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WATERLOGGED AREA MAPPING AND HYDROLOGICAL DATA ANALYSIS OF MOKAMA TAL AREA

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ABSTRACT

The drainage problems of the agriculture land are basically associated with the stagnation of runoff and the rise of the water table. Generally the runoff stagnation is a result of intense rain, which produces excessive runoff for which the existing drainage capacity is not adequate or outlet conditions are not favourable. The rise of water table beyond a critical limit or surface ponding results in water logging conditions. Water logging in a low lying land of about 1062 sq. km. (Mokama Group of Tals) in the district Patna, Nalanda and Munger is caused due to excessive rainfall in the catchment, stagnation of water on land surface for long period, inadequate surface drainage, natural and artificial obstruction to surface outflow and poor topography.

A synoptic method of monitoring water logging problem across large area is a valuable tool for many research and management applications. In recent years, remote sensing data have been used for qualitative assessment of water logging and soil moisture conditions. Use of remotely sensed data with landuse, soil and topography information appears to be a useful technique for the delineation of the temporal and spatial extent of water logged area.

To delineate the area of submergence in Mokama group of Tals an attempt has been made to integrate remote sensing data, land use, contours, soil and other relevant information. IRS 1A LISS II data for the year 1989 (Pre & Post monsoon) were utilized to study the dead storage and extent of submergence (lean period in pre-monsoon) and live storage and monsoon submergence (peak flood period/post monsoon) information of

Mokama group of Tals corresponding to highest flood levels and other hydrological information (rainfall and runoff).

The study also utilizes the peak flood discharge series at sites to fit various distributions. This gives the values of floods at higher recurrence interval. Such information is useful in deciding any water resources structure in the basin for flood/ water management purpose. Further, an attempt has also been made to formulate a management model for water logging and drainage congestion problem of Mokama group of Tals. The model outlined in this study require various hydrological, topographical and land use data.

INTRODUCTION

The drainage problems over vast agricultural lands of the eastern region is of a magnitude that require immediate attention. The success of a Kharif crop in such areas is dependent primarily on chance. Submergence in flood affected areas of the region sometime continues for a long period and delays the Rabi sowing. The term drainage congestion used in general encompasses the three different types of situations each requiring different treatment viz.

i. Area remaining under water throughout the year; only the extremity may expand during the rainy season.

ii. Agricultural area remaining submerged in a manner that crop production is affected, due to absence of field drainage system/or its malfunctioning.

iii. Areas submerged due to unfavourable outfall conditions and deterioration in efficiency of natural streams and sluices.

The total area suffering from ill drained condition due to a combination of the above causative factors in the states of Andhara Pradesh, Orissa, West Bengal, Bihar and Eastern U.P. is estimated to be about 3.3 million hectares (Bhattacharya, 1992). Out of this, the state Bihar constitutes an area of nearly 0.9 million hectare. The flood prone area in Bihar is reported to be 6.46 million hectare out of the total flood prone area of 40 million hectare of the country. Almost all the river basins of North Bihar are flood prone. In central Bihar Sone, Punpun, Kiul-Harohar, Badua and Chandan river basins are prone to flooding. There is practically no problem of flood in the region of South Bihar (Report of the Second Bihar State Irrigation Commission, 1994). In Bihar considerable area remains surface waterlogged due to drainage congestion during monsoon. They get inundated with onset of monsoon by runoff from adjoining uplands or areas fed by spill from some rivers. They are classified (in agriculture terms) in three different classes (Table 1.1).

Table 1.1: Classification of waterlogged area

Sl. No.	Classification	Depth of Submergence
1	**Shallow**	Where submergence for more than one month to a depth of 50 to 100 cm
2	**Medium**	Submergence from a depth of 100 to 200 cm
3	**Deep**	Submergence more than 200 cm

In the state of Bihar, nearly 0.8 million hectare area is facing the problem of water logging and drainage congestion in North Bihar, and 0.1 million hectare in the Central Bihar. This, 0.1 million hectare of water logged area comes under Mokama group of Tals. A number of tributaries with their final destiny as Tal area contribute flows to the areas. These tributaries during monsoon period carry a considerable magnitude of flows. The Tal area are mainly spreaded (lengthwise) towards west to east. Most of the tributaries originate from South Bihar and flow toward northward direction. The northern side of the Tal area is blocked by the raised bank of the river Ganga flowing along direction of Tal area. During flood, the water level in the river Ganga exceeds the water level of Tal area. As a result, natural drainage gets blocked and almost all the Tals in Mokama group of Tals get filled up with drainage waters from tributaries joining the Tals and create waterlogging. Due to this, land resources of Tal areas particularly during Kharif season get under utilized.

Efforts had been made by various individual experts and committees constituted by the Government to identify the major causes of waterlogging, and to find out possible solutions. To mention a few important names, Dr. K.L. Rao (1970-72), Dr. C.C. Patel (1976), Mokama Tal Technical-cum Development Committee (1988), and Second Bihar State Irrigation Committee (1994), etc. The Ganga Plains North Regional Centre, Patna of National Institute of Hydrology (Lohani & Jaiswal, 1995-96) has compiled all information of Tal area which include; hydrological features of the area, various remedial measures suggested by the experts and taken so far for management of Tal areas, and studies conducted by various organisatios etc. These background information reveal that the main problems of the tal areas are due to the congestion of hydrological factors which cause water logging and drainage problems to the area.

In the present study remote sensing technique and conventional methods have been applied to delineate surface water logged area in the Mokama group of Tals. For this purpose, pre-monsoon and post-monsoon FCC prints of remotely sensed data have been used and the interpretation was supported by ancillary data. Further, flood frequency analysis using annual peak discharge series (about 24 to 27 years) involving application of Normal Distribution, Two Parameter Lognormal Distribution, Three Parameter Lognormal Distribution, Pearson Type III Distribution, Log Pearson Type III Distribution and Extreme Value I Distribution at site is described and discussed.

Tal area being the final destinity of tributaries originating in the Tal basin, the management of Tal area can not be apprehended without coupling the regulation of tributary's water. Assuming the water logged area is a storage reservoir having inflow/ back water to/from various tributaries besides the effects of other hydrological factors, the problem can be vidualized as an optimization problem, with objective of minimization of total water logged area under the constrains of translation of inflows in the upper reaches.

The study also addresses a formulation of optimization model supported by the all possible constraints. A strategy for solving the model has also been discussed. Solutions and outcomes of the model are being dealt seperately under the work programme of 1997-'98.

GEOGRAPHICAL FEATURES OF STUDY AREA

2.1 Kiul-Harohar River Basin

Kiul-Harohar, the major rivers of South Bihar are rainfed and carry very little discharge during non-monsoon period. The total catchment area of Kiul-Hahorar river system is 17,223 Sq Km. It consists of a number of rivers like the *Mohane, Dhanyan, Sukhnar, Barnar, Damar, Nagi, Nakti, Bajan, Ajan, Falgu* etc. besides the river *Kiul* and *Hahorar*. The river *Kiul* is the main river of the *Kiul-Hahorar* river system and it originates at a latitude of 24° 23' N and longitude of 86° 10' E from an elevation of 605 m in Chotanagpur plateau. The river system is bounded by the *Badua-Chandan* system on the east, the *Ganga* on the north, the Chotanagpur plateau on the south and the *Punpun* river in the west. The upper catchment of the river system lies in Chotanagpur Plateau area which is characterised by low hills and slopes with depression and valleys. A number of small rivers in the river system bifurcate and rejoin each other a number of times during the course of flow and making it difficult to ascertain their exact length. Drainage pattern of the Kiul-Harohar river basin is shown in **Figure 2.1.** Brief description of a few important rivers is presented in the following paragraphs:

2.1.1 The River Kiul

The river Kiul is the main outfall channel of the *Kiul-Hahorar* basin, rises in the hills of Chotanagpur Plateau. *Bunbuni, Sukhnar, Barnar, Dohara, Nagi, Nakti, Bajan, Ajan* and *Morwe* are the important tributaries joining thr river *Kiul* at right bank. The river *Harohar* is the biggest and one of the most important tributaries joining it on the right

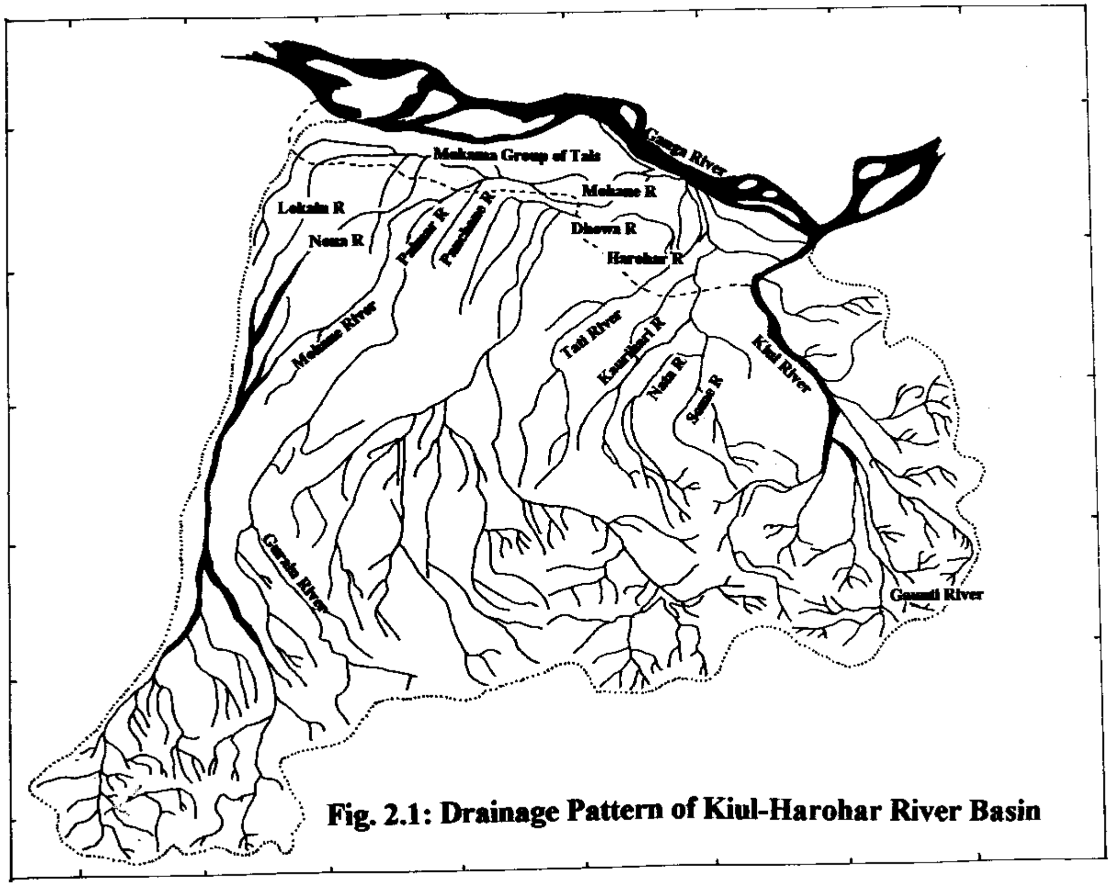


Fig. 2.1: Drainage Pattern of Kiul-Harohar River Basin

bank. Initially the river *Kiul* flows in the North-West direction, then in East direction close to the southern face of the Gidheshwari Hills and then in North direction. After that it flows in North-West direction up to Lakhisarai. It then turns in the North-East direction and joins the river *Ganga* near Surajgarha in the Munger district.

