp.	Annual Precipitation	Annual mean Rainy days<5.0mm	Annual mean wind speed	Annual mean relative humidity	Annual mean solar radiation
	^{0}C	^{0}C	mm	days	m/s	fraction	MJ/sqm
1979	32.99	17.85	363.58	20.00	2.70	0.39	18.92
1980	33.95	16.93	525.32	34.50	2.68	0.38	19.13
1981	32.80	17.72	697.74	37.50	2.66	0.42	18.43
1982	32.21	17.88	380.75	21.50	2.54	0.42	17.79
1983	31.98	16.93	654.00	39.50	2.44	0.44	18.55
1984	33.21	16.80	413.00	22.00	2.84	0.37	18.39
1985	33.45	17.22	566.00	26.50	2.80	0.40	19.02
1986	33.48	16.56	305.00	20.00	2.66	0.39	19.05
1987	34.83	17.38	210.00	10.50	2.58	0.34	18.26
1988	33.69	17.97	547.00	55.00	2.71	0.41	18.40
1989	33.30	16.51	454.00	23.00	2.69	0.37	18.89
1990	32.87	17.92	451.00	45.00	2.75	0.43	18.36
1991	33.52	17.35	302.00	20.50	2.56	0.39	18.19
1992	32.65	17.08	577.00	35.50	2.57	0.42	18.22
1993	33.51	18.16	606.00	34.50	2.69	0.39	18.31
1994	32.84	17.15	502.00	43.00	2.56	0.43	18.54
1995	32.83	17.57	856.00	44.00	2.55	0.42	18.39
1996	32.79	17.37	862.00	61.50	2.60	0.44	18.15
1997	31.39	16.91	541.00	37.50	2.58	0.46	17.32
1998	33.17	18.12	558.00	37.50	2.58	0.43	18.12
1999	35.77	18.75	446.00	19.00	2.75	0.34	19.14
2000	34.83	16.51	402.00	26.00	2.76	0.35	19.25
2001	34.49	16.89	364.00	24.50	2.53	0.36	19.10
2002	35.82	16.88	223.00	12.00	2.68	0.34	19.02
2003	33.22	17.18	922.00	58.00	2.46	0.42	19.03
2004	34.41	18.09	547.00	15.00	2.60	0.37	19.10
2005	33.60	16.69	856.00	18.50	2.55	0.38	18.51
2006	34.54	17.25	432.00	8.50	2.57	0.38	18.20
2007	34.09	17.84	412.00	22.50	2.60	0.39	17.74
2008	33.35	17.82	847.00	49.50	2.50	0.41	17.90
2009	34.46	18.48	361.00	26.50	2.68	0.38	18.59
2010	33.66	18.87	868.00	62.00	2.44	0.44	18.86
Average	33.55	17.46	532.86	31.59	2.62	0.40	18.53
Min.	31.39	16.51	210.00	8.50	2.44	0.34	17.32
Max.	35.82	18.87	922.00	62.00	2.84	0.46	19.25

Appendix-4 Weather Data of Bisalpur Dam Catchment

Year	Annual mean Max temp.	Annual mean min. temp.	Annual Precipitation	Annual mean Rainy days<5.0mm	Annual mean wind speed	Annual mean relative humidity	Annual mean solar radiation
	^{0}C	^{0}C	mm	days	m/s	fraction	MJ/sqm
1979	33.47	19.14	736.98	23	2.95	0.39	19.20
1980	34.07	19.19	360.22	22	2.95	0.36	19.50
1981	33.03	19.04	407.80	32	2.95	0.42	18.96
1982	32.87	19.05	585.20	24	2.87	0.42	18.63
1983	32.87	18.24	744.20	34	2.74	0.40	19.22
1984	33.27	18.12	497.50	18	3.03	0.36	19.55
1985	34.02	18.70	383.10	20	2.93	0.36	19.68
1986	33.55	18.45	516.20	21	3.01	0.37	19.68
1987	34.84	19.09	361.50	11	2.89	0.32	19.10
1988	33.82	19.35	564.10	52	2.92	0.40	18.89
1989	33.31	18.42	627.20	29	2.94	0.36	19.22
1990	33.02	19.17	740.50	46	2.99	0.42	18.47
1991	33.85	19.06	555.00	24	2.90	0.37	19.31
1992	33.15	18.67	675.30	33	2.80	0.40	19.02
1993	33.80	19.48	424.50	28	2.99	0.38	18.87
1994	32.66	18.88	805.80	44	2.78	0.43	18.41
1995	33.38	19.22	534.40	31	2.87	0.39	19.00
1996	33.04	18.70	803.40	46	2.90	0.41	19.02
1997	32.12	18.61	596.40	43	3.06	0.46	18.28
1998	33.98	19.41	416.60	30	2.87	0.40	18.98
1999	35.54	20.14	513.90	18	3.09	0.34	19.73
2000	34.87	18.74	394.10	25	3.08	0.32	19.73
2001	34.29	18.61	618.20	35	2.86	0.35	19.61
2002	35.45	19.56	335.60	20	3.19	0.31	20.00
2003	34.01	19.00	554.80	46	3.01	0.38	19.42
2004	34.63	19.22	696.00	19	2.88	0.35	19.50
2005	33.80	18.33	614.20	22	2.78	0.36	19.64
2006	34.10	19.26	786.30	23	2.74	0.39	18.90
2007	33.87	19.40	507.70	30	2.84	0.39	19.06
2008	33.69	18.94	566.80	40	2.89	0.38	18.90
2009	34.75	19.86	402.50	22	3.01	0.37	19.70
2010	33.89	19.86	614.60	48	2.84	0.43	19.80
2011	32.42	18.37	689.40	57	2.66	0.46	19.68
2012	32.73	17.84	684.60	34	2.76	0.41	19.95
2013	32.29	18.17	738.00	46	2.58	0.45	19.63
2014	34.40	19.33			3.08	0.36	
Average	33.69	18.96	572.93	31	2.91	0.39	19.26
Min.	32.12	17.84	335.60	11	2.58	0.31	18.28
Max.	35.54	20.14	805.80	57	3.19	0.46	20.00

Appendix-5 Various input and output data: Rajasthan

		OUTPUT	INPUT													
S. N.	**Year**	**Actual Inflow**	**LULC (Contributing effect)**	**Population density**	**Water Table**	**Rain-fall**	**Rainy days > 5.0mm**	**Mean of daily max. temp.**	**Mean of daily min. temp.**	**Wind speed**	**Relative Humidity**	**Solar radiation**	**Net area sown**	**Area sown more than once**	**Total Crop area**
		MCM	%		m	mm	days	^{0}C	^{0}C	m/sec	fraction	MJ/m^2	%	%	%
1	1990	71.01	37.58	*126*	21.6	731	46	33.02	19.10	2.98	0.42	18.47	45.57	6.71	52.27
2	1991	78.53	35.32	129	20.3	476	23	33.83	18.97	2.88	0.37	19.25	47.81	8.76	56.58
3	1992	66.16	37.81	*133*	20.9	657	33	33.13	18.59	2.79	0.40	18.98	45.22	7.60	52.82
4	1993	62.60	33.52	*136*	19.9	539	28	33.79	19.41	2.97	0.38	18.84	49.46	9.43	58.88
5	1994	85.76	35.47	*140*	20.8	706	44	32.67	18.79	2.77	0.43	18.42	47.41	8.83	56.23
6	1995	77.60	33.11	*143*	19.9	648	31	33.35	19.13	2.85	0.40	18.97	49.71	9.81	59.52
7	1996	76.70	34.37	*147*	19.6	769	47	33.03	18.64	2.89	0.41	18.98	48.41	9.05	57.46
8	1997	71.09	33.70	*151*	18.8	713	43	32.09	18.53	3.04	0.46	18.23	49.04	11.40	60.44
9	1998	57.78	32.76	*154*	18.6	597	30	33.94	19.35	2.86	0.40	18.94	49.84	15.32	65.16
10	1999	43.58	35.60	*158*	19.7	508	18	35.55	20.07	3.08	0.34	19.70	46.91	15.55	62.46
11	2000	42.03	37.12	*161*	20.0	395	25	34.87	18.63	3.06	0.32	19.71	45.27	11.03	56.30
12	2001	58.40	35.99	165	21.3	561	34	34.30	18.53	2.84	0.35	19.58	46.30	9.82	56.13
13	2002	30.87	33.24	*169*	21.2	276	19	35.47	19.43	3.16	0.31	19.95	48.93	11.77	60.70
14	2003	58.08	50.57	*173*	23.5	607	47	33.97	18.91	2.98	0.39	19.40	31.54	7.03	38.57
15	2004	71.01	31.31	*177*	22.5	537	19	34.62	19.17	2.87	0.35	19.48	50.77	12.46	63.23
16	2005	71.00	33.73	*181*	22.1	515	22	33.79	18.25	2.77	0.36	19.58	48.30	13.17	61.47
17	2006	83.58	32.69	*186*	22.9	711	22	34.12	19.16	2.73	0.38	18.86	49.13	14.19	63.33
18	2007	69.72	32.81	*190*	21.9	582	29	33.88	19.32	2.82	0.39	19.00	48.92	13.92	62.85
19	2008	56.20	31.44	*194*	22.9	603	41	33.67	18.89	2.87	0.39	18.85	50.07	14.58	64.65
20	2009	41.27	30.07	*198*	23.4	438	22	34.74	19.79	3.00	0.38	19.64	51.22	15.23	66.45
21	2010	51.52	27.94	*202*	24.6	710	49	33.87	19.81	2.82	0.43	19.76	53.55	22.33	75.88
22	2011	73.35	28.85	206	23.01	726	55	32.45	18.35	2.67	0.46	19.64	*53.09*	*20.61*	73.70
23	2012	76.78	28.85	211	22.14	653	34	32.79	17.80	2.76	0.41	19.91	52.63	18.88	71.51
24	2013	76.71	28.81	216	21.84	580	46	32.32	18.14	2.58	0.45	19.57	*52.17*	*19.69*	71.86

