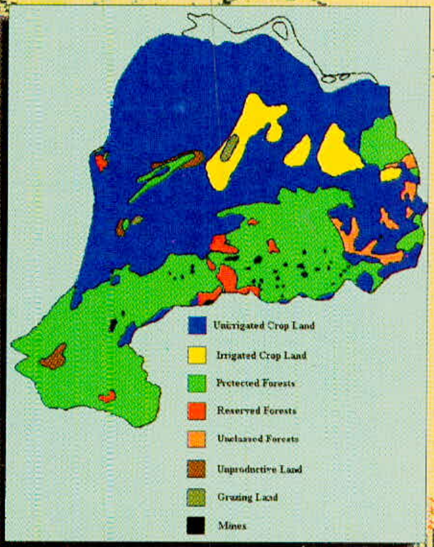
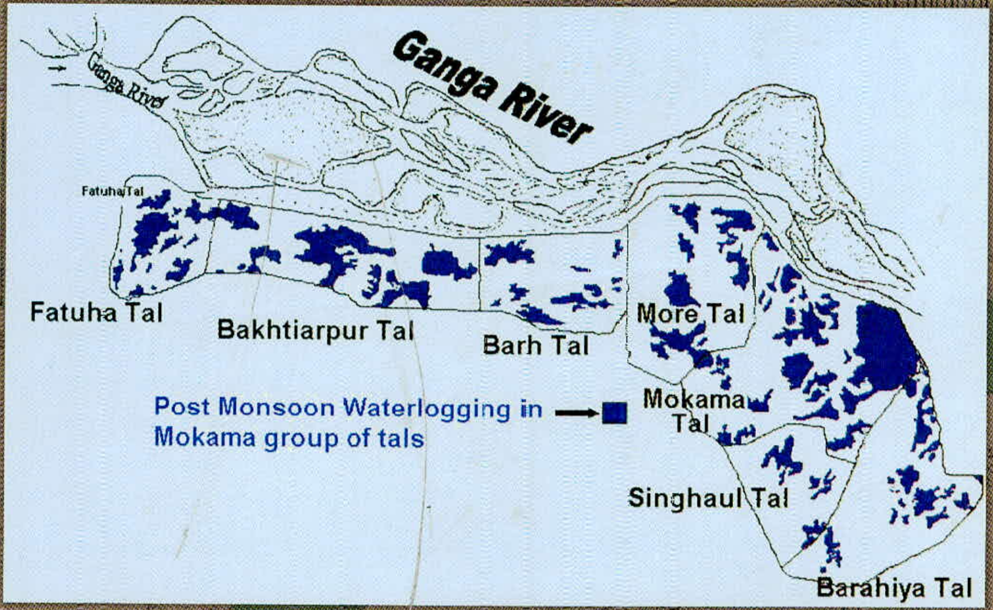
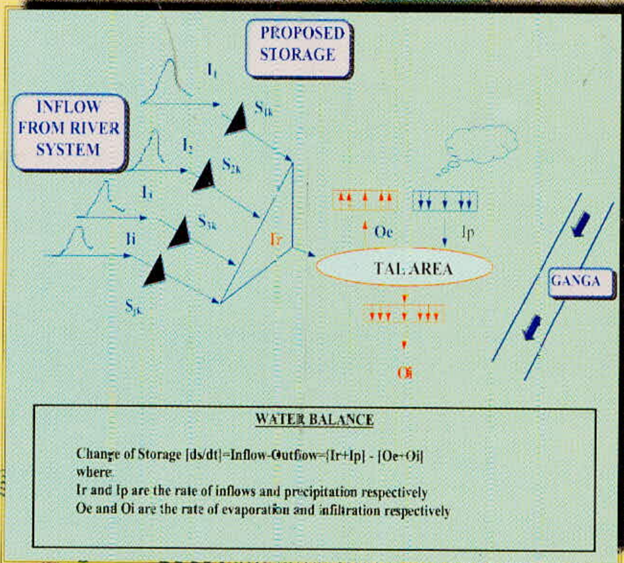
A MANAGEMENT MODEL FOR THE WATER LOGGING AND DRAINAGE CONGESTION PROBLEM OF MOKAMA GROUP OF TALS







आपो हि ष्ठा मयोभुव

National Institute of Hydrology
Jal Vigyan Bhawan
Roorkee - 247 667

1999-2000

Report

on

A MANAGEMENT MODEL FOR THE WATER LOGGING AND DRAINAGE CONGESTION PROBLEM OF MOKAMA GROUP OF TALS

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PREFACE

Surface waterlogging and drainage congestion usually created by the inadequate passage of a natural drainage system which may arise due to human intervention to the hydrologic regime, not only disturb the hydrological harmony of a region but also acquire loss in agricultural productivity. In the Gangetic plains, where topographical abnormalities (steep to mild to flatter) are in evidence, and networks of drainage are, on the other side, incapable of carrying bulk inflows of flood water to the outlets, further restriction to the drainage passage would definitely lead to submergence of areas in the form of flooding. The rate of recession of flood water of an area depends upon its outlet condition. Larger the outlet opening less the time of impoundment. More the time of impoundment means loss of agricultural productivity and thereby loss of economy. Blockage of water is an indication of surplus water, which usually drain to the river without its beneficial uses. If one finds ways for uses of this surplus water to the water scarcity region, a management is said to be optimal.

In Bihar, out of the total geographical area of 173,876 sq.km. about 9000 sq.km. area has been reported to be facing problems of surface water logging and drainage congestion, in which, about 7,938 sq. km. constitutes in the North Bihar and remaining 1062 sq.km. is in central Bihar. This 1062 sq. km. of waterlogged area is located in one stretch named as "Mokama Group of Tals".

The problems of waterlogging and drainage congestion in Mokama Group of Tals is a long standing issue to the water resources planners and managers in terms of its management and loss incurring in agricultural productivity. A number of high level committees constituted by the Govt. of India and Govt. of Bihar, and experts felt the complexities of problem and recommended number of remedial measures and schemes to combat the situation. However, the problem is still remained unsolved.

The study carried out by the Ganga Plains North Regional Centre, National Institute of Hydrology, Patna, is an attempt towards quantification of the approaches suggested by different groups and experts through systematic study of hydrological parameters of the basin. The methodology conceived in the form of development of a management model considering all levels constraints that one can visualise, is definitely an excellent work. Different management alternatives and their benefits suggested in the report can be useful guidelines for the planners to take an appropriate decision. The study titled ***"A Management Approach for Waterlogging Problem of Mokama Group of Tals"*** *has been carried out by* ***Shri A.K. Lohani****, Scientist 'C',* ***Dr. C. Chatterjee****, Scientist 'B' and* ***Shri N.C. Ghosh****, Scientist 'E' and assisted by* ***Shri Atm Prakash****, R.A. and* ***Shri. A.K. Sivadas****, Tech Gr. III.*

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Director

A MANAGEMENT MODEL FOR THE WATERLOGGED AND DRAINAGE CONGESTION PROBLEM OF MOKAMA GROUP OF TALS

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ABSTRACT

Waterlogging and drainage are usually refer to define the condition of sub-surface water table causing effect on growth and yield of crops. Hardly one finds any definition of waterlogging and drainage congestion linking the blockage of surface water which arises due to inadequate passage of draining out the monsoon water. Waterlogging and drainage problems of such nature, in one hand, cause flooding to areas suitable for kharif crops, resulting in loss of productivity, on the other hand, affects the socio-economic aspects of the region. The problems of Mokama group of tals in Central Bihar, comprising a depressed land of about 1062 km2 are an example and a long standing issue to the water resource planners in terms of management of such a complex problem, and loss incurring in agricultural front.

The drainage basin which contributes water to the tal areas, has a network of number of tributaries with its main stem known as Kiul-Harohar comprising about 17,223 sq.km of catchment area. The upstream catchment of the basin has steep slope of mountains with cultivable areas in pockets between them, whereas the middle stretches have mild slope of plain lands, and reaches to the flatter slopes as one moves towards the lower stretches where tal areas are located. During monsoon, upstream water translated very fast to the lower stretches with high peak of hydrograph, which the lower stretches is not capable of draining out through its single outlet joining the river Ganga. On the other hand, the water level of the river Ganga during monsoon, remains above the water level of tal areas. As a result, instead of creating passage for draining out the tal waters, it creates back water pressure which leads to a complete blockage of water till end of September, i.e., till the water level of Ganga recedes. Just after the monsoon, the upstream and middle catchment suffers in deficit of soil moisture content leading towards loss of agricultural productivity, while the downstream catchment remain under submergence due to blocked water. A dimensionally opposite problem is thus in evidence in the catchment.

A number of high level committees and experts attempted to find out solutions of this problem, however, as such no investigations could give a quantitative approach of management which involves maintaining hydrological balance of the basin.

Keeping the above points in view, the study presented here in addresses development of a management model aimed at minimization of the waterlogged area which is equivalent to maximizing the cropped area in the Tal under the constrains of check over inflows into the tal. The checks over inflows are again subjected to the water requirement of crops in the upper catchment. A two-tier maximization problem has been envisaged and solved setting 164 numbers of constraints both for Rabi and Kharif seasons. The quantitative and qualitative figures of the constraints are based on the field data and available information, and thus can be regarded as realistic assessment. Different scenarios of check over inflows and corresponding benefits have been analyzed and results of best alternatives have been included in the report. The report also addresses the extent and analyses of the problem in terms of hydrological variables.

1.0 INTRODUCTION

The term "Waterlogging" is usually refer to define the condition of sub-surface water table causing affect on the growth and yield of crops. It is customarily linked with balance of the sub-soil water table and the soil pores in the crop root zone. Accumulation of surface runoff, and thereby stagnation of water over the depressed lands due to the restriction of natural passages of water which may arise because of inadequate surface drainage or due to the higher water level elevation at the out-falls also cause waterlogging which is termed here as surface waterlogging. In fact, there are hardly any separate definitions to define surface waterlogging. Waterlogging and drainage problems of such nature cause flooding of areas suitable for Kharif crops, resulting in loss of productivity. Stagnation of water for a longer period besides affecting agricultural activities of the area due to the rise of sub-soil water table also affects the socio-economic aspects of the region. The problems of surface waterlogging and drainage congestion over depressed land of 1062 km^2 in Mokama tal area of Central Bihar are a long standing issue to the water resources planners in terms of management of such a complex problem, and loss incurring in achieving the requisite agricultural return.

As such, one finds no reasons of not getting a scientific solution of the problem when it is looked in overall perspectives of water resources management of basins contributing water to the tal area with intention to manage the incoming flows over time and space. A number of expert committees [details have been given elsewhere, NIH, CS(AR)-194] constituted both by the Govt. of India and Govt. of Bihar, had suggested various remedial measures to combat the situation. As such, hardly any attempt was made to quantify the problems and in evaluation of the remedial measures. Keeping in view the recommendations of various experts committees, the study of the "waterlogging and drainage" problems of tal area has been envisaged and addressed.

Based on type and nature of problems, waterlogging is defined in many ways. For example, according to Bureau of Indian Standard (BIS) [IS: 11493-1986] waterlogging refers to the condition of land in which it can not be put to its normal use as a result either or both of high water table and surface ponding. While the Central Board of Irrigation Power (CBIP) has defined waterlogging as; the rise of water table to an extent that the soil pores in the root zone of a crop, become saturated, resulting in restriction of the normal circulation of air, decline in the level of oxygen and increase in the level of carbon-dioxide. These definitions of waterlogging also refer that it depends upon the nature of soils and sub-soil. Eventually these reflect that waterlogging of an area in general is linked with sub-surface soil conditions.

In the lower gangetic plains, because of the flat nature of the country, and large scale topographical abnormalities, and also due to the hap-hazard alignment of roads, railroads and canals, large area experience afflux of flood waters during rainy reason causing inundation and stagnation of water which in turn increases the water table and soil moisture content. On the right bank of the river Ganga in Central Bihar, a large area locally known as "Mokama Tal area" has been reported to be experiencing the submergence of water every year particularly; during the monsoon period occurring from June through September. Reasons of submergence and stagnation of water have been reported to be due to the ineffective drainage system and blockage of water discharges by the different tributaries joining the tal area. Over most of the area, irrigation is perennial and consequently the inflow is considerable and the corresponding outflow is poor. Thus resulting in surface ponding of water for a period of about four months. During this period, in one hand, no crops can be harvested on the waterlogged area, on the other hand, a huge quantity of water is drained out from the upstream catchment. A number of attempts was made by different organizations and committees to find solutions of this problem, however, no investigations, as such, had quantified the magnitude of hydrological variables and the approaches to be followed in the remedial measures, and how much water is to be checked at the upstream to maintain a hydrological harmony in the whole drainage basin.

The report describes a management approach of the "waterlogging and drainage congestion problem of the tal area" which has been addressed through an optimization problem intending to maximize the expose area of the Tal commands (i.e., minimization of waterlogged area) under the constraints of check over inflows entering to the tal area during the monsoon period. The check over inflows has been demonstrated keeping in view the beneficial uses of water require at the different irrigation commands of the respective tributaries. Different scenarios of inflow restriction and its effects to the Tal area have been analysed and presented in the report.

2.0 DESCRIPTION OF THE PROBLEM

Tal is a local name of impounded water bodies created naturally by the abnormalities of topographical variation. Mokama group of Tals consisting of 7 tals which are connected in series and known by different names in different stretches (**Fig 2.1**), is a combination of naturally created and man-made obstructed water barriers with its sustenance of about 4 to 5 months in a year. The tal area is located around the right bank stretches of the river Ganga within Central Bihar. Several north flowing rivers of South Bihar have their outfalls in the Mokama group of Tals. However, the only drainage of the Tals' water is through river Harohar. During monsoon period, inflow from north flowing river and the pressure of backwater of the river Ganga often delay the drainage of tals' water. Most of the Tals remain under submergence almost with a frequency of 8 to 9 times in every 10 years, with a degree of submergence of about 50 % and more of the Tal area. This is obviously a very unique situation. Due to submergence of the Tal area, during monsoon period land resources are excessively under utilized and crop productivity, particularly; Kharif crops are hampered. The Rabi crop also suffers when the drainage of the Tal is delayed beyond the 15th of October. As a result, in one hand the agricultural return of the area is observed to be in the lesser side, on the other hand, problems of flood and its hazards are inevitable. The extent, magnitude and causes of water logging problem of Tal area are discussed in the following sections.

2.1 Malady and Magnitude of Water logging

The problems of water logging of the Mokama tal area can be classified in two categories: one due to the accumulation of water in low lying areas called Chaurs and Mauns which is partially locked due to poor drainage condition, and the other due to the surplus water and irrigation induced water. In general, the flood problem in the Kiul-Harohar river system is limited to the problem of poor drainage condition in the Tal area. In addition to discharge from the streams draining into the Tal, this area also gets spilling water from the Punpun river in the West and from the Ganga which finds its way into the Tal by overtopping the Patna-Monghyr road running parallel to the Ganga at some places and also through some culverts. Flooding is also caused by the entry of backwater of the river Ganga through the river Harohar. The only drainage outlet of the Tal is the river

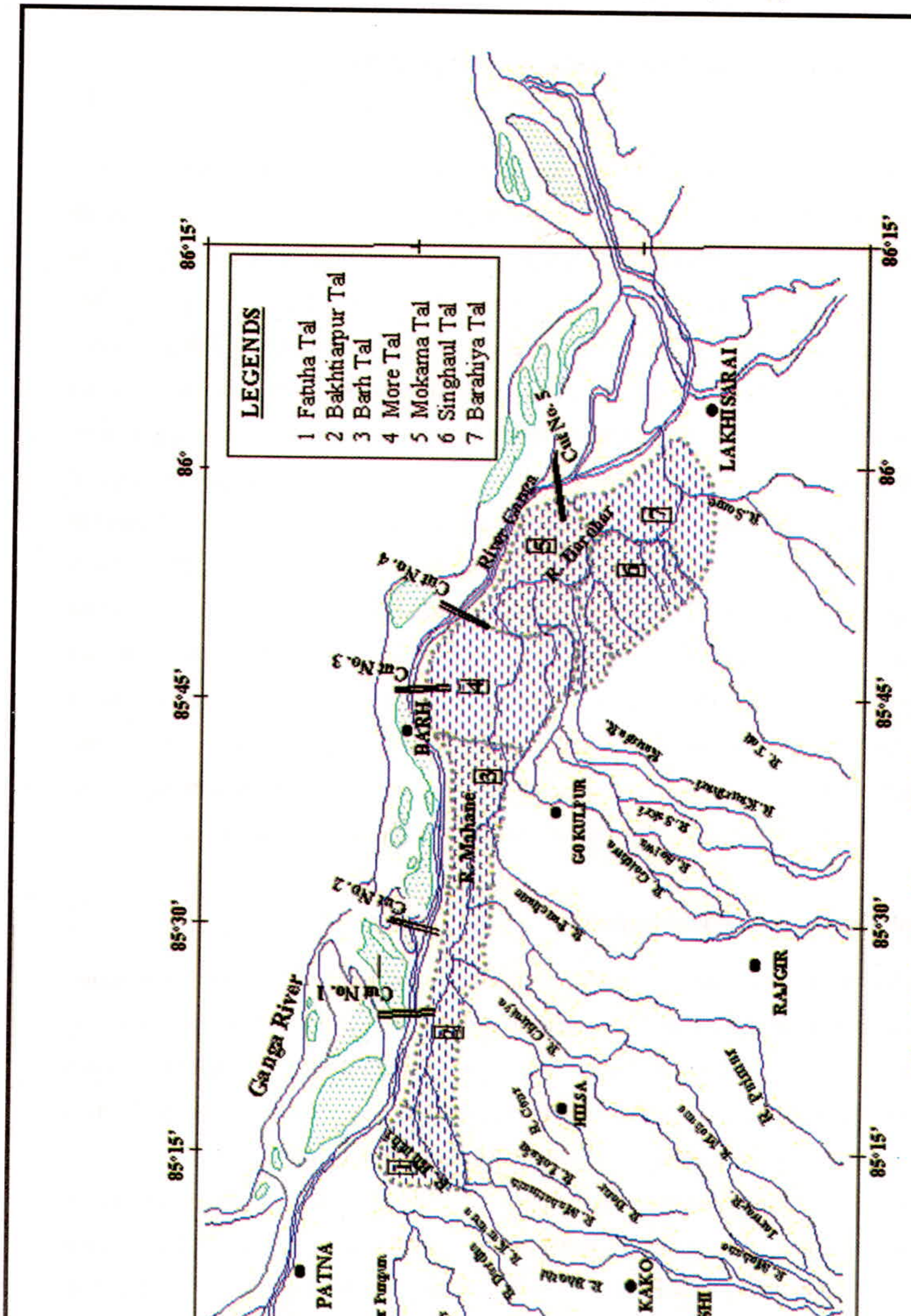


Fig. 2.1: Index Map of Mokama Group of Tals

Harohar-Kiul, which has inadequate drainage passage to drain out the total Tal water. Consequently, the land remains submerged practically up to the middle of November.

The upper region of the Kiul-Harohar catchment has very steep slope. Flood peaks originated by heavy rains, can not pass off quickly and there by accumulates in the lower region where the terrain is flat. Due to the peculiar topographical configuration, the floodwater continues to accumulate and vast tract of low-lying land is subjected to flooding. Harohar river, which is the ultimate drainage channel for the Tal, due to its inadequate drainage passage can not manage to drain out the flood water towards the Ganga resulting towards flooding in the vicinity. The flooding is more acute particularly when the level in the Ganga remains above danger level for long duration.

There are some internal drainage channels which connect the Mokama group of Tals to the Dhowa and the Harohar rivers. Although these channels help in draining the Tals' water but also lead to the winter flows into the low pockets and submerge the Rabi crops.

The river Kiul (the tributary of Horahor) usually spills over through its banks in the lower reaches near Lakhisarai. Occurrence of flash floods in the rivers Sakri and Falgu (tributaries of Horahor) is often and create drainage congestion problems. In recent past, the maximum depth of submergence was recorded in the year 1987, which varied from 3.86 m in Fatuha Tal to 5.76 m in More and Mokama Tals. Submergence frequencies of various Tals from 1972 to 1991 are presented in **Figure 2.2** to **Figure 2.8**. Fatuha Tal, Bakhtiarpur Tal, Barh Tal and More Tal have the submergence frequency (**Fig 2.2** to **Fig 2.5**) between 50% and 75% in 5 to 8 years. While the frequency of same submergence (**Fig 2.6** to **Fig 2.8**) seemed to be very high for Mokama Tal, Barahiya Tal and Singhul Tal (11, 16 and 15 years respectively) .

2.2 Water Logging in Tal Area – Its Causes

There were a number of facts finding committees constituted by the Govt. of India and State Govt. to identify the major causes of water logging in the Mokama Tal area. The following are the long felt major causes of water logging in the Tal area.

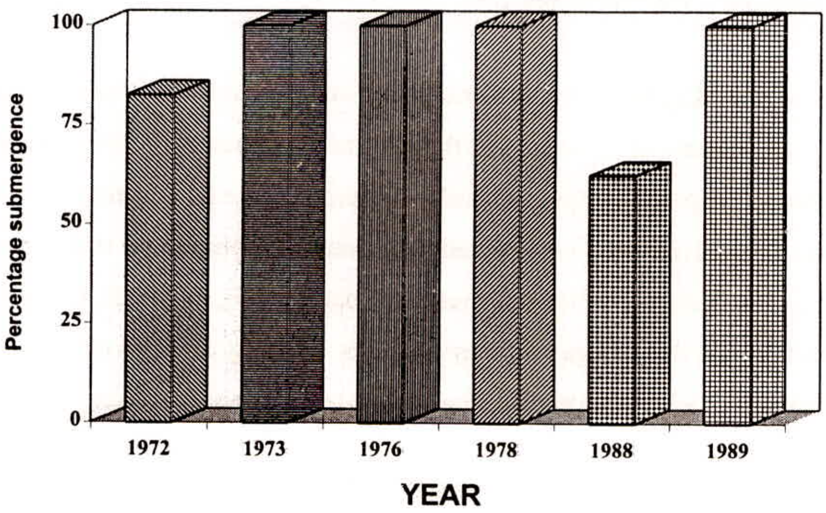


Fig 2.2: Frequency and Magnitude of Submergance in Fatuha Tal

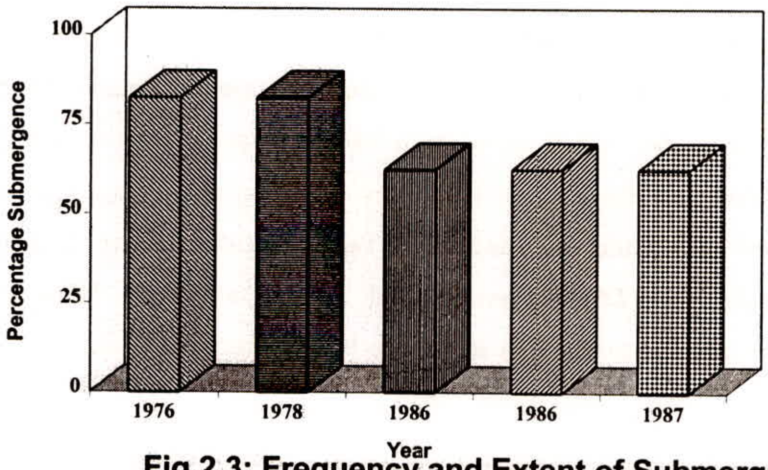


Fig 2.3: Frequency and Extent of Submergence in Bakhtiarpur Tal

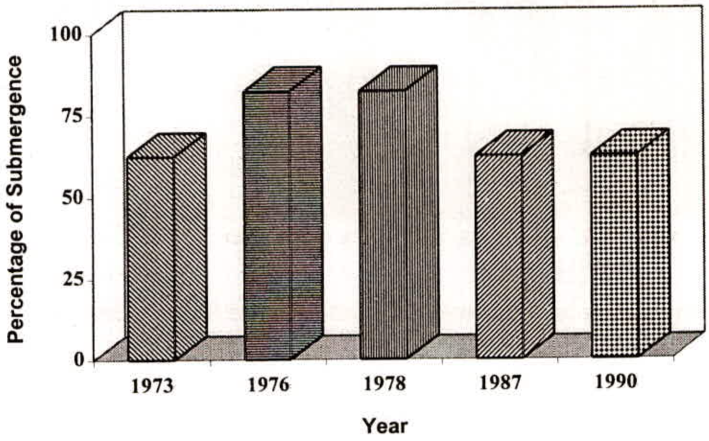


Fig 2.4: Frequency and Extent of Submergence in Barh

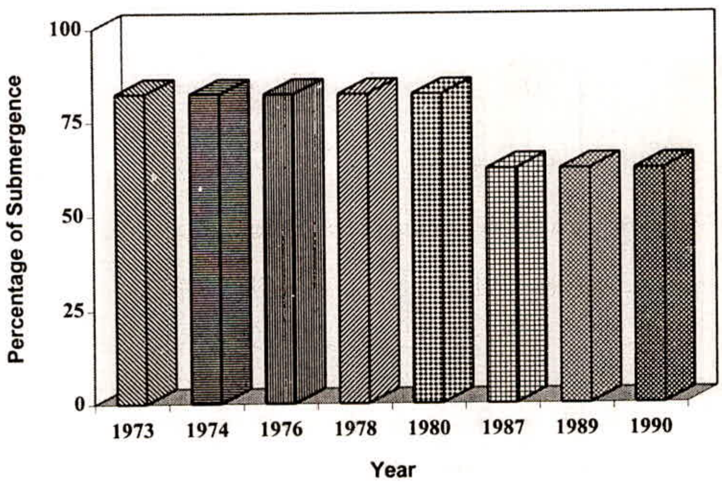


Fig 2.5: Frequency and Extent of Submergence More Tal

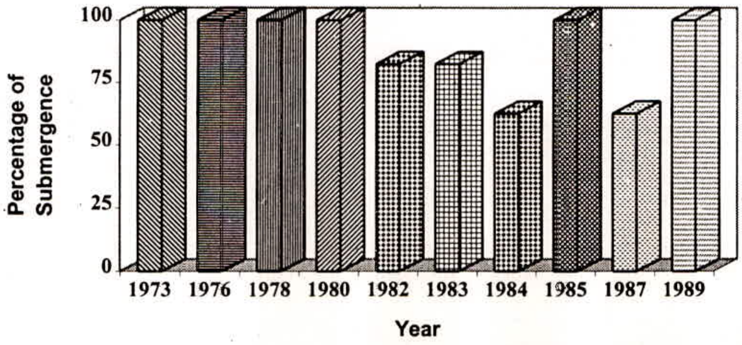


Fig 2.6: Frequency and Extent of Submergence in Mokama Tal

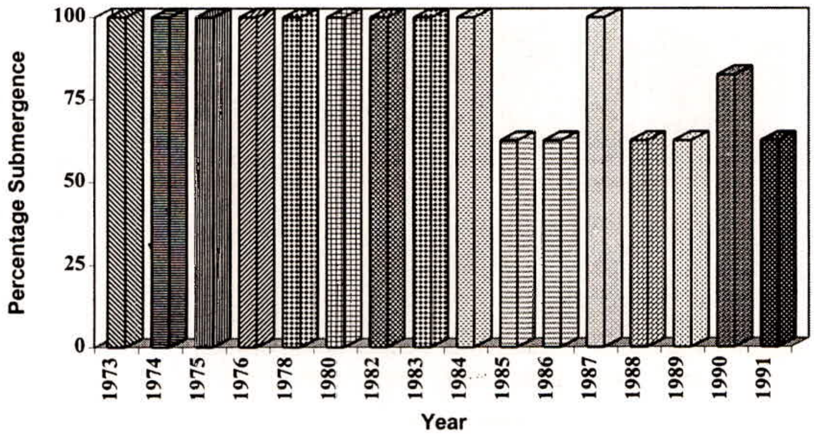


Fig 2.7: Frequency and Extent of Submergence in Barahiya Tal

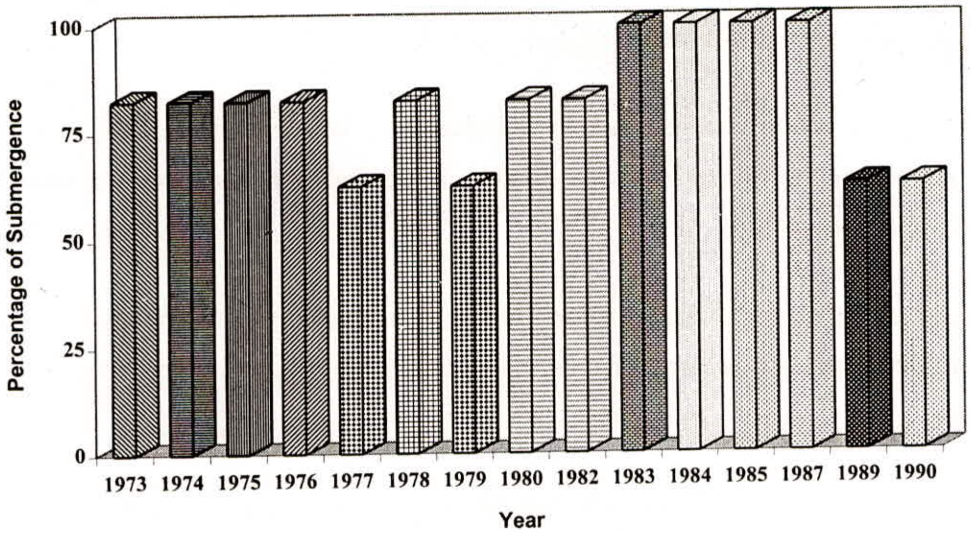


Fig 2.8: Frequency and Extent of Submergence in Singhual Tal

1. Total catchment area of various rivers draining into the Tal is 13,340 sq.kms against the total submergence area of 1062 sq.km. which indicates that even keeping the Tal is dry, the incoming water from the catchment of different tributaries can appreciably submerge the Tal area with a moderate runoff of 15 cm (Mokama Technical cum-Development Committee, 1988) . Inundation during monsoon period in the Tal area is mainly caused by the runoff of different rivers joining the Tal area.

2. The entry of backwater of the river Ganga by back flow through the river Punpun also causes additional pressure towards water logging in the Tal area.

3. The topography of the area does not provide passage to ensure drainage till the Ganga water level starts receding. Thus, often the drainage is delayed and some times progresses up to middle of the November.

4. There are no regulating arrangements in Harohar, which could prevent the entry of backwater of Ganga through Harohar, and also there is no provision to check the entry of backwater to the tal area.

5. Inundation is also caused by back flow through valley lines along the Fatuha-Lakhisarai road.

6. The paddy crop, in the double crop area (high lands) is damaged even during normal flood.

Beside the above causes, some other reasons e.g. road barriers, inadequate opening of bridges, and improper land and water management etc. also equally responsible for exaggeration of the problem. After critically examining the area and nature of waterlogging, possible reasons has been grouped into a schematic form. **Figure 2.9** indicates the schematized form of the problems in Mokama Tal area with their linkage to the hydrological factors.