2.1.2 The River Lilajan and Mohane (Falgu)

The river *Falgu* known as *Mohane* in the upper reach rises in the hills of Chatra district at an elevation of 914 m. After traversing through hills and forests for about 64 kms, it crossess the Grand Trunk Road and enters the plains of the Gaya district. After traversing a length of 40 km it receives *Lilajan*. The river *Lilajan* is a major tributary of the river *Mohane*. It also originates in the hills of Chatra district at latitude 24° 11' N and longitude 84° 45' E at an elevation of 534 m. After traversing a distance of 85 km through hills and forests, it crossess Grand Trunk Road near Dobhi and travels a distance of about 29 km before joining the river *Mohane*. The combined river is known as the *Falgu* after the confluence of the *Lilajan* and the *Mohane* and travels in North direction upto Khizirsarai where it again bifurcates into two channels. The right channel is again known as the *Mohane* and the left channel is known as the *Falgu*. Further this *Falgu* river runs in north direction where it is known as the *Mahatmain* and the *Lokain*. This is finallly known as the river *Dhowa*. Another right bifurcated channel from *Ghoshi* is known by local names of the *Jalwa* and the *Nona* which again reunite with the *Dhowa*. Bifurcated right branch of *Mohane* which is again known as *Mohane* joins the *Bagahi* river near Islampur and is again known as the *Mohane* in the down stream. The left branch of *Mohane* joins the *Jalwa* river taking off from *Falgu*. This right channel known as the *Mohane* flowing further down for about 51 km joining the river *Paimar*. *Paimar* is another important river of the basin and it originates from the foot hills of Hazaribagh near Paharpur Railway Station. The combined river enters the Bhaktiarpur Tal and meets the river *Dhowa* near Bakhtiyarpur. After this the combined river is again known as *Mohane*.

2.1.3 The River Panchane

The river *Panchane* is formed by a number of small streams namely *Mangur, Dhadhar, Tilaiya, Dhanarji* and *Khuri*. All these streams taking off from the Barakar valley in the hills of Kodarma range in Giridih/Hazaribagh district. The *Panchane* river bifurcates into a number of channels a few km upstream of Biharsharif town known as the *Goithawa*, the *Charsua* and the old *Panchane*. The *Charsua* again meets the old *Panchane* river after flowing about 26 km. Ultimately it joins the the river *Mohane* in the middle reach. The river *Goithawa* after flowing in the North direction for about 29 km takes a turn in eastern direction and meets the two branches (the *Jirain* and the *Kumbhari*) of the river *Sakri*. The combined river below village Chhatarpur is known as the *Dhanayan*. The river *Dhanayan* flowing in the east for about 16 km meets the river *Mohane* at Trimohani and the combined river is known as the river *Harohar*.

2.1.4 The River Sakri

It originates from the hills of Hazaribagh district at an elevation of 365 m near village Tisri. After flowing for about 64 km in the thick forest and hilly tracts of Hazaribagh district it enters the plains of Gaya district near village Dumri. The river *Sakri* crossess the Kiul-Gaya section of the Eastern Railway near village Paura which is about 9.6 km east of Nawada town. After flowing further down for about 19 km in the North, it bifurcares into two branches namely the *Jirain* and the *Kumbhari*. These two branches meet the river *Goithawa* and the combined river is known as *Dhanayan*.

2.1.5 The River Harohar

The river *Harohar* is the biggest and most important left bank tributary of the river *Kiul*. It joins the river *Kiul* downstream of Lakhisarai. In the tail reach, the river *Harohar* flowing for about 16 km below Trimohani in a serpentine course, is joined by the river *Tati*. The river *Tati* originates near Marui just on the east of Sakri valley. It traverses a distance of about 51 km before it meets the river *Harohar*.

2.2 Drainage Area

The *Kiul-Harohar* river system drains an area of 17,223 Sq Km. Upper zone of the *Kiul-Harohar* river basin lies in the Chotanagpur Plateau which is characterised by low Hills and slopes with depressions and valleys. In some areas there are hills from a series of ranges with general level gradually rising to an elevation of 600 m. The lower portion of the catchment lies in the Gangetic plains. This plain has been built-up in the process of land formation and the alluvial formation represents one continuous and conformable series whose accumulation is still going on. About 1062 Sq Km of total drainage area, lying in tne lower zone of the river system is sacucer shaped and is a vast tract of low lying land.

Kiul-Harohar river basin is drained by a number of important rivers. Area drained by these rivers is given in **Table 2.1**.

Table 2.1: Area drained by various rivers in Kiul-Harohar basin.

Sl. No.	Name of the River	Drainage Area (Sq Km)	% of Total Drainage Area
1.	Falgu	5,281	30.67
2.	Paimar	1,122	06.51
3.	Sakri	5,500	31.93
4.	Harohar	2,393	13.89
5.	Kiul	2,927	17.00
	Total	17,223	100.00

2.3 Geological Characteristics of the Basin

The upper zone of the river system is lying in Chotanagpur plateau while, the lower zone lies in the Gangetic plains. The entire Chotanagpur plateau area is characterised by low hills and slopes with depression and valleys. In some areas these hills form series of ranges. General level of the area gradually rises until eventually a hight of 600 m is obtained. On this gradual rising surface there are rises like Parasnath which is at a level of 1260 m. Also, there are other rising to lesser hights. These are formed of Archean quartzites and schists.

The lower zone of the catchment lies in the Gangetic plains. It has semi undulation and microrelif and looks like a saucer shaped and shallow depression. It has a surfacial cover of dense, poorly drained, unoxidised and humous rich clayey soil in the core or grading into progressively lighter soil towards peripheral part with progressive increase in silt fraction. Geomorphologically, the depression is divided into three substratas: Alluvial uplands; older flood plain and; present flood plain of the Ganga on the northern side of Patna-Mokama road and The Ganga.

In Kiul-Harohar basin the cropping sequence is widely governed by the three physiographic zones.These are given below (**Table 2.2**):

Table 2.2 : Classification of Physiographic zones in Kiul-Harohar basin

Sl. No.	Part of the Kiul-Harohar Basin	Physiographic Zone
1.	Southern Part	Old alluvium grey to greyish yellow soils with heavy texture.
2.	Middle Part	Tal area which remain under water for two to four months during Kharif and intensively cropped during Rabi.
3.	Extreme North Part	Alluvial zone up to the river Ganga.

2.4 Soil Characteristics

The lower zone (Mokama Tal) of the Kiul-Harohar river basin generally suffers from drainage congestion for a period of two to four months. The soil of these Tals are grey to dark grey in colour, medium heavy to heavy in texture, slightly to moderately alkaline in reaction and of good fertility status.

The principal soil type in various districts of the river system are presented in **Figure 2.2**. The general data regarding the soil of the river system indicates that mainly alluvial, red and yellow, red sandy soils and deltaic alluvium occur in the river system. The upper zone of the basin is lying on the Chotanagpur Plateau. It has red, yellow, reddish yellow, greyish yellow type of soils. The yellow soils are medium textured, silty soil,