Appendix-6 Various input and output data: Ramgarh

			OUTPUT	INPUT											
S. N.	**Year**	**Theoretical Yield**	**Actual Inflow**	**LULC (Contributing effect)**	**Population density**	**Water Table**	**Rainfall**	**Rainy days > 5.0mm**	**Mean of daily max. temp.**	**Mean of daily min. temp.**	**Wind speed**	**Relative Humidity**	**Solar radiation**	**Net area sown**	**Area sown more than once**
		MCM	MCM	%		m	mm	**days**	^{0}C	^{0}C	m/sec	fraction	MJ/m^2	%	%
1	1983	51.37	55.45	30.37	228	15.46	654	40	31.98	16.93	2.44	0.44	18.55	50.66	19.22
2	1984	16.39	8.38	28.70	234	16.95	413	22	33.21	16.80	2.84	0.37	18.39	51.76	21.98
3	1985	36.22	40.47	27.03	241	13.98	566	27	33.45	17.22	2.80	0.40	19.02	52.86	24.73
4	1986	6.83	20.56	26.96	248	19.11	305	20	33.48	16.56	2.66	0.39	19.05	53.80	23.45
5	1987	2.29	4.56	26.90	254	16.83	210	11	34.83	17.38	2.58	0.34	18.26	54.74	22.17
6	1988	33.47	20.25	26.83	261	18.07	547	55	33.69	17.97	2.71	0.41	18.40	55.68	20.89
7	1989	21.14	0.91	26.77	267	18.88	454	23	33.30	16.51	2.69	0.37	18.89	56.62	19.61
8	1990	20.74	1.39	26.70	274	18.47	451	45	32.87	17.92	2.75	0.43	18.36	57.56	18.33
9	1991	6.67	4.79	26.63	281	23.45	302	21	33.52	17.35	2.56	0.39	18.19	58.50	17.05
10	1992	37.91	29.00	26.57	292	21.07	577	36	32.65	17.08	2.57	0.42	18.22	59.45	15.78
11	1993	42.93	15.72	26.50	303	24.69	606	35	33.51	18.16	2.69	0.39	18.31	59.33	16.37
12	1994	27.30	5.89	26.44	314	23.90	502	43	32.84	17.15	2.56	0.43	18.54	59.22	16.96
13	1995	95.23	49.67	26.37	325	25.17	856	44	32.83	17.57	2.55	0.42	18.39	60.63	17.54
14	1996	96.59	53.10	26.30	337	24.09	862	62	32.79	17.37	2.60	0.44	18.15	60.85	19.75
15	1997	32.64	27.78	26.24	348	23.93	541	38	31.39	16.91	2.58	0.46	17.32	61.06	21.96
16	1998	35.02	14.22	26.17	359	23.58	558	38	33.17	18.12	2.58	0.43	18.12	61.28	24.17
17	1999	20.17	8.07	26.11	370	24.16	446	19	35.77	18.75	2.75	0.34	19.14	62.95	26.4
18	2000	15.30	3.54	26.04	381	23.08	402	26	34.83	16.51	2.76	0.35	19.25	60.27	23.66
19	2001	11.65	1.93	25.97	393	24.39	364	25	34.49	16.89	2.53	0.36	19.10	52.84	20.88
20	2002	2.72	0.06	25.91	405	24.62	223	12	35.82	16.88	2.68	0.34	19.02	56.29	23.23
21	2003	112.33	7.34	25.84	416	25.30	922	58	33.22	17.18	2.46	0.42	19.03	46.64	15.02
22	2004	33.54	1.73	24.02	428	27.19	547	15	34.41	18.09	2.60	0.37	19.10	51.45	18.35
23	2005	95.24	7.31	22.20	439	29.59	856	19	33.60	16.69	2.55	0.38	18.51	56.25	21.67
24	2006	18.44	1.87	21.21	451	28.29	432	9	34.54	17.25	2.57	0.38	18.20	56.25	21.97

25	2007	16.24	0.85	*20.22*	*462*	29.46	412	23	34.09	17.84	2.60	0.39	17.74	56.25	22.27
26	2008	92.95	0.76	*19.23*	*474*	30.72	847	50	33.35	17.82	2.50	0.41	17.90	*57.66*	*25.14*
27	2009	11.41	0.00	*18.24*	*485*	33.61	361	27	34.46	18.48	2.68	0.38	18.59	59.06	28.01
28	2010	98.21	1.08	17.25	*497*	36.68	868	62	33.66	18.87	2.44	0.44	18.86	59.09	25.41
29	2011	64.33	0.00	*16.26*	508	39.63	721	*20*	*32.99*	*17.85*	*2.70*	*0.39*	*18.92*	*60.13*	*31.45*
30	2012	47.40	0.00	*15.27*	*519*	43.64	632	*35*	*33.95*	*16.93*	*2.68*	*0.38*	*19.13*	61.17	37.49
31	2013	59.37	0.00	*14.28*	*531*	43.62	696	*38*	*32.80*	*17.72*	*2.66*	*0.42*	*18.43*	*62.05*	*36.85*
32	2014	26.60	0.00	*13.29*	*542*	44.50	497	*22*	*32.21*	*17.88*	*2.54*	*0.42*	*17.79*	*62.75*	*35.43*

Appendix-7 Various input and output data: Bisalpur

			OUTPUT	INPUT											
S.N.	**Year**	**Theoretical Yield**	**Actual Inflow**	**LULC (Contri-buting effect)**	**Population density**	**Water Table**	**Rainfall**	**Rainy days > 5.0mm**	**Mean of daily max. temp.**	**Mean of daily min. temp.**	**Wind speed**	**Relative Humidity**	**Solar radiation**	**Net area sown**	**Area sown more than once**
		MCM	MCM	%		m	mm	**days**	^{0}C	^{0}C	m/sec	fraction	MJ/m^2	%	%
1	1979	1489.79	1233.93	45.59	216	10.50	737	23	33.47	19.14	2.95	0.39	19.20	31.07	10.77
2	1980	244.95	712.26	45.9	221	10.54	360	22	34.07	19.19	2.95	0.36	19.50	30.48	9.2
3	1981	339.28	476.64	45.08	226	10.58	408	32	33.03	19.04	2.95	0.42	18.96	31.15	9.7
4	1982	838.86	3592.47	44.26	231	10.62	585	24	32.87	19.05	2.87	0.42	18.63	31.82	10.2
5	1983	1504.39	2333.90	43.44	236	10.66	744	34	32.87	18.24	2.74	0.40	19.22	32.49	10.7
6	1984	571.51	2464.46	42.62	240	10.71	498	18	33.27	18.12	3.03	0.36	19.55	33.16	11.2
7	1985	295.38	1075.62	41.8	245	11.60	383	20	34.02	18.70	2.93	0.36	19.68	33.85	12.7
8	1986	623.62	4914.76	41.464	250	12.52	516	21	33.55	18.45	3.01	0.37	19.68	34.2	12.83
9	1987	245.82	1542.34	41.128	255	12.92	362	11	34.84	19.09	2.89	0.32	19.10	34.55	12.96
10	1988	770.32	661.29	40.792	260	14.32	564	52	33.82	19.35	2.92	0.40	18.89	34.9	13.09
11	1989	996.88	1375.81	40.456	264	14.03	627	29	33.31	18.42	2.94	0.36	19.22	35.25	13.22
12	1990	1492.21	2182.95	40.12	269	12.54	741	46	33.02	19.17	2.99	0.42	18.47	35.6	13.35
13	1991	742.00	1951.57	39.784	274	11.56	555	24	33.85	19.06	2.90	0.37	19.31	35.95	13.47
14	1992	1186.07	791.28	39.45	281	13.38	675	33	33.15	18.67	2.80	0.40	19.02	36.3	13.6
15	1993	376.38	810.82	38.61	287	12.14	425	28	33.80	19.48	2.99	0.38	18.87	36.72	14.67
16	1994	1779.10	2070.80	37.77	294	14.52	806	44	32.66	18.88	2.78	0.43	18.41	37.14	15.74
17	1995	677.71	442.93	36.94	300	12.34	534	31	33.38	19.22	2.87	0.39	19.00	37.57	16.82
18	1996	1766.64	3122.34	37.24	307	13.89	803	46	33.04	18.70	2.90	0.41	19.02	37.04	15.04
19	1997	882.75	323.99	37.54	314	11.25	596	43	32.12	18.61	3.06	0.46	18.28	36.51	13.26
20	1998	357.97	90.06	37.84	320	12.66	417	30	33.98	19.41	2.87	0.40	18.98	35.98	11.48
21	1999	617.11	537.24	38.14	327	14.99	514	18	35.54	20.14	3.09	0.34	19.73	35.45	9.7
22	2000	312.94	313.79	38.43	333	14.93	394	25	34.87	18.74	3.08	0.32	19.73	34.91	7.92
23	2001	963.18	1034.55	38.62	340	16.05	618	35	34.29	18.61	2.86	0.35	19.61	34.61	6.95
24	2002	195.13	16.99	38.80	346	15.30	336	20	35.45	19.56	3.19	0.31	20.00	34.31	5.98
25	2003	741.15	176.72	38.99	353	17.21	555	46	34.01	19.00	3.01	0.38	19.42	34.01	5.00
26	2004	1271.88	1767.49	36.19	359	16.56	696	19	34.63	19.22	2.88	0.35	19.50	35.88	8.95
27	2005	948.46	168.51	33.39	365	14.27	614	22	33.80	18.33	2.78	0.36	19.64	37.75	12.90
28	2006	1683.09	2011.89	30.58	372	15.59	786	23	34.10	19.26	2.74	0.39	18.90	39.62	16.85