Generally, the Tal area faces two types of extreme problems: flood and famine; the former one is due to the inadequate drainage while the later one is due to the shortage of irrigation water needed for cultivation of Rabi crop. A common concern among the users and beneficiaries is that the drainage problem of the Tal area is required to be solved to ensure timely drainage after the

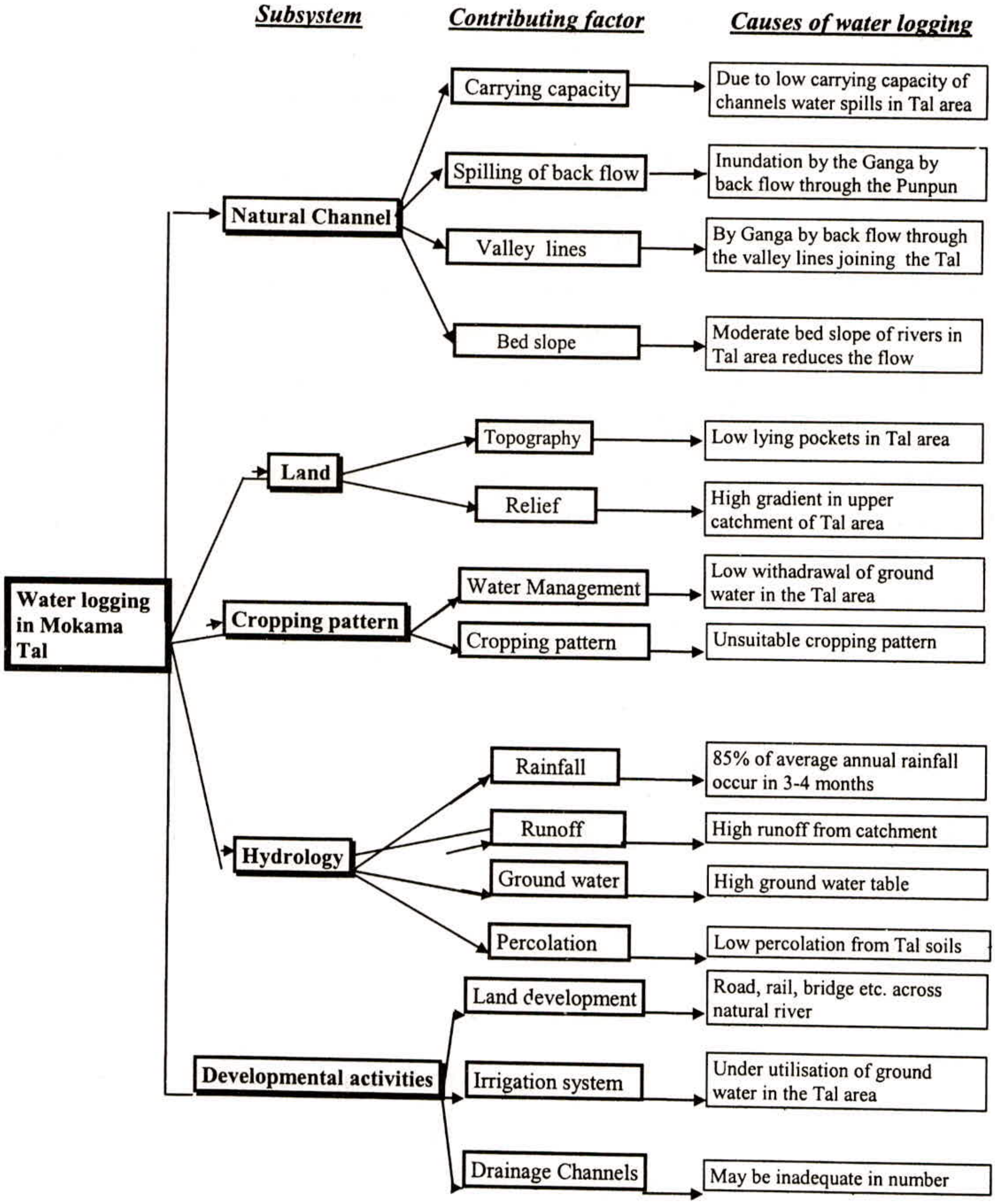


FIG. 2.9 : POSSIBLE CAUSES OF WATER LOGGING IN MOKAMA GROUP OF TALS

monsoon flooding in order to make efficient Rabi cultivation. Water logging hampers Rabi cultivation during the years when; (a) the Ganga water level at the out fall point remains persistently high after the end of September, and/ or, (b) there is heavy runoff contribution from the north flowing rivers draining into the Tal. Due to the proneness of the Tal area to frequent inundation, the agricultural activities and productivity during the wet season is very 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 area by the 15th October is very crucial. Delay in getting drained the Tal water adversely affects the Rabi crop. **Figure 2.10** shows the frequency of years in which different Tals were free from submergence by the 15th of October within the period from 1972 to 1991. It is also clearly evident from the figure (2.9) that the Rabi crop suffers irreparably due to the delayed drainage of Tals.

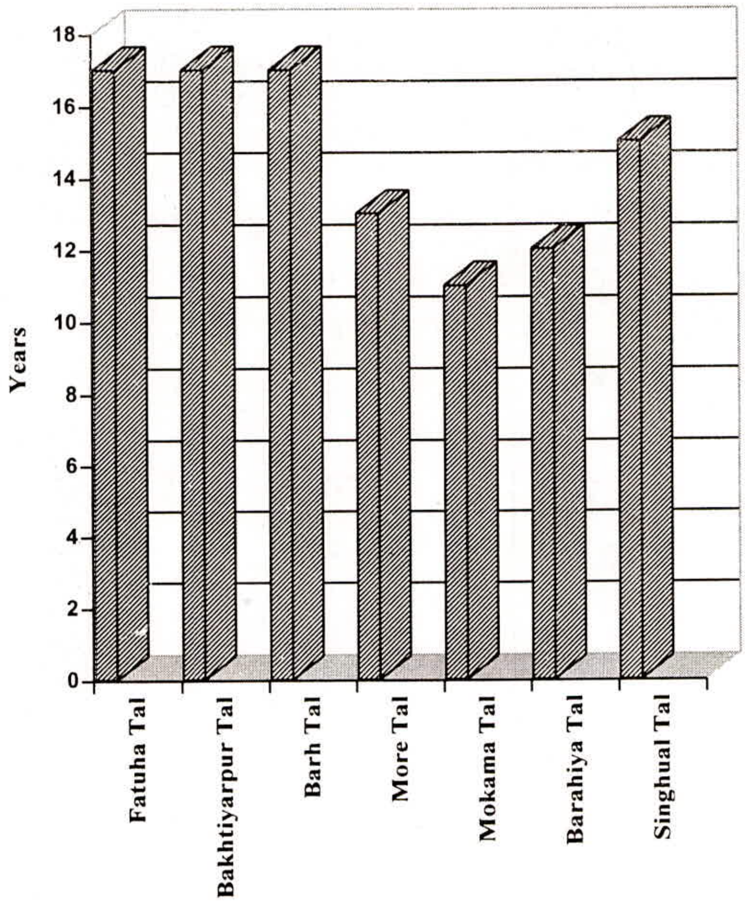


Figure 2.10: Frequency in Years in which Tals were free from submergence by 15th October

3.0 RECONNAISSANCE OF THE PROBLEM

Being located in the lower middle stretches of the river Ganga, the Gangetic plains within the Bihar State mostly have flat topography, and most of the tributaries joining the river Ganga in stretches within the State have either Himalayas origin or Vindhayas origin or Chottanagpur plateau origin. Tributaries joining the Mokama group of Tals are mostly Chottanagpur plateau origin.

In one hand, due to the abnormalities in topographical variation (steep to milder), on the other hand, presence of depressed lands (locally known by "Tals" or Mauns created due to seismic disturbance or due to the shifting of river courses), during monsoon period upstream runoff gets blockade in the outfalls because of inadequate passage of drainage, or gets entrapped over the depressed lands. Large scale inundation of monsoon of water and its retention for a longer time (usually observed to be of 4 months from June to September) rise the groundwater table causing complete saturation of sub-surface soils also. Deteriorated situation of sub-surface effects the agricultural activities for Kharif crops and, in some parts, it continues till beginning of November /December resulting in non-productive state of Rabi crops also.

In Bihar, out of its total geographical area of 1,73,876 km^2, about 9,000 km^2 area has been reported to be facing the problems of surface waterlogging and drainage congestions. Out of the 9,000 km^2 of waterlogging area, about 7,938 km^2 constitutes the waterlogged area in North Bihar while remaining 1,062 km^2 is in Central Bihar. This, 1062 km^2 of waterlogged area comes under "Mokama group of Tals". The problem of water logging in North Bihar is different than the problem in Mokama group of Tals. In North Bihar, it is due to the excessive pressure of inflows over a shorter duration, while in the Central Bihar a large area in one stretch which is saucer in shape, acts as receiver of surface runoff and creates water logging in the area till end of September. As a result, these areas can not put for use to grow Kharif crops. Though the Tal area is normally got drained out by the end of September, but the saturated condition of sub-surface effects the cultivation of Rabi crops in about 50% of the Tal area. There exist a common belief among the farmers that due to the condition of water logging in every year they could harvest bumper crops (even from one crop) from the Tal area. While in the upper stretches (total Tal catchment) of the drainage basin, cultivation of Rabi crops and also in many places Kharif crops suffer because of scarcity of water.

The problems of surface water logging and drainage hazards in the Tal area and scarcity of irrigation water in the upper commands of the Tal basins are serious concern among the water resources planners, users and beneficiaries, and also to the researchers. Since nineteen seventy the Water Resources Department of Government of India, and Government of Bihar have been attempting for identifying the malady of water logging in Mokama Tal and its possible solutions. Some of the important attempts are: i) *Dr.K.L.Rao (1970 and 1972),* ii) *Sri C.C. Patel (1976),* and *Mokama Tal Technical-cum-development committee (1988).* An account of the chronological development highlighting the approaches and achievements is presented in following subsections.

3.1 Dr. K.L. Rao's Recommendations (1970 & 1972)

Dr. K.L. Rao, the then Union Minister, Irrigation, visited the Mokama Tal on August 22, 1970. During his first visit he recognized the severity of the problem and suggested the following measures:

i. *Draining out the water from the Tal quickly so that the area is available for cultivation. Presently land is available for second crop only.*
ii. *To provide water for irrigation by Tubewells and pumping from the river Ganga.*

Further, he suggested the following comprehensive preventive scheme for the Mokama Tal area:

i. *Prevention of the Punpun water coming into the Tal by constructing embankment on the right side of the river Punpun.*
ii. *Investigation of dam site on the upper reach of the various rivers that flow into the Tal to retain water.*
iii. *Draining the area by construction another 2 or 3 outlets to Ganga.*

iv. *Preventing entry of Ganga water into Tal area by constructing Anti-Flood Sluice in Harohar river.*

v. *Confining flooding within embankment by constructing embankment along the both banks of the river if necessary.*

vi. *Preventing flow of various streams entering into the Tal by constructing parallel drain on the upper reach so that the water of these streams may be trapped there and diverted.*

Again on 12th July 1972 Dr. Rao visited the Tal area. He highlighted the problems of Tal area and suggested the following:

a) Requirement in Tal area

i. *Water in the Tal must be drained out by 15th October every year.*

ii. *Irrigation water must be available after 15th October to end June.*

iii. *Water from South side must be prevented from entering Tal low areas.*

iv. *Rabi cultivation gets delayed due to inadequate drainage outlet for in-flood from 5150 sq. miles.*

b) Schemes Suggested

He suggested the following schemes.

i. *Construction of storage reservoir and embankment on right side of Punpun river to check flow into Tal.*

ii. *Construction of Anti-Flood Sluice on river Harohar.*

iii. *Construction of embankments on both banks of Harohar river with outlet sluice for taking water for irrigation.*

For the solution of water logging problem in Mokama group of Tal he further stressed for the adoption of following techniques:

a) *Adoption of Mathematical modeling and system analysis technique for getting a proper solution of Mokama Tal problem.*

b) *Setting up of hydraulic model from Patna to Munger for studying flood control measures of Tal area.*

3.2 Recommendations by Sri. C.C. Patel, Secretary, GOI (1976)

A high level technical committee was set up for studying the water logging problem of Mokama Tal. The committee was headed by Sri C.C. Patel, the then Secretary, Government of India. On February 5, 1976, the committee inspected the site and suggested the following measures.

I) Long Term measures

i. *Construction of reservoir in the upper catchments of the rivers, which enters the Tal area, proposed to intercept 25 percent of the total catchment area.*

ii. *To collect all the inflow of rivers, coming into the Tal and to drain them into the river Ganga. It is proposed to construct a drainage channel for this at higher contour on the southern periphery of Tal area.*

iii. *It is proposed to adopt soil conservation measures and contour bounding in the hills on the south of Tal area to reduce inflow into the Tal.*

II) Short-Term Measures

i. *To stop inflow of Punpun river into Tal areas.*

ii. *Following measures were suggested to stop entry of Ganga water in the Tal area and early depletion of Tal water.*

   a. *Construction of Dowel Bundh between Barh and Bariyarpur in the Patna-Munger road where Ganga water overtops the road.*

   b. *To stop the flow of Ganga water through the bridges and culverts in Patna-Munger road and construction of the sluices therein.*

c. *Construction of marginal bundh from Indupur village to the confluence of Kiul-Harohar- Ganga.*
d. *Construction of anti-flood sluice in the river Harohar along-with construction of afflux bundh. Sill level of this sluice should be such that some water can be retained in the Tal area for irrigation in the Rabi season.*
e. *Construction of 13.00 km. long embankment on the right side of the Punpun river to stop backwater of Ganga from entering Tal through Punpun river.*
f. *Construction of a channel on the up stream of the Kuil-Harohar confluence for discharging the flow of Harohar into Ganga directly.*
g. *"S" loop between Balgudarghat should be made straight.*
h. *For allround development of the Tal area, Tal Development Committee should be formed.*

3.3 Recommendations by Mokama Tal Technical-Cum-Development Committee (1988)

On November 29, 1982, the Government of Bihar constituted the Mokama Tal Technical Committee. The terms of reference of Technical committee were as under:

a) *To recommend possible schemes for mitigating the water logging problems in the Mokama Tal area.*
b) *To recommend about irrigation schemes for providing irrigation facilities in the Mokama Tal area.*

The committee submitted an interim report on 18th May 1983, in which the needs for further studies and collection of further data were stressed.

On June 28, 1984, the Irrigation department reconstituted the Mokama Tal Technical Committee as Mokama Tal Technical-Cum-Development Committee headed by Shri N. Sanyal. The committee recommended the following measures.

I) Possible schemes to mitigate the water logging problems

a) Construction of embankment along the right bank of Punpun

Embankment along the Right Bank of the river Punpun and the river Morhar can prevent inundation caused by the Ganga by back flow through the Punpun. It was proposed to construct an embankment from the rail bridge approach embankment near Fatuha to some few kilometers upstream up to the reach influenced by the backwater of the Ganga. It was suggested that the right bank embankment of the Punpun and Morhar which was under execution, should be expeditiously completed to cease off backwater inundation.

b) Construction of Road side dowel/embankment

The committee has observed that construction of roadside dowel and renovation of road embankments in isolated lengths would be necessary to prevent entry of the Ganga spill in the Tal area through the low lying of the Road.

c) Construction of Anti flood sluice

By constructing a suitable anti-flood sluice, the inundation caused by the Ganga back flow through the Balgudarghat bridge over the Harohar can be eliminated. As the drainage of the Tal occurs entirely through the Harohar, caution is needed in finalising the dimensions of the waterway of the anti-flood sluice, so that there is no vertical or horizontal construction of the available waterway. This sluice could be located immediately up stream of the road bridge as the river Harohar has some length of depended bed immediately downstream of the road bridge. The sluice should be a barrage like structure with a crest almost flush with the river bed and on account of head the gate may have to be two tiered or radial.

d) Excavation of channel

Ingress of water of north flowing rivers could be prevented by having a west-east excavated channel, that is an artificial or man made river which shall intercept all these north flowing rivers before they enter the Tal and carry the water of these intercepted rivers directly to the river Kiul at a higher level where the Kiul shall not be flood-locked by the back water of Ganga. Such a channel shall be costly but the benefits will also be enormous. Once the dug channel is completed the Tal area itself which at times may be more than the requirement of Kharif cultivation. This would mean that almost the entire Tal area of more than one lakh ha can be available for Kharif cultivation as well, where as the present Kharif cultivation is rather a chance crop. Thus, the Tal area developed as a Kharif growing area may be a major break through in the effort of the State to expand the Kharif production.

e) **Using Tal as flood detention basin**

Committee reviewed the possibility of using the Tal as a flood detention basin to moderate the peak flow of the Ganga. The cutting off of the flood plain storage accentuates the peak flow in the Ganga, which needs to be remedied by suitably located flood moderation detention basins. Mokama Tal already a chronically inundated area can be effectively used as a flood moderation detention basin. In case the scheme materialise, the cultivators in the Tal area should have to be given prior warning of a dependable nature before such deliberate inundation.

f) **Providing Cuts for draining Mokama group of Tals**

The issue of expediting the drainage of Mokama group of Tals by having cuts at various possible alternative sites be reviewed after the data of dependable nature be collected for some 7 to 10 years, to adjudge the technical and economic viability of each of the possible cut sites.

g) **Selection of suitable Cropping pattern**

The committee noted the availability of a fairly large range of water resistant varieties of Kharif crop and the rapid pace in which new varieties are being introduced and felt that the Tal area should be classified in different zones with relative degree of proneness and magnitude of inundation so that the specific variety which would be most suited to the specific characteristic of a particular zone could be introduced there through demonstration plots and other extension services.

II) Irrigation Schemes to Provide Irrigation Facilities in the Mokama Tal area

a) State tubewells

State tubewells are considerably under-utilised. Results of existing tubewells indicate significantly good figures of irrigation potentiality of existence of suitable aquifer underneath.

b) Private tubewells

So far as private tubewells are concerned their availability depend on the socio-economic condition of the farmers. There are few private tubewells within the area. Other sources of irrigation like river pumping, but there is no notable pumping from the rivers have been reported.

c) Lift irrigation schemes

The area of the Tal north of the Harohar has some lift irrigation from the Ganga, and such lift irrigation schemes are usually used to irrigate the high land between the Ganga and the Tal.

d) Sluice across the Harohar

Keeping in view all these factors the committee did not favour any sluice across the Harohar for irrigation purpose and felt that the recommended anti-flood sluice near Balgudarghat should not be misused for retaining water in Tal, which may encourage conflicts between cultivators of lower land and upper land.

III) Development Aspects in Mokama Tal Area

a) Prevention of ingress of the Ganga spill

A doubt was raised as to whether prevention of ingress of the Ganga spill would not reduce the fertility of the Tal, as it would be deprived of the silt brought by the Ganga. In this context, the committee noted that after centuries of ingress of the Ganga water and so called deposit of silt on the low land of Tal, the Tal still continues to be a depressed land. This indicates that the deposition of fertilising silt must be microscopic in nature, as otherwise the Tal should have been filled up as a level land by now. Possibly the effect of silt deposit is confined to the fringe area where the incoming silt gets deposited. The fertilising benefit of this small quantity of silt that might be there shall have to be compensated by natural and artificial fertilizer, like any other inundated area, which is, made flood free for better agriculture.

b) **Effect of Reduced inundation**

Some apprehension was expressed before the Committee that reduced inundation may enhance the problems of insects and pests in the Rabi season adversely affecting the crop. This aspect needs further research study to evaluate the validity of such apprehension. But it is felt that this problem can be suitably tackled with judicious agricultural practice, such as; by proper selection of type of crop and use of appropriate doses of insecticides and pesticides.

c) **Distribution of land**

If the development of intensive irrigated Rabi and Hot Weather agriculture is to be achieved, an appropriate land-water management is needed.

d) **Communication system**

Better communication system in the Tal area should be developed, but at the same time care, should be taken that new roads are provided with adequate waterways to permit free passage of Tal water during wet season.

3.4 Suggestions by Second Bihar State Irrigation Commission

Though cultivation is done in almost entire area of the Tal, but for want of water, scientifically irrigated cultivation is not being practiced. It is an irony that though the Tal is full of water during the monsoon season, the same is not available at the time of Rabi cultivation. The following measure have been suggested to meet these exigencies:

- **Construction of anti-flood sluices ,**
- **Raising and Strengthening of Zamadari Embankments,**
- **Renovation of pynes,**
- **Closure of Culverts and Construction on Anti-Flood Sluice,**
- **Construction of tanks/ponds in Tal area,**
- **Construction of high level land on southern periphery,**
- **Construction of Barrage across the Punpun,**
- **Development of private tubewells.**

3.5 Status of Remedial Measures

The Government of Bihar accepted some of the recommendations pertaining to development of the land and water resources of the Mokama Tal areas. The Water resources Department, Govt. of Bihar had prepared the schemes for tackling the problem in phased manner.

a) Phase I of Scheme

Phase I of the schemes was prepared to execute the following works.

i. Excavation and renovation of drainage channels connecting low lying pockets with Trunk River Harohar, Mohane and Dhowa.

ii. Construction of bed-bar cum regulator at the outfall of each drainage channel into Harohar in order to prevent to retrogression and also to regulate flood water.

The scheme is prepared to achieve two objectives (i) accelerating drainage during the kharif season and (ii) storing water especially during winter rains in December and January for Rabi irrigation. These works for cutting and renovating 16 numbers of existing channels connecting local depressions in the Tal with the main outlet channel, i.e. the Harohar were completed in 1969.

b) Phase II of Scheme

In Phase II, construction of Punpun right bank embankment for a length of 14 km was taken up and it was reported that 60 percent have been completed. The embankment is expected to prevent the spill of the Punpun river and the backwater of the Ganga through the Punpun from entering the Tal areas from the Fatuha end. This embankment may certainly provide much relief to Fatuha and Bakhtiarpur Tals.

c) Phase III of Scheme

The third phase of the scheme include provision of storage dams in the hilly catchment of the north flowing rivers into the Tals. Harohar, which flows from west to east in the middle of the Tal, receives water from various rivers originating from South Bihar hills. The Tal areas get filled up primarily due to inflow of these rivers. For providing real relief from extent and duration of submergence in the Tal area the importance of reservoirs, weirs, ahars, tanks, pynes and canals etc. in the catchment above the Tal in the south is visualised. Various storage dams **(Table 3.1)** suggested in the hilly catchments of the rivers flowing into the Tal.

Table 3.1: Storage Dams Suggested on the Rivers Flowing into the Tal

Sl No.	Name of the Reservoir	River
1	Fulwaria reservoir	Tilaiya
2	Dhadhar reservoir	Dhadhar
3	Lilajan reservoir	Lilajan
4	Mohane reservoir	Mohane
5	Sakri reservoir	Sakri
6	Job reservoir	Job

3.6 Priorities for future works

The State Govt. is planning to execute further works to reduce the submergence and facilitate agricultural operation in the Tal areas. These works are explained below.

1. It is decided to construct five cuts with anti-flood sluices at *Rukunpura*, *Rawaich*, *Ralley*, *Kanhiapur* and *Hemza* on Patna-Munger road with antiflood sluices to drain the Tal water into Ganga.
2. Raising and strengthening of 17 nos. of Zamidari embankments located at different places in the Tal areas.
3. There is a plan to renovate 63 nos. of Pynes.
4. Closure of 13 nos. of culverts on Patna-Munger road to stop entrance of the Ganga water into the Tal.
5. Providing anti-flood sluices in two culverts on Patna-Munger road to expedite drainage of Tal as soon as the Ganga water level permits it with antiflood sluices on them.

4.0 DESCRIPTION OF THE STUDY AREA

4.1 General

As mentioned earlier, the drainage area of the "Mokama group of Tals" is the Kiul-Harohar river basin. Hence, for the present problem and the proposed solution strategy, the Kiul-Harohar basin forms the study area. The following sections describe briefly the various river systems, topographical and physical features, geology, soils, land use, hydrology and cropping pattern in the study area. A brief description of "Mokama Group of Tals" is also presented.

4.2 Kiul-Harohar River Basin

4.2.1 Salient features of the river basin

The salient features of the river basin are as follows:

- The Kiul-Harohar river basin is situated between latitudes $24^{0}10'$ N and $25^{0}30'$ N and longitudes $84^{0}40'$ E and $86^{0}30'$ E.
- The total geographical area of the basin is 17223.5 sq. km. covering fully the district of Nawada and partially the districts of Patna, Jehanabad, Gaya, Hazaribagh, Giridih, Munger and Nalanda.
- The basin covers 26.11 percent of Patna district, 11.16 percent of Jehanabad district, 47.40 percent of Gaya district, 31.16 percent of Hazaribagh district, 18.31 percent of Giridih district, 67.63 percent of Munger district and 99.12 percent of Nalanda district.
- As per the 1991 Census Report, the population of the basin is 71.324 lakh, the intensity of the population being 473 persons per sq. km.

4.2.2 The river system

The river basin is bounded by the river Ganga in the north, Ajay and Badua-Belharna river basins in the east, North Koel and the Damodar Barakar river basins in the south and the Punpun river basin in the west. It consists of a number of tributaries like the *Mohane, Dhanyan, Sakri, Panchane, Tati, Some, Sukhnar, Barnar, Damar, Nagi, Nakti, Bajan, Ajan, Falgu* etc. besides the main stem *Kiul* and *Hahorar*. These tributaries are rainfed and carry very little discharge during non-monsoon period. The total catchment area of the Kiul-Hahorar river system is 17,223 Sq Km. 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 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 tributaries of the river system bifurcate and rejoin each other a number of times during the course of flow making it difficult to ascertain their exact length. Drainage pattern of the Kiul-Harohar river basin is shown in **Figure 4.1**. The contour, slope and relative relief of the Kiul-Harohar river basin are presented in **Figures 4.2, 4.3 and 4.4** respectively. The following paragraphs present a brief description of a few important tributaries in the river basin.

4.2.2.1 The River Kiul

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

4.2.2.2 The River Lilajan and Mohane (Falgu)

The river *Falgu* known as *Mohane* in the upper reach originates from 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 *Lilajan* is a major tributary of 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 finally known as the river *Dhowa*. Another

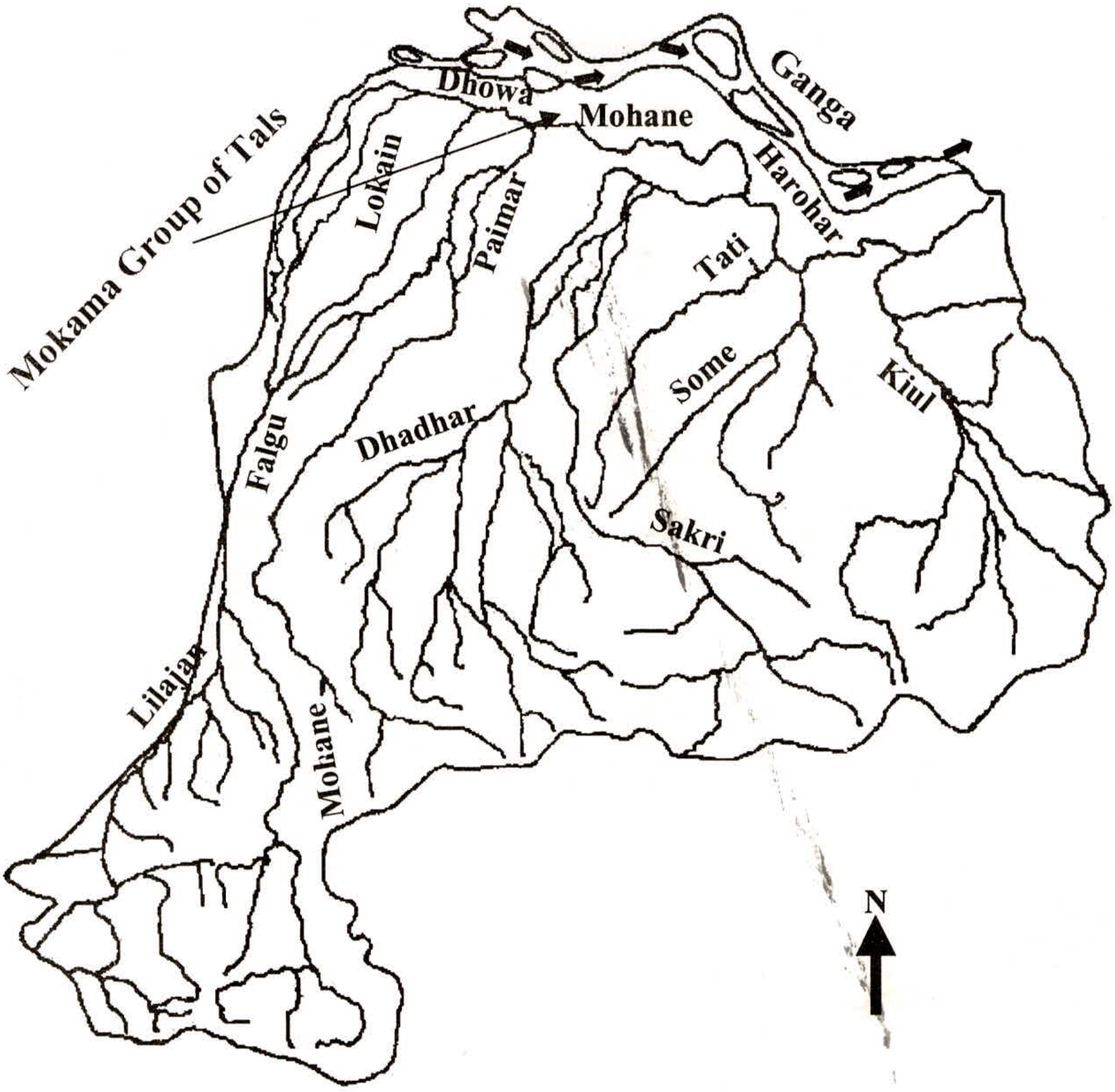


Figure 4.1: Drainage Map of Kiul-Harohar River Basin

Figure 4.2: Contour Map of Kiul-Harohar River Basin

(Contours are in metre)