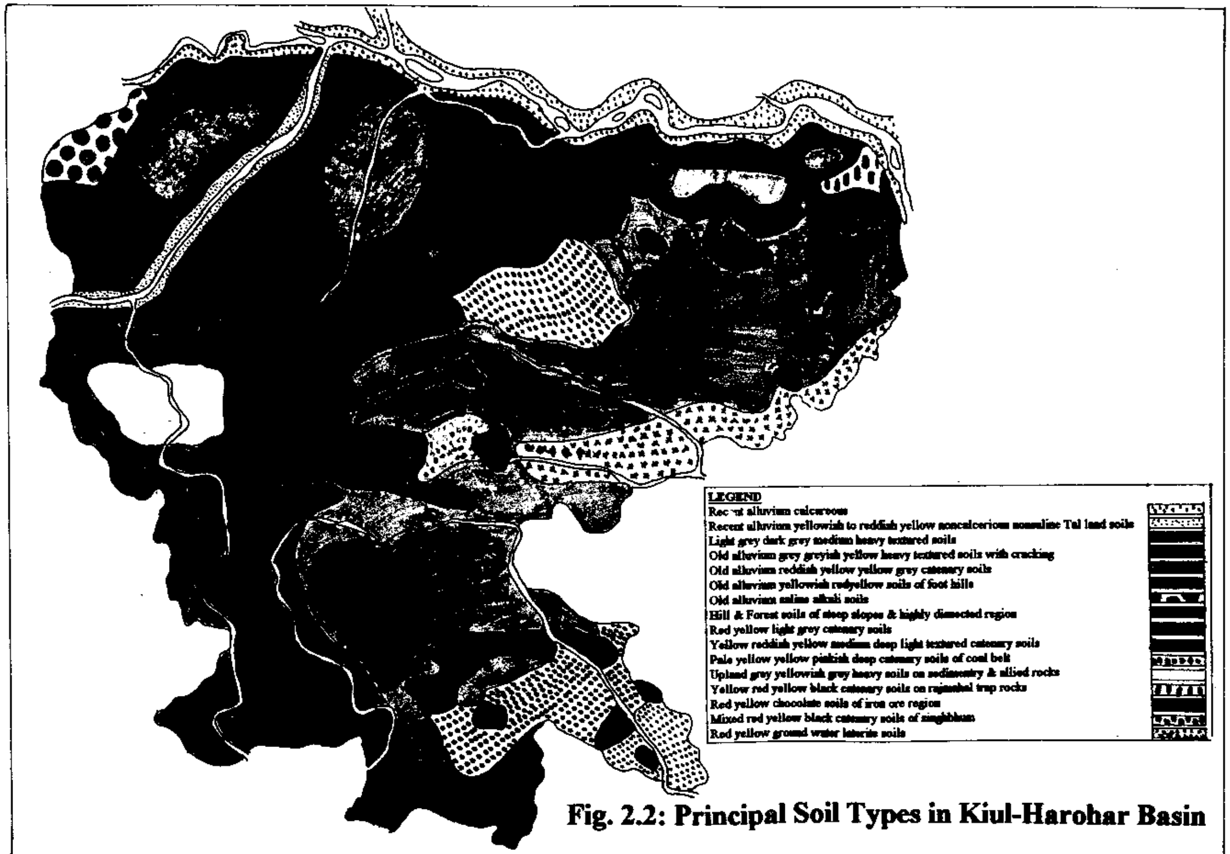


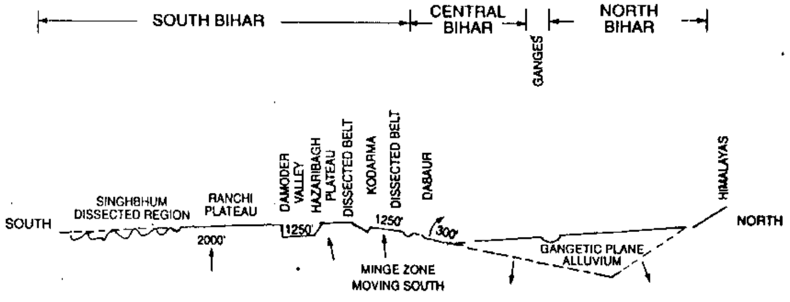
Fig. 2.2: Principal Soil Types in Kiul-Harohar Basin

heaving practically no gravels. The pH value of the soil is strongly to moderately acidic.The red and yellow type of soil are moderately well drained. These are having good fertility and are less acidic. The redish yellow soil resemble the yellow soil and are light textured.

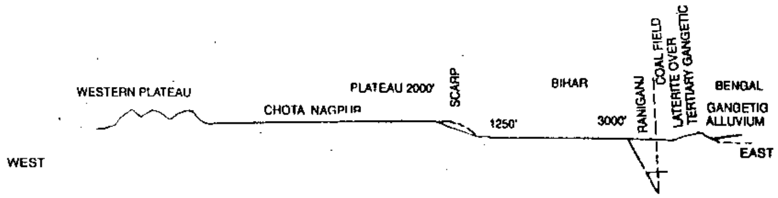
The alluvium soil found in various districts can further be classified on the basis of colour and other properties. The grey and greyish yellow type which is found in the district of Patna, Gaya, Jahanabad, Nalanda, Munger, and Nawada remains greyish yellow to grey in colour, medium heavy in texture and neutral to slightly alkaline in reaction. These soils on drying crack heavily. Reddish soil and yellow type soils are found in the district of Patna, Gaya, Jehanabad, Nalanda, Munger and Nawada. These soils are somewhat poorly drained and show a tendency to crack during the dry months. The yellowish red and yellow type soil found at the foot hills separating the alluvial plain from the plateau region. These excessively drained to moderately drained, shallow to medium deep soil over the bed rocks and pebble. These are also strongly to moderately acidic and are of poor to moderate fertility. Calcareous alluvium soils are found in Munger and Jamui districts. There main characteristics is the high content of calcium carbonate. These soils are alkline in nature. They are light coloured and their texture varies from sandy loam to loam.

FLOOD AND DRAINAGE CONGESTION PROBLEM

The Ganga sub-bain is a part of the main Brahamputa-Meghana-Ganga river basin. It is the largest river basin in the country. A large part of this basin particularly the portions lying in the Eastern Utter Pradesh and Bihar is flat in topography with poor drainage. Very high intensity of rainfall with poor drainage result flooding and drainage congestion almost every year in this region. The river Ganga flows from west to east in the central part of Bihar. The portion lying on the northern side of the left bank of the Ganga is known as North Bihar and that lying on the southern side as South Bihar. The State comprises alluvial plains of Indo-Gangetic basin in the north and Kaimur-Chotanagpur-Santhal Pargana plateau in the south. The alluvial plains is divided by the river Ganga flowing from west to east. The state, therefore, can be physiographically be divided into three regions. These are North Bihar, Central Bihar and South Bihar. Physiographical map of Bihar is shown in **Figure** 3.1. The North Bihar rivers are fed by the melting snows and glaciers of the great Himalayan range during spring and summer, and also from rains during monsoon and hence they are perennial. They carry significant flows during the dry weather due to snow melt and carry minimum flow during the winter. On the other hand, the peninsular rivers originate at much lower altitudes, flow through stable areas. Their flow is characterised by heavy discharges during monsoon followed by very low discharges during the rainless months. In order to give an idea of the problems of floods and drainage congestion in the Kiul-Harohar basin, the nature, characteristics and overall situation of these problems existing in the basin are being discussed in brief as follows:



(a) SECTION FROM S.N. ACROSS BIHAR
ARROWS INDICATE DIRECTION OF MOVEMENT



(b) SECTION FROM WESTERN PLATEAU
TO RANIGANJ

Source: Second Bihar State Irrigation Commission

Fig. 3.1: Physiographical Map of Bihar

3.1 Flood Problem - Nature and Extent

In the State of Bihar, almost all the rivers carry heavy discharges during the monsoon months when their catchments receive intense and heavy rainfall. The floods occur almost every year in the various river basins in Bihar. Flood prone basins in Bihar with their respective flood prone areas in Lakh ha are indicated in the **Table 3.1**. Due to non favourable outfall conditions in monsoon season the North Bihar plains are affected by

Table 3.1 : Flood Prone Area Under Different Basins in Bihar

Sl. No.	Name of Basin	Flood Prone Area in Lakh ha
1	Ghaghara	2.53
2	Gandak	3.35
3	Burhi Gandak	8.21
4	Bagmati	4.44
5	Kamla-Balan	3.70
6	Kosi	10.15
7	Mahananda	5.15
8	Sone	3.70
9	Punpun	6.13
10	Kiul-Harohar	6.34
11	Badua	1.05
12	Chandan	1.13
13	Main Ganga Stem	12.92
	Total	**68.80**

acute problems of flood, waterlogging and drainage congestion due to very flat topography. The southern Bihar is characterised by low hills and slopes in some parts and Gangetic plain in the rest. Most of the rivers originating from South Bihar join the river Ganga. These rivers have steep slope in the upper reach and a very mild in lower reach. Many rivers like Karmanasa, Sone, Punpun, Kiul-Harohar, Badua-Chandan, Gumani etc. which originate from Hilly region of South Bihar join the river Ganga. In comparison to North Bihar flood problems of Kiul-Harohar are not of very serious in nature. However, flash floods have been occurring during period of heavy rains in the catchment. The river Sakri experienced heavy flooding in 1896 and the river Kiul also experienced comparatively bigger flood in 1961. Besides this moderate flooding have been noticed in the year 1962, 1963, 1967, 1971 and in 1976, in the river Kiul. The river Falgu caused flooding in the year 1971 and severe flooding in the year 1986.

In the Kiul-Harohar river system, the bankful capacities of the rivers like the Kiul, the Harohar and the Punpun etc. are inadequate. Due to which they are unable to contain the flood discharges and as a result spilling takes place over their bank causing floods in the basin. Zamidari embankments are provided in places where spills causing floods in the basin. These embankments are generally of inadequate section and incapable of withstanding even medium floods. Rivers draining the Kiul-Harohar basin are non-perennial in nature. Due to spilling during monsoon season, sometimes flooding in lower reaches of these rivers takes place. Flood problem of the basin as identified is presented in **Table 3.2**.

Table 3.2: Causes of Flooding in Kiul-Harohar Basin

Sl. No.	RIVER	CAUSES OF FLOODING
1	KIUL	• River spills near Lakhisarai and flooding takes place in nearby area.
2	SAKRI	• It carries lot of silt. • Flash flood in the river. • Zamindari embankment are existing below Sakri weir in which there are number of gaps and the flood water spills through these gaps.
3	FALGU	• Occasional flash flood in the river.
4	PANCHANE	• Inadequate capacity of its several bifurcated channels.