29	2007	599.83	142.74	*30.94*	*378*	13.00	508	30	33.87	19.40	2.84	0.39	19.06	41.68	20.8
30	2008	778.25	161.43	31.3	*384*	15.16	567	40	33.69	18.94	2.89	0.38	18.90	40.89	17.1
31	2009	327.95	21.23	*32.6*	*390*	16.15	403	22	34.75	19.86	3.01	0.37	19.70	39.92	15.68
32	2010	949.87	234.67	33.9	*397*	17.76	615	48	33.89	19.86	2.84	0.43	19.80	39.26	9.11
33	2011	1244.41	804.29	*32.44*	403	15.87	689	57	32.42	18.37	2.66	0.46	19.68	*40.72*	15.29
34	2012	1224.30	576.32	30.97	409	15.30	685	34	32.73	17.84	2.76	0.41	19.95	42.17	21.47
35	2013	1465.00	803.88	*29.51*	416	14.41	738	46	32.29	18.17	2.58	0.45	19.63	*35.96*	*12.58*

Appendix-8a Cosine Amplitude Method (CAM): Rajasthan

							X-1		X-2		X-3		X-4	
Year	x1	x2	x3	x4	y	Y2	xy	x2	xy	x2	xy	x2	xy	x2
1990	0.92	0.75	0.69	0.27	0.73	0.53	0.68	0.85	0.55	0.57	0.50	0.47	0.20	0.07
1991	0.41	0.36	0.52	0.50	0.87	0.75	0.35	0.17	0.31	0.13	0.45	0.27	0.44	0.25
1992	0.77	0.59	0.36	0.30	0.64	0.41	0.50	0.60	0.38	0.35	0.23	0.13	0.19	0.09
1993	0.53	0.47	0.68	0.49	0.58	0.33	0.31	0.28	0.27	0.22	0.39	0.46	0.28	0.24
1994	0.87	0.78	0.32	0.17	1.00	1.00	0.87	0.76	0.78	0.60	0.32	0.10	0.17	0.03
1995	0.75	0.55	0.47	0.37	0.85	0.72	0.64	0.57	0.47	0.31	0.40	0.22	0.31	0.13
1996	1.00	0.68	0.53	0.27	0.83	0.70	0.83	1.00	0.57	0.46	0.44	0.28	0.23	0.07
1997	0.89	1.00	0.78	0.00	0.73	0.54	0.65	0.78	0.73	1.00	0.57	0.62	0.00	0.00
1998	0.65	0.57	0.48	0.54	0.49	0.24	0.32	0.42	0.28	0.32	0.24	0.23	0.26	0.29
1999	0.47	0.15	0.86	1.00	0.23	0.05	0.11	0.22	0.03	0.02	0.20	0.73	0.23	1.00
2000	0.24	0.02	0.83	0.80	0.20	0.04	0.05	0.06	0.00	0.00	0.17	0.69	0.16	0.65
2001	0.58	0.26	0.45	0.64	0.50	0.25	0.29	0.34	0.13	0.07	0.22	0.20	0.32	0.41
2002	0.00	0.00	1.00	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.95
2003	0.67	0.48	0.69	0.54	0.50	0.25	0.33	0.45	0.24	0.23	0.34	0.48	0.27	0.29
2004	0.53	0.26	0.49	0.73	0.73	0.53	0.39	0.28	0.19	0.07	0.36	0.24	0.54	0.54
2005	0.48	0.31	0.32	0.49	0.73	0.53	0.35	0.23	0.22	0.09	0.24	0.11	0.36	0.24
2006	0.88	0.48	0.25	0.59	0.96	0.92	0.85	0.78	0.46	0.23	0.24	0.06	0.57	0.35
2007	0.62	0.48	0.42	0.52	0.71	0.50	0.44	0.39	0.34	0.23	0.30	0.18	0.37	0.27
2008	0.66	0.49	0.51	0.46	0.46	0.21	0.31	0.44	0.22	0.24	0.23	0.26	0.21	0.21
2009	0.33	0.41	0.72	0.77	0.19	0.04	0.06	0.11	0.08	0.17	0.14	0.52	0.15	0.59
2010	0.88	0.78	0.41	0.52	0.38	0.14	0.33	0.77	0.29	0.60	0.15	0.17	0.19	0.27
2011	0.91	0.98	0.15	0.10	0.77	0.60	0.71	0.83	0.76	0.96	0.11	0.02	0.08	0.01
2012	0.77	0.63	0.31	0.20	0.84	0.70	0.64	0.59	0.53	0.40	0.26	0.09	0.17	0.04
2013	0.62	0.93	0.00	0.07	0.84	0.70	0.51	0.38	0.77	0.86	0.00	0.00	0.06	0.00
					Sum=	10.70	10.52	11.30	8.62	8.14	6.52	7.53	5.75	7.00
								120.99		87.14		80.59		74.98
Cosine Amplitude Method (CAM): Relative Influence Value (R_{ij})=								0.96		0.92		0.73		0.66

Where X1= Rainfall, X2= = Mean of Relative Humidity, X3= Mean of daily wind speed, X4= Mean of daily max. temp., Y= Output (Inflow %)