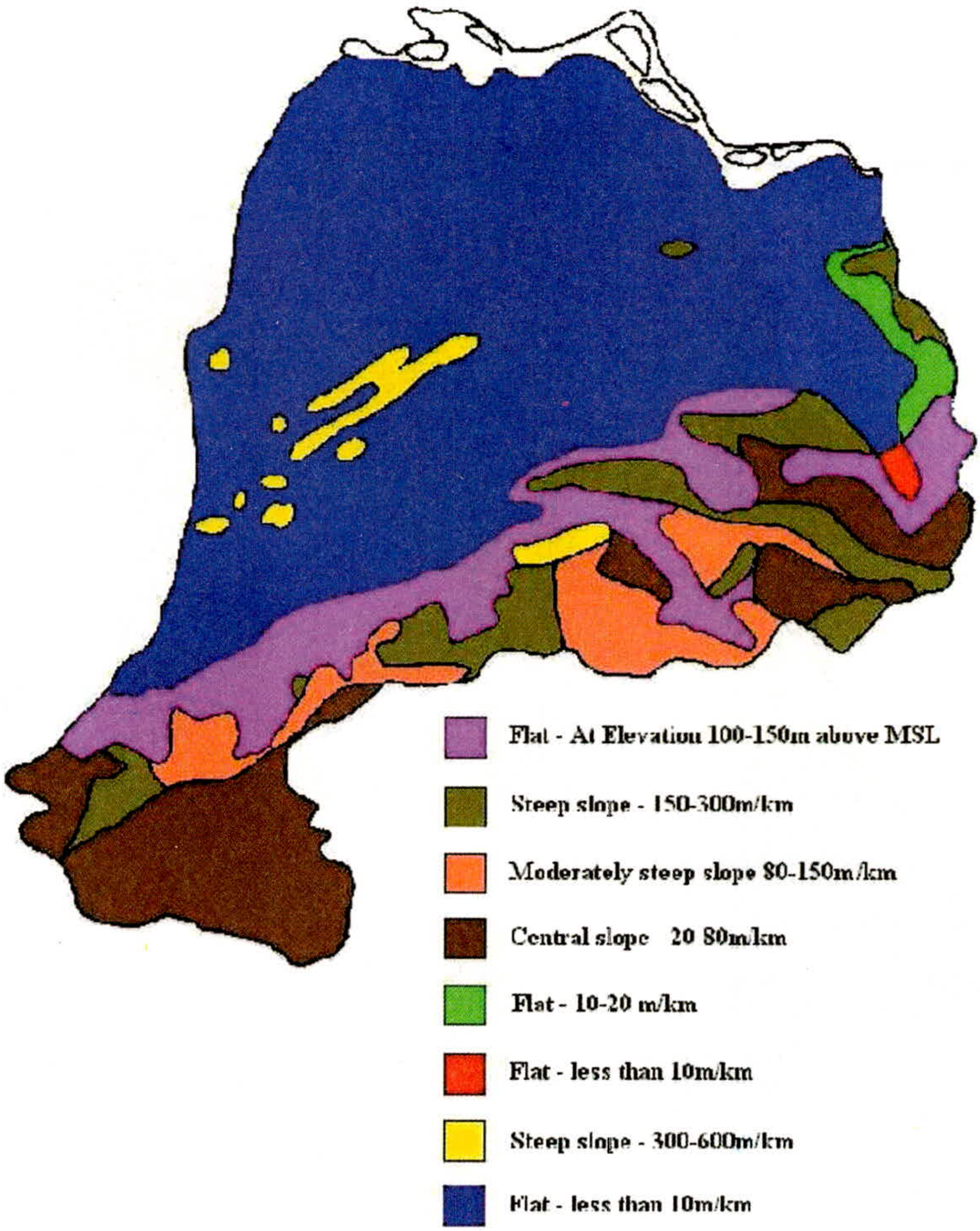


Figure 4.3: Different Slope Regions in Kiul-Harohar River Basin

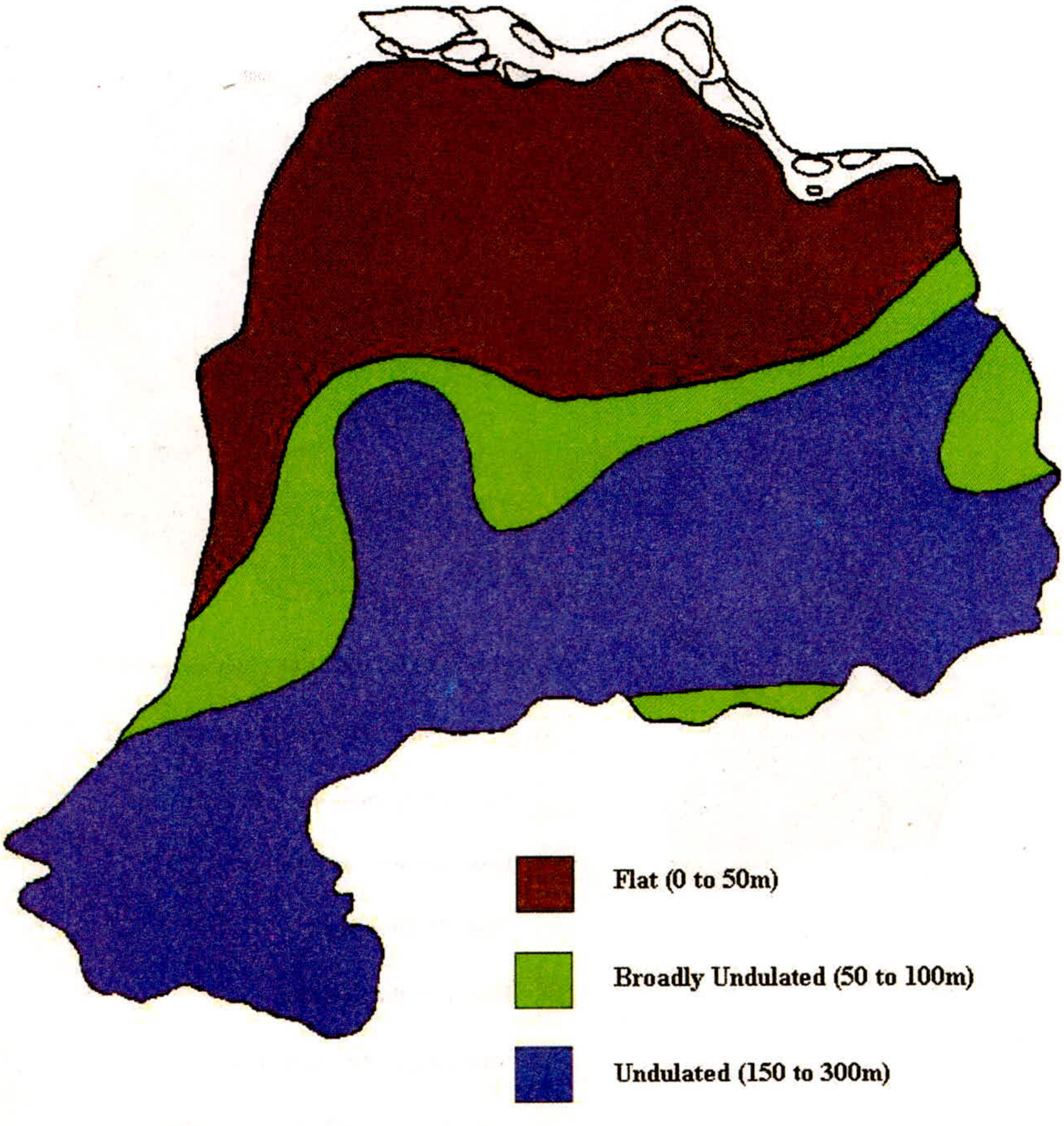


Figure 4.4 : Relative Relief of Kiul-Harohar River Basin

right bifurcated channel from *Ghoshi* is locally known as *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* flows 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*.

4.2.2.3 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 river *Panchane* bifurcates into a number of channels a few km upstream of Biharsharif town where it is 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 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*.

4.2.2.4 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 bifurcates into two branches namely the *Jirain* and the *Kumbhari*. These two branches meet the river *Goithawa* and the combined river is known as *Dhanayan*.

4.2.2.5 The River Harohar

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 with 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*.

4.2.3 Geomorphological parameters of the basin

The *Kiul-Harohar* river system has a drainage 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. 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 which is known as the "***Mokama Group of Tals***"

The Kiul-Harohar river basin has the drainage network of a number of important tributaries. A few geomorphological parameters like the length of the main streams, drainage area and the perimeter of some of the important contributing tributaries of the basin are given in **Table 4.1**.

Table 4.1: Length of Main Stream, Drainage Area and Perimeter of various rivers in Kiul-Harohar River Basin.

Sl. No.	Name of the River	Length of Main Stream (Km)	Drainage Area (Sq Km)	Perimeter (Km)
1.	Kadra Nadi	14.15	67.475	34.0
2.	Malu Nadi	16.45	61.275	36.3
3.	Heru Nadi	28.5	160.025	59.65
4.	Golai Nadi	16.85	59.0	38.85
5.	Dhardhari Nadi	24.45	124.1	60.80
6.	Gulshakri Nadi	21.0	168.6	56.35
7.	Danra Nadi	19.95	99.925	48.25
8.	Gahri Nadi	42.7	282.45	77.1
9.	Baksa Nadi	13.9	38.725	27.75
10.	Chakora Nadi	20.25	111.15	45.45
11.	Dhab Nadi	26.9	148.575	53.35
12.	Jharna Nadi	19.5	79.85	42.4

Sl. No.	Name of the River	Length of Main Stream (Km)	Drainage Area (Sq Km)	Perimeter (Km)
13.	Dhadhar Nadi (at its junction with Jharna nadi)	25.75	154.9	59.75
14.	Chadri nadi	10.9	41.2	32.15
15.	Tilaiya Nadi (outlet at Dhanarji nadi)	20.8	99.7	53.25
16.	Dhanarji Nadi (outlet at junction with Tilaiya nadi)	38.7	238.975	98.5
17.	Job Nadi	24.65	66.225	51.0
18.	Khuri Nadi (outlet at junction with Job nadi)	26.65	99.775	55.5
19.	Pipra-koni Nadi	19.75	133.525	52.15
20.	Barki Nadi	18.6	157.95	60.25
21.	Sukhner Nadi	15.45	90.20	39.6
22.	Kunda Nadi (including Sukhner)	31.45	303.325	94.9
23.	Ghagra Nadi	20.65	113.875	65.45
24.	Tati Nadi	52.5	351.2	103.45
25.	Baghail Nadi	22.1	121.75	54.9
26.	Korihari Nadi (including Baghail)	57.3	593.423	121.95
27.	Nata Nadi	47.95	341.375	98.6
28.	Kailas Nadi	19.4	46.2	37.6
29.	Bahuar Nadi	12.55	104.525	36
30.	Some Nadi (outlet at Harohar)	41.75	598.795	115.25

4.2.4 Geological characteristics of the basin

The upper zone of the river basin lies 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 depressions and valleys. In some areas these hills form series of ranges. General level of the area gradually rises until eventually a height of 600 m is obtained. On this gradual rising of surfaces there are rises like Parasnath which is at a level of 1260 m. Also, there are other rises to lesser heights. These are formed of Archean quartzites and schists.

The lower zone of the catchment lies in the Gangetic plains. It has semi-undulation and micro- relief and looks like a saucer shaped and shallow depression. It has a surfacial cover of dense, poorly drained, unoxidised and humous rich clayey soils 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 river basin, the cropping sequence can broadly be catagerised into three physiographic zones. These are presented in **Table 4.2.**

Table 4.2 : 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 Northern Part	Alluvial zone up to the river Ganga.

4.2.5 Soil characteristics of the basin

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 soils 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 soil cover, soil type, soil texture and soil reaction are presented in **Figures 4.5, 4.6, 4.7 and 4.8** respectively. The general data regarding the soil of the river system indicates that mainly alluvial, red and yellow, red sandy soils and deltaic alluvium are present 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, heaving practically no gravels. The pH value of the soil is strongly to moderately acidic. The red and yellow types of soils are moderately well drained. These are having good fertility and are less acidic. The redish yellow soils resemble the yellow soil and are light textured.

The alluvium soil found in various districts can further be classified on the basis of

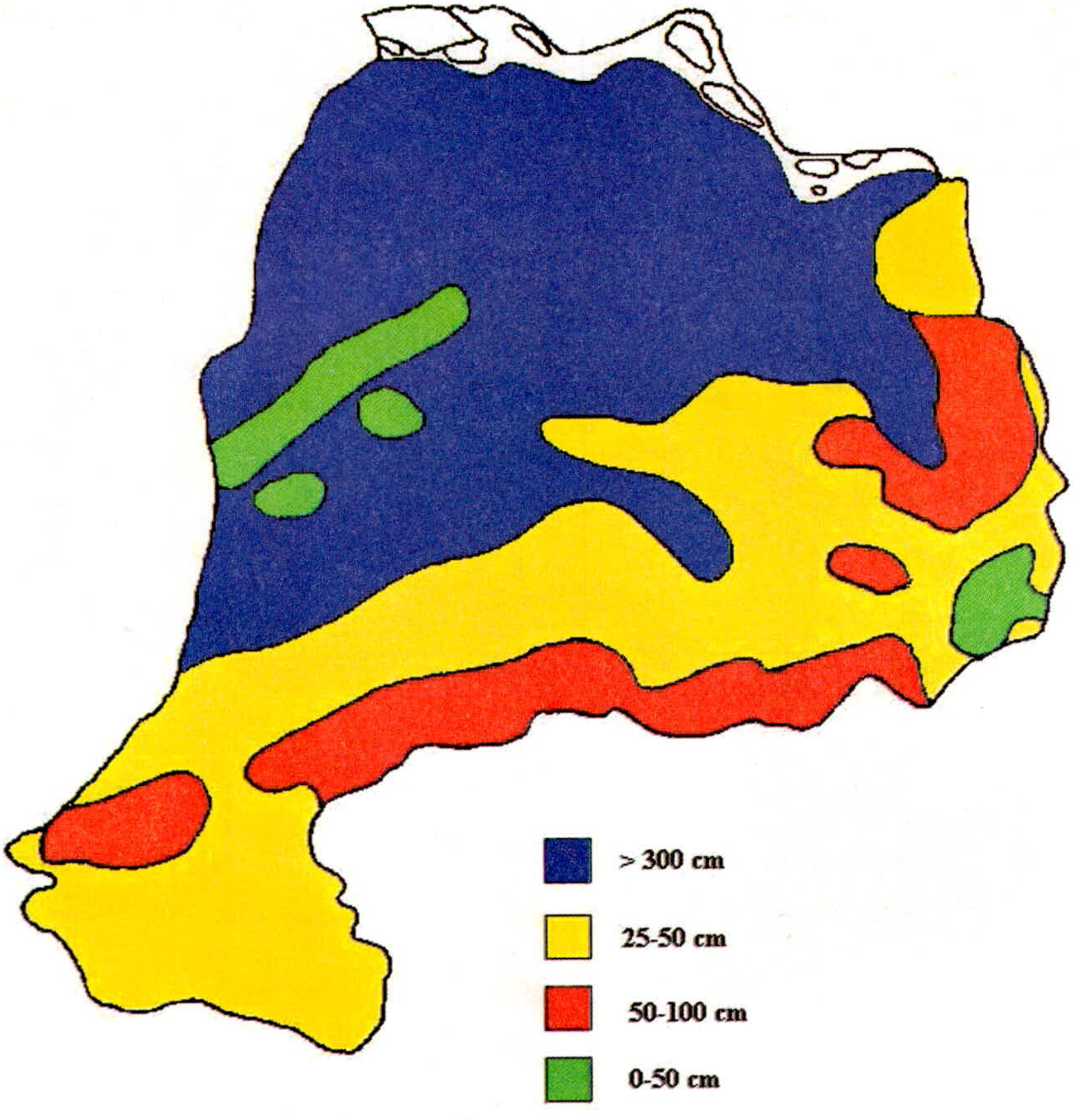


Figure 4.5: Soil Cover in Kiul-Harohar River Basin

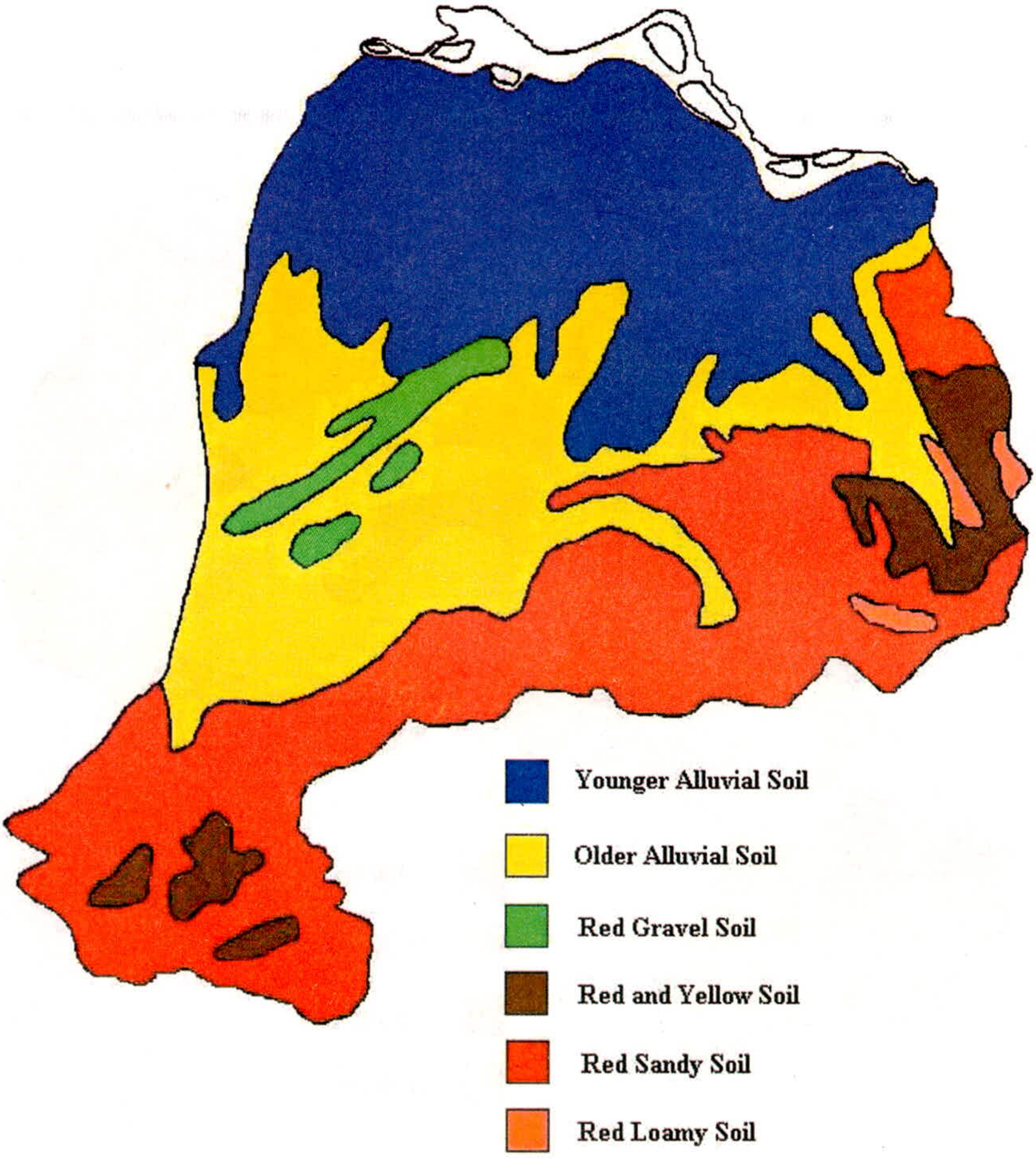


Figure 4.6: Different Soil Types in Kiul-Harohar River Basin

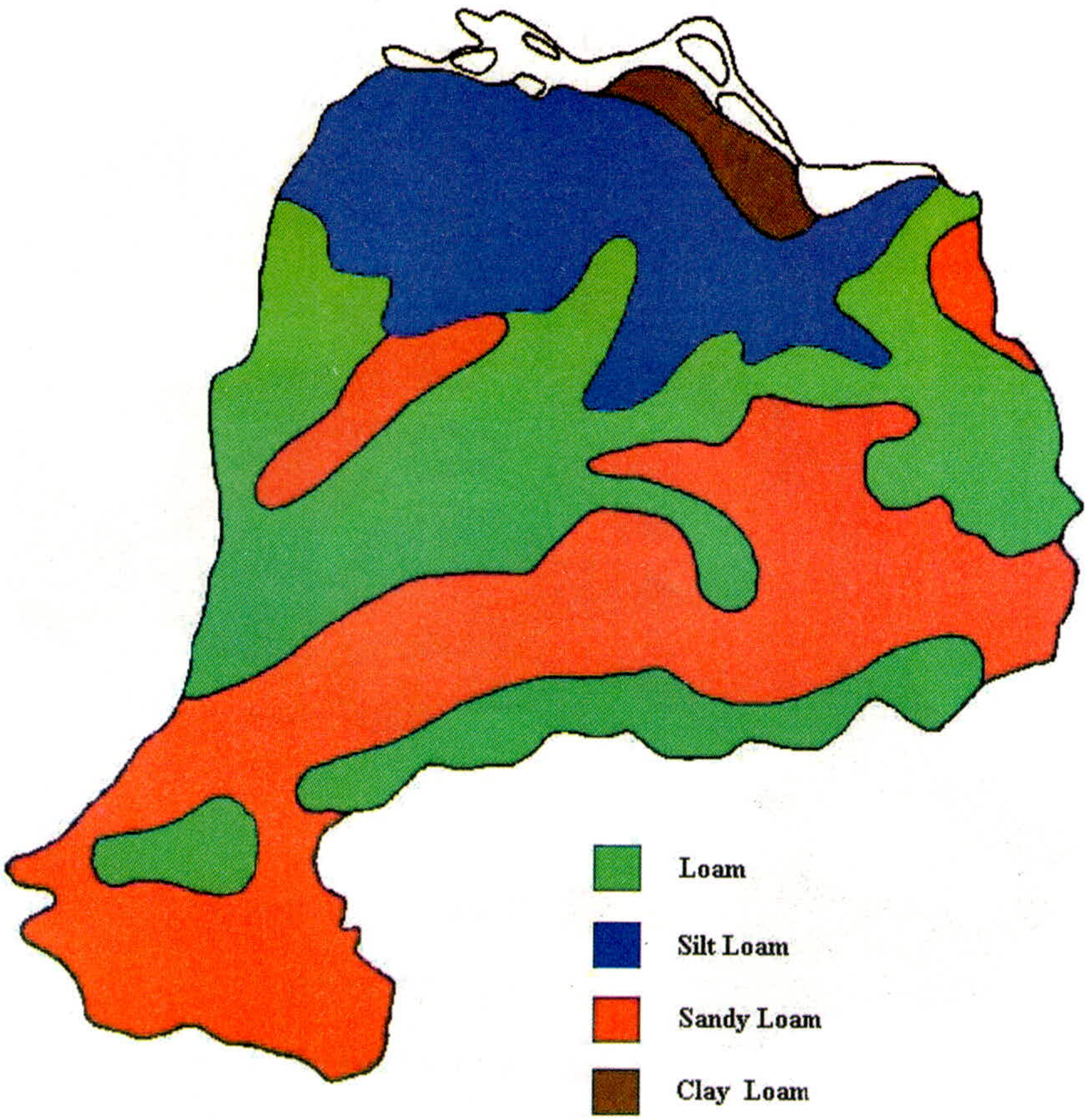


Figure 4.7 : Soil Texture of Kiul-Harohar River Basin

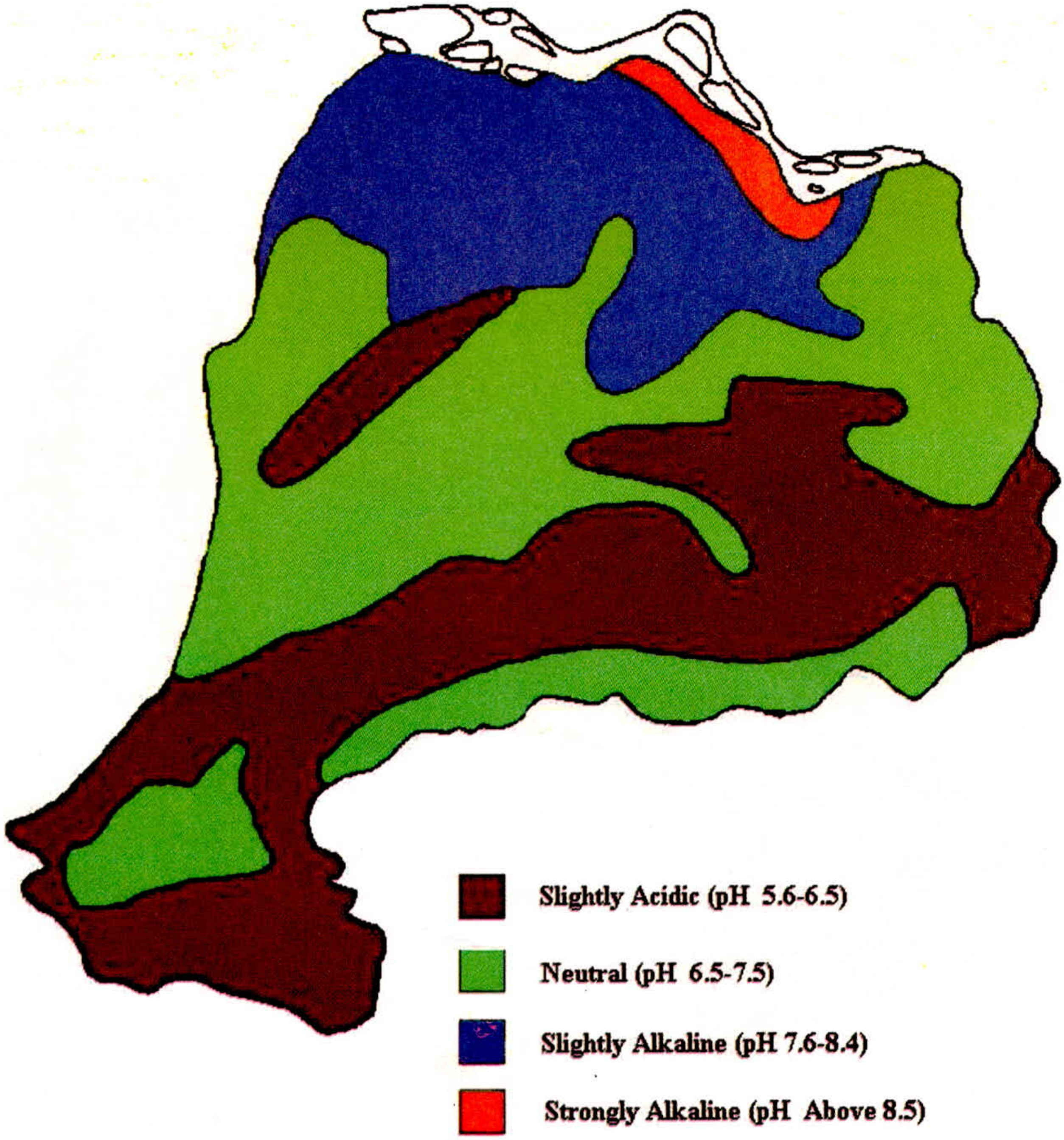


Figure 4.8 : Different Soil Reactions of Kiul-Harohar River Basin

colour and other properties. The grey and greyish yellow type soils which is found in the district of Patna, Gaya, Jahanabad, Nalanda, Munger, and Nawada, are greyish yellow to grey in colour, medium heavy in texture and neutral to slightly alkaline in reaction. These soils on drying crack heavily. The district of Patna, Gaya, Jehanabad, Nalanda, Munger and Nawada have mostly reddish soil and yellow type soils. These soils are somewhat poor drainage capacity and have a tendency to crack down during the dry months. The yellowish red and yellow type soil found at the foothills, which separates the alluvial plain from the plateau region. These excessiv to moderate drainage capacity soils and shallow to medium deep soil are the bed rocks and pebble. These soils are also strongl to moderately acidic and are of poor to moderate fertility. Calcareous alluvium soils are found in Munger and Jamui districts. Their main characteristics are the high content of calcium carbonate. These soils are alkline in nature and light coloured, and their texture varies from sandy loam to loam.

4.2.6 Land Use of the basin

The land use of Kiul-Harohar basin can broadly be classified into forest land, land under miscellaneous trees and grooves, current fallow, other fallow, culturable waste, net area under cultivation, barren land and permanent pastures and area under non-agricultural use. The land use pattern of Kiul-Harohar basin is presented in **Figure 4.9**.

The forest cover is approximately 4136 sq. km. which is 24.01 percent of the basin area. Adding to it the area under miscellaneous trees and grooves of 1140 sq. km. the percentage rises to 24.67 percent only. This is less than the minimum requirement of 33 percent considered necessary for maintenance of ecological balance and environmental protection. The other areas which are of fallow, culturable waste, barren land and permanent pastures types in the basin covering a vast area of 2197 sq. km. which is 12.76 percent of the basin area. This provides good scope for increasing the forest cover even beyond 33 percent. The climatic and soil conditions of the basin are eminently suited for development of forests and orchards. The net area under cultivation of the basin is 7466 sq. km. which is 43.35 percent of the basin area. Adding to it the current fallow of 1355 sq. km., the total cultivable land comes to 8821 sq. km., which is 51.22 percent of the basin area. The present area under non-agricultural use is 11.35 percent. The trends indicate that the future developments of rails, roads, irrigation facilities, industries, new townships and villages may grow atleast another 5 percent of the cultivable land.

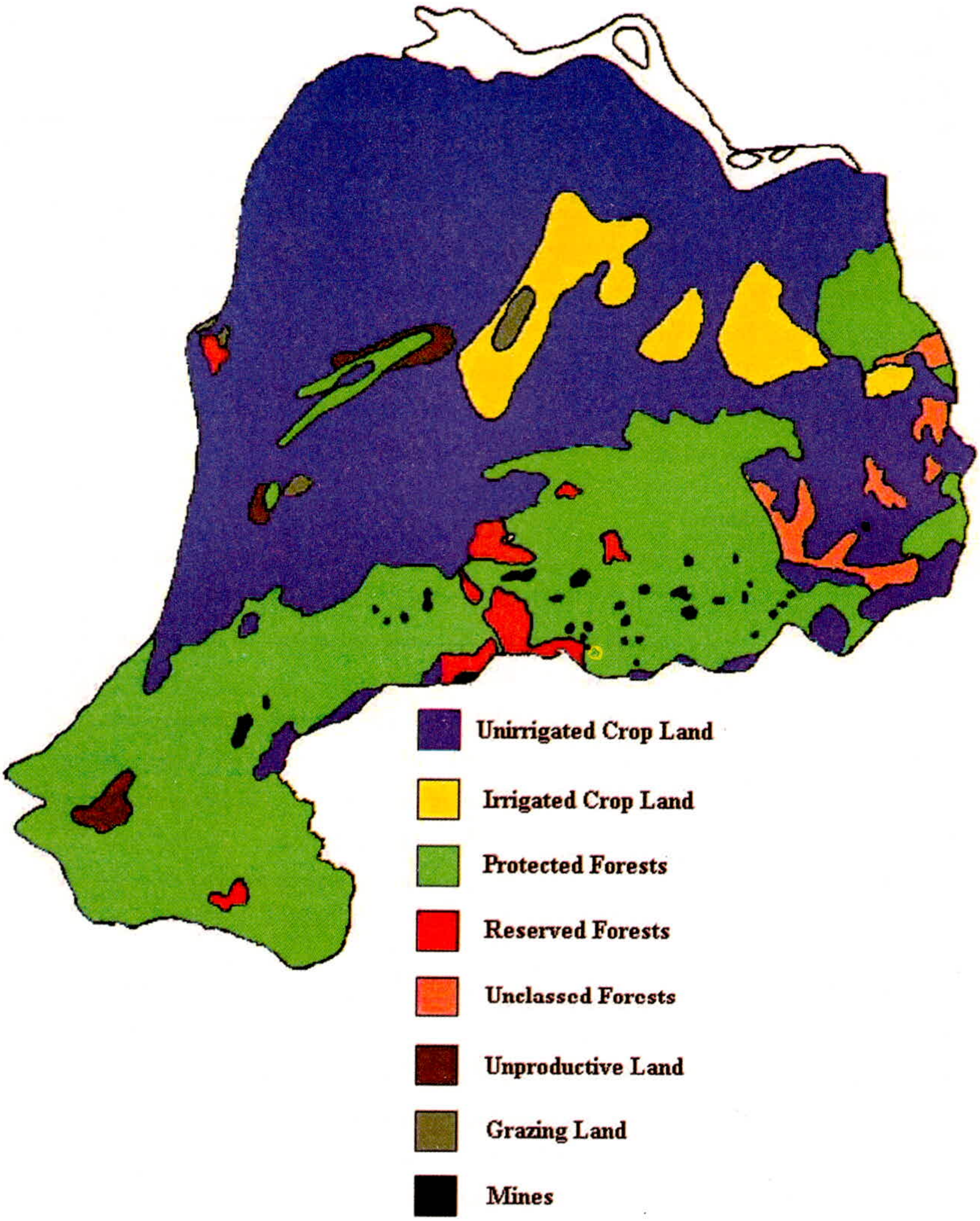


Figure 4.9: Land Use Pattern in Kiul-Harohar River Basin

4.2.7 Hydrology of the basin

4.2.7.1 Rainfall

The Kiul-Harohar river basin forms a part of the Gangetic plain and it is situated in the direct path of the tropical depression which forms in the Bay of Bengal during the monsoon season and travels in north-westerly direction. As such most of the precipitation, about 85 percent of the annual rainfall, occurs during the monsoon months of June to October.