3.2 Drainage Congestion Problem

The Kiul-Harohar river system drains an area of 17,223 Sq Km. The upper catchment of the river system lies in Chotanagpur Plateau area which is characterised by low hills and steep slopes with depression and valleys. Flood peaks caused by heavy rains which pass off quickly and accumulates in the lower region where the terrain is flat. About 1062 Sq. Km. of this area, lying in the lower zone of the system is saucer shaped. It is commonly known as Mokama Group of Tal. The drainage problem in the Kiul-Harohar basin is confined to Mokama group of Tals. It consists of seven Tals. Though the Mokama group of Tals is continuous, it is differently named in its different reaches from west to east as Fatuha Tal, Bakhtiarpur Tal, Barh Tal, More Tal, Mokama Tal, Barahiya Tal and

Singhaul Tal. During monsoon months, the Tal gets filled up with water due to inflow of rivers entering the Tal and also due to obstruction in drainage caused by back water of Ganga entering the Tal. The maximum depth of submergence in the recent past was recorded in the year 1987 which varied from 3.86 m in Fatuha to 5.76 m in More and Mokama Tals. Out of total Tal area 93 Sq Km area consists of high lands which are submerged only during high floods. 788 Sq Km area consists of very low lands where only Rabi crop is possible and in the remaining 181 Sq Km area it is possible to grow two crops. A Pie diagram (Fig 3.2) shows the percentage of Tal area under different topography. Due

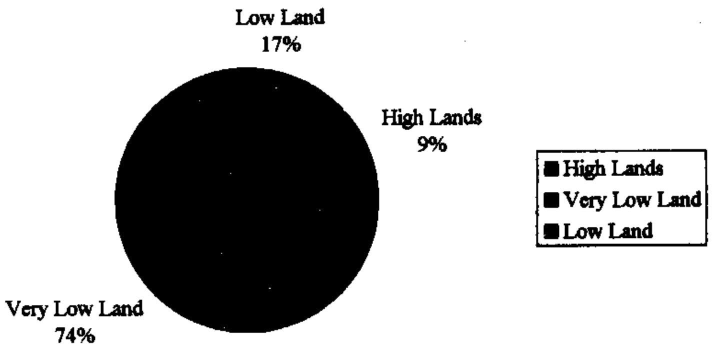


Figure 3.2: Topographical Features of Tal Area

to the peculiar configuration, the flood water continues to accumulate and vast tract of this low lying land is subjected to flooding and waterlogging. The monsoon submergence of the Tal area hamper the optimum utilization of its land resources. The continued submergence of most of the Tal areas, from July to September, makes it impossible to grow any Kharif crop in a vast area. Rabi crop is grown almost in the entire Tal area when the accumulated water of the Tals gets drained out by its natural drainage through the Harohar and the Kiul into the Ganga by 15th October. The Rabi cultivation is also dependent on the availability of the residual moisture of the soil freed from submergence. As the Tal area do not get fully submerged every year, Kharif cultivation is practiced in peripheral areas of the Tal where depth of submergence is small. In some areas where irrigation facility has been created, even double crop, during both Kharif and Rabi season are being grown. In a very limited area hot weather crop is also grown. An average cropping pattern for the entire Mokama Tal area is shown in **Figure 3.3.**

Various factors are responsible for frequent inundation of the Tal area. These can be broadly categorised as under :

(a) Ingress of Ganga Water in Tal

i. Inundation in the Tal area by back flow of Ganga water through the Balgudarghat bridge over the Harohar.

ii. Inundation caused by the back flow of Ganga water through the valley lines joining the Tal area to the Ganga across the high lands forming the right bank of the Ganga.

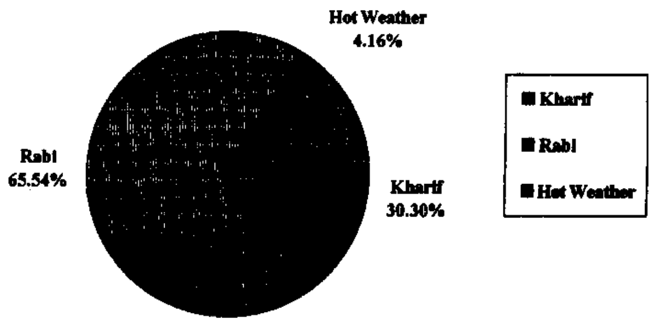


Figure 3.3: Average Existing Cropping Pattern of the Tal Area

iii. Inundation caused by the back flow of Ganga water through the Punpun and spilling of this back flow over the right bank of the Punpun and flowing over the low country side into the Tal.

(b) Inundation Caused by the Catchment Runoff

Inundation caused by the north flowing rivers of Kiual-Harohar basin which have an aggregate catchment of 13,340 Sq. Km. Inundation during monsoon period is caused by these numerous rivers which drain the runoff of this large catchment into the Tal area at their out falls.

(c) Inundation Caused by Rainfall in the Tal

Inundation is also caused by rainfall received by the Tal area itself during the monsoon period.

Due to proneness of the Tal area to frequent inundation the agricultural activities during the wet season is kept at a low. On the other hand, for the successful Rabi crop in major portion of the Tal which remain submerged in monsoon period, drainage of Tal by 15th October is very crucial. Any delay in drainage adversely affects the Rabi crop. **Figure 3.4** shows the frequency in years in which different Tals were free from submergence by 15th of October in the period 1972 to 1991. It is obvious from the figure that the Rabi crop suffers irreparably due to delayed drainage of Tals.

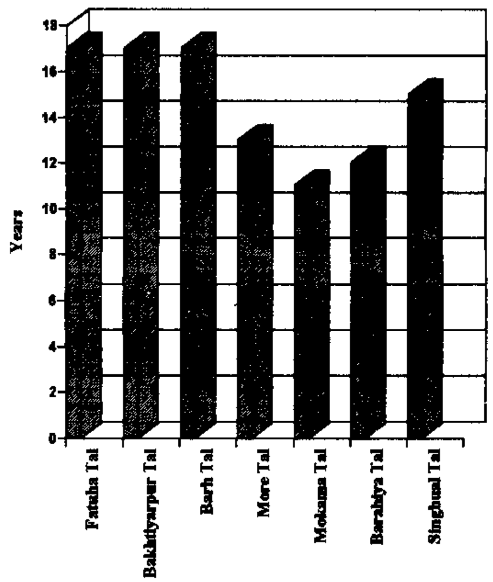


Figure 3.4: Frequency in Years in which Tals were free from submergence by 15th October

DATA COLLECTION

To delineate water logged area in the Mokama Tal and for hydrological data analysis in the Kiul-Harohar basin the following hydrological, remote sensing and ancillary data were collected.

4.1 Remote Sensing Data

The remote sensing data of IRS-1A satellite were collected from NRSA, Hyderabad. Satellite imageries of different dates have been used in the study. For delineation of waterlogged area scenes of different dates have been utilized. Details of the satellite remote sensing data used in the present study is given in **Table 4.1.**

Table 4.1: Remote Sensing Data used for delineation of waterlogged area

Sl. No.	Date	Satellite	Sensor	Format	Scene	Path/Row
1	09.04.89	IRS-1A	LISS-II	FCC	B1	22/50
2	07.12.89	IRS-1A	LISS-II	FCC	B1	22/50
3	08.04.89	IRS-1A	LISS-II	FCC	A1	21/50
4	14.11.89	IRS-1A	LISS-II	FCC	A1	21/50
5	08.04.89	IRS-1A	LISS-II	FCC	B1	21/50
6	14.11.89	IRS-1A	LISS-II	FCC	B1	21/50

4.2 Hydrological Data

Hydrological data collection of the basin includes the collection of Discharge and rainfall of various gauging station located in the vicinity of the basin.

4.3 Discharge Data

Peak discharge data of four gauge and discharge sites were collected from the report of Second Bihar State Irrigation Commission. These data were utilised in the present study. Period of data availability and catchment areas of these sites are given below:

Table 4.2 : Discharge sites and availability of data

Sl. No.	Name of site	Name of river/ tributary	Catchment area (Sq. Km.)	Nature of data available	Period
1.	Gaya	Falgu	3171	Annual Peak Discharge	1960-90
2.	Kadarganj	Sakri	1590	Annual Peak Discharge	1962-91
3.	Lakhisarai	Kiul	2619	Annual Peak Discharge	1963-90
4.	Mankatha	Harohar	14177	Annual Peak Discharge	1962-91

4.4 Rainfall Data

Average annual monsoon rainfall data from 1974 to 1989 of the catchment areas of the rivers entering the Mokama group of Tals is available in the report of Second Bihar State Irrigation Commission. These annual averages were computed from the rainfall data of sixty five blocks falling in the Kiul-Harohar basin.

4.5 Ancillary Data

Ancillary data includes the collection of following information and maps of the basin.

i. Topographical features

ii. Landuse information

iii. Soil map

iv. Geological information

v. Toposheets of the scale 1:50,000 and 1:2,50,000

METHODOLOGY

In the present study, water logged area map of the Mokama Tal was prepared using remote sensing technique. Peak discharge data of four rivers in the Kiul-Harohar system were used to carry out flood frequency analysis. Further, a management model for the water logged area has been developed. Various methods/techniques used in the study are described below.

5.1 Remote Sensing Approach for Inundated Area Mapping

Remote sensing technique facilitate in efficient monitoring of water logged and flood inundated area due to its repetitive synoptic coverage. It allows to visualise the things and the phenomenon in their entirety over the time and near real time measurement. Remote sensing data either in the digital format or in the imagery form can be quickly analysed on a computer or visually, as the case may be, to provide reliable estimate of waterlogged area. The interpretation of remote sensing data and acquisition of useful information in the present study was based on the basic image interpretation elements like site, shape, shadow, tone/colour, texture, pattern, size and association. A tentative classification scheme was drawn based upon knowledge and experience of the study area.

Two basic approaches have been used for water logged area mapping - dynamic and static.

5.1.1 Dynamic Approach

The dynamic or actual or direct approach uses the historical evidence to map the extent of waterlogging and drainage congestion or flood inundation mainly caused by monsoon rainfall. An inundated area-frequency relationship can be developed by observing the evidence of events. This approach is highly agreeable to remote sensing wherein the successful application utilises the changes influenced by additional water that include increased soil moisture, vegetation moisture stress and standing water. All of this result in characteristically reduced reflectivity that lasts up to two weeks after the events and thereby reducing the need for obtaining satellite observations at the time of peak inundation.

5.1.2 Static Approach

The static approach utilises the indicators of water logging or inundation which can be identified using in-situ observations or by remote sensing techniques. The indicators broadly include meteorologic, physiographic, geomorphic and topographic features. Remotely sensed data based delineation of surface waterlogging or flood inundation area using static approach involves identification of indicators through their multispectral response and the spatial response pattern.

In the present study, the waterlogged areas from IRS-1A LISS II Fals Colour Composites had been transferred on to the base map by optical processing the two scenes of different dates i.e. before and after monsoon. The delineated map can be confirmed with the help of ancillary data such as drainage map, contour map, submergence level and percentage submergence data. The extent of waterlogging can be depicted by two colour temporal composites. Post-monsoon IRS LISS II scene was superimposed on a pre-monsoon scene to prepare a composite water logged area scene. Further, the area frequency analysis of the historical data have also been done.