Appendix-8b Cosine Amplitude Method (CAM): Ramgarh

								X-1		X-2		X-3		X-4		X-5	
Year	x1	x2	x3	x4	x5	y	Y2	xy	x2	xy	x2	xy	x2	xy	x2	xy	x2
1983	1.00	0.62	0.00	0.05	0.13	1.00	1.00	1.00	1.00	0.62	0.39	0.00	0.00	0.05	0.00	0.13	0.02
1984	0.90	0.29	0.02	0.10	0.41	0.15	0.02	0.14	0.81	0.04	0.08	0.00	0.00	0.01	0.01	0.06	0.17
1985	0.80	0.50	0.04	0.00	0.46	0.73	0.53	0.59	0.65	0.36	0.25	0.03	0.00	0.00	0.00	0.34	0.22
1986	0.80	0.13	0.06	0.17	0.47	0.37	0.14	0.30	0.64	0.05	0.02	0.02	0.00	0.06	0.03	0.18	0.22
1987	0.80	0.00	0.08	0.09	0.78	0.08	0.01	0.07	0.63	0.00	0.00	0.01	0.01	0.01	0.01	0.06	0.60
1988	0.79	0.47	0.10	0.13	0.52	0.37	0.13	0.29	0.63	0.17	0.22	0.04	0.01	0.05	0.02	0.19	0.27
1989	0.79	0.34	0.13	0.16	0.43	0.02	0.00	0.01	0.62	0.01	0.12	0.00	0.02	0.00	0.03	0.01	0.19
1990	0.79	0.34	0.15	0.15	0.33	0.03	0.00	0.02	0.62	0.01	0.11	0.00	0.02	0.00	0.02	0.01	0.11
1991	0.78	0.13	0.17	0.31	0.48	0.09	0.01	0.07	0.61	0.01	0.02	0.01	0.03	0.03	0.10	0.04	0.23
1992	0.78	0.52	0.20	0.23	0.28	0.52	0.27	0.41	0.60	0.27	0.27	0.11	0.04	0.12	0.05	0.15	0.08
1993	0.77	0.56	0.24	0.35	0.48	0.28	0.08	0.22	0.60	0.16	0.31	0.07	0.06	0.10	0.12	0.14	0.23
1994	0.77	0.41	0.27	0.32	0.33	0.11	0.01	0.08	0.59	0.04	0.17	0.03	0.08	0.03	0.11	0.03	0.11
1995	0.77	0.91	0.31	0.37	0.32	0.90	0.80	0.69	0.59	0.81	0.82	0.28	0.10	0.33	0.13	0.29	0.11
1996	0.76	0.92	0.35	0.33	0.32	0.96	0.92	0.73	0.58	0.88	0.84	0.33	0.12	0.32	0.11	0.30	0.10
1997	0.76	0.46	0.38	0.33	0.00	0.50	0.25	0.38	0.57	0.23	0.22	0.19	0.15	0.16	0.11	0.00	0.00
1998	0.75	0.49	0.42	0.31	0.40	0.26	0.07	0.19	0.57	0.13	0.24	0.11	0.17	0.08	0.10	0.10	0.16
1999	0.75	0.33	0.45	0.33	0.99	0.15	0.02	0.11	0.56	0.05	0.11	0.07	0.21	0.05	0.11	0.14	0.98
2000	0.75	0.27	0.49	0.30	0.78	0.06	0.00	0.05	0.56	0.02	0.07	0.03	0.24	0.02	0.09	0.05	0.60
2001	0.74	0.22	0.53	0.34	0.70	0.03	0.00	0.03	0.55	0.01	0.05	0.02	0.28	0.01	0.12	0.02	0.49
2002	0.74	0.02	0.56	0.35	1.00	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.32	0.00	0.12	0.00	1.00
2003	0.73	1.00	0.60	0.37	0.41	0.13	0.02	0.10	0.54	0.13	1.00	0.08	0.36	0.05	0.14	0.05	0.17
2004	0.63	0.47	0.64	0.43	0.68	0.03	0.00	0.02	0.39	0.01	0.22	0.02	0.40	0.01	0.19	0.02	0.47
2005	0.52	0.91	0.67	0.51	0.50	0.13	0.02	0.07	0.27	0.12	0.82	0.09	0.45	0.07	0.26	0.07	0.25
2006	0.46	0.31	0.71	0.47	0.71	0.03	0.00	0.02	0.22	0.01	0.10	0.02	0.50	0.02	0.22	0.02	0.51
2007	0.41	0.28	0.75	0.51	0.61	0.02	0.00	0.01	0.16	0.00	0.08	0.01	0.56	0.01	0.26	0.01	0.37
2008	0.35	0.89	0.78	0.55	0.44	0.01	0.00	0.00	0.12	0.01	0.80	0.01	0.61	0.01	0.30	0.01	0.20
2009	0.29	0.21	0.82	0.64	0.69	0.00	0.00	0.00	0.08	0.00	0.04	0.00	0.67	0.00	0.41	0.00	0.48
2010	0.23	0.92	0.86	0.74	0.51	0.02	0.00	0.00	0.05	0.02	0.85	0.02	0.73	0.01	0.55	0.01	0.26
2011	0.17	0.72	0.89	0.84	0.36	0.00	0.00	0.00	0.03	0.00	0.52	0.00	0.79	0.00	0.71	0.00	0.13
2012	0.12	0.59	0.93	0.97	0.58	0.00	0.00	0.00	0.01	0.00	0.35	0.00	0.86	0.00	0.94	0.00	0.33
2013	0.06	0.68	0.96	0.97	0.32	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.93	0.00	0.94	0.00	0.10
2014	0.00	0.40	1.00	1.00	0.19	0.00	0.00	0.00	0.00	0.00	0.16	0.00	1.00	0.00	1.00	0.00	0.03
						sum	4.31	5.57	14.43	4.18	9.72	1.60	9.71	1.62	7.31	2.45	9.20
									62.15		41.86		41.82		31.47		39.60
Cosine Amplitude Method (CAM): Relative Importance Value (R_{ij})=									0.71		0.65		0.25		0.29		0.39

Where X1= LULC (Contributing area %), X2= = Rainfall, X3= Population density, X4= GWL below GL, X5= Mean of daily max. temp., Y= Output (Inflow, MCM)

Appendix-8c Cosine Amplitude Method (CAM): Bisalpur

							X-1		X-2		X-3		X-4	
Year	x1	x2	x3	x4	y	Y2	xy	x2	xy	x2	xy	x2	xy	x2
1979	0.00	0.98	0.85	0.00	0.25	0.06	0.00	0.00	0.24	0.96	0.21	0.73	0.00	0.00
1980	0.02	1.00	0.05	0.01	0.14	0.02	0.00	0.00	0.14	1.00	0.01	0.00	0.00	0.00
1981	0.05	0.95	0.15	0.01	0.09	0.01	0.00	0.00	0.09	0.90	0.01	0.02	0.00	0.00
1982	0.07	0.90	0.53	0.02	0.73	0.53	0.05	0.01	0.66	0.81	0.39	0.28	0.01	0.00
1983	0.10	0.85	0.87	0.02	0.47	0.22	0.05	0.01	0.40	0.72	0.41	0.76	0.01	0.00
1984	0.12	0.80	0.34	0.03	0.50	0.25	0.06	0.01	0.40	0.64	0.17	0.12	0.01	0.00
1985	0.14	0.75	0.10	0.15	0.22	0.05	0.03	0.02	0.16	0.56	0.02	0.01	0.03	0.02
1986	0.17	0.73	0.38	0.28	1.00	1.00	0.17	0.03	0.73	0.53	0.38	0.15	0.28	0.08
1987	0.19	0.71	0.06	0.33	0.31	0.10	0.06	0.04	0.22	0.50	0.02	0.00	0.10	0.11
1988	0.22	0.69	0.49	0.53	0.13	0.02	0.03	0.05	0.09	0.47	0.06	0.24	0.07	0.28
1989	0.24	0.67	0.62	0.49	0.28	0.08	0.07	0.06	0.19	0.45	0.17	0.38	0.13	0.24
1990	0.27	0.65	0.86	0.28	0.44	0.20	0.12	0.07	0.29	0.42	0.38	0.74	0.12	0.08
1991	0.29	0.63	0.47	0.15	0.39	0.16	0.11	0.08	0.25	0.39	0.18	0.22	0.06	0.02
1992	0.32	0.61	0.72	0.40	0.16	0.02	0.05	0.10	0.10	0.37	0.11	0.52	0.06	0.16
1993	0.36	0.56	0.19	0.23	0.16	0.03	0.06	0.13	0.09	0.31	0.03	0.04	0.04	0.05
1994	0.39	0.50	1.00	0.55	0.42	0.18	0.16	0.15	0.21	0.25	0.42	1.00	0.23	0.31
1995	0.42	0.45	0.42	0.25	0.09	0.01	0.04	0.18	0.04	0.21	0.04	0.18	0.02	0.06
1996	0.45	0.47	0.99	0.47	0.63	0.40	0.29	0.21	0.30	0.22	0.63	0.99	0.30	0.22
1997	0.49	0.49	0.55	0.10	0.06	0.00	0.03	0.24	0.03	0.24	0.03	0.31	0.01	0.01
1998	0.52	0.51	0.17	0.30	0.01	0.00	0.01	0.27	0.01	0.26	0.00	0.03	0.00	0.09
1999	0.55	0.53	0.38	0.62	0.11	0.01	0.06	0.31	0.06	0.28	0.04	0.14	0.07	0.38

2000	0.59	0.54	0.12	0.61	0.06	0.00	0.04	0.34	0.03	0.30	0.01	0.02	0.04	0.37
2001	0.62	0.56	0.60	0.76	0.21	0.04	0.13	0.38	0.12	0.31	0.12	0.36	0.16	0.58
2002	0.65	0.57	0.00	0.66	0.00	0.00	0.00	0.43	0.00	0.32	0.00	0.00	0.00	0.44
2003	0.68	0.58	0.47	0.92	0.03	0.00	0.02	0.47	0.02	0.33	0.02	0.22	0.03	0.85
2004	0.72	0.41	0.77	0.83	0.36	0.13	0.26	0.51	0.15	0.17	0.27	0.59	0.30	0.70
2005	0.75	0.24	0.59	0.52	0.03	0.00	0.02	0.56	0.01	0.06	0.02	0.35	0.02	0.27
2006	0.78	0.07	0.96	0.70	0.41	0.17	0.32	0.61	0.03	0.00	0.39	0.92	0.29	0.49
2007	0.81	0.09	0.37	0.34	0.03	0.00	0.02	0.66	0.00	0.01	0.01	0.13	0.01	0.12
2008	0.84	0.11	0.49	0.64	0.03	0.00	0.02	0.71	0.00	0.01	0.01	0.24	0.02	0.41
2009	0.87	0.19	0.14	0.78	0.00	0.00	0.00	0.76	0.00	0.04	0.00	0.02	0.00	0.61
2010	0.91	0.27	0.59	1.00	0.04	0.00	0.04	0.82	0.01	0.07	0.03	0.35	0.04	1.00
2011	0.94	0.18	0.75	0.74	0.16	0.03	0.15	0.88	0.03	0.03	0.12	0.57	0.12	0.55
2012	0.97	0.09	0.74	0.66	0.11	0.01	0.11	0.94	0.01	0.01	0.08	0.55	0.08	0.44
2013	1.00	0.00	0.86	0.54	0.16	0.03	0.16	1.00	0.00	0.00	0.14	0.73	0.09	0.29
					sum	3.75	2.74	11.02	5.09	12.16	4.96	11.91	2.74	9.22
								41.32		45.58		44.65		34.56
Cosine Amplitude Method (CAM): Relative Importance Value (R_{ij})=								0.43		0.75		0.74		0.47