The list of raingauge stations maintained in the Kiul-Harohar river basin and in adjacent basins is presented in **Tables 4.3 and 4.4** respectively. A comparison between the number of stations existing and those required as per recommendation of the IMD & WMO are given in **Table 4.5**. This table shows that the number of raingauge stations in plain is adequate and in hilly region it is inadequate but acceptable. Similarly self-recording raingauges (SRRG) are also as per norms i.e., 2 in plains (Patna and Gaya) and 1 in hilly area (Hazaribagh).

Table 4.3: Raingauge Stations in Kiul-Harohar River Basin

Sl. No	Raingauge Station	Location		District	Maintain-ed by	Type
		Lat	Long			
1	Chatra	$24^{0}12'0''$	$84^{0}52'0''$	Hazaribagh	IMD	Ordinary
2	Hunterganj	$24^{0}27'0''$	$84^{0}48'0''$	Hazaribagh	IMD	Ordinary
3	Gujhandi	$24^{0}28'0''$	$85^{0}30'0''$	Hazaribagh	State	Ordinary
4	Barachati	$24^{0}30'0''$	$85^{0}02'0''$	Gaya	IMD	Ordinary
5	Tisri	$24^{0}25'0''$	$86^{0}04'0''$	Giridih	State	Ordinary
6	Bamdah	$24^{0}35'0''$	$86^{0}24'0''$	Munger	State	Ordinary
7	Rajauli	$24^{0}39'0''$	$85^{0}30'0''$	Nawada	IMD	Ordinary
8	Satgawan	$24^{0}45'0''$	$85^{0}47'0''$	Hazaribagh	IMD	Ordinary
9	Gaya	$24^{0}45'0''$	$84^{0}57'0''$	Gaya	IMD	Self Rec.
10	Nawada	$24^{0}53'0''$	$85^{0}33'0''$	Nawada	IMD	Ordinary
11	Gidhaur	$24^{0}52'0''$	$86^{0}19'0''$	Munger	IMD	Ordinary
12	Jhajha	$24^{0}47'0''$	$86^{0}23'0''$	Munger	IMD	Ordinary
13	Jamui	$24^{0}56'0''$	$86^{0}13'0''$	Munger	IMD	Ordinary
14	Sikandra	$24^{0}48'0''$	$86^{0}02'0''$	Munger	State	Ordinary
15	Pakribaraman	$24^{0}57'0''$	$85^{0}44'0''$	Nawada	IMD	Ordinary
16	Silao	$25^{0}05'0''$	$85^{0}25'0''$	Nalanda	IMD	Ordinary
17	Nalanda	$25^{0}08'0''$	$85^{0}28'0''$	Nalanda	IMD	Ordinary
18	Jahri	$25^{0}05'0''$	$86^{0}00'0''$	Munger	State	Ordinary
19	Sheikhpura	$25^{0}09'0''$	$85^{0}51'0''$	Munger	IMD	Ordinary

Sl. No	Raingauge Station	Location		District	Maintain-ed by	Type
		Lat	Long			
20	Islampur	$25^0 09'0''$	$85^0 13'0''$	Nalanda	IMD	Ordinary
21	Ekangersarai	$25^0 13'0''$	$85^0 14'0''$	Nalanda	IMD	Ordinary
22	Bihar Sharif	$25^0 11'0''$	$85^0 33'0''$	Nalanda	IMD	Ordinary
23	Asthanwan	$25^0 13'0''$	$85^0 37'0''$	Nalanda	IMD	Ordinary
24	Sarmera	$25^0 15'0''$	$85^0 48'0''$	Patna	IMD	Ordinary
25	Chandi	$25^0 15'0''$	$85^0 20'0''$	Nalanda	IMD	Ordinary
26	Hilsa	$25^0 19'0''$	$85^0 17'0''$	Nalanda	IMD	Ordinary
27	Badalpur (Khagole)	$25^0 20'0''$	$86^0 05'0''$	Patna	IMD	Ordinary

Table 4.4: Raingauge Stations in Catchments Adjacent to Kiul-Harohar River Basin

Sl. No.	Raingauge Station	Location		District	Maintained by	Type
		Lat	Long			
1	Hazaribagh	$23^0 59'0''$	$85^0 22'0''$	Hazaribagh	IMD	Self Rec.
2	Barhi	$24^0 18'0''$	$85^0 25'0''$	Hazaribagh	IMD	Ordinary
3	Dhanwar	$24^0 25'0''$	$85^0 59'0''$	Giridih	IMD	Ordinary
4	Chakai	$24^0 33'0''$	$86^0 24'0''$	Munger	IMD	Ordinary
5	Sherghati	$24^0 33'0''$	$84^0 48'0''$	Gaya	IMD	Ordinary
6	Jehanabad	$25^0 13'0''$	$85^0 00'0''$	Jehanabad	IMD	Ordinary
7	Munger	$25^0 23'0''$	$86^0 28'0''$	Munger	IMD	Ordinary
8	Mokama	$25^0 25'0''$	$85^0 43'0''$	Patna	State	Ordinary
9	Kodarma	$24^0 17'0''$	$85^0 32'0''$	Hazaribagh	IMD	Ordinary
10	Begusarai	$25^0 26'0''$	$86^0 09'0''$	Begusarai	IMD	Ordinary
11	Bakhtiarpur	$25^0 27'0''$	$85^0 32'0''$	Patna	IMD	Ordinary
12	Barh	$25^0 29'0''$	$85^0 43'0''$	Patna	IMD	Ordinary
13	Patna	$25^0 37'0''$	$85^0 10'10''$	Patna	IMD	Self Rec.

Table 4.5: Comparison between the Number of Stations Existing and those Required as per Recommendation of the IMD & WMO

Sl. No.	Catchment Area (sq. km.)	Existing No. of Raingauge Stations	Required as per Norm		Remarks
			Ideal	Accepted	
1	Plain Area (14,330)	33	20	10	Ideal
2	Hilly Area (2,893)	7	15	6	Inadequate but acceptable

The monthly and annual normal rainfall at raingauge stations in Kiul-Harohar and its adjacent basin are presented in **Appendix I**. From this table it is observed that the annual normal rainfall varies between 775 mm to 1344 mm from station to station. It is also observed that the lower catchment receives lesser rainfall than upper catchment and generally all the raingauge stations receive 90 percent of their annual rainfall during monsoon months from June to October. The average annual rainfall in the river basin is 1104 mm while the average monsoon rainfall is 1029 mm. The 90 percent dependable monsoon rainfall and 75 percent dependable monsoon rainfall are 913 mm and 818 mm respectively.

4.2.7.2 Gauge and Discharge

According to the norms prescribed by the WMO, one gauge discharge site is required for every 300 sq. km. of drainage area in hilly region and for 1000 sq. km. in plain region. **Table 4.6** lists the different gauge and discharge sites in the Kiul-Harohar river basin.

Table 4.6 List of Gauge and Discharge Sites in Kiul-Harohar Basin

Sl. No.	Station (Name of Site)	Stream	Maintained by	Method
1	Kaithan	Lilijan	WRD	FM
2	Bhuiadih	Lilijan	WRD	FM
3	Weir site	Lilijan	WRD	FM
4	Udrasthan	Falgu	WRD	FM
5	Manui	Falgu	WRD	FM
6	Jeevanchak	Bhaitamain	WRD	FM
7	Armedag	Mohane	WRD	FM

Sl. No.	Station (Name of Site)	Stream	Maintained by	Method
8	Bhaluchatti	Mohane	WRD	FM
9	Bardih	Mohane	WRD	FM
10	Islampur	Mohane	WRD	FM
11	Ekangalsarai	Daha	WRD	FM
12	Weir Site	Paimar	WRD	FM
13	Aamghat	Tilaiya	WRD	FM
14	Jalalpur	Tilaiya	WRD	FM
15	Siur	Dhanarji	WRD	FM
16	Padmaul(Wier)	Dhanarji	WRD	FM
17	Rahimpur(Weir)	Rabri	WRD	FM
18	Nawada	Rabri	WRD	FM
19	Giriyak	Panchane	WRD	FM
20	Baribali	Tilaiya	WRD	FM
21	Weir site	Goithawa	WRD	FM
22	Rahimpur	Khuri	WRD	FM
23	Gath	Chiraiya	WRD	GS
24	Chandi	Mohane	WRD	FM
25	Bihar-Barbigha rd.	Paimar	WRD	FM
26	Bihar-Barbigha rd.	Panchane	WRD	FM
27	Dhamauli	Panchane	WRD	GS
28	Panchane Weir1&2	Khunti	WRD	FM
29	Khunta	Sakari	WRD	FM
30	Baskoi	Sakari	WRD	FM
31	Goharnagar	Bhauara	WRD	FM
32	Bihar-Barbigha	Jirain	WRD	FM
33	Aamgachi	Sakari	WRD	GS
34	Bihar-Barbigha	Kumhari	WRD	GS
35	Nata weir	Nata	WRD	FM
36	Weir site	Kanahari	WRD	FM
37	Sheikpura Sarbigha	Tati	WRD	FM
38	Dam site(Kashoia)	Banbani	WRD	FM
39	Dam site	Kundghat	WRD	FM
40	Sheikpura-Lakhisarari	Kanhari	WRD	FM

Sl. No.	Station (Name of Site)	Stream	Maintained by	Method
41	Sheikpura Kuil	Saru	WRD	FM
42	Dam site	Ulai	WRD	GS
43	Kari-Hari Harihar complex	Harihar	WRD	FM
44	Lakhisarai- Munger	Kuil	WRD	FM
45	Barahia-Lakhisarai	Harohar	WRD	GS
46	Fatuha –Daniyawa	Dhoba(Tal)	WRD	GS
47	Khusrupur	Ganga	WRD	GS
48	Bidhipur	Ganga	WRD	GS
49	Bhaktiarpur	Ganga	WRD	GS
50	Piparia	Ganga	WRD	GS
51	Barh	Ganga	WRD	GS
52	Siunar	Ganga	WRD	GS
53	Mahendrapur	Ganga	WRD	GS
54	Hemaja	Ganga(Tal)	WRD	GS
55	Hemaja	Ganga	WRD	GS
56	Railway crossing	Harohar	WRD	GS
57	Sarma	Kuil	WRD	GS
58	Piparia	Ganga	WRD	GS
59	Kuil-Harohar Bridge	Kuil	WRD	GS
60	Suryagarha	Harohar	WRD	GS
61	Hevarghat	Harohar	WRD	GS
62	Sudarpur	Ganga-Harohar	WRD	GS
63	Munger	Ganga	WRD	GS
64	Lehra	Dhadhar	WRD	FM
65	Ratukha	Mohane	WRD	FM
66	Hafua	Lilajan	CWC	FM
67	Lakhisarai	Kuil	CWC	CMG
68	Mankatha	Harehar	CWC	CMG
69	Gaya	Faigu	WRD	CMG

4.2.8 Cropping pattern in the basin

The present cropping pattern in the Kiul and Harohar river basins are is shown in **Table 4.7**.

Table 4.7 Cropping Pattern in Kiul and Harohar River Basins.

Sl No	Crop Season	Percentage of Net Sown Area					
		Irrigated		Rainfed		Total	
		Harohar	Kiul	Harohar	Kiul	Harohar	Kiul
1	Bhadai (Early kharif)	0.58	0.21	3.96	11.00	4.54	11.21
2	Kharif	45.37	22.60	8.46	30.28	53.83	52.88
3	Rabi	27.08	15.48	24.79	20.55	51.87	36.03
4	Hot weather	0.92	0.89	0.62	0.35	1.54	1.24
5	Annual crop (Sugarcane)	0.33	0.32	0.01	0.05	0.34	0.37
	Total	74.28	39.50	37.84	62.23	112.12	101.73

The main kharif crop is paddy but some maize, millets, pulses, oilseed and vegetables are also grown in some areas. Wheat is the main crop of rabi. Pulses, oilseeds, potato and winter vegetables are also grown in limited areas. Paddy and vegetable are the main *garma* (hot weather) crops. The cropping pattern of Kiul-Harohar river basin is also shown in **Figure 4.10**.

4.3 Mokama Group of Tals

The Mokama group of Tals extend from Fatuha in the west to Lakhisarai in the east, lying between Latitude $25^0 10^{'}$ N to $25^0 35^{'}$ N and Longitude $85^0 5^{'}$ E to $86^0 8^{'}$ E in the districts of Patna, Nalanda and Munger, and lies in the Kiul-Harohar river basin, as shown in **Figure 4.1**. It is a saucer shaped depression and the length of the depression is about 100 km and its width varies from 6 km to 17 km. It has a total area of about 1062 sq. km., on the south of the eastern railway embankment running close and almost parallel to the right bank of the river Ganga, from Fatuha to Lakhisarai. The Tal extends over Fatuha, Bakhtiarpur, Barh, Pandarak and Mokama blocks of Patna districts, Harnaut and Sarmera of Nalanda district, and Barahiya and Lakhisarai of Munger district.

The Tal area is intercepted by north-south running embankments; rail, road or other natural divides, subdividing the entire area into individual Tal areas, namely, Fatuha Tal, Bakhtiarpur Tal, Barh Tal, More Tal, Mokama Tal, Barahiya Tal and Singhaul Tal. All these individual Tal areas are connected through the master drain known by Dhowa in the upper stretches and Horahar in the remaining stretches. The area, ground elevation, and range of

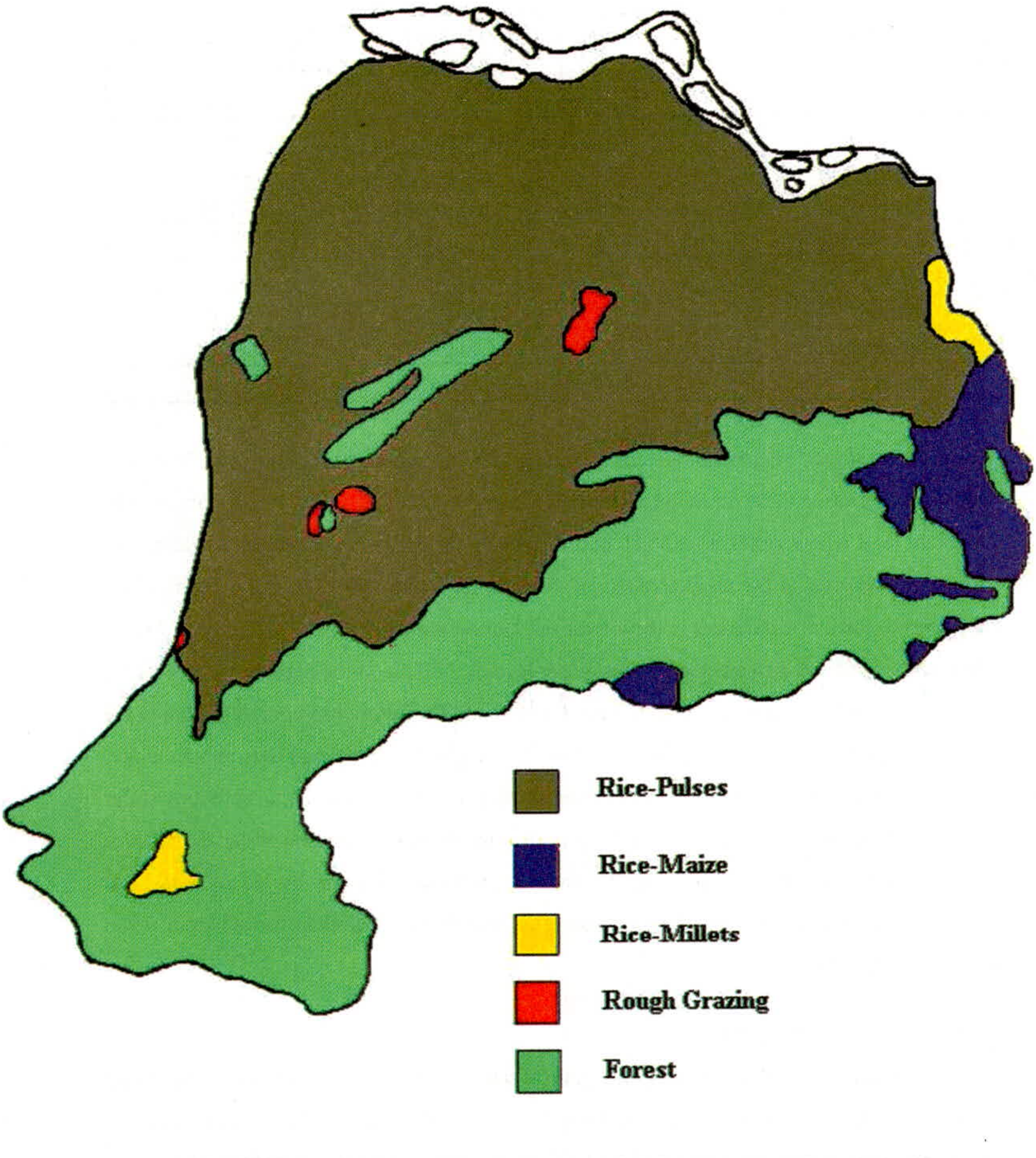


Figure 4.10: Different Crop Regions in Kiul-Harohar River Basin

highest water levels, as observed between 1972-1991 are as shown in **Table 4.8.**

Table 4.8: Area, Ground Elevation and Highest Water Levels of Different Tals

Sl. No.	Name of the Tal	Area (sq. km)	Ground Elevation (m)	Highest water level between 1971 to 1991 (m)
1	Fatuha Tal	52.00	46.94 to 47.25	50.80
2	Bakhtiarpur Tal	168.00	43.58 to 47.24	48.67
3	Barh Tal	132.00	42.06 to 46.06	47.30
4	More Tal	215.00	39.32 to 44.20	45.07
5	Mokama Tal	200.00	38.40 to 41.75	44.16
6	Barahiya Tal	171.00	38.70 to 41.65	43.10
7	Singhaul Tal	124.00	38.40 to 39.62	43.10
	Total	**1062.00**		

The "Tal area" in general remains dry except during the monsoon months i.e., from June to September. During these monsoon months, as shown in Table 3.8, the tal water reaches to its maximum level which varies from 50.80 m in Fatuha tal to 43.10 m in Barahiya tal against the average ground level at the respective tals of 47.00 m for Fatua and 39.00 m for Barhiya Tal. From west to east the differences in the lowest and highest ground levels are 8.54 m and 7.63 m respectively while the difference of highest water level is 7.70 m. At the highest water level the capacity of the tals has been reported to be 4.37×10^5 ham. During monsoon months, due to the submergence of water the area cannot be put to use for growing crops and thus remain under-utilized while during hot weather because of scarcity of water agricultural activities suffer massively. However, it has been reported that after recession of monsoon water the tal area comes under bumper rabi cultivation and productivity increases. This may be due to the fact that tal area being receiver of surface runoff, becomes enrich with nutrients carried from upper stretches through runoff.

4.3.1 Description of the tals

As mentioned earlier, the Mokama group of tals is known by different names at different places i.e., *Fatuha Tal, Bakhtiarpur Tal, Barh Tal, More Tal, Mokama Tal, Barahiya Tal, and Singhaul Tal.* A brief description of individual Tal areas from west to east is as follows:

4.3.1.1 Fatuha Tal

The *Fatuha Tal* is in the eastern most part of the Tal area and has the smallest area. River *Dhowa*, an important branch of river *Falgu* flowing in serpentine course enters *the Fatuha Tal* area and flowing centrally in north east direction makes an exit through a railway culvert 4.8 km south of the Fatuha railway station on the Fatuha-Islampur railway embankment and enters the *Bakhtiarpur Tal*. River *Mahatmain*, another branch of river *Falgu*, enters the *Fatuha Tal*, travels some distance and enters the *Bakhtiarpur Tal* through another railway culvert.

4.3.1.2 Bakhtiarpur Tal

River *Mahatmain* flowing down joins River *Dhowa* which flows eastwards almost centrally of *Bakhtiarpur Tal*. A spill channel *Kathautia*, taking off from river *Mahatmain* and flowing almost parallel to *Dhowa* is joined by another branch of river *Falgu* and finally meets the river *Dhowa* at *Landih*. *Dhowa* flowing down from here to eastward is joined by two other branches of river *Falgu* namely river *Nonai* and river *Chiraiya* coming from south. It finally meets river *Mohane* combined with river *Paimar* at the end of the *Bakhtiarpur Tal* (just before entry in the Tal). Now the combined river *Dhowa* is known as river *Mohane* after their confluence makes an exit from the *Bakhtiarpur Tal* through a culvert and enters *Barh Tal*. The *Bakhtiarpur Tal* is bounded on west-east and north by railway embankments.

4.3.1.3 Barh Tal

River *Mohane* passing through a railway culvert brings water from *Bakhtiarpur Tal* and travels eastward. River *Panchane* meets river *Mohane* flowing from the south in the Tal. The river *Mohane* crosses the *Barh Tal* and enters *More Tal*. *Barh Tal* is bounded by railway embankment on the west and north and by road embankment on the east.

4.3.1.4 More Tal

River Mohane flowing in serpentine course in the southern half part of More Tal, crosses this Tal and enters Mokama Tal. More Tal is bounded by a road on the west, railway embankment on the north and the left bank of the river Bari in the south.

4.3.1.5 Mokama Tal

River Mohane carrying water from More Tal enters into Mokama Tal from northern boundary and travels almost southward. Then it is joined by river Bari and further down by river Dhanayan. It flows downward and is known as river Harohar which enters the Barahiya

Tal. Mokama Tal is bounded on the north by the railway embankment and most of its southern boundary by a road.

4.3.1.6 Singhaul Tal

The central river flowing in Mokama Tal and Barahiya Tal makes northern and eastern boundary of Singhaul Tal. Some small tributaries of river Harohar enter this Tal from the south. River Tati flows through the southeastern part of the Tal and joins river Harohar in the Barahiya Tal. Most of the northern boundary of Singhual Tal is formed by the course of the river Harohar while road embankment bound part of the Tal on the west as well as east.

4.3.1.7 Barahiya Tal

River Harohar, entering from Mokama Tal, traverse along the western boundary of Barahiya Tal. The river Tati, originating near Morui, east of Sakri valley, traverses a distance of about 50 kms and meets the river Harohar in Barahaiya Tal area. After meeting with river Tati, its course turns eastward. Two more rivers Kaurihari and some entering the Tal from the south meet river Harohar at two different points. Harohar, which is the outlet channel from the entire Tal area, flows eastward more than 16 kms after exit from the Tal boundary and is joined by river Kiul from the south. From this confluence, it continues to flow in the northeastern direction towards its ultimate destination of the confluence with river Ganga about 16 km downstream. The western side of Barahiya Tal forms the boundary of Mokamah Tal in the north and Singhual Tal in the South. Eastern boundary of this Tal is formed by the embankment of eastern railway and southern boundary by road embankment.

5.0 FORMULATION OF OPTIMISATION MODEL

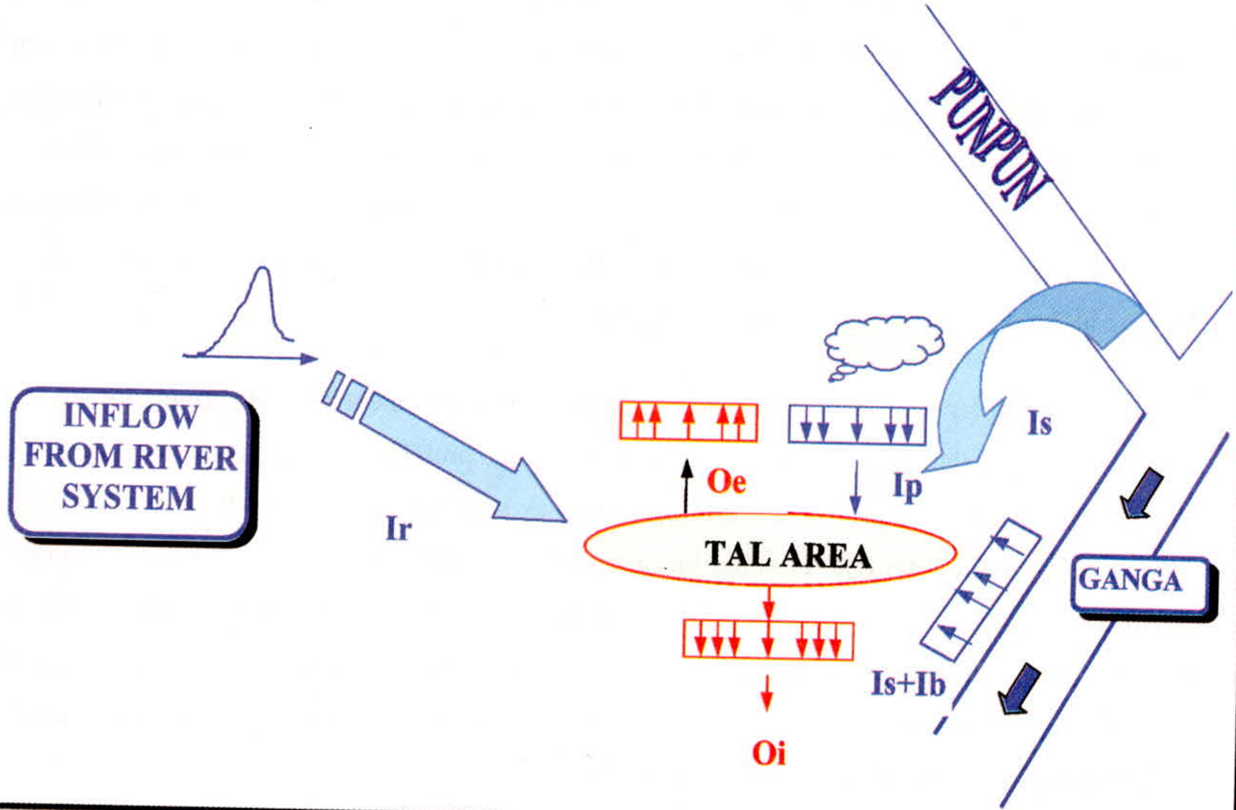
The earlier discussions clearly indicate that it is basically a problem of blockage of monsoon water runoff originating from the upper catchment and discharging to an area which has a longer detention time to dispose off the incoming water. Alternately, the rate of inflow for a considerable period is much more than the rate of outflow, resulting in higher rate of storage of water in the vicinity. Towards solution of the problem, a management approach intending to check over inflows at the pace of need of water requirement at Tal area, and with no risk of water logging at the downstream would be the logical strategy.

This chapter deals with the conceptualization, and the mathematical formulation of the water logging problem of the Mokama group of Tals. The problem has been conceptualized as a management model considering water logged area has been acting as a storage reservoir whose drainage area is the total Kiul-Horahor basin, and during monsoon period the upstream runoffs are to be so regulated that storage does not create any danger of flooding rather would be able to meet the irrigation water requirement in the tal area and also at the upstream commands. Thus, the model is formulated taking into account the crop factors, the monthly reservoir storage values in the upstream catchment and the area expected to be exposed in the Tals.

The tal area being irregular (saucer) in shape, its area-capacity and stage-capacity form a non-linear curve. Thus, ***a non-linear programming technique*** is used in model formulation. The following sections present the details of model formulation.

5.1 Water Balance of the Waterlogged Area

A detailed description of the waterlogging problem in Mokama group of Tals is presented in Chapter 2. **Figure 5.1** shows the schematic representation of the water balance of the Mokama group of Tals in monsoon season. It is seen that apart from



WATER BALANCE

Change of Storage [ds/dt]=Inflow-Outflow=[Ir+Is+Ib+Ip+Isp] - [Oe+Oi]
where,
Ir, Is, Ib, Ip and Isp are the rate of inflows, seepage from Ganga, back water flow from Ganga, precipitation and spill from Punpun respectively
Oe and Oi are the rate of evaporation and infiltration respectively

Figure 5.1: Schematic Representation of Water Balance in Mokama Group of Tals

precipitation, the Tal area receives water from three major sources, namely, the inflow from various tributaries in Kiul-Harohar river basin, overflow from right bank of the river Punpun, and backwater flow and seepage from the river Ganga.