5.2 Flood Frequency Analysis

Following methods were used in the study to fit the annual peak discharge series and to carry out flood frequency analysis.

i. Normal distribution
ii. Two parameter Log normal distribution
iii. Three parameter Log normal distribution
iv. Pearson type III distribution
v. Log Pearson type III distribution
vi. Extreme Value I or Gumble distribution

5.2.1 Normal Distribution

Probability density function (PDF) of the normal distribution is given by

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]; \ -\infty < x < \infty \qquad .....(5.1)$$

where,

μ is the location parameter, and σ is the scale parameter. The density of normal distribution is continuous $-\infty < x < +\infty$ and tends to zero as x tends to $\pm\infty$. It has a symmetrical bell shape and as a result the mean, median and mode are equal.

By integrating the equation (5.1), we can write the Cumulative Density Function (CDF) as:

$$F(x) = \int_{-\infty}^{x} f(x)dx = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] dx \qquad ......(5.2)$$

in eq. (5.2) if $Z = \dfrac{x-\mu}{\sigma}$; where z is called the reduced variate or standardized variate, then equation (5.2) reduces to

$$F(z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} \exp\left[-\frac{z^2}{2}\right]dz \qquad \text{.........(5.3)}$$

The PDF and CDF of normal distribution corresponding to standardized variate z can be calculated from the standard tables.

5.2.2 Two Parameter Lognormal Distribution

If Y = ln (X) follows normal distribution then X follows log normal distribution. Assuming that the mean and variance of Y are μ_y and σ_y^2 respectively, the PDF of X can be written as:

$$f(x) = \frac{1}{\sigma_y\sqrt{2\pi}x}\exp\left[-\frac{1}{2}\left(\frac{\log_e(x)-\mu_y}{\sigma_y}\right)^2\right] \qquad \text{........(5.4)}$$

In relation to the variable X, μ_y controls the scale so it is called the scale parameter, while σ_y controls the skewness and hence it may be regarded as a shape parameter.

5.2.3 Three Parameter Lognormal Distribution

If the variable X has a lower bound x_0, different from zero, and the variable $z = x - x_0$ follows a lognormal distribution with two parameters then X is lognormally distributed with three parameters. Its PDF can be written as

$$f(x) = \frac{1}{\sqrt{2\pi}(x - x_0)\sigma_y} \exp\left[-\frac{1}{2}\left(\frac{\log_e(x - x_0) - \mu_y}{\sigma_y} \right)^2 \right] \qquad .....(5.5)$$

In equation (5.5) μ_y, σ_y and x_0 are called the scale (mean of ln($X - X_0$)) the shape (Standard deviation of ln($X - X_0$)), and the location parameters, respectively. Parameter X_0 is estimated by trial and error.

The cumulative density function (CDF) of the three parameter lognormal distribution is given by

$$F(x) = \int_{x_0}^{x} \frac{1}{(x - x_0)\sigma_y \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln(x - x_0) - \mu_y}{\sigma_y} \right)^2 \right] dx \qquad ....(5.6)$$

The three parameter lognormal PDF can be applied to positive or negative valued events provided $(X - X_0) > 0$, while the two parameter lognormal distribution should always be applied to positive valued events.

5.2.4 Pearson Type III Distribution

Pearson type III distribution is a three parameter distribution. This is also known as Gamma distribution with three parameters, The PDF of the distribution is given by

$$f(x) = \frac{(x - x_0)^{\gamma - 1} e^{-(x - x_0)/\beta}}{\beta^{\gamma}\Gamma(\lambda)} \qquad ....(5.7)$$

$$F(x) = \int_{x_0}^{x} \frac{(x - x_0)^{\gamma - 1} e^{-(x - x_0)/\beta}}{\beta^{\gamma}\Gamma(\lambda)} dx \qquad ......(5.8)$$

Where,

x_0 = Location parameter

β = Scale parameter

γ = Shape parameter

5.2.5 Log Pearson Type III distribution

The probability density function of log Pearson type III distribution is given by

$$f(x) = \frac{1}{|\beta| \cdot)\lambda \cdot x}\left[\frac{\log_e x - y_0}{\beta}\right]^{\gamma-1} \exp\left[-\frac{\log_e x - y_0}{\beta}\right] \qquad .....(5.9)$$

Where,

y_0 = location parameter

β = scale parameter

γ = shape parameter

5.2.6 EV I Distribution or Gumble Distribution

The probability density function of EV I distribution function is given by

$$f(x) = \frac{1}{\alpha}\exp\left[-\frac{x-u}{\alpha} - e - (x-u)/\alpha\right] \qquad ......(5.10)$$

Where,

u = location parameter

α = shape parameter

The cumulative density function of the EV I distribution is given by

$$F(x) = e^{-e^{-(x-\mu)/\alpha}} \quad \text{......(5.11)}$$

The parameter of the distribution can be estimated from the following equations using methods of moments.

$$\mu = u + 0.5772\alpha \quad \text{.....(5.12)}$$

$$\sigma^2 = \left(\frac{\pi^2\alpha^2}{6}\right) \quad \text{.....(5.13)}$$

5.3 Evaluation Criteria for Selecting a Suitable Frequency Method

Evaluation criteria used in the present study for selecting an appropriate frequency analysis are :

i. Average of the relative deviations between computed and observed values of annual maximum discharge peak (ADF)

ii. Efficiency (EFF)

iii. Standard Error (SE)

5.3.1 Computation of ADF Values

The following relationship is used for computation of ADF values.

$$ADF = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|QO_i - QC_i|}{QO_i}\right) \quad \text{........(5.14)}$$

5.3.2 Computation of EFF Values

EFF values are computed using the relations:

$$EFF = \frac{(IV - MV)}{IV} \quad \text{.......(5.15)}$$

where,

$$IV = \sum_{i=1}^{n}\left(QO_i - \bar{Q}\right)^2 \qquad ....(5.16)$$

$$MV = \sum_{i=1}^{n}\left(QO_i - QC_i\right)^2 \qquad ....(5.17)$$

$\bar{Q}$ = Mean of the observed peak discharge series, QO_i

QO_i = ith value of the computed peak discharge series

n = Sample size

5.3.3 Computation of SE Values

SE values are computed, in non dimensional form using the following relationships:

$$SE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(QRO_i - QRC_i\right)^2} \qquad ....(5.18)$$

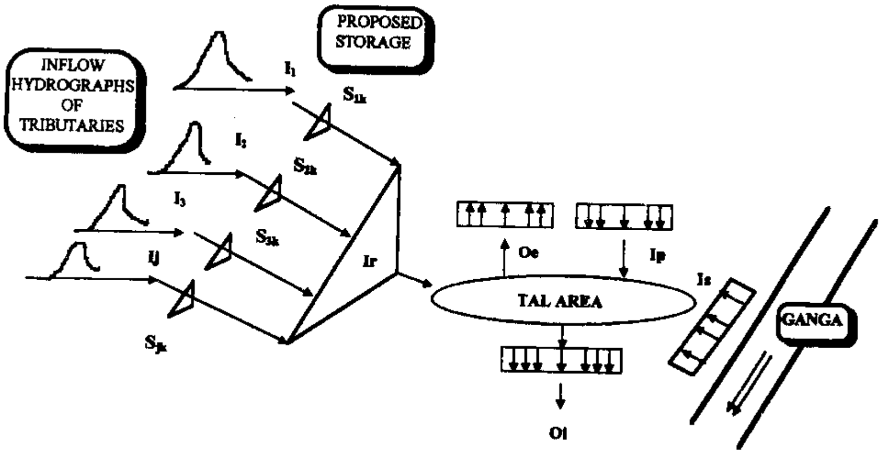
where,

$$QRO_i = QO_i \,/\, \bar{Q} \qquad ....(5.19)$$

$$QRC_i = QC_i \,/\, \overline{QC} \qquad ....(5.20)$$

5.4 Outline of Optimization Model for the Waterlogged Area

For the formulation of the management model it is considered that water logged area serve as a storage reservoir having inflows/back watur flow to/from various tributaries and outflow to/from the river Ganga (A schematic of the conceptualization is given in Fig 5.1. The objective function, which minimizes the total surface water logged area under the



WATER BALANCE

Change of Storage [ds/dt]=Inflow-Outflow=[Ir+Is+Ip] - [Oe-Oi]
where,
Ir,Is and Ip are the rate of inflows, seepage and precipitation respectively
Oe and Oi are the rate of evaporation and infiltration respectively

FIG. 5.1: Schematic Representation of the Conceptualization of Mokama Tal Area

constraints of check over inflows (translation of inflow hydrographs) from different tributaries, and considering minimum crop water requirement in the upper reaches and in the Tal area, assumes that the back water flow from the river Ganga is completely checked.

The objective function to be minimized to obtain the optimum level of area free from surface water logging is thus:

$$\textbf{Min } f(I) = \text{Min} \sum_{j=1}^{n} \left[I_j - \sum_{k=1}^{m_j} S_{jk} \right] \qquad \text{......(5.21)}$$

Where,

$f(I)$ = Total inflow into the Tal area from various tributaries

I_j = Total inflow into the Tal area from jth tributary with no check dam

S_{jk} = Storage capacity of kth check dam on jth river

mj = Maximum possible number of check dams on jth river

j = 1 to n = Number of rivers

k = 1 to m_j = Number of check dams on jth river

The above objective function can be solved under the following constraints:

5.4.1 Inflow into the Tal area

Total storage in all check dams in a tributary can not be more than the total runoff contribution of that tributary to the Tal area.

$$I_1 - \sum_{j=1}^{n} \sum_{k=1}^{mj} S_{jk} \geq 0 \qquad \text{.....(5.22)}$$

$$I_2 - \sum_{j=1}^{n} \sum_{k=1}^{mj} S_{jk} \geq 0 \qquad \text{.....(5.23)}$$

$$I_n - \sum_{j=1}^{n} \sum_{k=1}^{mj} S_{jk} \geq 0 \qquad \text{.....(5.24)}$$

where, $I_1, I_2, I_3, ... I_n$ are inflows into the Tal area from tributary numbering 1, 2, 3,..... and n.