Where X1= Population density, X2= LULC (Contributing area %), X3= = Rainfall, X4= GWL below GL, X5= Mean of daily max. temp., Y= Output (Inflow, MCM)

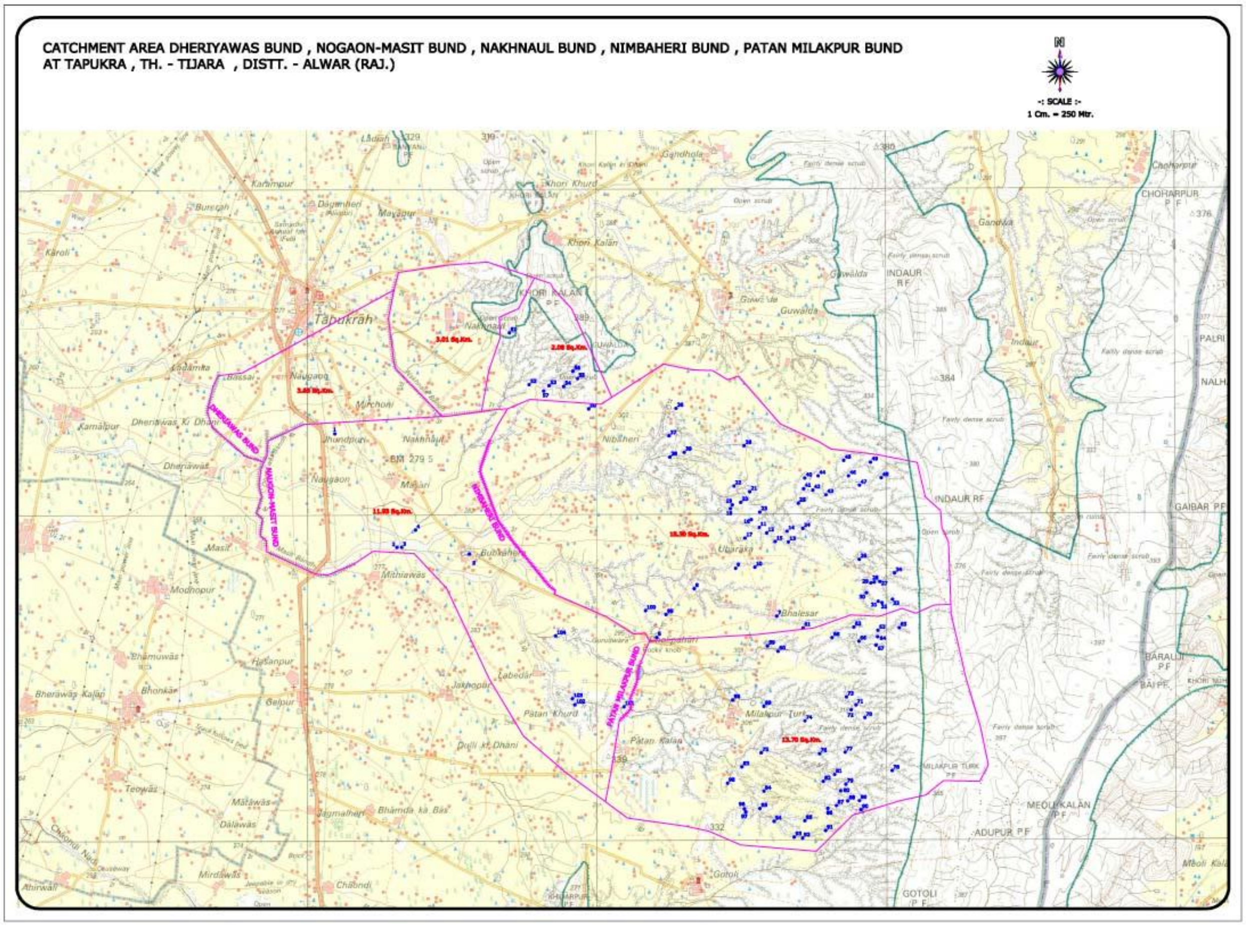
Appendix-9: Weighted rainfall in the catchment of Ramgarh Dam

S. No.	Year	Shahpura		Amer		Jamwa Ramgarh		Virat Nagar		Weighted Rainfall (mm)
		Monsoon RF	**I. F.**	**Monsoon RF**	**I. F.**	**Monsoon RF**	**I. F.**	**Monsoon RF**	**I. F.**	
			0.49		**0.08**		**0.30**		**0.13**	**1.00**
1	1983	-	-	685.6	107.5	666.9	392.3	605.0	154.2	654.1
2	1984	-	-	486.9	102.5	393.9	311.0	-	-	413.5
3	1985	-	-	588.3	92.3	564.7	332.2	554.0	141.2	565.7
4	1986	-	-	373.3	58.6	291.7	171.6	293.0	74.7	304.8
5	1987	-	-	295.4	46.3	**192.8**	113.4	196.1	50.0	209.7
6	1988	-	-	376.1	59.0	505.9	297.6	747.1	190.4	547.0
7	1989	-	-	651.5	102.2	405.8	238.7	444.0	113.2	454.1
8	1990	-	-	587.5	92.2	430.0	252.9	415.0	105.8	450.9
9	1991	**196.5**	96.3	495.0	39.6	440.5	132.2	265.0	34.5	302.5
10	1992	457.2	224.0	857.0	68.6	653.0	195.9	681.0	88.5	577.0
11	1993	640.0	313.6	809.0	64.7	468.4	140.5	672.0	87.4	606.2
12	1994	485.0	237.7	676.0	54.1	447.0	134.1	588.5	76.5	502.3
13	1995	832.0	407.7	**963.0**	77.0	870.9	261.3	847.8	110.2	856.2
14	1996	781.0	382.7	840.0	67.2	993.0	297.9	875.6	113.8	861.6
15	1997	544.0	266.6	524.9	42.0	495.0	148.5	648.0	84.2	541.3
16	1998	507.4	248.6	685.4	54.8	568.0	170.4	643.5	83.7	557.5
17	1999	444.0	217.6	354.0	28.3	445.0	133.5	514.9	66.9	446.3
18	2000	361.0	176.9	264.0	21.1	505.0	151.5	407.0	52.9	402.4
19	2001	373.0	182.8	335.0	26.8	312.5	93.8	464.5	60.4	363.7
20	2002	211.0	103.4	**182.0**	14.6	269.0	80.7	**183.5**	23.9	222.5
21	2003	**902.0**	442.0	631.0	50.5	996.0	298.8	**1005.0**	130.7	921.9
22	2004	505.0	247.5	628.0	50.2	697.0	209.1	313.0	40.7	547.5
23	2005	851.0	417.0	453.0	36.2	959.0	287.7	887.0	115.3	856.2
24	2006	469.0	229.8	316.0	25.3	422.0	126.6	387.0	50.3	432.0
25	2007	309.2	151.5	434.0	34.7	596.5	179.0	360.0	46.8	412.0
26	2008	751.4	368.2	469.0	37.5	**1118.0**	335.4	814.5	105.9	847.0
27	2009	300.0	147.0	241.0	19.3	521.0	156.3	296.0	38.5	361.1
28	2010	868.0	425.3	656.0	52.5	945.0	283.5	821.0	106.7	868.0
29	2011	831.0	407.2	539.0	43.1	541.0	162.3	830.0	107.9	720.5
30	2012	636.0	311.6	786.0	62.9	599.0	179.7	599.0	77.9	632.1
31	2013	615.0	301.4	854.0	68.3	684.0	205.2	931.0	121.0	695.9
32	2014	398.0	195.0	568.0	45.4	679.0	203.7	405.0	52.7	496.8
Min.		196.5		182.0		192.8		183.5		209.7
Max.		902.0		963.0		1118.0		1005.0		921.9
Avg.		552.8		550.2		583.6		570.8		550.9