5.2 Formulation of the Non-linear Optimisation Model

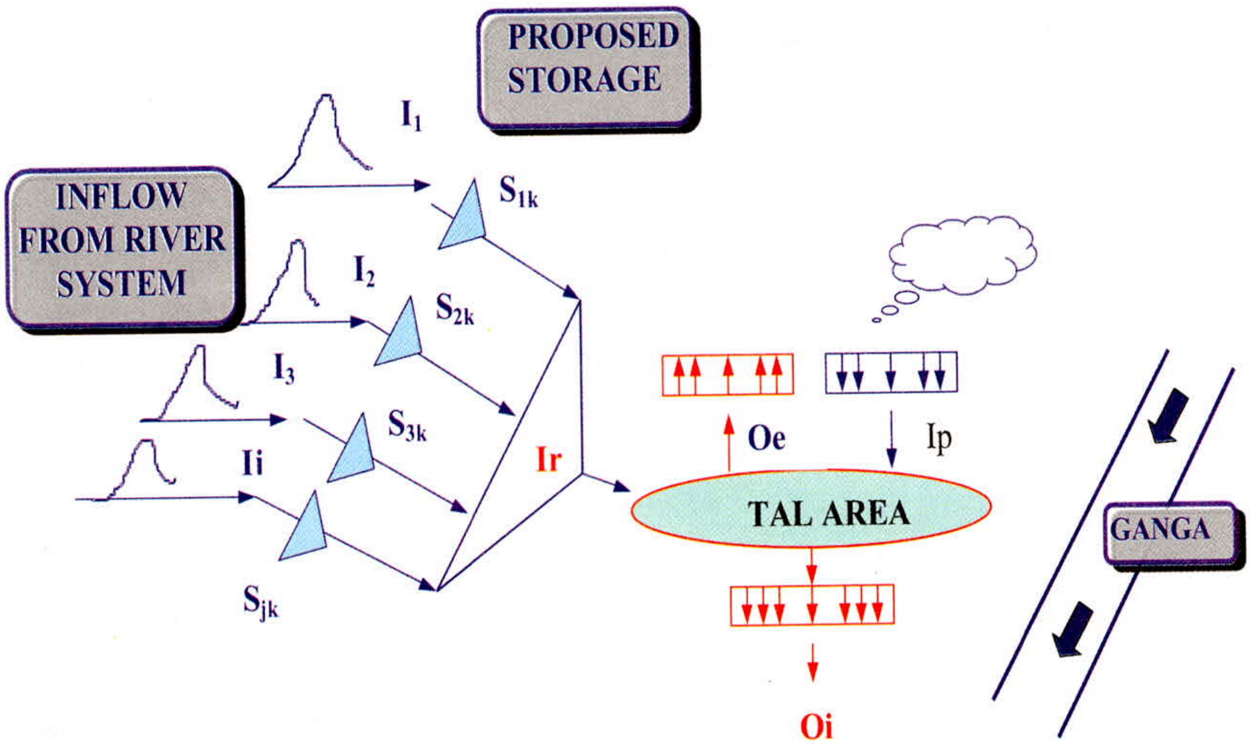
For the formulation of the optimisation model, two assumptions are made:

(i) There is no overflow from the right bank of the river Punpun to the waterlogged area. This can be achieved by construction of an embankment on the right bank of the river Punpun.

(ii) There is no backwater flow and seepage from the river Ganga to the water logged area. Also, no flow takes place from the waterlogged area to the river Ganga in the monsoon season. These can be achieved by construction of appropriate flood sluice gates.

Hence, it is assumed that the Tal area gets waterlogged in the monsoon season due to precipitation in the Tal area and the inflows to the Tal area from various tributaries in the Kiul-Harohar river basin. The present optimisation model aims at minimising the waterlogged area by storing the inflows from various sub-basins of the Kiul-Harohar river basin in storage reservoirs and utilising this water to meet the crop water requirements of the upstream catchment and the Tal area, both in kharif as well as rabi season. The schematic representation of the water balance of the Mokama group of Tals in monsoon season considering the assumptions in the optimisation model is shown in **Fig. 5.2.**

The objective of minimising the waterlogged area in the monsoon season is equivalent to maximising the cropped area in the Tal. This is possible by minimising the inflow into the Tal, ensuring at the same time that the crop water requirement of the Tal area is met by the water stored in it (Tal area). Again, minimising the inflow into the Tal area is equivalent to maximising the water stored in the upstream reaches which is to be



WATER BALANCE

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

Figure 5.2: Schematic Representation of Water Balance in Mokama Group of Tals Considering the Assumptions in the Optimisation Model

subsequently used for meeting the crop water requirements in the upstream reaches and the Tal area. The minimisation problem thus reduces to maximisation of cropped area both in the upstream reaches as well as in the Tal area.

5.2.1 Objective function

The objective function to be maximised to obtain the optimum Tal area free from surface waterlogging is thus:

$$\text{Maximise } f(\text{Cropped Area}) = \text{Maximise} \sum_{i=1}^{m} \sum_{j=1}^{n1} SBAK_{ij} + \sum_{j=1}^{n1} TAK_{j} +$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n2} SBAR_{ij} + \sum_{j=1}^{n2} TAR_{j} \qquad ...(1)$$

in which

m = number of sub-basins in the upper catchment (Kiul – Harohar basin)

n1 and n2 = number of crops grown in kharif and rabi seasons respectively

$SBAK_{ij}$ = area of i^{th} sub-basin allocated to j^{th} crop in kharif season, sq. km.

TAK_j = Tal area allocated to j^{th} crop in kharif season, sq. km.

$SBAR_{ij}$ = area of i^{th} sub-basin allocated to j^{th} crop in rabi season, sq. km.

TAR_j = Tal area allocated to j^{th} crop in rabi season, sq. km.

This objective function is subjected to the following constraints:

5.2.2 Storage constraints in the upper catchment

The monthly storage of the reservoirs in the upstream catchment is based on the water balance of the inflow (runoff) from the respective sub-basins, outflow to the Tal area, outflow for irrigation in the upstream catchment, evaporation and percolation losses. The inflow from the sub-basin depends on the runoff characteristics of the catchment. For the Kiul-Harohar basin, the inflow (runoff) occurs only in the monsoon months. The outflow to the Tal area meets the crop water requirements of the Tal. The outflow for irrigation in the upstream catchment is a function of the area allocated to different crops, the irrigation requirement of these crops and the irrigation system efficiency. The percolation and the evaporation losses are function of water spread area which itself is a function of the total amount of water stored in that month.

Based on the water balance, the storage constraints in the upper catchment for kharif and rabi seasons are as follows:

5.2.2.1 For kharif season

$$S_{ik} = \sum_{k=1}^{k} I_{ik} - \sum_{k=1}^{k} O_{ik} - \frac{1}{\eta} \sum_{k=1}^{k} \sum_{j=1}^{n1} WR_{kj}.SBAK_{ij} - \sum_{k=1}^{k} (E_k + P_k).SA_{ik} \qquad ...(2)$$

For $i = 1$ to m
$k = 1$ to s

in which

s = number of months in kharif season

S_{ik} = cumulative water storage in the reservoir of i^{th} sub-basin in k^{th} month, sq. km. M (It is assumed that there is no dead storage at the beginning of Kharif season)

I_{ik} = inflow (Runoff) from the i^{th} sub-basin to the reservoir in k^{th} month, sq. km. m

O_{ik} = outflow from the reservoir in the i^{th} sub-basin in k^{th} month, sq. km. m

η = irrigation efficiency, fraction

WR_{kj} = water requirement of j^{th} crop in k^{th} month, m

E_k = evaporation loss from reservoir in k^{th} month, m

P_k = percolation loss from reservoir in k^{th} month, m

SA_{ik} = water spread of the reservoir in the i^{th} sub-basin in k^{th} month, sq. km.

The irrigation water requirement of a crop is a function of the evaporation, the crop coefficient, the percolation loss and the effective rainfall. Doorenbos and Pruitt (1977) recommended the following equation to estimate the irrigation water requirement in the kth month of growth stage of the crop.

$$WR_{kj} = E_k.Kc_{kj} + P_{kj} - Re_k \qquad ...(3)$$

in which

WR_{kj} = irrigation water requirement of the j^{th} crop in the k^{th} month, m

E_k = Evaporation in the K^{th} month.

Kc_{kj} = crop coefficient of j^{th} crop in k^{th} month

P_{kj} = percolation loss for j^{th} crop in k^{th} month, m

Re_k = effective rainfall in k^{th} month, m

5.2.2.2 For rabi season

$$S_{ik} = \sum_{k=1}^{s} I_{ik} - \sum_{k=1}^{k+s} O_{ik} - \frac{1}{\eta} \sum_{k=1}^{s} \sum_{j=1}^{n1} WR_{kj}.SBAK_{ij} - \frac{1}{\eta} \sum_{k=1}^{k} \sum_{j=1}^{n2} WR_{kj}.SBAR_{ij} - \sum_{k=1}^{k+s} (E_k + P_k).SA_{ik} \qquad ...(4)$$

For i = 1 to m

k = 1 to r

in which

r = number of months in rabi season

5.2.3 Area constraints

The area constraints for crops in the upper catchment and Tal area are defined to account for the total area available for cultivation both in kharif and rabi seasons, the crop rotation, the soil texture, topography and the affinity of the farmers in the area who may wish to grow a specific crop in a season. The area under waterlogged conditions further governs the area constraints for the Tal.

5.2.3.1 Area constraints in upper catchment

The total area allocated to different crops in a particular season should be less than or equal to the total culturable area available for canal irrigation. The total culturable area available for canal irrigation further depends on the topography of the area.

(i) For kharif season

$$\sum_{j=1}^{n1} SBAK_{ij} \leq CA_i \qquad \text{...(5)}$$

For i = 1 to m

in which

CA_i = total cultivable area available for canal irrigation in ith sub-basin, sq. km.

(ii) For rabi season

The total cultivable area available for rabi cropping depends on the area allocated to the perennial crops which are sown in kharif season but are harvested only after the rabi season.

$$\sum_{j=1}^{n2} SBAR_{ij} \leq CA_i - \sum_{j=1}^{p} SBAK_{ij} \qquad \text{...(6)}$$

in which

p = number of perennial crops which are sown in kharif season but are harvested only after rabi season. However, these crops do not require water during rabi season.

5.2.3.2 Area constraints in Tal area

(i) For kharif season

As mentioned earlier, the Tal area gets waterlogged during the monsoon season. Hence, the total cropped area in kharif season in the Tal should be less than or equal to the exposed Tal area, which is free from waterlogging. Thus,

$$\sum_{j=1}^{nl} TAK_j \le TEA_k \qquad ...(7)$$

For k = 1 to s

in which

TEA_k = exposed tal area in kth month, sq. km.

The exposed Tal area is again a function of the amount of water stored in the Tal during that month. The exposed Tal area is thus determined by the exposed area – storage relationship of the Tal. This relationship is a sixth degree polynomial and hence its incorporation in the optimisation model makes it non-linear in nature. The non-linear expression is of the form

$$TEA_k = a + b.V_k + c.V_k^2 + d.V_k^3 + e.V_k^4 + f.V_k^5 + g.V_k^6 \qquad ...(8)$$

in which

a, b, c, d, e, f and g = coefficients of sixth order polynomial regression equation for exposed area versus volume of water in Tal.

V_k = Volume of water in Tal area at the end of k^{th} month, sq. km.m.

The volume of water in the Tal area at the end of a particular month is governed by the water balance of inflow (runoff) from the Tal, outflow from the sub-basins of the upper catchment, irrigation water requirement in the Tal area and the evaporation and percolation losses from the waterlogged area in the Tal. The expression for volume of water is thus given by

$$V_k = \sum_{k=1}^{k} IT_k + \sum_{k=1}^{k} \sum_{i=1}^{m} O_{ik} - \frac{1}{\eta} \sum_{k=1}^{k} \sum_{j=1}^{nl} WR_{kj}.TAK_j - \sum_{k=1}^{k} (E_k + P_k).WL_k$$

...(9)

in which

IT_k = runoff from Tal area in k^{th} month, sq. km.

O_{ik} = outflow from the reservoir in the i^{th} sub-basin in k^{th} month and hence is the inflow to the Tal area, sq. km.m

WL_k = waterlogged area in Tal in k^{th} month, sq. km.

$$= \mathbf{TTA - TEA_k} \quad \text{...(10)}$$

TTA = total tal area

From Eq. (9), it is observed that the expression for volume of water is again a function of the waterlogged area, which in turn is a function of the exposed Tal area. Hence, for simplicity of calculation of WL_k, TEA_k is calculated using (8) with the following relations for V_k.

For k = 1

$$V_1 = IT_1 + \sum_{i=1}^{m} O_{i1} \quad \text{...(11)}$$

For k = 2 to s

$$V_k = \sum_{k=1}^{k} IT_k + \sum_{k=1}^{k} \sum_{i=1}^{m} O_{ik} - \frac{1}{\eta} \sum_{k=1}^{k-1} \sum_{j=1}^{n1} WR_{kj}.TAK_j - \sum_{k=1}^{k-1} (E_k + P_k).WL_k$$

...(12)

(ii) For rabi season

In rabi season, water level in Ganga recedes and hence the water from Tal area gets drained out preventing excessive waterlogging. Hence, the total Tal area excepting the permanently waterlogged areas is available for rabi cropping. Therefore, the total cropped area in rabi season in the Tal should be less than or equal to the difference of the total cultivable area in the Tal and the area occupied by the perennial crops.

$$\sum_{j=1}^{n2} TAR_j \leq TA - \sum_{j=1}^{p} TAK_j \quad \text{...(13)}$$

in which

TA = Total cultivable area in Tal, sq.km.

5.2.4 Water requirement constraints

The water requirement constraint states that the monthly requirement of the command area is less than or equal to the monthly availability of water. However, this is equivalent to stating that in any given month, the cumulative water requirement is less than or equal to the cumulative water availability till that month.

5.2.4.1 Water requirement constraints for upper catchment

(i) For kharif season

The water requirement constraint for the upper catchment in kharif season can be expressed as below.

$$\frac{1}{\eta}\sum_{k=1}^{k}\sum_{j=1}^{n1} WR_{kj}.SBAK_{ij} \le \sum_{k=1}^{k} I_{ik} - \sum_{k=1}^{k} O_{ik} - \sum_{k=1}^{k}(E_k + P_k).SA_{ik} \qquad \text{...(14)}$$

For i = 1 to m

k = 1 to s

(ii) For rabi season

The water requirement constraint for the upper catchment in rabi season can be expressed as below.

$$\frac{1}{\eta}\sum_{k=1}^{k}\sum_{j=1}^{n2} WR_{kj}.SBAR_{ij} \le \sum_{k=1}^{s} I_{ik} - \sum_{k=1}^{k+s} O_{ik} - \frac{1}{\eta}\sum_{k=1}^{s}\sum_{j=1}^{n1} WR_{kj}.SBAK_{ij} - \sum_{k=1}^{k+s}(E_k + P_k).SA_{ik} \qquad \text{...(15)}$$

For i = 1 to m

k= 1 to r

5.2.4.2 Water requirement constraints for Tal area

(i) For kharif season

The water requirement constraint for the Tal area in kharif season can be expressed as follows.

$$\frac{1}{\eta}\sum_{k=1}^{k}\sum_{j=1}^{n1} WR_{kj}.TAK_j \le \sum_{k=1}^{k} IT_k + \sum_{k=1}^{k}\sum_{i=1}^{m} O_{ik} - \sum_{k=1}^{k}(E_k + P_k).WL_k \quad ...(16)$$

For k = 1 to s

(ii) For rabi season

In the Tal area, water is available from tubewells also. Hence, for rabi season, water from tubewells can also be utilised in addition to the outflow from the sub-basins in the upper catchment, to meet the crop water requirements. The water requirement constraint for rabi season in Tal area can thus be expressed as follows.

$$\frac{1}{\eta}\sum_{k=1}^{k}\sum_{j=1}^{n2} WR_{kj}.TAR_j \le \sum_{k=s+1}^{s+k}\sum_{i=1}^{m} O_{ik} + \sum_{k=1}^{k} TU_k \quad ...(17)$$

For k = 1 to r

in which

TU_k = water available from tubewells in k^{th} month, sq.km.m.

Further, it is required that the outflow from the upper catchment be totally utilised for meeting the crop water requirements in the Tal area in rabi season. This ensures that waterlogging in Tal area in rabi season does not aggravate. The resulting constraint can thus be expressed as follows:

$$\frac{1}{\eta}\sum_{k=1}^{k}\sum_{j=1}^{n2} WR_{kj}.TAR_j \geq \sum_{k=s+1}^{s+k}\sum_{i=1}^{m} O_{ik} \qquad ...(18)$$

5.2.5 Affinity constraints

Farmers of the region have a great tendency to go for paddy cultivation during kharif season. Keeping this in mind, the lower limit of the area under paddy cultivation is kept as 60% of the total irrigated area.

$$SBAK_{i1} \geq 0.6\sum_{j=1}^{n1} SBAK_{ij} \qquad ...(19)$$

For i = 1 to m

in which

$SBAK_{i1}$ = Area of i^{th} sub-basin under paddy cultivation.

Similarly, for rabi season, the minimum area under wheat cultivation is kept as 55% of the total irrigated area.

$$SBAR_{i1} \geq 0.55\sum_{j=1}^{n1} SBAR_{ij} \qquad ...(20)$$

For i = 1 to m

in which

$SBAR_{i1}$ = Area of i^{th} sub-basin under wheat cultivation.

5.2.6 Cropping pattern constraints

Keeping in view the cropping pattern of the area, various constraints setting the lower/ upper limit of the area under different crops have been fixed.

5.3 Formulation of Non-linear Optimisation Model with Constrained Outflow

The optimisation model outlined in section 4.2 would obviously result in a solution in which the outflows from the upper catchment (i.e. the inflows to the Tal area) is minimised so as to minimise the waterlogged area in the Tal in monsoon season. In other words, this would require a huge amount of water storage in the upstream catchment. This in turn requires construction of a number of water storage structures/ reservoirs. However, from a practical point of view, it may not be possible to construct so many water storage structures/ reservoirs at the same time. Construction of these structures has to be taken up in a phased manner. Also, in some places, the topography may not permit the construction of water storage structures/ reservoirs. In such places, it may not be possible to store any water at all. Thus, construction of a few water storage structures/ reservoirs would result in a partial storage of water in the upstream catchment. A partial storage of water in the upstream catchment means that some water, in addition to the outflows obtained from the solution of the optimisation problem outlined in section 4.2, is allowed to flow to the Tal area. In such a case it would be wise to have an idea of the extent of waterlogged area in the Tal so as to assess the benefit of construction of the water storage structures/ reservoirs. This requires that the non-linear optimisation model, outlined in section 4.2, be solved with additional outflow constraints as follows.

$$O_{ik} \geq c(I_{ik}) \quad \text{...(21)}$$

For i = 1 to m

k = 1 to s

in which

c = a fraction, which may take values ranging from 0.1 to 0.9.

The constraint, 21 essentially means that the outflow from the various sub-basins in various monsoon months should be at least equal to certain fraction of the inflow.

6.0 INPUT DATA PREPARATION

This chapter deals with the preparation of input data for the non-linear optimisation model outlined in section 5.2 as well as for the non-linear optimisation model with constrained outflow outlined in section 5.3. The published reports of various State Government and Central Government Organisations, and also the field investigations and interviewing of farmers and local people, provide the main sources of data.

The problem of surface water accumulation is basically the problem of difference of input and output of waters in a system, which can mathematically be described by the mass balance equation, i.e., Input – Output = Change of storage. The inputs to the system are: direct runoff resulting from a specific rainfall and all external flow entering to the system either into a basin or into a sub-system, whereas the outputs from the system are: crop water requirement, loss due to the seepage and evaporation etc.. The data requirements for the formulated model includes the following:

- *Formulation of various sub-units of the Kiul-Horahor basin.*
- *Estimation of rainfall.*
- *Estimation of runoff due to the rainfall.*
- *Selection of cropping pattern and estimation of crop water requirements.*
- *Water available through tubewells.*
- *Estimation of evaporation and seepage losses.*
- *Waterlogged area mapping.*

6.1 Sub-Division of Kiul-Harohar River Basin into Various Sub-Basins

A detailed description of the various river systems in the Kiul-Harohar river basin is given in section 4.2.2. The non-linear optimisation model requires the sub-division of the Kiul-Harohar river basin into various sub-basins. This sub-division would facilitate the storage of water in different pockets in various sub-basins.

The tributaries contribute water in the Kiul-Harohar river basin are crisscrossing in nature, particularly towards the downstream reaches of the Harohar basin. Based on their drainage patterns , the Kiul-Harohar river basin is, however, classified into four major sub-basins excluding the waterlogged portion in the Tal area, as shown in **Fig. 6.1**. These river basins are **(a) Falgu sub-basin** which includes the rivers *Mohane, Lilajan, Mahatmain* and *Lokain*, **(b) Dhadhar-Sakri sub-basin** which includes the rivers *Panchane, Mangur, Dhadhar, Tilaiya, Dhanarji, Khuri, Sakri, Jirain* and *Kumbhari*, **(c) Tati-Some sub-basin** which includes the rivers Tati and Some, and **(d) Kiul sub-basin** which includes the rivers *Bunbuni, Sukhnar, Barnar, Dohara, Nagi, Nakti, Bajan, Ajan* and *Morwe*. The **Tal area** includes the rivers *Harohar* which is known by the names *Dhowa* and *Mohane* in its upper reaches. The areal extent of the four sub-basins and the Tal area are given in **table 6.1**. The total cultivable area available for canal irrigation in the various sub-basins and Tal area is also presented in table 6.1.

Table 6.1: Areal Extent and Total Cultivable Area Available for Canal Irrigation in Various Sub-Basins of Kiul-Harohar River Basin

Sl. No.	Name of Sub-Basin	Area (sq. km.)	Percentage of Total Area	Total Cultivable Area Available for Canal Irrigation (sq. km.)
1.	Falgu sub-basin	5747	33.4	1495
2.	Dhadhar-Sakri sub-basin	5370	31.2	1393
3.	Tati-Some sub-basin	2114	12.3	992
4.	Kiul sub-basin	2930	17.0	1244
5.	Tal area	1062	6.1	925
	Total	**17223**	**100**	**6049**

6.2 Estimation of Mean Areal Rainfall

As mentioned earlier, rainfall in the Kiul-Harohar river basin occurs in the monsoon months of June to October. Also, as mentioned earlier (section 4.2.7.1), the monthly and annual normal rainfall of raingauge stations located in and around Kiul-

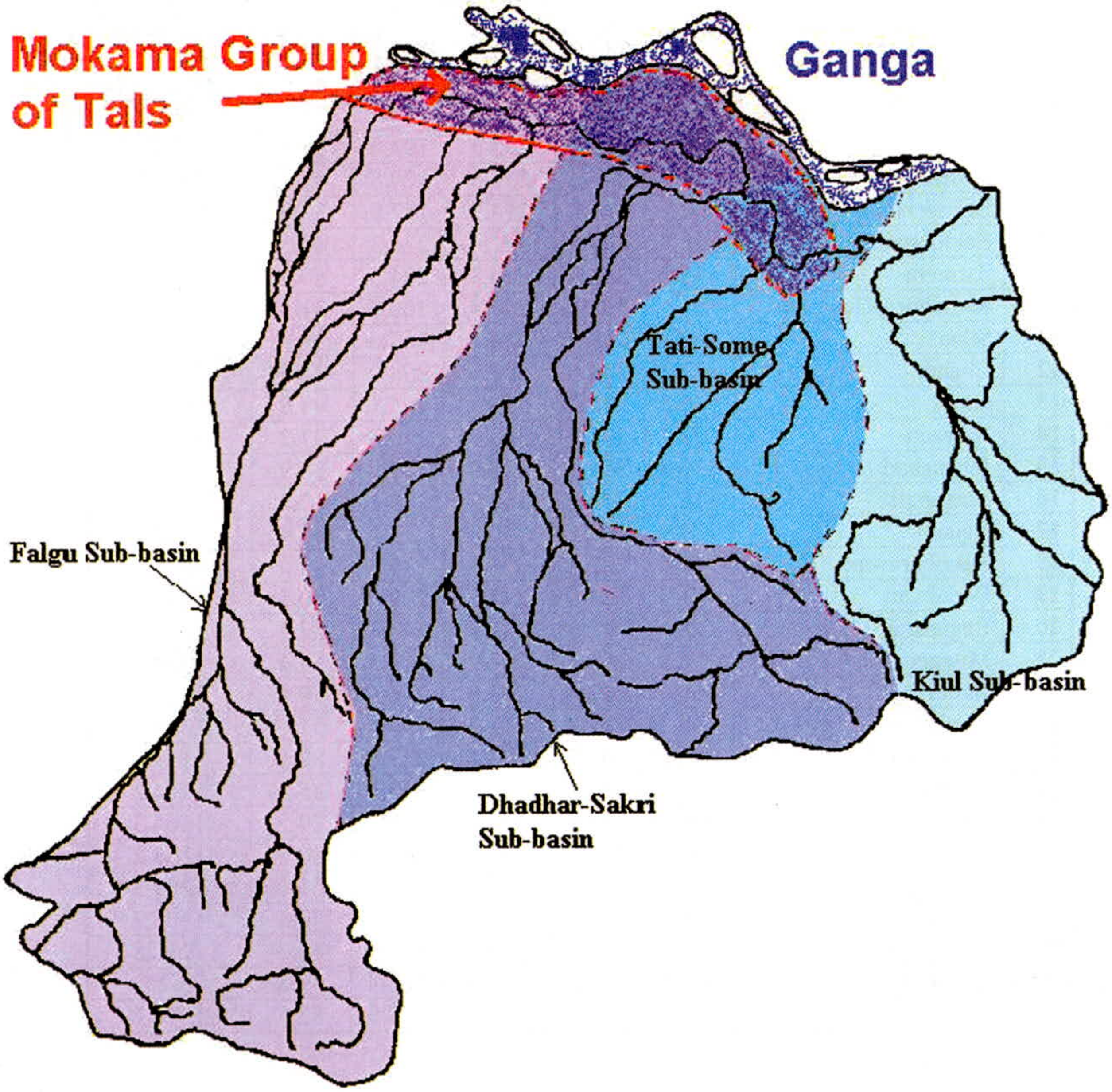


Figure 6.1: Drainage map of Kiul-Harohar river basin showing major sub-basins

Table 6.2: Monthly and Annual Normal Rainfall at Raingauge Stations in Kiul-Harohar and its Adjacent Basin Maintained by IMD

Sl. No.	Raingauge Station	June (mm)	July (mm)	August (mm)	Sept. (mm)	Oct. (mm)	Total (mm)
1	Patna	158.0	276.1	340.4	237.7	54.6	1066.8
2	Bihar Sharif	138.2	283.0	305.8	185.7	42.9	955.6
3	Barh	140.2	238.8	265.4	185.4	43.9	873.7
4	Hilsa	120.1	248.4	310.6	188.5	37.1	904.7
5	Islampur	128.0	285.2	293.6	193.8	32.3	932.9
6	Asthanwan	129.3	249.2	236.8	179.8	43.7	888.8
7	Ekangersarai	85.1	221.2	214.9	157.0	32.0	710.2
8	Bakhtiarpur	125.7	294.6	351.8	224.3	49.3	1045.7
9	Sarmera	135.9	289.6	319.3	204.5	60.5	1009.8
10	Badalpur (Khagole)	75.7	206.8	249.4	160.0	31.5	723.4
11	Silao	108.2	268.5	266.2	167.6	38.9	849.4
12	Chandi	122.7	305.1	302.0	204.0	44.5	978.3
13	Gaya	140.5	331.0	366.5	197.1	48.8	1083.9
14	Nawada	123.7	267.7	308.6	176.8	47.2	924.0
15	Jehanabad	130.8	283.0	325.9	213.6	38.9	992.2
16	Sherghati	128.3	297.4	362.5	213.1	52.8	1054.1
17	Rajauli	139.9	308.1	350.8	213.1	55.4	1067.3
18	Pukribarawan	117.3	227.3	379.7	176.3	48.5	849.4
19	Baradwati	121.4	324.6	377.9	209.0	50.5	1083.4
20	Begusarai	178.1	271.3	324.9	243.8	57.1	1075.2
21	Munger	174.0	263.4	324.9	212.3	55.4	1030.0
22	Jamui	160.0	292.6	292.9	216.4	59.4	1021.3
23	Sheikhpura	165.3	277.1	312.2	199.4	51.6	1005.6
24	Chakaibanda	193.3	300.2	305.1	227.6	87.6	1113.8
25	Gidhaur	200.1	327.1	317.1	233.4	85.9	1164.2
26	Hazaribagh	194.3	321.8	349.0	219.7	79.5	1164.3
27	Barhi	183.4	334.5	365.8	201.2	80.3	1165.2
28	Chatra	73.2	360.9	385.1	229.1	61.0	1209.3
29	Kodarma	175.5	305.6	342.7	210.3	70.6	1104.7
30	Hunterganj	151.4	380.7	388.6	231.9	60.2	1212.8
31	Satgawan	113.0	288.5	325.6	186.4	49.3	962.8
32	Dhanwar	166.4	326.4	303.5	197.9	82.5	1076.7

Table 6.3: Mean Monthly Areal Rainfall of Falgu Sub-Basin by the Thiessen Polygon Method

Raingauge Stations	Thiessen Polygon Area (km^2)	Thiessen Weights	Rainfall (mm)					Weighted rainfall (mm)				
			June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
Hazaribagh	428.7	0.075	194.3	321.8	349.0	219.7	79.5	14.5	24.0	26.0	16.4	5.9
Barhi	255.2	0.044	183.4	334.5	365.8	201.2	80.3	8.1	14.9	16.2	8.9	3.6
Chatra	1327.0	0.231	73.2	360.9	385.1	229.1	61.0	16.9	83.3	88.9	52.9	14.1
Hunterganj	561.4	0.098	151.4	380.7	388.6	231.9	60.2	14.8	37.2	38.0	22.7	5.9
Sherghati	40.8	0.007	113.0	288.5	325.6	186.4	49.3	0.8	2.0	2.3	1.3	0.4
Gaya	980.0	0.171	140.5	331.0	366.5	197.1	48.8	24.0	56.4	62.5	33.6	8.3
Jahanabad	91.9	0.016	130.8	283.0	325.9	213.6	38.9	2.1	4.5	5.2	3.4	0.6
Silao	367.5	0.064	108.2	268.5	266.2	167.6	38.9	6.9	17.2	17.0	10.7	2.5
Islampur	622.7	0.108	128.0	285.2	293.6	193.8	32.3	13.9	30.9	31.8	21.0	3.5
Bihar	255.2	0.044	138.2	283.0	305.8	185.7	42.9	6.1	12.6	13.6	8.2	1.9
Chandi	296.0	0.052	122.7	305.1	302.0	204.0	44.5	6.3	15.7	15.6	10.5	2.3
Hilsa	275.6	0.048	120.1	248.4	310.6	188.5	37.1	5.8	11.9	14.9	9.0	1.8
Ekangersarai	245.0	0.043	85.1	221.2	214.9	157.0	32.0	3.6	9.4	9.2	6.7	1.4
Total	**5747.0**	**1.000**	**Mean Areal Rainfall (mm)**					**123.8**	**320.1**	**341.2**	**205.4**	**52.1**

Table 6.4: Mean Monthly Areal Rainfall of Dhadhar-Sakri Sub-Basin by the Thiessen Polygon Method