5.4.2 Storage in Tal Area

$$\sum_{j=1}^{n} I_j - \sum_{j=1}^{n} \left[\sum_{k=1}^{m_j} S_{jk} \right] \geq V_1 \qquad \text{.....(5.25)}$$

$$\sum_{j=1}^{n} I_j - \sum_{j=1}^{n} \left[\sum_{k=1}^{m_j} S_{jk} \right] \leq V_2 \qquad \text{.....(5.26)}$$

where,

V_1 = Minimum required storage volume in Tal area for successful Rabi and Kharif cropping.

V_2 = Maximum storage in the Tal.

5.4.3 Maximum Storage Constraints in Check Dams

$$S_{11} \leq S_{m11} \qquad \text{.....(5.27)}$$

$$S_{12} \leq S_{m12} \qquad \text{.....(5.28)}$$

$$S_{1k} \leq S_{m1k} \qquad \text{.....(5.29)}$$

$$S_{2k} \leq S_{m2k} \qquad \text{.....(5.30)}$$

$$S_{jk} \leq S_{mjk} \qquad .....(5.31)$$

where,

S_{jk} = Storage in the kth check dam on jth river

S_{mjk} = Maximum storage in the kth check dam on jth river

5.4.4 Water Requirement in the Catchment

Storage in the check dams should be sufficient to fulfill water requirement of the command area of each check dam. It is considered that the 30% of cultivable land in the command require irrigation during Kharif cultivation, 70% during Rabi cultivation and 80% during hot weather.

$$0.3A_j \cdot WR_{Kharif \cdot k} + 0.7A_j \cdot WR_{Rabi \cdot k} + 0.8A_j \cdot WR_{HW \cdot k} \leq S_{jk} \qquad .....(5.32)$$

where,

j = 1 to n = Number of rivers

k = 1 to m_j = number of check dams on jth river

Ajk = Cultivable area in the command of kth check dam on jth river

$WR_{Kharif.k}$ = Water requirement from kth check dam for irrigation of Kharif crop

$WR_{Rabi.k}$ = Water requirement from kth check dam for irrigation of Rabi crop

$WR_{HW.k}$ = Water requirement from kth check dam for irrigation of Hot weather crop

RESULTS AND DISCUSSION

The drainage problems of the Mokama Group of Tals is associated with the stagnation of runoff and ingress of the Ganga water by back flow. Stagnation of runoff in the area is caused by intense rain during monsoon period, resulting into excessive runoff for which drainage conditions are not favourable due to high water levels in the Ganga. Waterlogging problem arise in the area due to excessive rainfall, stagnation of water on land surface for long periods, inadequate surface drainage conditions during monsoon period and poor topography. The present study was carried out in order to delineate waterlogged area in the Mokama Group of Tals using the satellite remote sensing technique. Further, the historical discharge data of various sites have been analysied for flood frequency analysis.

6.1 Waterlogged Area Mapping

The waterlogged areas was delineated based upon the sharp contrast between water spread and the adjacent areas on the satellite data. It was also possible to delineate the areas where the water had receded. The post-monsoon scenes of the IRS LISS II data were used to delineate the standing water areas and wet areas during monsoon. While, pre-monsoon scenes were used to delineate the permanent water logged/wet areas. These areas were demarcated as water logged areas during monsoon season. The standing water areas appeared as dark blue depending upon the depth of water, while the wet areas appeared as dark grey to light grey in colour/tone on the imagery.

Remote sensing technique in integration with ancillary data such as soil map, contour map, rainfall in the catchment, runoff in to the Tal, submergence level and control structures etc. has been used to delineate the water logged areas. Historic data (**Table 6.1**) regarding frequency and extent of submergence in different Tals from year 1972 to 1991

Table 6.1: Extent of submergence in different years in Mokama Tal area.

Sl. No.	Name of Tal	Year in which more than 50% submerged	Year in which more than 75% submerged	Year in which 100% submerged
1	Fatuha Tal	1972,73,76,78,88,89	1972,73,76,78,89	1973,76,78,89
2	Bakhitarpur Tal	1976,78,83,86,87	1976,78	-
3	Barh Tal	1973,76,78,87,90	1976,78	-
4	More Tal	1973,74,76,78,80,87, 89,90	1973,74,76,78,80	-
5	Mokama Tal	1973,76,78,80,82,83, 84,85,87,89,90	1973,76,78,80,82,83, 84,87,90	1973,76,78,80, 82,87,90
6	Barahiya Tal	1973,74,75,76,78,80, 82,83,84,85,86,87,88, 89,90,91	1973,74,75,76,78,80, 82,83,84,87,90	1987
7	Singhaul Tal	1973,74,75,76,77,78, 79,80,82,83,84,85,87, 89,90	1973,74,75,76,78,80, 82,83,84,85,87	1983,84,85,87

were used in this study. Submergence frequency and extent of submergence of various Tals is shown in **Figure 6.1 to 6.7**. Contour map at the interval of one foot was taken from the Report of Mokama Tal drainage Scheme, Water Resources Department Government of Bihar. The contour map of the Tal area is shown in **Figure 6.8**. A surface plot of theses contours was prepared to indicate the low lying areas susceptible to submergence. 3-D surface plot with contour map is presented in **Figure 6.9**. Water logged area map so delineated was further supported by the historic submergence data and surface plot to assess water logging in the Tal area. The water logged area map developed by pre-monsoon and post-monsoon remote sensing data for the year 1989 and ancillary data is shown in **Figure 6.10**. It was observed that due to moderate to low rainfall in the basin the submergence in the More Tal, Mokama Tal, Barahiya Tal and Singhaul Tal was between 50 to 75%. While, Bakhtiarpur Tal and Barh Tal got submergence below 50%. Fatuha Tal