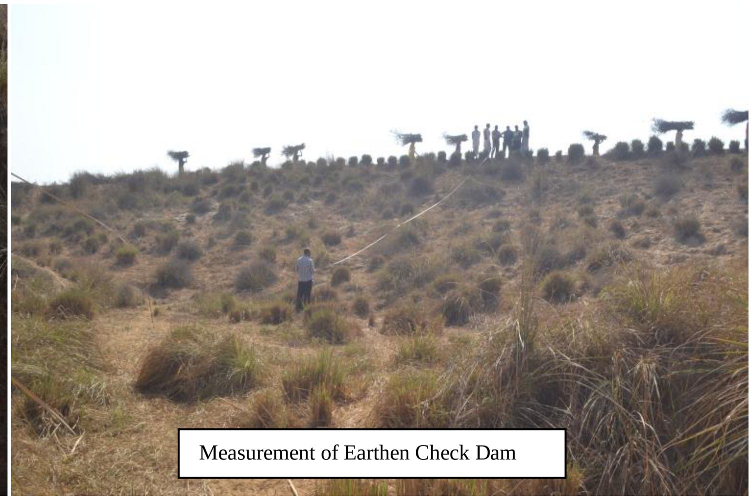
Appendix-10: Groundwater resources of Rajasthan state as on 31.03.2011 **(CGWB 2014)** OE=Over Exploited, C= Critical, SC= Semi-Critical

Sl. No.	Assessment Unit/ District	Area	Potential Area	Total Annual Replenishable Water Recharge	Natural Discharge during Non - Monsoon season	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for irrigation	Existing Gross Ground Water Draft for domestic and industrial water supply	Existing Gross Ground Water Draft for All Uses	Net Groundwater Availability for future Irrigation Development	Groundwater Allocation for Domestic & Industrial Development	Stage of G.W. Develop-ment.	Category
		Sq. km	Sq. km	MCM	MCM	MCM	MCM	MCM	MCM	MCM	MCM	%	
1	Ajmer	8481	7467	355.11	33.05	322.06	415.47	46.91	462.38	0	46.91	143.57	OE
2	Alwar	8720	6825	795.51	63.82	731.69	1215.52	95.66	1311.18	3.99	95.95	179.20	OE
3	Banswara	4536	3980	257.62	26.96	230.66	92.31	19.61	111.92	166.87	28.53	48.52	SAFE
4	Baran	6955	6892	519.67	48.04	471.63	525.96	39.38	565.34	55.62	44.75	119.87	OE
5	Barmer	28387	12735	272.53	25.24	247.29	239.01	67.66	306.67	21.17	68.47	124.01	OE
6	Bharatpur	5044	3413	492.5	43.14	449.36	458.39	63.78	522.17	3.96	65.69	116.20	OE
7	Bhilwara	10455	9355	464.32	44.76	419.56	501.98	37.96	539.94	0	39.8	128.69	OE
8	Bikaner	30382	13603	252.65	12.63	240.02	258.67	83.74	342.41	40.11	90.33	142.66	OE
9	Bundi	5500	4240	422.65	59.7	362.95	336.69	27.11	363.8	53.28	34.72	100.23	OE
10	Chittorgarh	7880	6095	352.76	34.17	318.59	432.27	13.79	446.06	0	13.79	140.01	OE
11	Churu	13793	5192	141.01	7.05	133.96	94.45	24.08	118.53	30.96	43.98	88.48	SC
12	Dausa	3420	3086	263.73	26.2	237.53	378.86	24.87	403.73	0	24.87	169.97	OE
13	Dholpur	3009	2486	283.12	23.82	259.3	307.06	25.26	332.32	15.96	25.76	128.16	OE
14	Dungarpur	3770	2634	141.03	12.91	128.12	83.96	8.82	92.78	0	44.16	72.42	SC
15	Ganganagar	11604	1546	407.98	40.8	367.18	156.17	5.45	161.62	200.68	10.33	44.02	SAFE
16	Hanumnagarh	9580	1279	226.49	22.65	203.84	157.16	7.05	164.21	34.46	11.07	80.56	SAFE
17	Jaipur	11061	9995	712.38	66.85	645.53	1081.11	256.86	1337.97	9.79	257.33	207.27	OE
18	Jaiselmer	38401	12090	67.92	6.33	61.59	93.56	28.93	122.49	18.74	29.61	198.88	OE
19	Jalore	10640	8228	462.85	40.86	421.99	779.52	40.9	820.42	9.69	41.91	194.42	OE
20	Jhalawar	6219	6106	441.71	29.48	412.23	476.01	15.83	491.84	4.79	19.4	119.31	OE
21	Jhunjhunu	5928	5274	263.51	23.5	240.01	456.04	85.71	541.75	3.3	86.04	225.72	OE
22	Jodhpur	22250	18868	429.52	42.39	387.13	727	103.97	830.97	47.61	113.03	214.65	OE
23	Karauli	5039	3902	373.14	36.17	336.97	411.77	50.64	462.41	12.39	49.84	137.23	OE
24	Kota	5204	5123	566.89	53.59	513.3	420.97	48.91	469.88	77.76	62.51	91.54	C
25	Nagaur	17718	16379	580.75	56.49	524.26	811.86	178.93	990.79	41.2	189.53	188.99	OE
26	Pali	12357	7363	328.59	32.29	296.3	314.36	27.47	341.83	9.59	30.48	115.37	OE
27	Pratapgarh	4360	2950	155.21	14.36	140.85	168.84	5.97	174.81	3.99	9.82	124.11	OE
28	Rajasmand	4635	3540	118.72	11.87	106.85	102.7	15.25	117.95	0.63	15.25	110.39	OE
29	Sawaimadhop	5021	7263	321.48	30.37	291.11	370.52	58.42	428.94	2.09	83.75	147.35	OE
30	Sikar	7881	4326	396.36	35.94	360.42	374.08	79.47	453.55	9.72	62.38	125.84	OE
31	Sirohi	5136	4076	303.38	28.54	274.84	299.52	11.08	310.6	11.26	14.84	113.01	OE
32	Tonk	7200	6525	483.53	44.59	438.94	357.45	76.35	433.8	18.41	91.04	98.83	C
33	Udaipur	11761	7771	286.85	33.94	252.91	229.31	31.95	261.26	4.5	39.46	103.30	OE
	STATE	**342327**	**220604**	**11941.5**	**1112.49**	**10829**	**13133.182**	**1709.8153**	**14843**	**912.5**	**1885.32**	**137.07**	**OE**

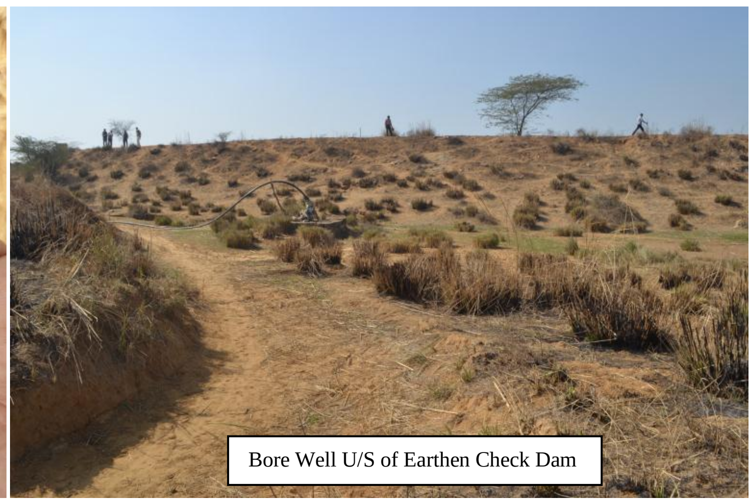
Appendix-10 (b): Abstractions in the catchment area of existing dams and resulting in nearly nil inflow to these dams




River/Drain Survey


Measurement of Earthen Check Dam

GPS Instrument used for Co-ordinates


Bore Well U/S of Earthen Check Dam


S.N.50: Earthen Check Dam at Baniara


S.N.83: Earthen Check Dam at Milakpur

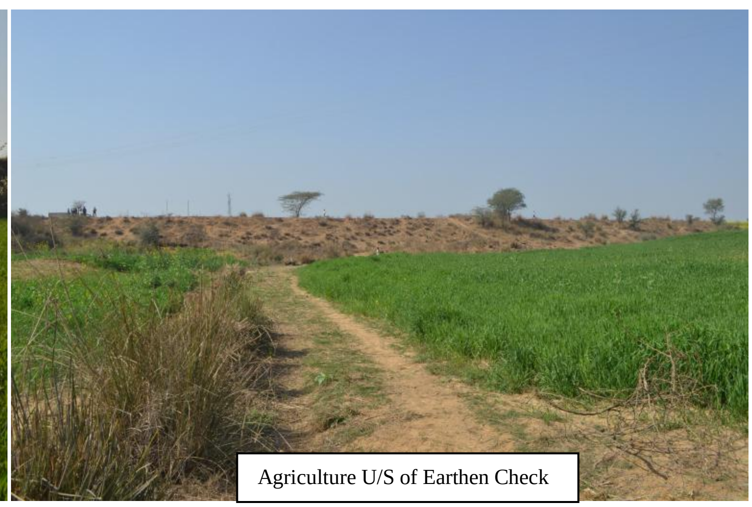

S.N.52: Showing Measurement and Extensive Agriculture along Earthen Check Dam at Banjara