Raingauge Stations	Thiessen Polygon Area (km^2)	Thiessen Weights	Rainfall (mm)					Weighted rainfall (mm)				
			June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
Gaya	162.1	0.030	140.5	331.0	366.5	197.1	48.8	4.2	10.0	11.1	6.0	1.5
Barhi	314.1	0.058	183.4	334.5	365.8	201.2	80.3	10.7	19.6	21.4	11.8	4.7
Rajauli	1459.0	0.272	139.9	308.1	350.8	213.1	55.4	38.0	83.7	95.3	57.9	15.1
Nawada	810.6	0.151	123.7	267.7	308.6	176.8	47.2	18.7	40.4	46.6	26.7	7.1
Silao	334.4	0.062	108.2	268.5	266.2	167.6	38.9	6.7	16.7	16.6	10.4	2.4
Bihar	192.5	0.036	138.2	283.0	305.8	185.7	42.9	5.0	10.1	11.0	6.7	1.5
Asthawan	415.4	0.077	129.3	249.2	236.8	179.8	43.7	10.0	19.3	18.3	13.9	3.4
Sarmera	162.1	0.030	135.9	289.6	319.3	204.5	60.5	4.1	8.7	9.6	6.2	1.8
Pakribarman	91.2	0.017	117.3	227.3	279.7	176.3	48.5	2.0	3.9	4.7	3.0	0.8
Satgawan	820.7	0.153	113.0	288.5	325.6	186.4	49.3	17.3	44.1	49.8	28.5	7.5
Dhanwar	607.9	0.113	166.4	326.4	303.5	197.9	82.5	18.8	37.0	34.4	22.4	9.3
	5370.0	1.000	Mean Areal Rainfall (mm)					**135.5**	**293.5**	**318.7**	**193.4**	**55.2**

Table 6.5: Mean Monthly Areal Rainfall of Tati-Some Sub-Basin by the Thiessen Polygon Method

Raingauge Stations	Thiessen Polygon Area (km^2)	Thiessen Weights	Rainfall (mm)					Weighted rainfall (mm)				
			June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
Shekhpura	704.7	0.333	165.3	277.1	312.2	199.4	51.6	55.1	92.4	104.1	66.5	17.2
Pakribarman	684.8	0.324	117.3	227.3	279.7	176.3	48.5	38.0	73.6	90.6	57.1	15.7
Nawada	29.8	0.014	123.7	267.7	308.6	176.8	47.2	1.7	3.8	4.3	2.5	0.7
Satgawan	426.8	0.202	113.0	288.5	325.6	186.4	49.3	22.8	58.2	65.7	37.6	10.0
Jamui	268.0	0.127	160.0	292.6	292.9	216.4	59.4	20.3	37.1	37.1	27.4	7.5
Total	**2144.0**	**1.000**	**Mean Areal Rainfall (mm)**					**137.9**	**265.1**	**301.9**	**191.1**	**51.1**

Table 6.6: Mean Monthly Areal Rainfall of Kiul Sub-Basin by the Thiessen Polygon Method

Raingauge Stations	Thiessen Polygon Area (km^2)	Thiessen Weights	Rainfall (mm)					Weighted rainfall (mm)				
			June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
Dhanwar	58.8	0.020	166.4	326.4	303.5	197.9	82.5	3.3	6.5	6.1	4.0	1.7
Chakai	539.0	0.184	193.3	300.2	305.1	227.6	87.6	35.6	55.2	56.1	41.9	16.1
Gidhaur	793.7	0.271	200.1	327.1	317.1	233.4	85.9	54.2	88.6	85.9	63.2	23.3
Jamui	1175.9	0.401	160.0	292.6	292.9	216.4	59.4	64.2	117.4	117.6	86.8	23.8
Satgawan	39.2	0.013	113.0	288.5	325.6	186.4	49.3	1.5	3.9	4.4	2.5	0.7
Shekhpura	19.6	0.007	165.3	277.1	312.2	199.4	51.6	1.1	1.9	2.1	1.3	0.3
Begusarai	225.4	0.077	178.1	271.3	324.9	243.8	57.1	13.7	20.9	25.0	18.8	4.4
Munger	78.4	0.027	174.0	263.4	324.9	212.3	55.4	4.7	7.0	8.7	5.7	1.5
Total	**2930**	**1.000**	**Mean Areal Rainfall (mm)**					**178.3**	**301.4**	**305.8**	**224.2**	**71.8**

Table 6.7: Mean Monthly Areal Rainfall of Tal Area by the Thiessen Polygon Method

Raingauge Stations	Thiessen Polygon Area (km^2)	Thiessen Weights	Rainfall (mm)					Weighted rainfall (mm)				
			June	July	Aug.	Sept.	Oct.	June	July	Aug.	Sept.	Oct.
Chandi	126.0	0.119	122.7	305.1	302.0	204.0	44.5	14.6	36.2	35.8	24.2	5.3
Bakhtipur	243.0	0.229	125.7	294.6	351.8	224.3	49.3	28.8	67.4	80.5	51.3	11.3
Barh	234.0	0.220	140.2	238.8	265.4	185.4	43.9	30.9	52.6	58.5	40.9	9.7
Sarmera	279.0	0.263	135.9	289.6	319.3	204.5	60.5	35.7	76.1	83.9	53.7	15.9
Shekhpura	180.0	0.169	165.3	277.1	312.2	199.4	51.6	28.0	47.0	52.9	33.8	8.7
Total	**1062.0**	**1.000**	**Mean Areal Rainfall (mm)**					**137.9**	**279.3**	**311.6**	**203.9**	**50.9**

Harohar river basin are given in **table 6.2.** The location of these raingauge stations are shown in **figure 6.2**. Thiessen polygon method is used to calculate the mean monthly areal rainfall of the various sub-basins and the Tal area.

The thiessen polygons are constructed around each station for each of the sub-basins and the Tal area as shown in **figures 6.3 to 6.7**. The area of the polygons is then planimetered, thiessen weights calculated, and the mean monthly areal rainfall determined for each of the sub-basins and the Tal area. The details of the calculations are presented in **tables 6.3 to 6.7.**

6.3 Estimation of Runoff

The runoff from different sub-basins and the Tal area is estimated using the computed rainfall values (calculated in section 6.2) and the requisite runoff characteristics of the catchment. The runoff characteristics of the catchment are determined from the landuse and soil maps given in chapter 4. The computed monthly values of runoff from each sub-basin and Tal area are presented in **table 6.8**.

Table 6.8: Monthly Runoff Values from Various Sub-basins and Tal Area

Sl. No.	Name of Sub-Basin	Runoff (km^2.m)				
		June	July	August	September	October
1.	Falgu	243.267	628.91	670.389	403.619	102.332
2.	Dhadhar-Sakri	248.719	538.48	584.824	354.81	101.309
3.	Tati-Some	99.638	191.497	218.064	138.063	36.882
4.	Kiul	178.501	301.8	306.158	224.442	71.843
5.	Tal area	50.053	101.343	113.077	73.992	18.461

The computed values of runoff indicate that the Falgu sub-basin contributes 2048.5 km^2m of water, while the Dhadhar-Sakri sub-basin is 1828.1 km^2m, Tati-Some sub-basin is 684.1 km^2m, and Kiul sub-basin is 1082.7 km^2m, whereas that from Tal area contributes 356.9 km^2m. The total runoff from the Kiul-Harohar river basin (including the Tal area) amounts to 6000 km^2m or 6 Lham.

Figure 6.2: Location of Raingauge stations in and around Kiul-Harohar Basin

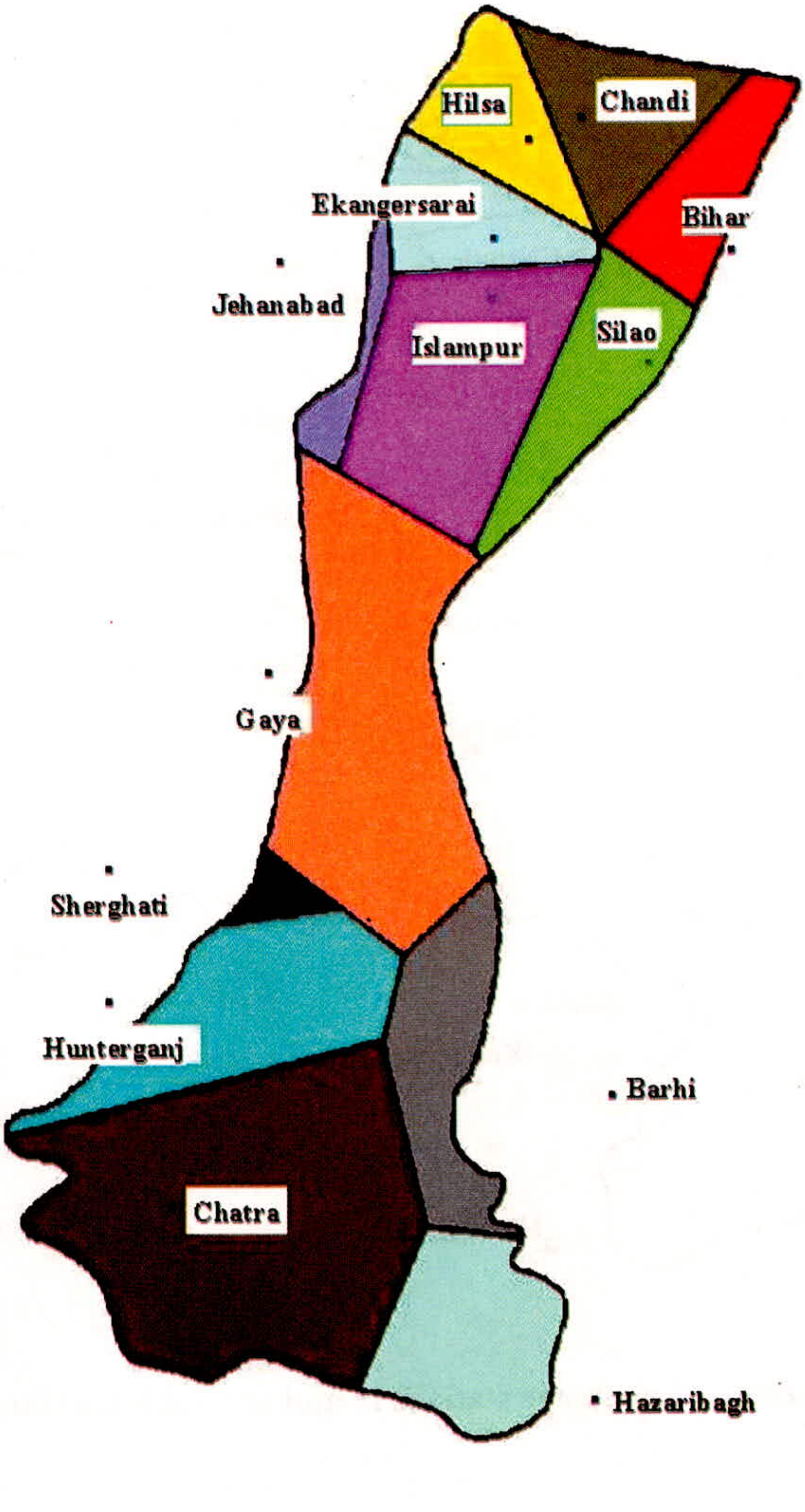


Figure 6.3: Thiessen Polygons for Computing the Mean Areal Rainfall of Falgu Sub-basin

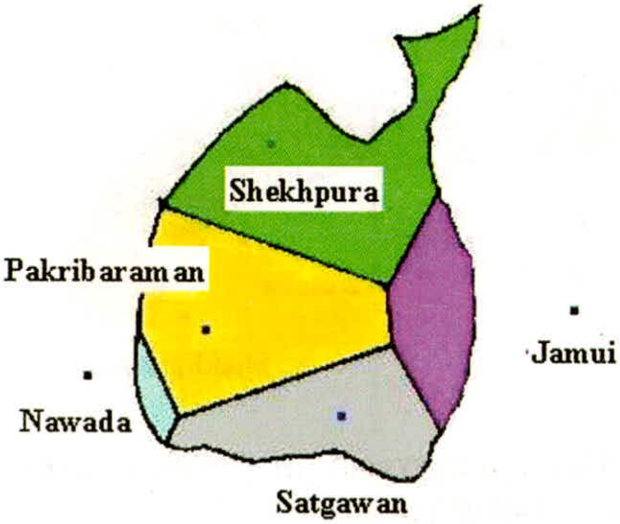


Figure 6.4: Thiessen Polygon for Computing the Mean Areal Rainfall of Tati-Some Sub-basin

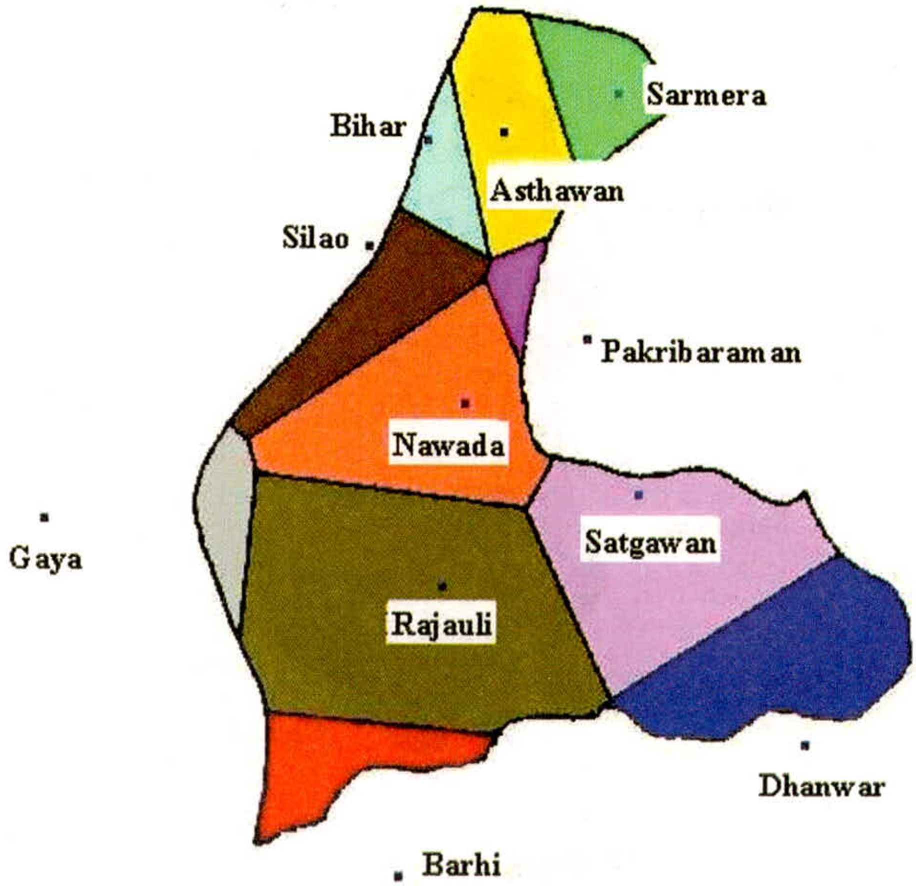


Figure 6.5: Thiessen Polygons for Computing Mean Areal Rainfall of Dhadhar-Sakri Sub-basin

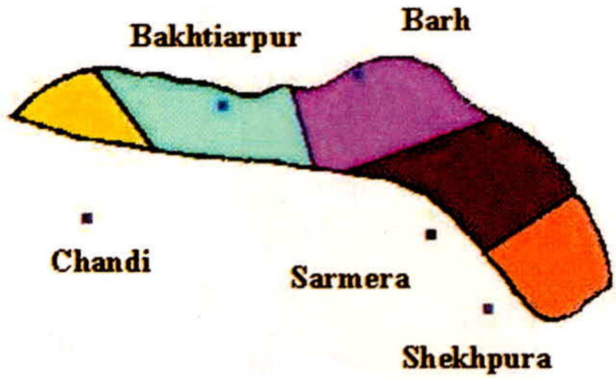


Figure 6.6: Thiessen Polygons for Computing the Mean Areal Rainfall of Tal Area

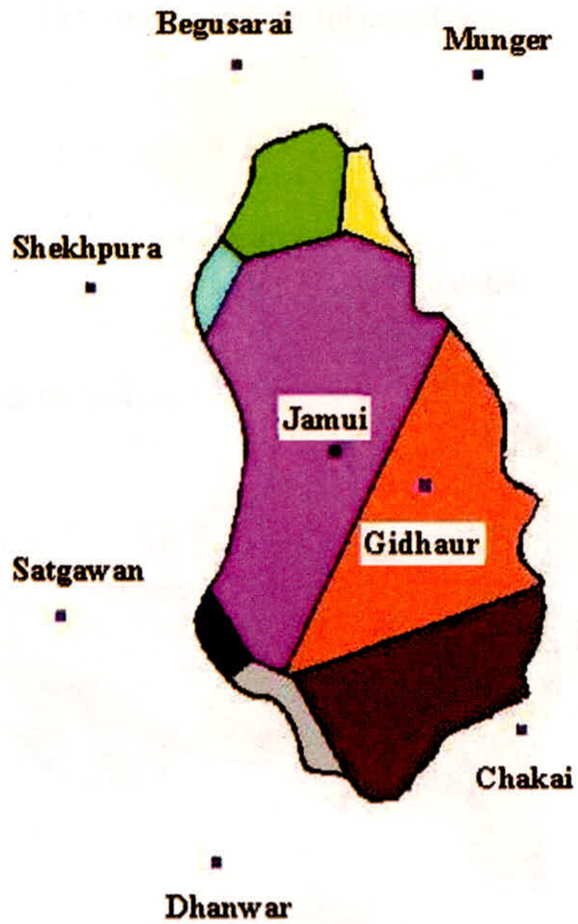


Figure 6.7: Thiessen Polygons for Computing the Mean Areal Rainfall of Kiul Sub-basin

6.4 Cropping pattern in the Kharif and Rabi Seasons

The existing cropping pattern in the Kiul-Harohar river basin is detailed in section 4.2.8. Kharif season generally ranges from June to October while rabi season ranges from November to March. The crops to be grown in kharif and rabi season in the the various sub-basins and Tal area were decided on the basis of the existing cropping pattern, the soil and topographic maps detailed in chapter 4, and also detailed conversations with a number of farmers and local people. The crops to be grown in **kharif season** are **(i) Paddy (ii) Maize (iii) Vegetables and (iv) Arhar**. The crops to be grown in **rabi season** are **(i) Wheat (ii) Gram (iii) Mustard (iv) Potato and (v) Vegetables**. Arhar is a perennial crop which is sown in kharif season but is harvested only after rabi season.

6.5 Estimation of Cropwise Monthly Irrigation Water Requirements

The irrigation water requirement of a crop for its growth period has been estimated monthwise by Eq. 5.3. The monthly rainfall values estimated in section 6.2 are used. The monthly values of evaporation estimated using Christiansen's method (as detailed in section 6.8) are used. The crop coefficients for a particular crop at different growth stages have been taken from Doorenbos and Pruitt (1977). Percolation loss has been taken for paddy crop only at a rate of 3 mm per day. The monthwise net irrigation requirement for all the crops are presented in **table 6.9**.

6.6 Irrigation System Efficiency

Supposing that all irrigation networks would be lined canals. Therefore, in the beginning of the project implementation, the irrigation system efficiency will be pretty high. However, with time the irrigation system efficiency reduces unless improvement measures are taken. In the present formulation, the irrigation system efficiency has been considered to be 70 percent. However, the solution of the optimisation model with lower values of irrigation system efficiency (say 60% or 50%) have also to be looked into so as to have a realistic picture of the ground situation in later stages of the project.

Table 6.9: Monthly Net Irrigation Water Requirements of Different Crops Sown in Kharif and Rabi Seasons, mm

Month	Kharif			Perennial	Rabi				
	Paddy	Maize	Vegetables	Arhar	Wheat	Gram	Mustard	Potato	Vegetables
June	15.00	0	0	0	-	-	-	-	-
July	28.21	0	0	0	-	-	-	-	-
Aug.	60.24	2.19	0	0	-	-	-	-	-
Sep.	183.13	68.03	23.69	44.05	-	-	-	-	-
Oct.	56.35	0	0	11.84	-	-	-	-	-
Nov.	-	-	-	0	46.77	34.48	14.78	35.07	49.35
Dec.	-	-	-	0	78.03	49.52	47.96	72.40	77.38
Jan	-	-	-	0	85.24	79.43	69.49	73.68	61.39
Feb	-	-	-	0	49.50	78.27	70.12	42.58	10.71
March	-	-	-	0	12.66	26.85	0	0	0
Total	**342.93**	**70.22**	**23.69**	**55.89**	**272.2**	**268.55**	**202.35**	**223.73**	**198.83**

6.7 Water Availability from Tubewells

It has been reported that some parts of irrigation water is also met by the tube wells. Quantity of water available through existing tube wells has been considered in the estimation of crop water requirement. There are two types of tubewells in the Tal area. One is Government owned while the other is private owned. The latest figures on the number of Government and private tubewells along with their discharge and command area are presented in **Tables 6.10 and 6.11** respectively.

Table 6.10: Data of State Tubewells

Sl. No.	Name of Tal	No. of State Tubewells	No. of Tubewells under Operation	Discharge of Tubewells	Total Irrigation Capacity (Acre)
1.	Fatuha	29	10	12" open boring	2000
2.	Bakhtiarpur	36	12	-do-	2400
3.	Barh	42	17	-do-	3400
4.	Mokama	28	8	-do-	1600
5.	More	32	8	-do-	1600
6.	Lakhisarai	43	7	-do-	1400
7.	Barahiya	21	7	-do-	1400
	Total	**231**	**69**		**13800**

Table 6.11: Data of Private Tubewells

Sl. No.	Name of Tal	No. of State Tubewells	No. of Tubewells under Operation	Discharge of Tubewells	Total Irrigation Capacity (Acre)
1.	Fatuha	567	567	4" open boring	1417
2.	Bakhtiarpur	477	477	-do-	1192
3.	Barh	814	792	-do-	1980
4.	Mokama	2050	2050	-do-	5125
5.	More	80	80	-do-	200
6.	Lakhisarai	3238	3238	-do-	8095
7.	Barahiya	402	402	-do-	1065
	Total	**8348**	**8326**		**19074**

The annual volume of water obtained from a single state tubewell is 0.4759 km^2m (considering standard average working hours) while that from a private tubewell is 0.0105 km^2m. Hence, the total annual volume of water obtained from the state tubewells that are operational amounts to 0.4759×69 = 32.8371 km^2m. Similarly, the total annual volume of water obtained from the private tubewells that are operational amounts to 0.0105×8326 = 87.423 km^2m. Hence, the total annual volume of water available from tubewells (both state and private owned) equals 32.8371 + 87.423 = 120.2601 km^2m. Assuming that 40 percent of this volume (120.2601 km^2m) is available during rabi season, the total available water stands at 0.40×120.2601 = 48.104 km^2m.

6.8 Estimation of Evaporation and Percolation Losses

Monthly pan evaporation data for the study area are not available. However, climatic data for the study area are available. Christiansen (1968), as reported by Michael (1978), proposed an empirical formula to estimate pan evaporation from climatic data when reliable measured pan evaporation data are not available. The following is the Christiansen's empirical formula developed at Logan (Utah), USA, for estimating pan evaporation.

$$E_v = K_{ev}.\ R.\ C_t.\ C_w.\ C_h.\ C_s.\ C_e.\ C_m \qquad \ldots (6.1)$$

in which E_v is the computed pan evaporation equivalent to Class A pan evaporation, K_{ev} is a dimensionless empirically developed constant, the value of which is given by Christiansen as 0.473, R is extra-terrestrial radiation in the same evaporation units as E_v and C_t, C_w, C_h, C_s, and C_e are the coefficients for temperature, wind velocity, relative humidity, percent of possible sunshine hours and elevation respectively, and C_m is a monthly coefficient or factor by which all the basic formulae would have to be multiplied to obtain the measured evaporation. The values of C_m mostly range between 0.90 to 1.10 and vary from latitude to latitude.

Table 6.12: Computation of Pan Evaporation by using Christiansen's Formula from the Climatological Data of the Study Area (Kiul-Harohar River Basin)

Months	R (mm/month) for 25° N Latitude (From Tables)	Mean Monthly Temperature (°C)	C_t (From Tables)	Mean Relative Humidity (%)	C_h (From Tables)	Percentage of Possible Sunshine Hours	C_s (From Tables)	Wind velocity at 2m (km/day)	C_w (From Tables)	C_e for an Average Elavation of 60 m (From Tables)	Estimated Pan Evaporation, E_v (mm/month)
June	490	32.9	1.442	62.85	0.957	50	0.824	273	1.164	0.976	**299.4**
July	500	29.8	1.332	51.97	1.035	50	0.824	246	1.111	0.976	**291.3**
August	478	29.2	1.311	36.40	1.111	50	0.824	234	1.086	0.976	**287.6**
September	422	28.8	1.297	56.63	1.005	50	0.824	210	1.037	0.976	**217.0**
October	376	26.5	1.218	77.79	0.790	80	1.000	135	0.893	0.976	**149.2**
November	307	21.3	1.043	80.68	0.750	80	1.000	121	0.867	0.976	**96.1**
December	283	17.2	0.909	78.53	0.780	80	1.000	183	0.983	0.976	**91.1**
January	304	16.4	0.884	69.18	0.900	80	1.000	131	0.885	0.976	**98.8**
February	330	19.3	0.977	61.16	0.977	80	1.000	160	0.938	0.976	**136.4**
March	419	25.1	1.170	61.07	0.980	80	1.000	189	0.994	0.976	**220.5**

Equation 6.1 is used to calculate the monthly pan evaporation values for the study area. Based on the climatic data of the study area, various parameters of Eq. 6.1 are found from standard tables reported by Michael (1978). These are presented in **table 6.12**. The value of K_{ev} is taken as 0.473 and that of C_m is taken as 1.0. The monthly pan evaporation values thus calculated are also presented in **Table 6.12**.

On the basis of the soil maps given in chapter 4, the percolation losses are determined to be approximately 90 mm/month. The percolation losses are assumed to be uniform over the entire region as well as time period.

6.9 Waterlogged Area Mapping

Remote sensing and ancillary data are used to delineate the waterlogged areas in the Mokama group of Tals. The remote sensing data of IRS-1A satellite are collected from NRSA, Hyderabad. Satellite imageries of different dates are used for delineation of waterlogged areas. Details of the satellite remote sensing data used in the present study are given in **table 6.13**. Ancillary data includes information on the topographical features, landuse, soil and geology, as detailed in chapter 4. Toposheets of the scale of 1:50,000 and 1:2,50,000 are also used.

Table 6.13: Remote Sensing Data used for Delineation of Waterlogged Areas

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

The waterlogged areas are 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 water had receded. The post-monsoon scenes of the IRS LISS II data are used to delineate the standing water areas and wet areas during monsoon season, while pre-monsoon scenes are used to delineate the permanent water logged/wet areas. These areas are demarcated as water logged areas during monsoon season. The standing water areas appear as dark blue depending upon the depth of water, while the wet areas appear 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 entering the Tal, submergence level and control structures etc. are used to delineate the water logged areas (Lohani et al 1999). The waterlogged area map thus developed by pre-monsoon and post-monsoon remote sensing data for the year 1989 and ancillary data is shown in **figure 6.8**.

Field visits were also made to the waterlogged areas in Mokama group of Tals in monsoon as well as post monsoon season. **Figures 6.9 and 6.10** show a view of the vast waterlogged areas in Mokama group of Tals in monsoon season. **Figures 6.11 and 6.12** show a view of the Mokama group of Tals in the post-monsoon season when the water receedes to the river Ganga.

6.10 Storage Characteristics of Mokama Group of Tals

The contour map of Mokama group of Tals as well as the boundary map of Mokama group of Tals is digitised. **Figure 6.13** shows the Digital Elevation Model (DEM) of Mokama group of Tals. **Figure 6.14** shows the Digital Terrain Model (DTM) of Mokama group of Tals. Using GIS, the waterlogged area (and hence the exposed area) for various storage values in the Tal are computed and shown in **table 6.14.** The values of exposed area are then plotted against the water storage values as shown in **figure 6.15**. The best fit curve is found to be a sixth degree polynomial of the following form.

$$E_a = 1010.5 - 1374.4V + 1252.4V^2 - 596.7V^3 + 145.5V^4 - 17.4V^5 + 0.8V^6 \qquad r^2 = 0.99 \qquad ...(6.2)$$

in which E_a is the exposed area in km^2 and V is the storage volume in km^3.