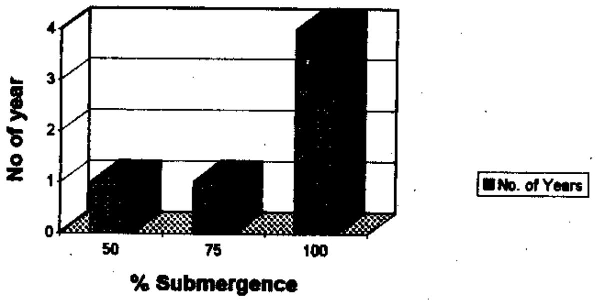


Fig 6.1: Frequency of Submergance in Fatuha Tal

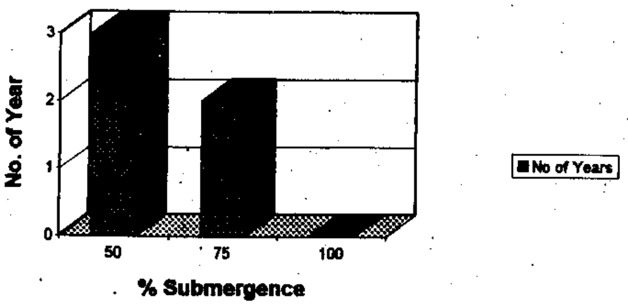


Fig 6.2: Frequency of Submergence in Bakhtiarpur Tal

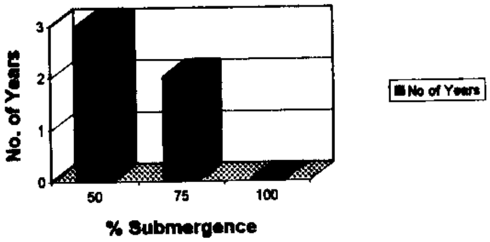


Fig 6.3: Frequency of Submergence in Barh Tal

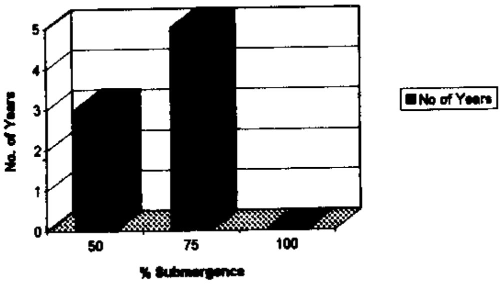


Fig 6.4: Frequency of Submergence Morh Tal

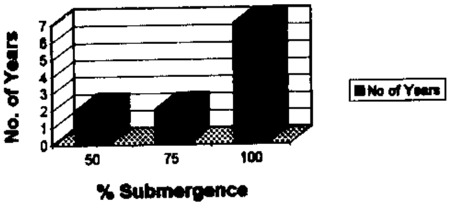


Fig 6.5: Frequency of Submergence in Mokama Tal

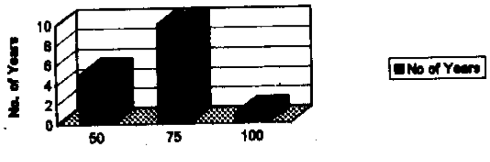


Fig 6.6: Frequency of Submergence in Barahiya Tal

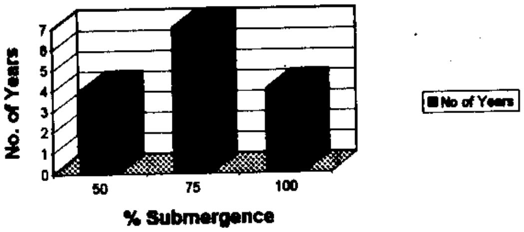


Fig 6.7: Frequency of Submergence in Singhual Tal

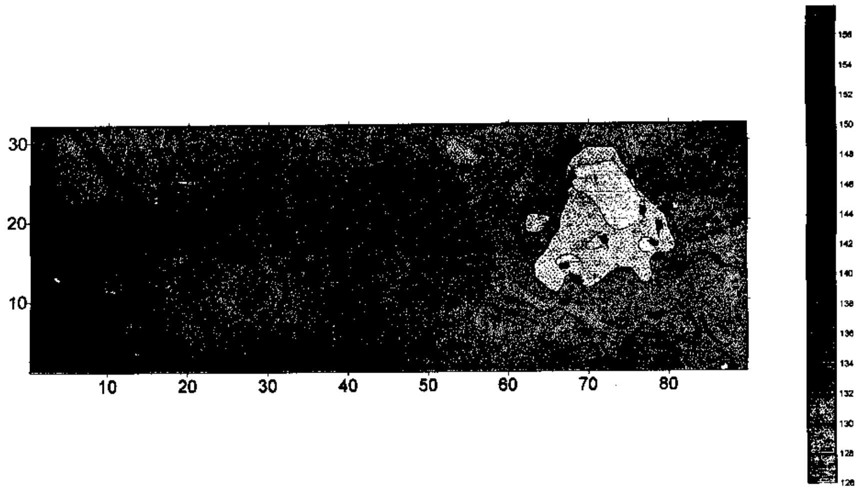


Fig 6.8: Contour Map of Mokama Tal Area

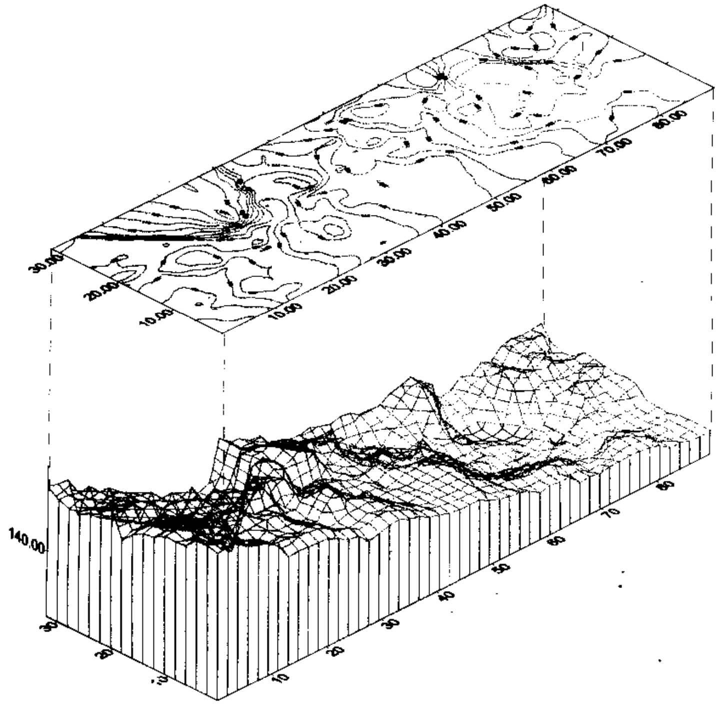


Fig 6.9: -D Surface Plot of Mokama Tal Area

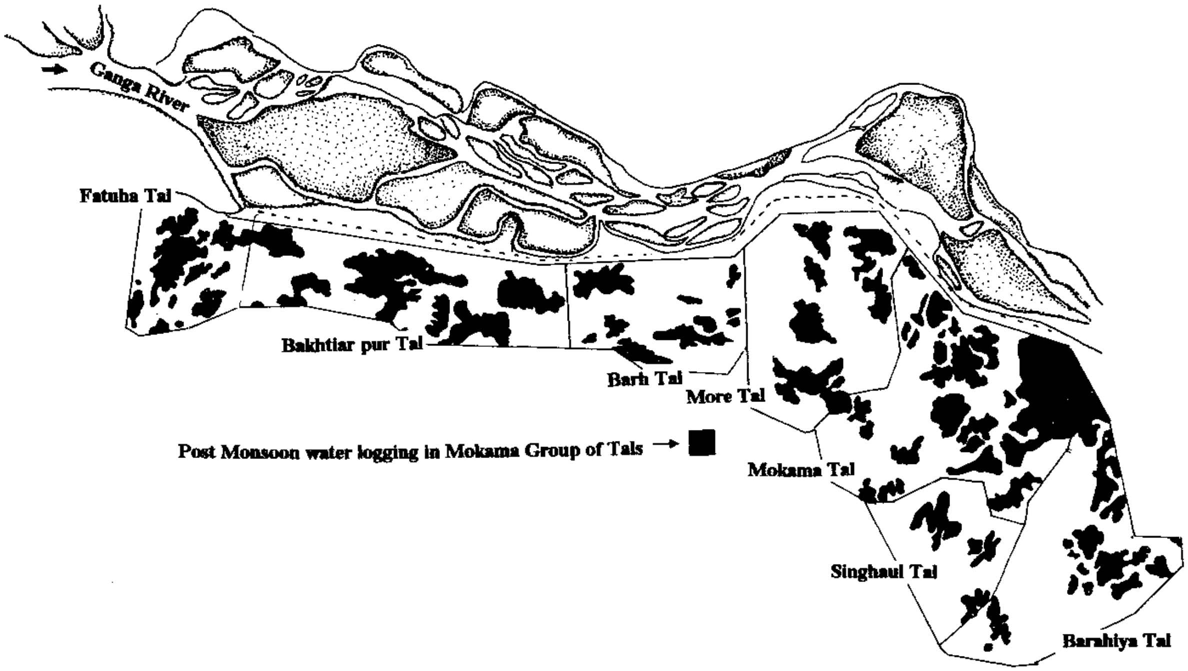


Fig. 6.10: Water logged Area Map Delineated from Remote Sensing Data

is the exception with 100% submergence. This may be due to inundation caused by the Ganga by back flow through the Punpun.

6.2 Flood Frequency Analysis

The statistical parameters of original and log transformed series of the historical flood records of four gauging sites are given in **Table 6.2**. It is observed from the table that the mean maximum flood of the gauging sites vary from 565.57 cumec to 967.41 cumec.

Table 6.2 : Sample statistics of the original and logs of the data

NAME OF SITE	ORIGINAL DATA				LOGS OF DATA			
	MEAN (Cumec)	**SD** (Cumec)	**CV**	**SKEW**	**MEAN** (Cumec)	**SD** (Cumec)	**CV**	**SKEW**
GAYA	745.08	799.98	1.074	2.596	6.214	0.898	0.144	0.187
KADARGANJ	565.57	629.62	1.113	2.128	5.837	1.061	0.182	-0.221
LAKHISARAI	628.40	409.55	0.652	1.033	6.243	0.654	0.105	0.027
MANKATHA	967.41	536.48	0.555	0.521	6.697	0.657	0.098	-0.726

Data series computed through various distribution methods and actual data series is plotted on the probability paper by Weibull plotting position formula. These plots are shown in **Figures 6.11 to 6.14**. The flood estimates for different recurrence intervals obtained by different methods are given in **Table 6.3 to Table 6.6**. The descriptive abilities of different methods have been evaluated by computing ADF, EFF and SE values. These values are given in **Table 6.7 to 6.9**. It can be seen that the values of ADF, EFF and