S.N.53: Stone Mine at Nimbahedi


S.N.30: River at Milakpur Turk


S.N.37: Earthen Check Dam at Bhaleshwar


Agriculture in River Bed


Agriculture U/S of Earthen Check

Detail of earthen check dams/other WHS in the catchment of existing dams

S.N.	Location Detail	Co-ordinates		Approximate Capacity					
		Latitude	Longitude	Nos.	L	W	H	Quantity	Quantity
1	Johad, Jhundpuri	28^{0}05'36.70"	76^{0}50'12.2"	1	50	35	2.25	3937.5	0.139
2	deep excavation mitiya was	28^{0}04'44.95"	76^{0}50'45.05"	1	40	150	3	18000	0.636
3	deep excavation mitiya was	28^{0}04'44.71"	76^{0}50'47.28"	1	60	25	2.25	3375	0.119
4	deep excavation mitiya was	28^{0}04'52.9"	76^{0}50'54.7"	1	70	20	2	2800	0.099
5	old johad bubkahera	28^{0}04'42"	76^{0}51'22.4"	1	25	25	2	1250	0.044
6	old johad dholi pahadi	28^{0}04'3.9"	76^{0}52'59.6"	1	110	90	1.5	14850	0.524
7	old johad bhalesar	28^{0}04'13.9"	76^{0}54'1.7"	1	40	40	3	4800	0.169
8	E.C.D. ubaraka	28^{0}04'26.3"	76^{0}53'19.1"	1	100	20	4	8000	0.282
				2	200	10	1	4000	0.141
9	E.C.D. ubaraka	28^{0}04'35.9"	76^{0}53'40.4"	1	55	30	4	6600	0.233
11	E.C.D.			1	150	10	4	6000	0.212
10	E.C.D. bhalesar	28^{0}04'36.2"	76^{0}53'50.1"	1	60	30	1.75	3150	0.111
11	E.C.D. ubaraka	28^{0}04'54"	76^{0}53'52.5"	1	100	20	3	6000	0.212
12	E.C.D. ubaraka	28^{0}04'52"	76^{0}53'56.6"	1	80	80	3.5	22400	0.791
				1	200	25	2	10000	0.353
13	E.C.D. bhalesar	28^{0}04'47.2"	76^{0}54'7.4"	1	200	20	2.5	10000	0.353
14	E.C.D. bhalesar	28^{0}04'52.2"	76^{0}54'6.8"	1	150	30	2	9000	0.318
15	E.C.D. bhalesar	28^{0}04'47.9"	76^{0}54'1"	1	200	10	1.5	3000	0.106
16	E.C.D. ubaraka	28^{0}04'57.7"	76^{0}53'48.4"	1	30	25	2	1500	0.053
17	old johad ubaraka	28^{0}04'49.2"	76^{0}53'45.2"	1	150	150	2	45000	1.589
18	E.C.D. ubaraka	28^{0}05'2.5"	76^{0}53'37.7"	2	100	10	2	4000	0.141
19	E.C.D. ubaraka	28^{0}05'4.3"	76^{0}53'38.4"	1	200	20	3	12000	0.424
20	E.C.D. ubaraka	28^{0}05'5.5"	76^{0}53'42.9"	1	300	30	1	9000	0.318
21	E.C.D. gwalda	28^{0}05'10.2"	76^{0}53'47.3"	1	100	20	2	4000	0.141
				1	300	20	2	12000	0.424
22	E.C.D. gwalda	28^{0}05'12.8"	76^{0}53'39.4"	1	40	20	3	2400	0.085
				1	100	10	2	2000	0.071
23	E.C.D. ubaraka	28^{0}05'1.1"	76^{0}53'52.6"	1	40	20	1.5	1200	0.042
24	E.C.D. bhalesar	28^{0}04'53.8"	76^{0}54'14.9"	1	250	20	3	15000	0.530
25	E.C.D. bhalesar	28^{0}05'4.8"	76^{0}54'12.2"	1	120	20	2	4800	0.169
				1	150	10	2	3000	0.106
				1	60	30	3	5400	0.191
26	E.C.D. bhalesar	28^{0}04'39.7"	76^{0}54'44.2"	1	300	40	2	24000	0.847
27	E.C.D. bhalesar	28^{0}04'29.5"	76^{0}54'54.7"	2	200	10	3	12000	0.424
28	E.C.D. bhalesar	28^{0}04'28.7"	76^{0}54'51.6"	1	50	10	1.5	750	0.026
29	E.C.D. milakpur turk	28^{0}04'28.7"	76^{0}54'50.4"	1	100	10	2	2000	0.071
30	E.C.D. milakpur turk	28^{0}04'24.3"	76^{0}54'48"	1	100	10	2	2000	0.071
31	E.C.D. milakpur turk	28^{0}04'20.5"	76^{0}54'54.3"	1	100	20	2	4000	0.141
32	E.C.D. milakpur turk	28^{0}04'19.7"	76^{0}54'55.6"	1	30	5	1	150	0.005
33	E.C.D. milakpur turk	28^{0}04'21.1"	76^{0}54'1.3"	1	100	10	3	3000	0.106
34	E.C.D. bhalesar	28^{0}04'33.2"	76^{0}55'2.5"	2	100	10	2	4000	0.141
35	E.C.D. gwalda	28^{0}05'31.7"	76^{0}53'44.8"	1	70	100	1.5	10500	0.371
36	old johad patla ki dhani gwalda	28^{0}05'49.3"	76^{0}53'9.1"	1	60	150	1	9000	0.318
37	E.C.D. gwalda patla ki dhani	28^{0}05'36.6"	76^{0}53'5.5"	1	60	30	3	5400	0.191
				1	250	40	1	10000	0.353
38	E.C.D. gwalda	28^{0}05'27.2"	76^{0}53'6.4"	1	60	60	2.5	9000	0.318
				1	150	20	1.5	4500	0.159

				1	200	10	1.5	3000	0.106
39	E.C.D. gwalda	28^{0}05'29.3"	76^{0}53'13.4"	1	200	200	1.5	60000	2.119
40	E.C.D. gwalda supheda ki dhani	28^{0}05'17"	76^{0}54'16"	1	40	40	1	1600	0.056
41	E.C.D. gwalda supheda ki dhani	28^{0}05'12.1"	76^{0}54'15.5"	1	100	5	3	1500	0.053
				1	40	30	3	3600	0.127
42	E.C.D. gwalda	28^{0}05'11.8"	76^{0}54'20.3"	1	100	10	4	4000	0.141
				1	70	20	4	5600	0.198
43	E.C.D. gwalda ghamandi ki dhani	28^{0}05'9.2"	76^{0}54'26.6"	1	60	40	4	9600	0.339
				1	150	20	3	9000	0.318
44	E.C.D. gwalda ghamandi ki dhani	28^{0}05'17.6"	76^{0}54'22.7"	1	30	10	3	900	0.032
				1	20	10	3	600	0.021
45	E.C.D. banjhda	28^{0}05'24.9"	76^{0}54'35.9"	1	40	30	1.5	1800	0.064
				1	150	10	1	1500	0.053
46	E.C.D. banjhda	28^{0}05'17.8"	76^{0}54'38.5"	1	60	30	4	7200	0.254
				1	170	10	2	3400	0.120
47	E.C.D. banjhda	28^{0}05'13.7"	76^{0}54'44"	1	40	30	4	4800	0.169
				1	200	20	3	12000	0.424
48	E.C.D. banjhda	28^{0}05'17.2"	76^{0}54'55.6"	1	50	30	4	6000	0.212
				1	150	20	2	6000	0.212
				1	200	20	2	8000	0.282
49	E.C.D. banjhda	28^{0}05'24.1"	76^{0}54'49.9"	1	60	10	3	1800	0.064
				1	100	5	2	1000	0.035
				1	20	10	2	400	0.014
50	deep excavated mines nimbahedi	28^{0}05'49.1"	76^{0}52'24"	1	200	100	15	300000	10.593
51	johad nakhnoal	28^{0}06'23.7"	76^{0}51'42.8"	1	60	40	1	2400	0.085
52	anicut nimbaheri	28^{0}06'0.1"	76^{0}51'53.1"	1	50	30	1.5	2250	0.079
53	Stone Mine nimbaheri	28^{0}05'59.8"	76^{0}52'3.4"	1	70	150	1.5	15750	0.556
54	E.C.D. nimbaheri	28^{0}05'59.4"	76^{0}52'11"	1	50	100	1.3	6500	0.230
55	anicut nimbaheri	28^{0}06'2.9"	76^{0}52'18.1"	1	80	20	1	1600	0.056
56	E.C.D. nimbaheri	28^{0}06'6.3"	76^{0}52'15.8"	1	50	10	1.5	750	0.026
				2	100	10	1.5	3000	0.106
57	deep excavated mines, Nakh.	28^{0}05'57.3"	76^{0}52'0.6"	1	60	40	4	9600	0.339
58	johad milakpur turk	28^{0}03'35.4"	76^{0}53'38.9"	1	30	30	2	1800	0.064
59	E.C.D. bhalesar	28^{0}04'0.1"	76^{0}53'56.9"	1	50	5	1	250	0.009
60	E.C.D. bhalesar hyat ki dhani	28^{0}03'57.7"	76^{0}54'1.9"	1	40	10	2	800	0.028
				1	50	5	1	250	0.009
61	E.C.D. Milakpur turk	28^{0}04'8.4"	76^{0}54'15.1"	1	150	40	2	12000	0.424
				1	150	10	1	1500	0.053
62	E.C.D. milakpur turk chonchpuri	28^{0}04'8.7"	76^{0}54'41.5"	1	60	20	2	2400	0.085
63	E.C.D. milakpur turk chonchpuri	28^{0}04'6.6"	76^{0}54'53.9"	1	100	40	4	16000	0.565
				1	200	15	2	6000	0.212
64	E.C.D. milakpur turk chonchpuri	28^{0}04'4"	76^{0}54'53.3"	1	100	10	2	2000	0.071
65	E.C.D. milakpur turk chonchpuri	28^{0}04'8.2"	76^{0}55'4.7"	2	100	10	1.5	3000	0.106
66	E.C.D. milakpur turk chonchpuri	28^{0}04'1.9"	76^{0}54'44.1"	2	50	5	1.5	750	0.026
67	E.C.D. milakpur turk chonchpuri	28^{0}04'0.1"	76^{0}54'52.9"	1	300	15	3	13500	0.477
				1	50	5	2	500	0.018
68	E.C.D. milakpur turk chonchpuri	28^{0}04'4"	76^{0}54'30.4"	1	200	15	3	9000	0.318
69	E.C.D. milakpur turk	28^{0}03'33"	76^{0}53'55.3"	1	150	50	3.5	26250	0.927
				1	300	40	2	24000	0.847
70	E.C.D. milakpur turk	28^{0}03'27.4"	76^{0}54'47.4"	1	40	20	3	2400	0.085