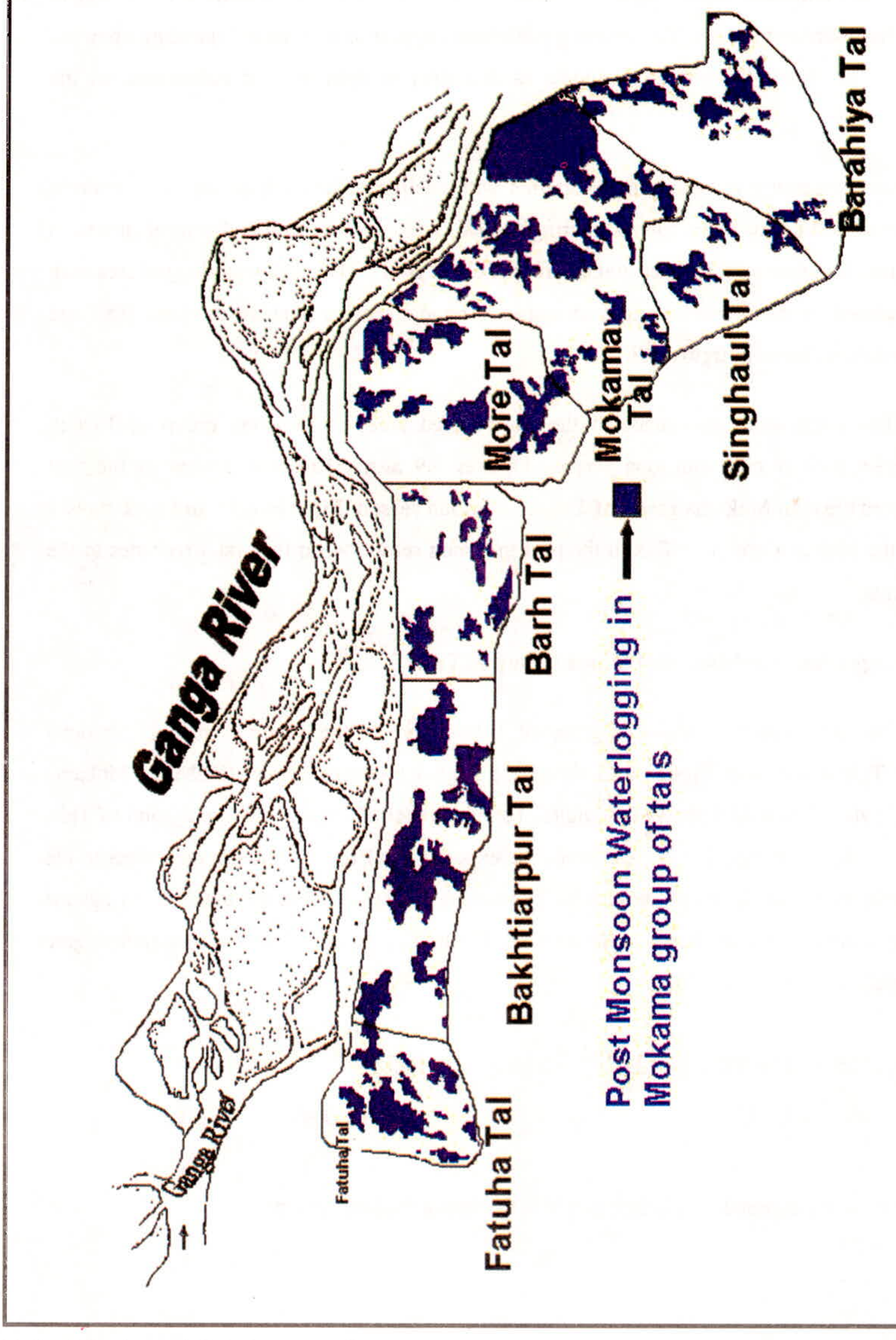


Fig. 6.8 : Water Logged Area Map delineated from remote sensing data

Fig 6.9: A view of Mokama Tal during August, 1999

Fig. 6.10: A view of the Barh Tal during September, 1998

Fig. 6.11: A View of Fatuha Tal during October, 1998

Fig. 6.12: A View of Barh Tal during October, 1998

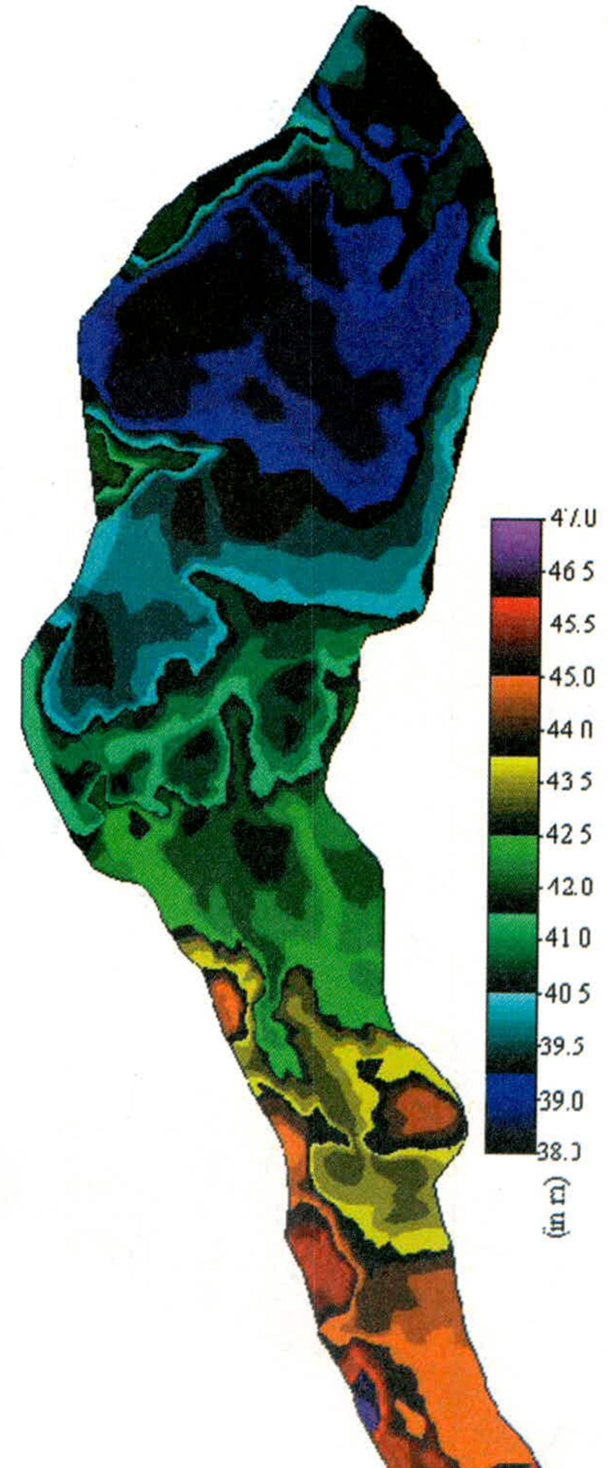


Figure 6.13: Digital Elevation Model (DEM) of Mokama Group of Tals

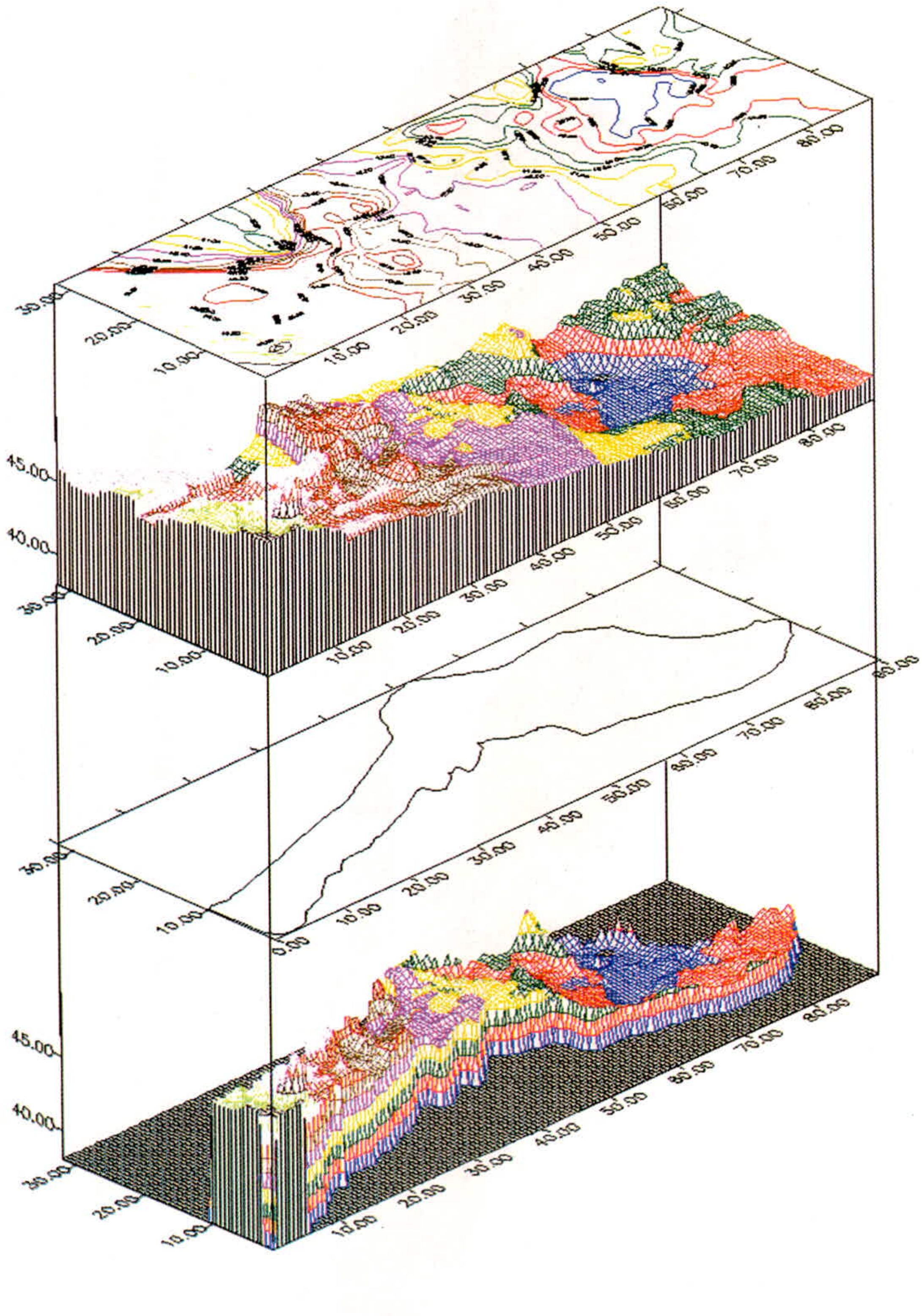


Figure 6.14: Digital Terrain Model (DTM) of Mokama Group of Tals

Table 6.14: Waterlogged and Exposed Areas for Various Storage Values in Mokama Group of Tals

Sl. No.	Storage (cu. km.)	Exposed Area (sq. km.)	Waterlogged Area (sq. km.)	Sl. No.	Storage (cu. km.)	Exposed Area (sq. km.)	Waterlogged Area (sq. km.)
1	6.622	0.63	1061.37	26	1.854	321.21	740.79
2	6.403	7.51	1054.49	27	1.704	345.44	716.56
3	6.185	11.05	1050.95	28	1.560	368.06	693.94
4	5.969	21.49	1040.51	29	1.420	387.18	674.82
5	5.756	40.25	1021.75	30	1.283	399.56	662.44
6	5.545	48.65	1013.35	31	1.150	423.56	638.44
7	5.336	53.91	1008.09	32	1.023	452.71	609.29
8	5.129	63.22	998.78	33	0.900	471.89	590.11
9	4.923	75.25	986.75	34	0.782	496.61	565.39
10	4.721	84.30	977.70	35	0.669	519.60	542.40
11	4.519	93.51	968.49	36	0.561	540.01	521.99
12	4.320	105.69	956.31	37	0.457	569.21	492.80
13	4.125	122.35	939.66	38	0.362	619.75	442.25
14	3.934	143.68	918.32	39	0.277	676.15	385.85
15	3.746	153.80	908.20	40	0.205	723.92	338.08
16	3.560	163.45	898.55	41	0.144	808.39	253.61
17	3.377	174.08	887.92	42	0.098	864.29	197.71
18	3.195	185.60	876.40	43	0.063	896.45	165.56
19	3.016	198.11	863.89	44	0.033	938.76	123.24
20	2.840	214.43	847.58	45	0.013	992.26	69.74
21	2.669	237.75	824.25	46	0.004	1031.67	30.33
22	2.501	247.73	814.27	47	0.001	1042.15	19.85
23	2.334	254.39	807.61	48	0.00006	1058.95	3.05
24	2.169	270.46	791.54	49	0	1062.00	0
25	2.009	288.63	773.37				

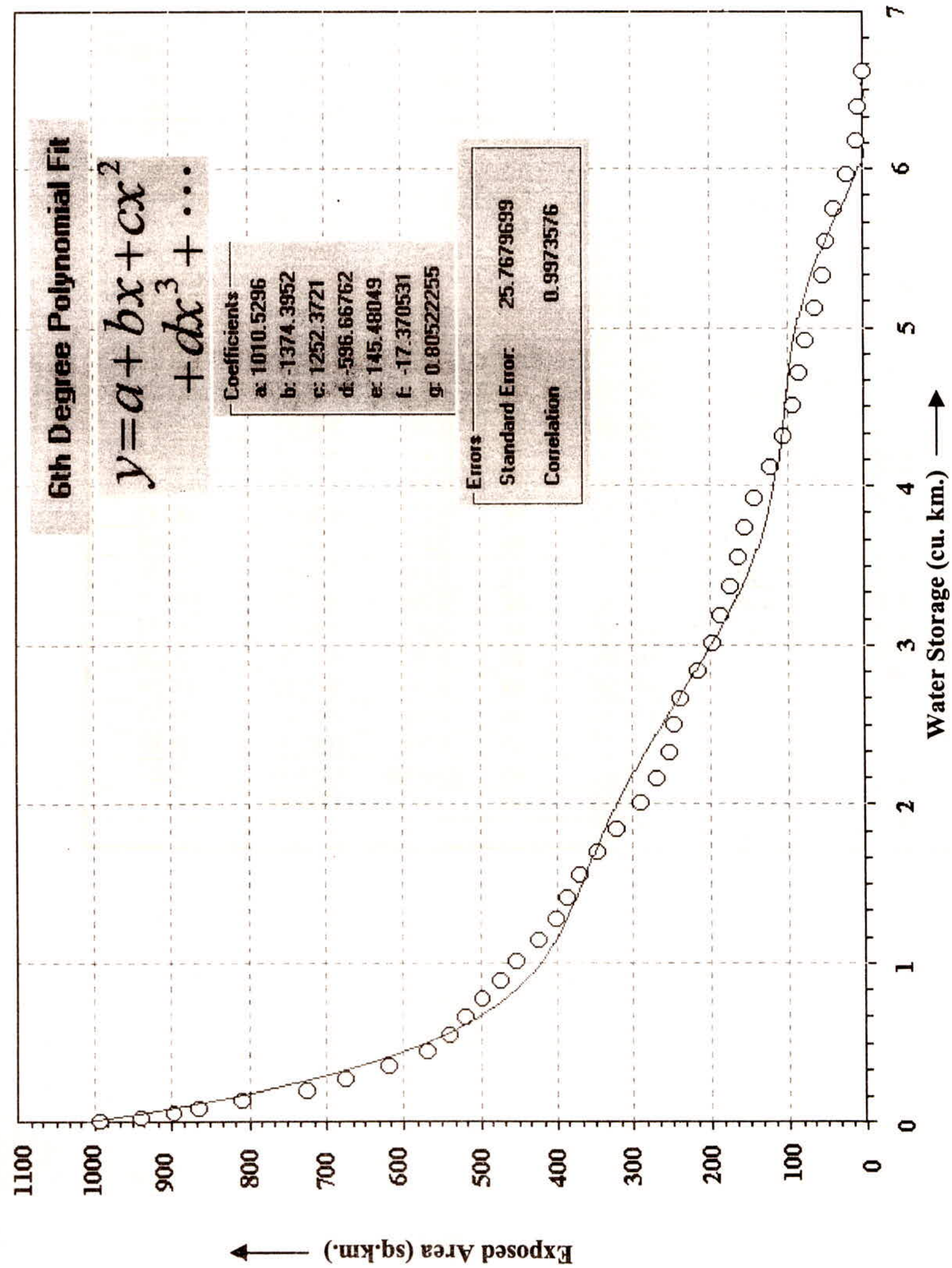


Figure 6.15: Exposed area versus water storage curve for Mokama Group of Tals

7.0 RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the solution of non-linear optimisation model, outlined in chapter five, obtained with the data presented in chapter six. The chapter has been outlined in five sections in accordance with the data presented in chapter six. The results are presented in ***two parts***: in the first part the solution of the non-linear optimisation model, outlined in section 5.2, are presented and in the second part the solution of the non-linear optimisation model with constrained outflow, outlined in section 5.3, are presented. The results obtained from the model runs have been compared with the existing field scenario prevailed in the **Tal area** and also in **the upper catchment.** Further, the crop water requirements (including the conveyance losses), which in turn would dictate the reservoir scheduling, in the various sub-basins in the upper catchment are also presented.

7.1 Software Used

Although the objective function of the programme is linear but one of its constains namely; area-capacity expression, is a non-linear function. Therefore, the programme as a whole stands to be a ***non-linear optimization model.***

A software, namely QSB (Quantitative Systems for Business) developed by Yih-Long Chang of Prentice Hall Inc., is used. There are various optimisation modules in this package. However, for the present problem, the non-linear optimisation module is used. In this module, a line search methodology is used to solve unconstrained problems and a sequential unconstrained minimization technique (SUMT) with penalty function methodology is used to solve constrained problems. The size of the problems that can be solved depends on the memory of the computer. For the present problem, a computer with 32 MB RAM is used which handles 160 constraints.

7.2 Results of Non-Linear Optimisation Model

As outlined in section 5.2.1, the objective of the non-linear optimisation model is to maximise the cropped area in the Tal as well as in the upstream reaches. The solution obtained using the QSB software is presented in **table 7.1**. Table 7.1 shows the areas allocated to different crops in kharif and rabi season in various sub-basins of the upper catchment and Tal area. The maximised value of the objective function is obtained as ***11,441.84 km²***.

7.2.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi seasons are shown in **figure 7.1**. It is observed that in kharif season, out of a total area of 1062 km^2, only 137.38 km^2 remains waterlogged and the remaining area of 924.62 km^2 is allocated to different kharif crops. Similarly, in rabi season, only 137 km^2 remains waterlogged while an area of 925 km^2 is allocated to different crops. Out of the 925 km^2 of cropped area in rabi season, 883.39 km^2 is allocated to different rabi crops and the remaining area of 41.61 km^2 is allocated to Arhar crop. In figure 7.1, inspite of Arhar being an annual crop, its area is included in the cropping area of rabi season so as to have an idea of the extent of waterlogging in the Tal. Hence, it is observed that an area of approximately 137 km^2 remains waterlogged in the Tal in both kharif as well as rabi season under the objective of maximisation of cropped area. However, these areas of 137 km2 in the Tal are permanently waterlogged areas that cannot be made free of waterlogging even in rabi season. The cultivable area in the Tal is only 925 km^2 Further, the cropping intensity in the Tal is 195.46%, as indicated in Table 7.1.

Figures 7.2 and 7.3 show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 13% of the Tal area remains waterlogged in both the kharif as well as rabi season. In kharif season, the area allocated to paddy is maximum, i.e., 75.75% and that for vegetables it is a minimum, i.e., 1.31%. In rabi season, the area allocated to wheat is

Table 7.1: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	1181.05	1100.47	458.67	960.56	804.42
Maize	224.25	208.95	90.53	186.60	64.72
Vegetables	22.43	20.90	18.11	37.32	13.87
Arhar	67.28	62.69	36.21	59.52	41.61
Rabi Season					
Wheat	1120.76	1044.30	573.47	710.69	693.46
Gram	107.08	99.77	143.37	177.67	66.25
Mustard	85.66	79.82	114.69	142.14	53.00
Potato	71.39	66.52	76.46	94.76	44.17
Vegetables	42.83	39.91	47.79	59.22	26.50
Total Area, km^2	2922.72	2723.31	1559.31	2428.48	1808.01
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	195.50	195.50	157.19	195.21	195.46

Figure 7.1: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area

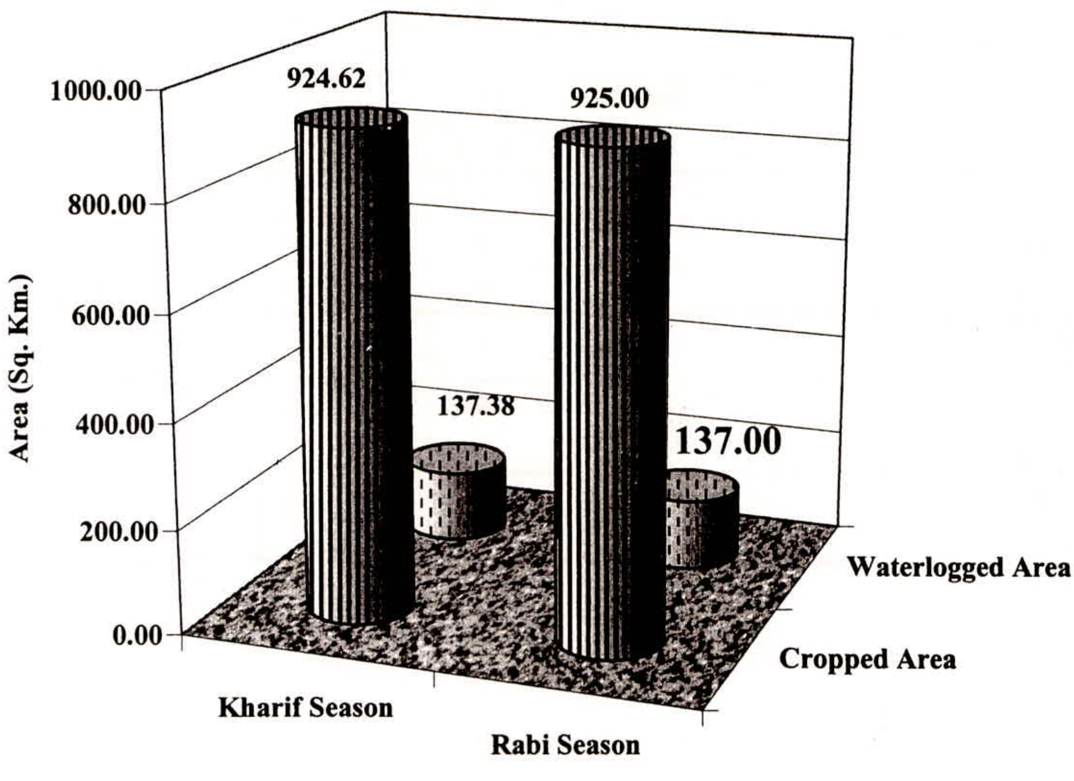


Figure 7.2: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area

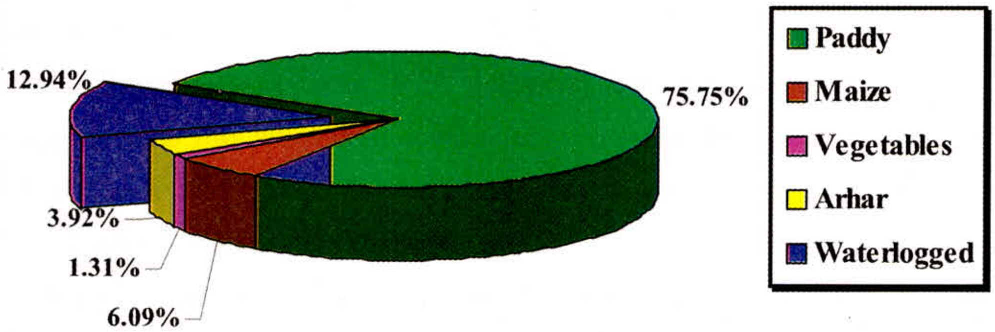
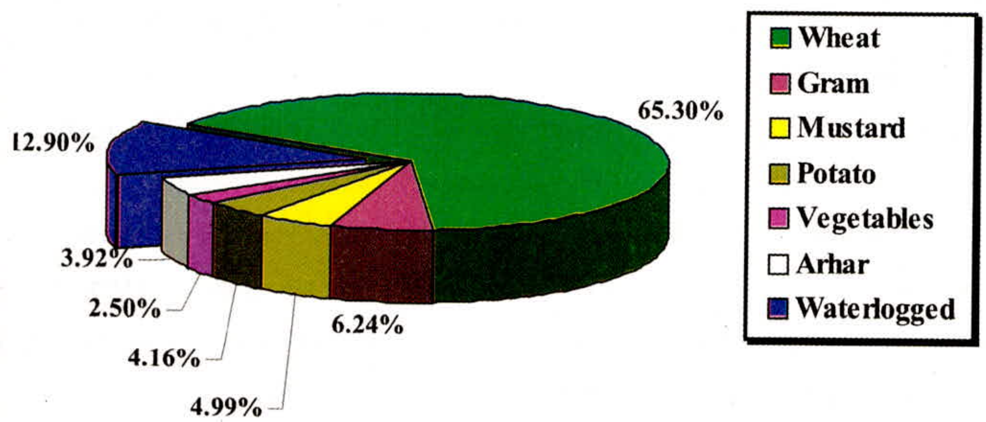


Figure 7.3: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area



maximum, i.e., 65.30% and that for vegetables it is a minimum, i.e., 2.50%. These are in accordance with the affinity constraints.

Figure 7.4 shows the comparison of existing cropped and waterlogged area in Mokama group of Tals with the results obtained from the non-linear optimisation model for both kharif and rabi season. It is seen that, at present only 30% of the Tal area is cultivated and the remaining 70% remains waterlogged in kharif season. Similarly, in rabi season, around 65% of the Tal area is cultivated and the remaining 35% remains waterlogged. However, by implementing the results of the non-linear optimisation model, the area under cropping can be substantially increased to 87% in both the kharif as well as rabi season, thus reducing the waterlogged area to a bare minimum of 13%. The non-linear optimisation model thus minimises the waterlogged area in the Mokama group of Tals by judiciously using the water in the upstream catchment as well as in the Tal area and also storing a part of it in the upper catchment.

7.2.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.1. **Figures 7.5 and 7.6** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that in all the sub-basins except Tati-Some, the total cultivable area remains under cropping in both the kharif as well as rabi season. In the Tati-Some sub-basin, 39.16% of the total cultivable area remains fallow only in kharif season. This is because of shortage of irrigation water as all the crops considered in the present study are irrigated crops. Hence, the cropping intensity in various sub-basins is near about 195% except in Tati-Some where it is 157.19%, as shown in Table 7.1. Again, from figures 7.5 and 7.6, it is observed that the area allocated to paddy crop is maximum and that of vegetables is minimum in kharif season. Similarly, the area allocated to wheat is maximum and that of vegetables is minimum in rabi season. These are in accordance with the affinity constraints. In figure 7.6, the area allocated to Arhar, which is an annual

Figure 7.4: Comparison of Existing Cropped and Waterlogged Area in Mokama Group of Tals with those of Model Results (under the Objective of Maximisation of Cropped Area)

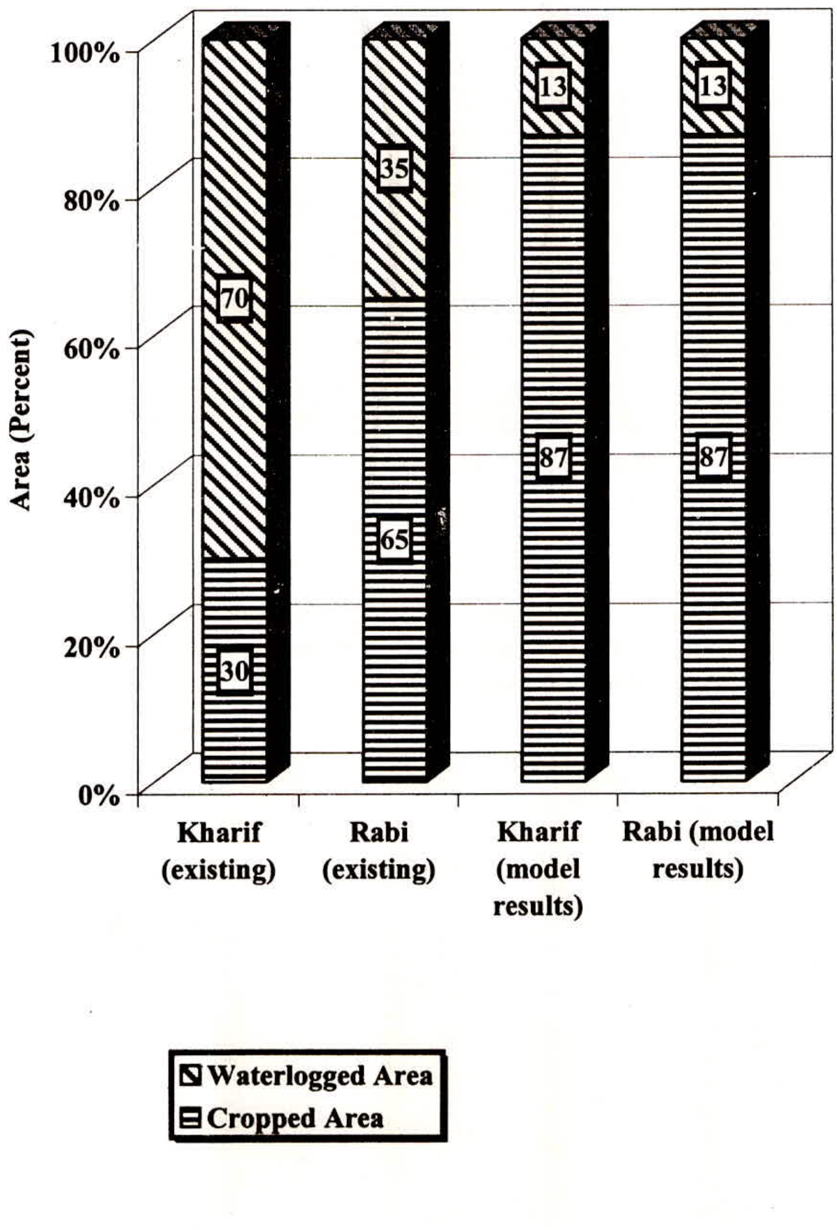


Figure 7.5: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area

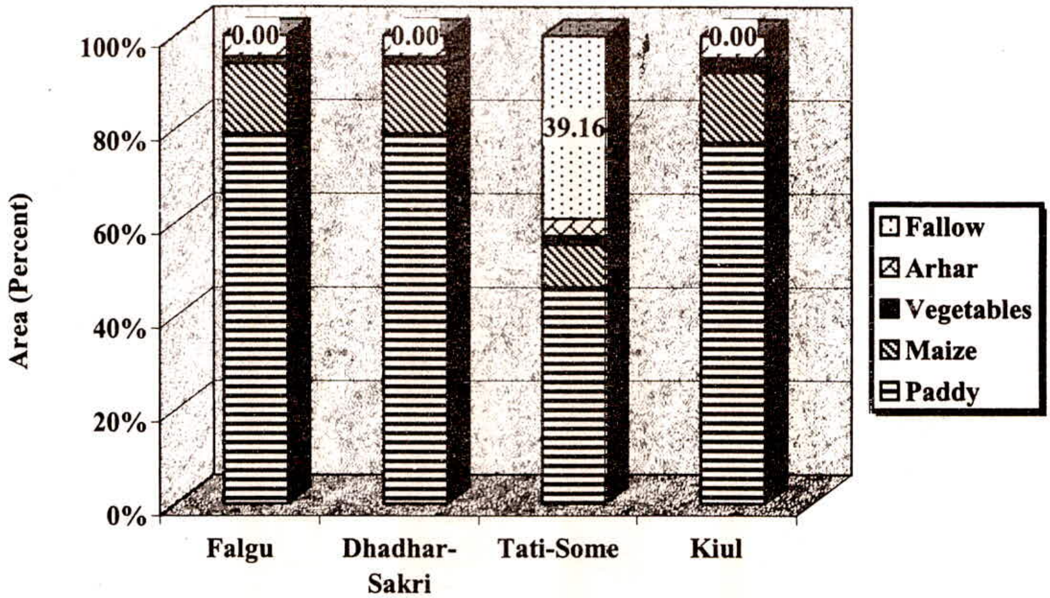
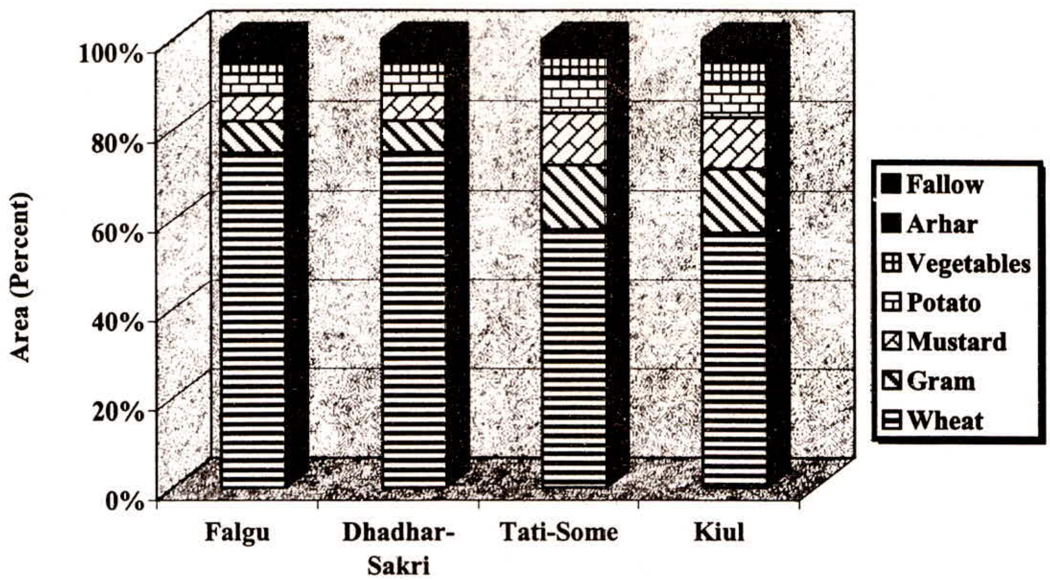


Figure 7.6: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area



crop, is included in rabi season so as to facilitate the calculation of percentage area under different crops.