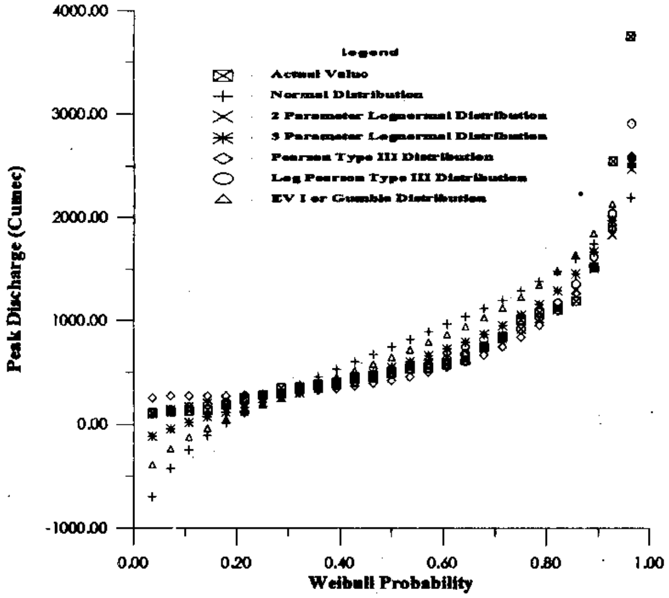


Fig. 6.11: Graphical Comparison of Distribution Fits at Gaya Site

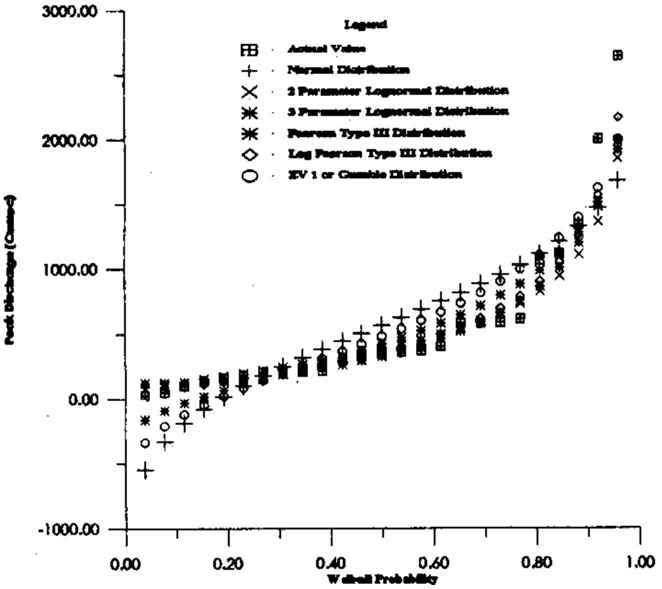


Fig 6.12: Graphical Comparison of Distribution Fits at Kadarganj Site

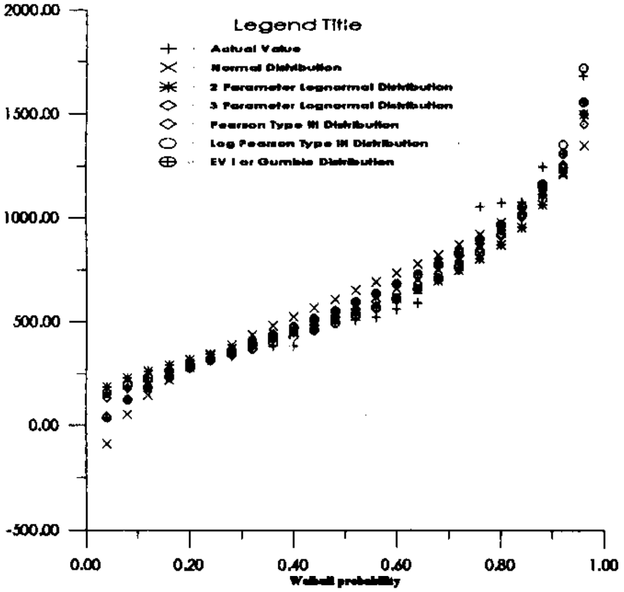


Fig. 6.13: Graphical Comparisin of Distribution Fits at Lakhisarai Site

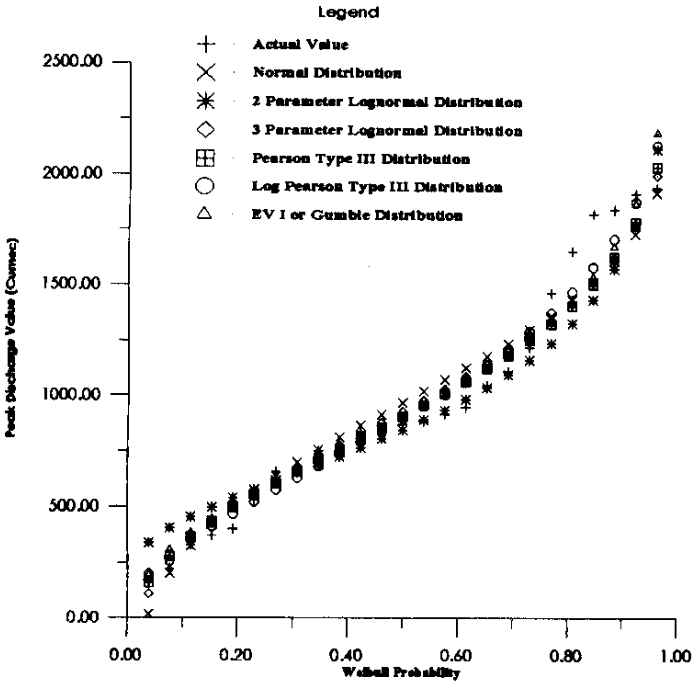


Fig. 6.14: Graphical Comparison of Distribution Fits at Mankatha Site

SE computed from different methods are quite comparable. It is, therefore, difficult to identify a suitable method based on the computed values of ADF, EFF and SE.

Table 6.3 : Flood estimates at Gaya site for different return periods

RETURN PERIOD (YEAR)	DISTRIBUTION METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
2	628.4125	507.8100	542.8911	421.3880	482.0495	634.9874
3	805.0131	740.7764	840.6208	643.3901	724.5238	989.9653
5	973.3410	1060.9660	1206.5880	998.7654	1081.2300	1383.612
10	1153.3410	1560.0330	1715.7620	1577.9410	1684.9170	1879.2660
25	1345.5610	2353.0080	2432.2690	2469.4890	2747.8820	2505.5270
50	1460.7000	3068.2800	3016.6740	3220.1040	3802.7600	2970.1240
100	1581.3420	3895.4860	3642.8780	4026.4880	5124.5150	3431.2890
200	1685.5030	4846.4750	4314.6160	4882.6560	6767.5900	3890.7720

Table 6.4: Flood estimates at Kadarganj site for different return periods

RETURN PERIOD (YEAR)	DISTRIBUTION METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
2	565.5793	377.9504	421.2690	328.8529	360.8307	478.7088
3	837.0793	556.6481	668.3586	538.4456	574.4058	762.7677
5	1095.3820	804.5499	961.7484	838.6358	878.6069	1077.7700
10	1372.5880	1194.6280	1355.8480	1292.8710	1361.0760	1474.4000
25	1668.1000	1820.7500	1889.9650	1954.3920	2126.1860	1975.5440
50	1858.9480	2390.2660	2312.1690	2492.3030	2804.8700	2347.3220
100	2030.5810	3053.1110	2753.9970	3058.0240	3572.3520	2716.3540
200	2187.6410	3819.5620	3217.8860	3648.8160	4430.9190	3084.0390

Table 6.5: Flood estimates at Lakhisarai site for different return periods

RETURN PERIOD (YEAR)	DISTRIBUTION METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
2	628.4125	526.4740	571.8397	538.0108	512.4172	571.8293
3	805.0131	680.4528	748.5093	713.3159	688.3127	758.2972
5	973.0291	868.5660	938.2299	914.5352	912.6794	965.0776
10	1153.3410	1128.6660	1168.3820	1171.3980	1237.2890	1225.4420
25	1345.5610	1492.2490	1448.0950	1496.0560	1714.3440	1554.4130
50	1469.7000	1787.1590	1649.9010	1735.7120	2118.2310	1798.4630
100	1581.3420	2101.8420	1847.0650	1972.5560	2563.7440	2040.7110
200	1683.5030	2438.1260	2041.5650	2207.7760	3054.6810	2282.0750

Table 6.6: Flood estimates at Mankatha site for different return periods

RETURN PERIOD (YEAR)	DISTRIBUTION METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
2	967.4154	846.0346	927.2565	905.7914	896.6702	893.3968
3	1198.7490	1057.6960	1162.2320	1142.5470	1166.3250	1135.4310
5	1418.8370	1308.0350	1400.4880	1390.1310	1449.4140	1403.8310
10	1655.0330	1642.9720	1673.1960	1681.2270	1770.5400	1741.7830
25	1906.8270	2094.9790	1984.6510	2021.8650	2116.7850	2168.7860
50	2069.4400	2451.0100	2197.8840	2259.1710	2334.2930	2485.5620
100	2215.6810	2822.5920	2398.1910	2484.5890	2521.3270	2799.9980
200	2349.5050	3211.7810	2588.8780	2701.0890	2682.7770	3113.2870

Table 6.7: ADF values for different stations

STATION	METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
GAYA	0.9718	0.1050	0.3298	0.2925	0.1005	0.6868
KADARGANJ	1.6870	0.2544	0.6770	0.3082	0.1590	1.1646
LAKHISARAI	0.2565	0.1232	0.1474	0.0896	0.0692	0.1418
MANKATHA	0.1284	0.1744	0.0972	0.0895	0.0911	0.1005

Table 6.8: EFF values for different stations

STATION	METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
GAYA	0.6668	0.8667	0.8682	0.8811	0.9369	0.8129
KADARGANJ	0.7125	0.8723	0.8843	0.9134	0.9458	0.8518
LAKHISARAI	0.8897	0.9381	0.9444	0.9574	0.9705	0.9613
MANKATHA	0.9414	0.9189	0.9528	0.9544	0.9653	0.9553

Table 6 9: SE values for different stations

STATION	METHOD					
	Normal	2 Parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Extreme Value Type I
GAYA	0.6082	0.3282	0.3602	0.2815	0.2242	0.4557
KADARGANJ	0.5848	0.3161	0.3496	0.2393	0.2147	0.4200
LAKHISARAI	0.2119	0.1380	0.1446	0.1176	0.1053	0.1255
MANKATHA	0.1315	0.1457	0.1161	0.1128	0.1012	0.1148

6.3 Management Model

The formulation of management model developed in the study require various hydrological, topographical and land use data for the upper zone of Kiul-Harohar basin and the Tal area. At present sufficient database is not available to solve the model for the actual field condition. An effort would be necessary for the contour surveying the total Tal land. It can help in developing an area capacity curve which would be the input to the model. Further, data ,such as; inflow data of various rivers meeting the Tal area and rainfall of the basin is required to compute total contribution of the catchment to the tal area. Information concerning evaporation and seepage from the Tal area are other data needed for evaluating the model response. Such information and other related data can help in to estimate the input data of the model. The estimation of model's response and evaluation of required input data form another study, and are being dealt separately under the work programme of 1997-'98.

CONCLUSIONS

The Mokama Group of Tal is having a very unique problem of surface water logging during the monsoon season. Though the Tal area is continuous from Fatuha to Lakhisarai, it is differently named in its different reaches. These are namely *Fatuha Tal, Bakhtipur Tal, Barh Tal, More Tal, Mokama Tal, Barahiya Tal and Singhaul Tal.* Remotely sensed data and historical discharge, rainfall and other related data of Mokama Tal area and Kiul-Harohar basin have been analysed. An attempt has also been made to formulate a management model for the entire Tal area so as to minimize the total water logged area in an optimal manner. From the study following conclusions are drawn:

1. Historical submergence data for a period of 20 years from 1972 to 1991 indicates that submergence above 50 per cent and up to 75 per cent in case of Fatuha, Bakhtiarpur, Barh and More Tal has occurred only in 25 to 40% of years. While in lower Tals of Mokama, Barahiya and Singhaul the frequency is 55 to 80% of years.
2. Remote sensing satellite scenes obtained during pre-monsoon and post-monsoon time were valuable to understand the problem of water logging and drainage congestion before the commencement of rainy season, during the rainy season and after the monsoon.
3. The remotely sensed information were integrated with the conventional ground survey data and ancillary data such as contour maps, soil maps, drainage map, submergence data, rainfall data and river discharge data. The water logged area map so prepared defines the area susceptible for waterlogging and drainage congestion.
4. The visual interpretation of IRS 1A LISS II FCC prints gives a reasonably accurate assessment and it is often possible to delineate different stages of soil moisture. The water logged area map so developed almost matches with the historical submergence data. The remote sensing data when collected and analysed in a continuous fashion can help in planning the optimum landuse strategy for the area.

5. The flood frequency analysis at site indicate that the superiority of one method over the other could not be established. The analysis provides the estimate of floods at higher recurrence interval. These can be considered as a base information while deciding a water resources structure in the basin for optimal minimization of inflows into the Tal area.
6. The management model developed in the study requires a hand full of data such as inflow of various tributaries contributing to the Tal area, area capacity curve of the Tal area, inflow/back flow to/from the river Ganga, rainfall in the basin, evaporation data, seepage from Tal area etc. An optimum land use planning with reduced area of submergence can be decided when the objective function of minimization of total water logged area is solved under various related constraints.

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