				2	150	15	2	9000	0.318
71	E.C.D. milakpur turk	$28^0$03'33"	$76^0$54'42.5"	2	150	12	2	7200	0.254
72	E.C.D. milakpur turk	$28^0$03'30.8"	$76^0$54'40.2"	1	50	10	1.5	750	0.026
73	E.C.D. milakpur turk	$28^0$03'36.8"	$76^0$54'37.6"	1	150	30	3	13500	0.477
74	E.C.D. milakpur turk	$28^0$03'25.7"	$76^0$54'16.1"	1	50	30	1.5	2250	0.079
75	E.C.D. milakpur turk	$28^0$03'11.4"	$76^0$53'53.9"	1	70	20	2	2800	0.099
				1	50	20	1.5	1500	0.053
76	E.C.D. milakpur turk	$28^0$03'10.7"	$76^0$54'24"	1	100	40	1.5	6000	0.212
77	E.C.D. milakpur turk	$28^0$03'11.4"	$76^0$54'37"	1	80	40	3	9600	0.339
				1	150	20	2	6000	0.212
				1	100	10	1	1000	0.035
78	E.C.D. milakpur turk	$28^0$03'3.4"	$76^0$55'1.4"	1	60	40	3	7200	0.254
				2	100	5	1	1000	0.035
				1	200	20	2	8000	0.282
79	E.C.D. milakpur turk	$28^0$02'57"	$76^0$54'37.5"	1	300	25	3	22500	0.794
80	E.C.D. milakpur turk	$28^0$02'53.9"	$76^0$54'34.9"	2	200	20	3	24000	0.847
				2	100	5	2	2000	0.071
81	E.C.D. milakpur turk	$28^0$03'1.6"	$76^0$54'31.9"	2	150	10	2	6000	0.212
82	E.C.D. milakpur turk	$28^0$02'58.3"	$76^0$54'26"	1	100	10	2	2000	0.071
83	E.C.D. milakpur turk	$28^0$03'4.3"	$76^0$53'43.8"	1	40	80	1	3200	0.113
84	E.C.D. milakpur turk	$28^0$02'53.5"	$76^0$53'53.3"	1	500	40	2	40000	1.412
85	E.C.D. milakpur turk	$28^0$02'40.4"	$76^0$54'16.6"	2	150	10	2	6000	0.212
				1	40	50	3	6000	0.212
86	E.C.D. milakpur turk	$28^0$02'45.8"	$76^0$54'28.2"	2	60	10	1	1200	0.042
				1	300	50	1	15000	0.530
87	E.C.D. milakpur turk	$28^0$02'47.1"	$76^0$54'32.1"	1	30	30	1	900	0.032
88	E.C.D. milakpur turk	$28^0$02'49.1"	$76^0$54'38.4"	1	40	10	1	400	0.014
89	E.C.D. milakpur turk	$28^0$02'49.1"	$76^0$54'44.4"	2	75	5	1	750	0.026
90	E.C.D. milakpur turk	$28^0$02'45.5"	$76^0$54'45"	1	100	30	1	3000	0.106
91	E.C.D. milakpur turk	$28^0$02'35.5"	$76^0$54'27.2"	1	40	60	1	2400	0.085
92	E.C.D. milakpur turk	$28^0$02'32"	$76^0$54'15.1"	1	50	20	2	2000	0.071
93	E.C.D. milakpur turk	$28^0$02'32.5"	$76^0$54'11.2"	1	20	10	2	400	0.014
				1	100	10	1	1000	0.035
94	E.C.D. milakpur turk	$28^0$02'39.7"	$76^0$54'0.4"	1	50	40	2	4000	0.141
				1	200	25	1.5	7500	0.265
95	E.C.D. milakpur turk	$28^0$02'45.2"	$76^0$53'53"	1	100	50	2.5	12500	0.441
				1	150	30	1	4500	0.159
				2	100	10	1	2000	0.071
96	E.C.D. milakpur turk	$28^0$02'44.3"	$76^0$53'46.1"	1	30	20	1	600	0.021
				1	50	5	1	250	0.009
97	E.C.D. milakpur turk	$28^0$02'44.9"	$76^0$53'45.3"	1	100	20	2.25	4500	0.159
98	E.C.D. milakpur turk	$28^0$02'56.9"	$76^0$53'36.3"	1	40	30	1.25	1500	0.053
				1	50	5	1.25	312.5	0.011
99	E.C.D. dholi pahadi	$28^0$04'14.5"	$76^0$53'4.6"	1	40	20	1	800	0.028
100	E.C.D. dholi pahadi	$28^0$04'16.2"	$76^0$52'53.7"	1	45	20	1.5	1350	0.048
				1	50	15	1	750	0.026
101	E.C.D. patan khurd	$28^0$03'31.9"	$76^0$52'42.8"	1	30	20	20	12000	0.424
102	E.C.D. patan khurd	$28^0$03'35.5"	$76^0$52'15.7"	1	100	40	0.75	3000	0.106
103	E.C.D. patan khurd	$28^0$03'32.9"	$76^0$52'17.1"	1	125	20	1.5	3750	0.132
104	E.C.D. dholi pahadi	$28^0$04'4.7"	$76^0$52'7.2"	1	300	50	2	30000	1.059
	TOTAL								45.203

E.C.D.= Earthen Check Dam

Appendix-11 Some actual site photographs showing the changes in LULC in the catchment areas of dams

‘(a)

(b)

‘(c)

(d)

‘(e)

(f)

Figure showing several of abstractions within the catchment of dams (a) Agricultural activity (b) Infrastructural development: road (c) Poor drainage at developed area: obstructing the flow of water to natural drainage (d & e) Forest development activities: CVH & DCB (f) Small water harvesting structures within the catchment of dams.

Some actual site photographs showing the stringent actions taken: Demolition of residential buildings constructed within the drainage area of the natural stream.

Building situated at Shyam Nagar, Janpath at Jaipur was razed to the ground using the blasting technique, alleged to be constructed in the drainage boundary of a natural stream.

Three multi-storied under construction buildings, one of them demolished by the blast with 50 kg explosion ordered to be demolished for flouting building norms at Amanishah Nullah, a tributary of a natural river, in Jaipur.

AUTHOR'S BIO-DATA

The author obtained his Bachelor's degree in Civil Engineering from MBM Engineering College, Jodhpur in the year 1995 and Master's degree in Structural Engineering from MNIT, Jaipur in 2011. Author has also obtained Master's degree in Business Administration (MBA) from Indira Gandhi National Open University, New Delhi in the year 2004. Author has been working as a water resources engineer since 1996. The author has been designated as Chartered Engineer (India) by Institution of Engineers (India), Kolkata. The author is presently working as Executive Engineer, Water Resources Department of Government of Rajasthan. Previously, the author has worked as Assistant Engineer and Junior Engineer in various engineering departments of Government of Rajasthan. The author is also in the expert panel of Engineering Staff Training Institute, Jaipur, which imparts training to the engineers of various government departments.

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