Figure 7.7 shows the comparison of existing cropped area in various sub-basins of the upper catchment with those of the results obtained from the non-linear optimisation model for both kharif and rabi season. It is seen that, at present the total area under cultivation in various sub-basins of the upper catchment in kharif and rabi season is 2879.90 km^2 and 1231.39 km^2 respectively. However, by implementing the results of the non-linear optimisation model, the area under kharif cropping can be substantially increased to 4735.52 km^2 and that under rabi cropping to 4898.30 km^2.

7.2.3 Water release schedule

In the present study, as mentioned earlier, the number of reservoirs in the various sub-basins and their location are not dealt with. However, the reservoir operation schedule is a function of the cropping pattern. Hence, the monthly crop water requirements (including conveyance losses) in various sub-basins and Tal area are worked out and presented in **table 7.2**. These water requirements serve as the guidelines for the monthly water release schedule of the reservoirs. Further, in addition to these, the reservoirs in the Falgu sub-basin should release 219.70 km^2m of water in September and 113.86 km^2m of water in rabi season to the Tal area and those of the Dhadhar-Sakri sub-basin should release 81.97 km^2m of water in October and 301.60 km^2m of water in rabi season to the Tal area so as to meet the crop water requirements in the Tal area. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

7.2.4 Water utilisation in the Tal and various sub-basins of upper catchment

As mentioned in section 6.3, the total runoff from the Kiul-Harohar river basin amounts to 6000 km^2m. A part of this water is used for irrigation in the Tal area and the upper catchment, some of it is stored in the Tal area and the upper catchment while the rest either evaporates or percolates into the soil. **Figure 7.8** shows the water utilisation in

Figure 7.7: Comparison of Existing Cropped Area in the Upper Catchment with those of Model Results

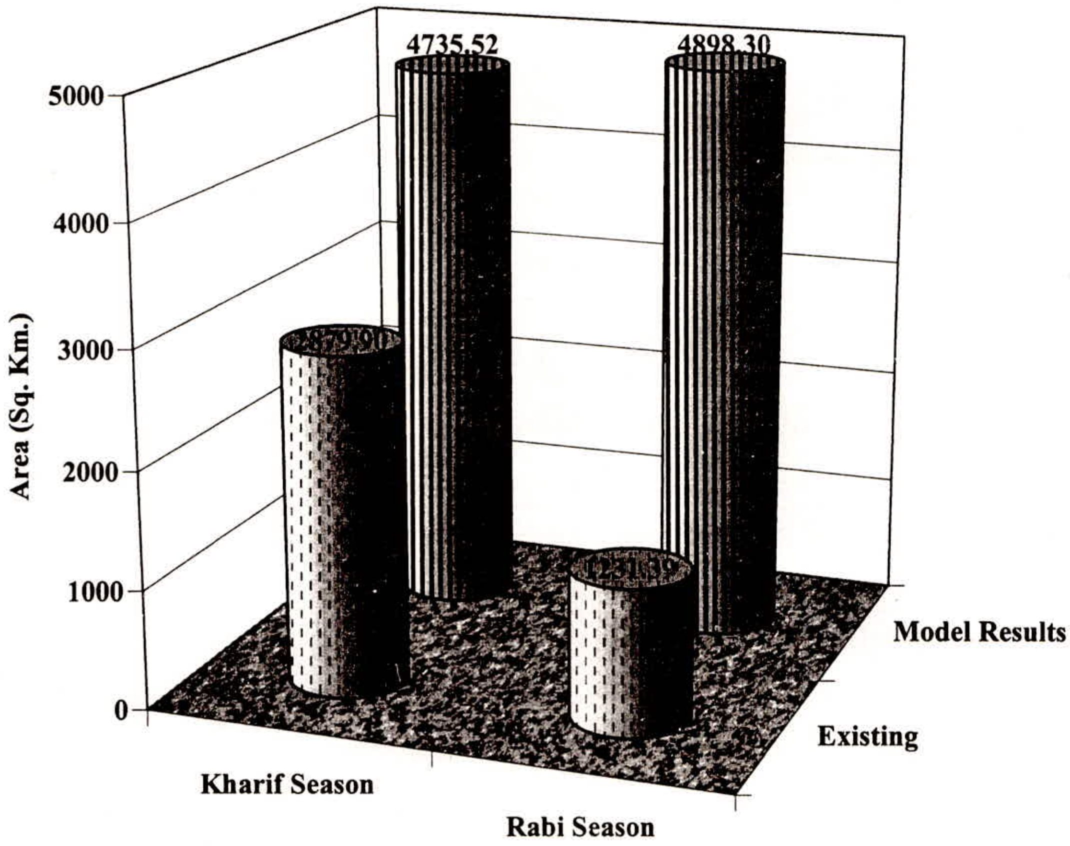
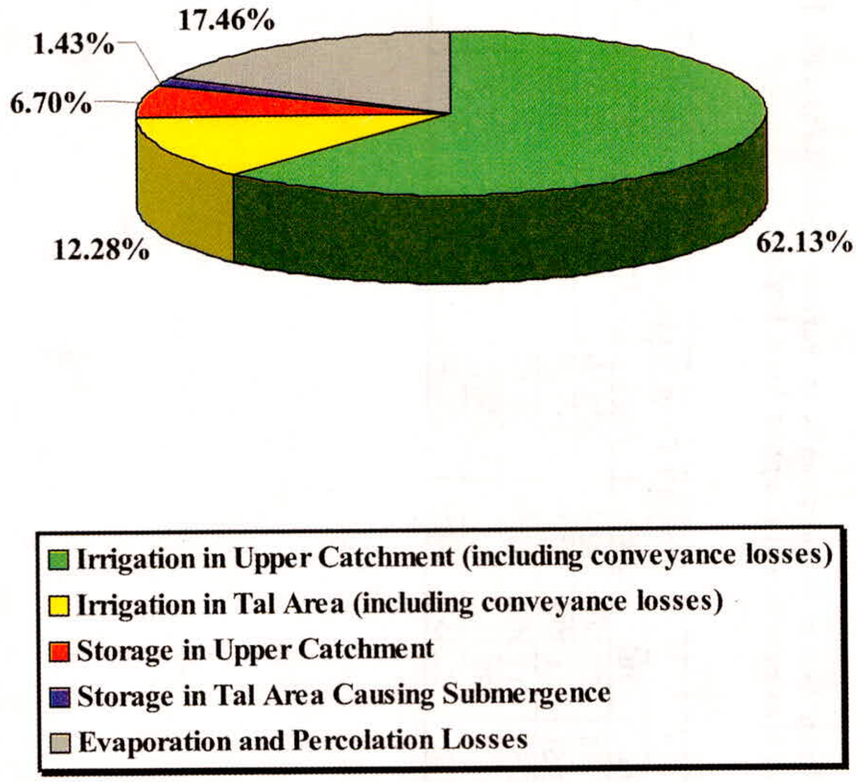


Table 7.2: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.									
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	25.33	47.64	102.44	336.10	96.31	88.65	150.65	168.57	104.91	24.40	1145.01
Dhadhar-Sakri	23.61	44.39	95.45	313.17	89.74	82.60	140.37	157.07	97.75	22.74	1066.89
Tati-Some	9.84	18.50	39.80	131.82	37.57	55.05	95.21	109.84	73.53	15.89	587.05
Kiul	20.60	38.75	83.33	274.71	78.41	68.23	117.99	136.12	91.12	19.69	928.96
Tal Area	17.25	32.45	69.50	220.04	65.52	54.85	93.21	104.30	64.91	15.10	737.15

Figure 7.8: Water Utilisation in Kiul-Harohar River Basin (Model Results)



Kiul-Harohar river basin for the results of the non-linear optimisation model. It is observed that 62.13% of the water is used for irrigation in the upper catchment while 12.28% is used for irrigation in the Tal area. Further, 6.70% of the water is stored in the upstream catchment, particularly in the Falgu and Dhadhar-Sakri sub-basins which means that more area can be brought under irrigation in these sub-basins. Around 1.43% of the water causes submergence in the Tal area whereas 17.46% of the water is lost in the form of evaporation and percolation from the upstream catchment and the Tal area.

7.3 Results of Non-Linear Optimisation Model with Constrained Outflow

The formulation of non-linear optimisation model is detailed in section 5.3. For the present study, the value of c in constraint no. 21 (section 5.3) has been taken to vary from 0.1 to 0.8 at intervals of 0.1. This essentially means that the solution of the non-linear optimisation model has been worked out for eight different cases, i.e., for the minimum value of outflow to the Tal area ranging from 10% to 80% of the inflow in upper catchment, at intervals of 10%. The upper limit is chosen as 80% (and not 100%) because in the present circumstances, 75 to 80% of the inflow in the upstream catchment is released to the Tal and the rest 20 to 25% is utilised in the upstream catchment. The following sections describe in detail the cropping conditions in the upper catchment and Tal area as well as the waterlogging conditions in the Tal area for these eight different outflow conditions. The monthly crop water requirements in the various sub-basins and the Tal area are also presented.

7.3.1 Case I - Minimum outflow being ten percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 10% inflow into the Tal are presented in **table 7.3**. The maximised value of the objective function is obtained as 10,724.78 km^2. The decrease in the value of the objective function (compared to the value obtained in section 7.2), is due to the fact that a minimum of 10% of the inflow in the upper catchment is allowed to flow

Table 7.3: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	1181.05	1100.47	338.62	779.47	487.24
Maize	224.25	208.95	66.83	153.84	39.20
Vegetables	22.43	20.90	13.37	30.77	8.40
Arhar	67.28	62.69	26.73	61.54	25.20
Rabi Season					
Wheat	1120.76	1044.30	579.16	709.48	706.34
Gram	107.08	99.77	144.79	177.37	67.48
Mustard	85.66	79.82	115.83	141.90	53.99
Potato	71.39	66.52	77.22	94.60	44.99
Vegetables	42.83	39.91	48.26	59.12	26.99
Total Area, km^2	2922.72	2723.31	1410.82	2208.08	1459.84
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	195.50	195.50	142.22	177.50	157.82

into the Tal which not only causes waterlogging in the Tal area but also creates shortage of irrigation water in the upstream catchment.

7.3.1.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.9**. It is observed that in kharif season, out of a total area of 1062 km^2, 501.96 km^2 remains waterlogged, while in rabi season, only 137 km^2 remains waterlogged. The increase in waterlogging (over the previous case outlined in section 7.2) in the Tal in kharif season, is due to the inflow of at least 10% which is allowed into the Tal area. However, this excess water in the Tal is drained out to the river Ganga by the end of kharif season thus reducing the waterlogging in rabi season. **Figures 7.10 and 7.11** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 47% of the Tal area remains waterlogged in kharif season and only 13% in rabi season.

7.3.1.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.3. **Figures 7.12 and 7.13** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 55.09% and 17.55% of the total cultivable area in Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. This is because of shortage of irrigation water. It is also observed that in Falgu and Dhadhar-Sakri sub-basins, the total cultivable area remains under cropping in kharif as well as rabi season inspite of a minimum outflow of 10% into the Tal area. This shows the abundance of water availability in these two sub-basins.

7.3.1.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and

Figure 7.9: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area

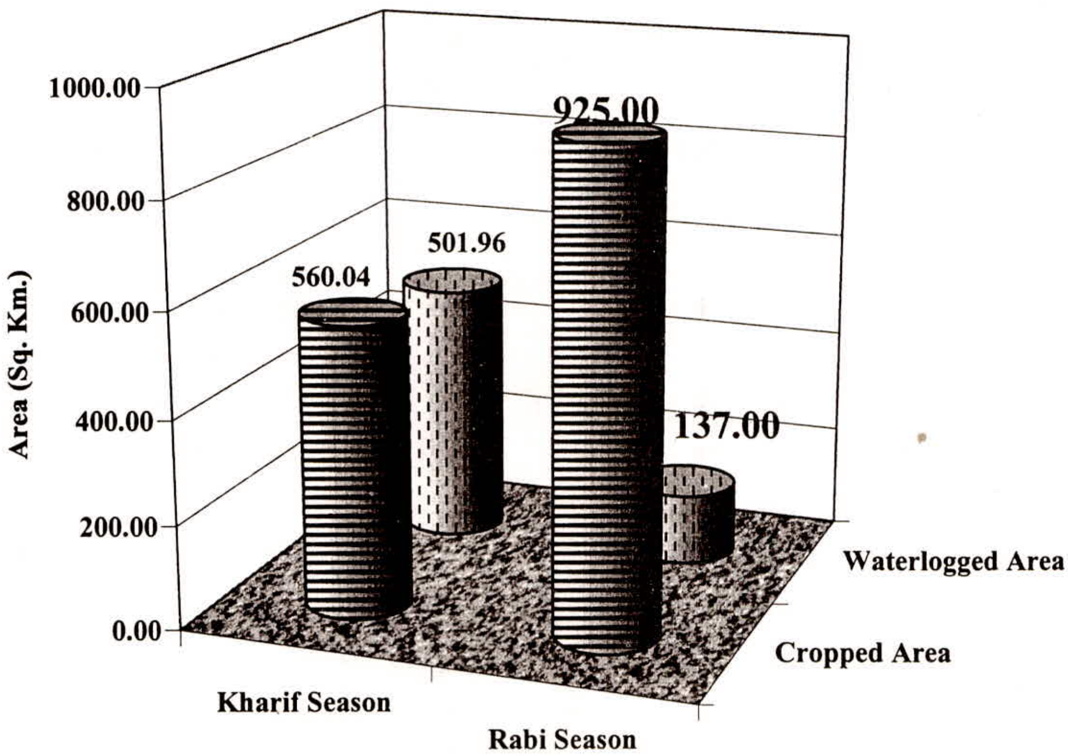


Figure 7.10: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area

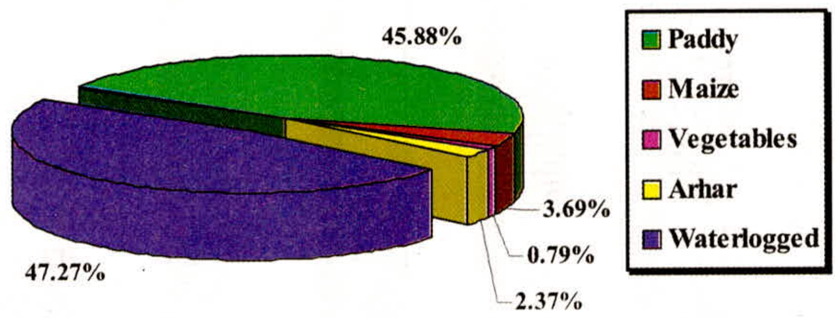


Figure 7.11: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area

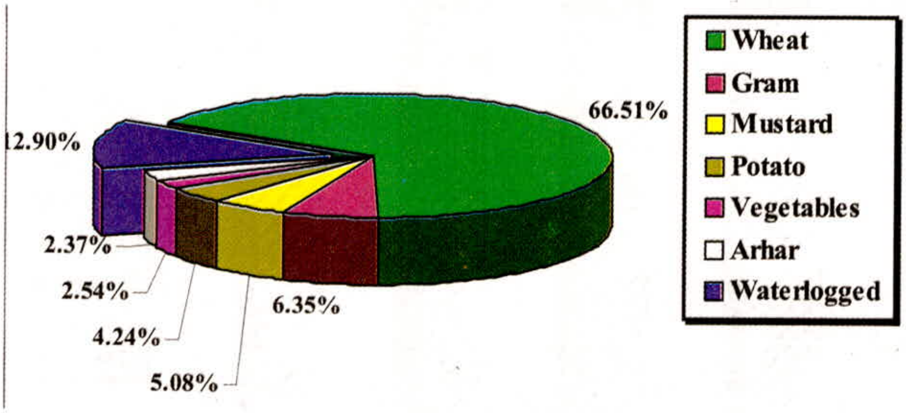


Figure 7.12: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area

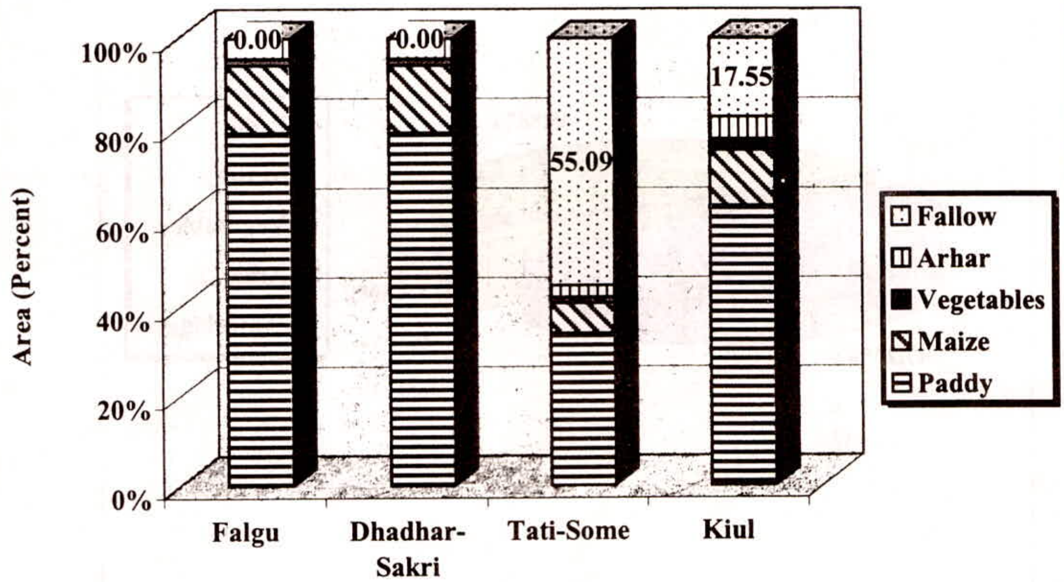
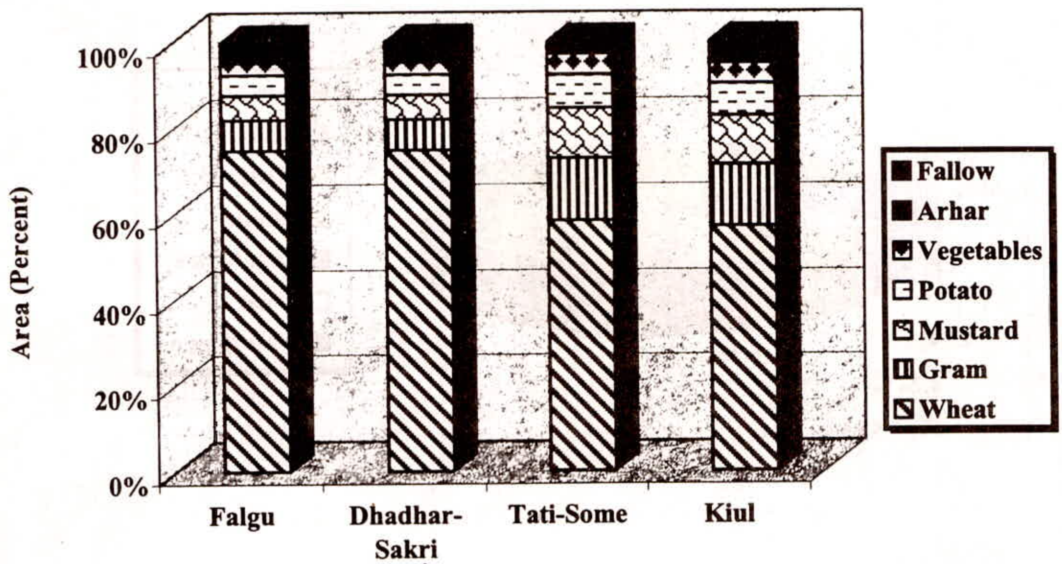


Figure 7.13: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area



Tal area are presented in **table 7.4**. In addition to the 10% inflow into the Tal (i.e., 10% of the runoff values from various sub-basins, as mentioned in table 6.7), the reservoirs in the Falgu sub-basin should release 81.76 km^2m of water in September, 10.08 km^2m of water in October and 236.77 km^2m of water in rabi season to the Tal area; and those of the Dhadhar-Sakri sub-basin should release 91.17 km^2m of water in October and 186.40 km^2m of water in rabi season to the Tal area, so as to meet the crop water requirements in the Tal area. In rabi season, the water available from tubewells is also used for irrigation in the Tal area. Further, at the end of kharif season, the excess water is to be drained out from the Tal area (which of course it does in its natural course) so as to facilitate rabi cropping.

7.3.2 Case II - Minimum outflow being twenty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 20% inflow into the Tal are presented in **table 7.5**. The maximised value of the objective function is obtained as 10,294.76 km^2.

7.3.2.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.14**. It is observed that in kharif season, out of a total area of 1062 km^2, 550.72 km^2 remains waterlogged, while in rabi season, only 137 km^2 remains waterlogged. The increase in waterlogging (over case I outlined in section 7.3.1) in the Tal in kharif season, is due to the inflow of at least 20% which is allowed into the Tal area. However, this excess water in the Tal is drained out to the river Ganga by the end of kharif season thus reducing the waterlogging in rabi season. **Figures 7.15 and 7.16** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 52% of the Tal area remain waterlogged in kharif season and only 13% in rabi season.

Table 7.4: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 10% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	25.33	47.64	102.44	336.10	96.31	88.65	150.65	168.57	104.91	24.40	1145.01
Dhadhar-Sakri	23.61	44.39	95.45	313.17	89.74	82.60	140.37	157.07	97.75	22.74	1066.89
Tati-Some	7.26	13.66	29.38	97.32	27.74	55.60	96.16	110.93	74.26	16.04	528.34
Kiul	16.72	31.44	67.63	224.01	63.85	68.11	117.79	135.88	90.97	19.65	836.06
Tal Area	10.45	19.66	42.09	133.28	39.69	55.87	94.94	106.24	66.12	15.38	583.72

Table 7.5: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area, km².

Crop	Area Allocated in Different Sub-Basins (km²)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	1158.63	1079.58	218.57	589.49	444.82
Maize	224.25	208.95	43.14	116.35	35.79
Vegetables	44.85	41.79	8.63	23.27	7.67
Arhar	67.28	62.69	17.26	46.54	23.01
Rabi Season					
Wheat	1069.01	1017.69	584.85	718.48	608.84
Gram	107.08	99.77	146.21	179.62	67.65
Mustard	108.86	79.82	116.97	143.70	108.24
Potato	71.39	66.52	77.98	95.80	72.16
Vegetables	71.39	66.52	48.74	59.87	45.10
Total Area, km²	2922.72	2723.31	1262.33	1973.11	1413.27
Total Cultivable Area, km²	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	195.50	195.50	127.25	158.61	152.79

Figure 7.14: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area

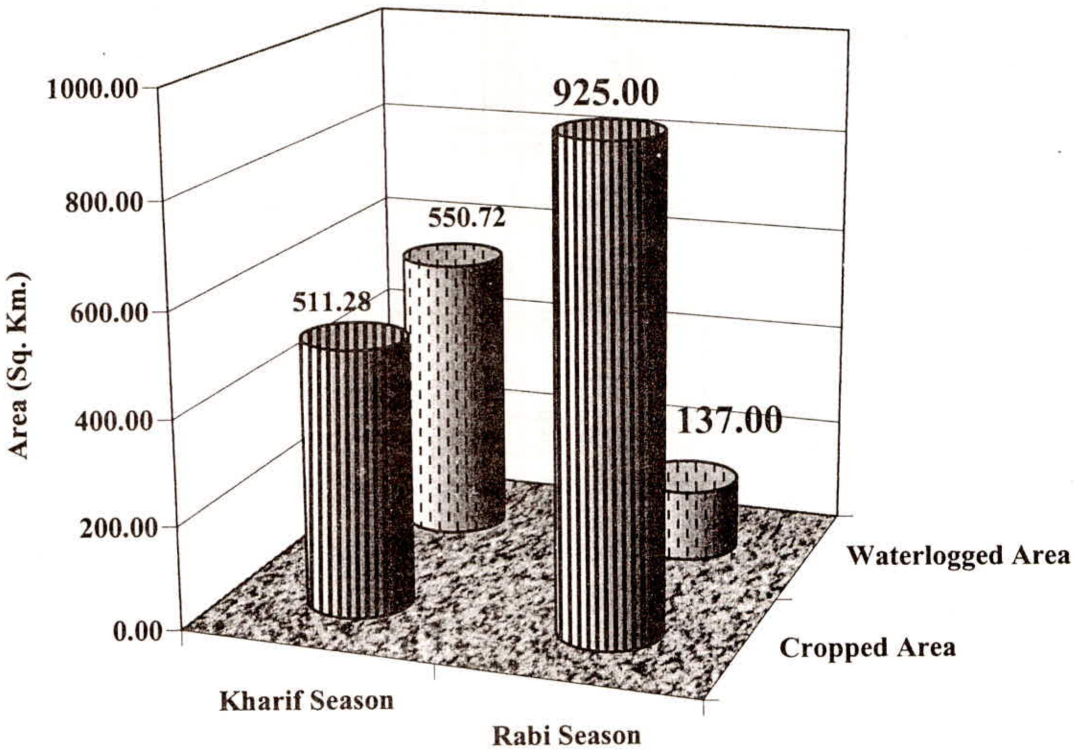


Figure 7.15: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area

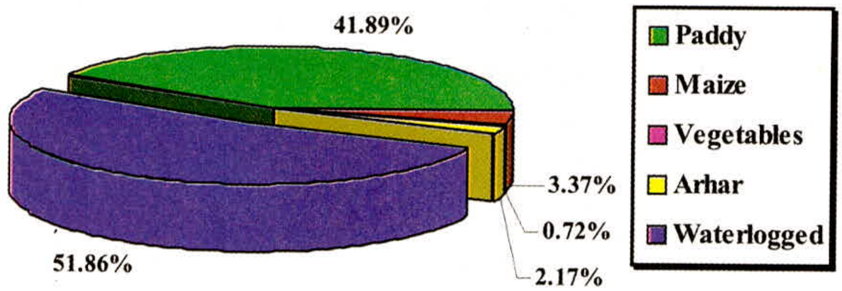
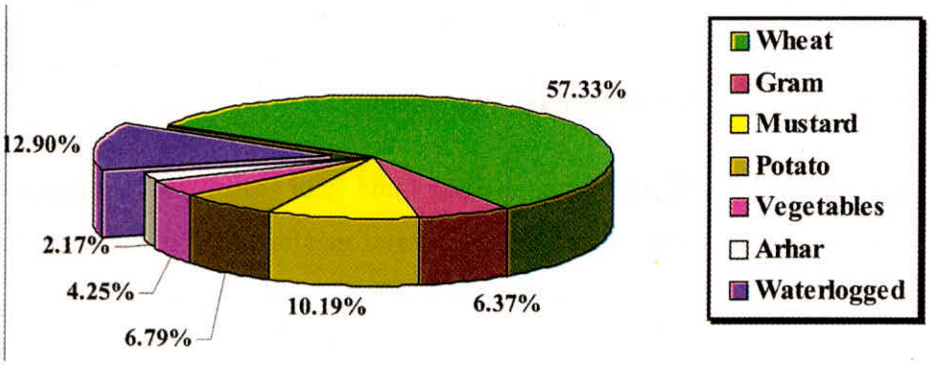


Figure 7.16: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area



7.3.2.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.5. **Figures 7.17 and 7.18** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 71.01% and 37.65% of the total cultivable area in Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. However, in Falgu and Dhadhar-Sakri sub-basins, the total cultivable area remains under cropping in kharif as well as rabi season inspite of a minimum outflow of 20% into the Tal area.

7.3.2.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.6**. In addition to the 20% inflow into the Tal (i.e., 20% of the runoff values from various sub-basins, as mentioned in table 6.7), the reservoirs in the Falgu sub-basin should release 193.45 km^2m of water in rabi season to the Tal area; and those of the Dhadhar-Sakri sub-basin should release 140.04 km^2m of water in rabi season to the Tal area, so as to meet the crop water requirements in the Tal area. In rabi season, the water available from tubewells is also used for irrigation in the Tal area. Further, at the end of kharif season, the excess water is to be drained out from the Tal area (which of course it does in its natural course) so as to facilitate rabi cropping.

7.3.3 Case III - Minimum outflow being thirty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 30% inflow into the Tal are presented in **table 7.7**. The maximised value of the objective function is obtained as 9,664.94 km^2.

Figure 7.17: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area

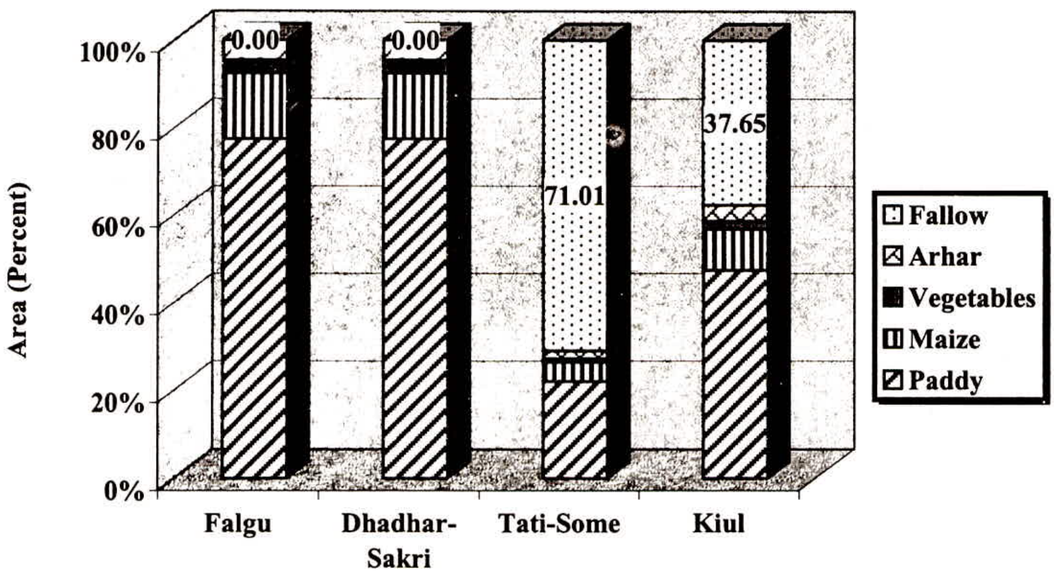


Figure 7.18: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area

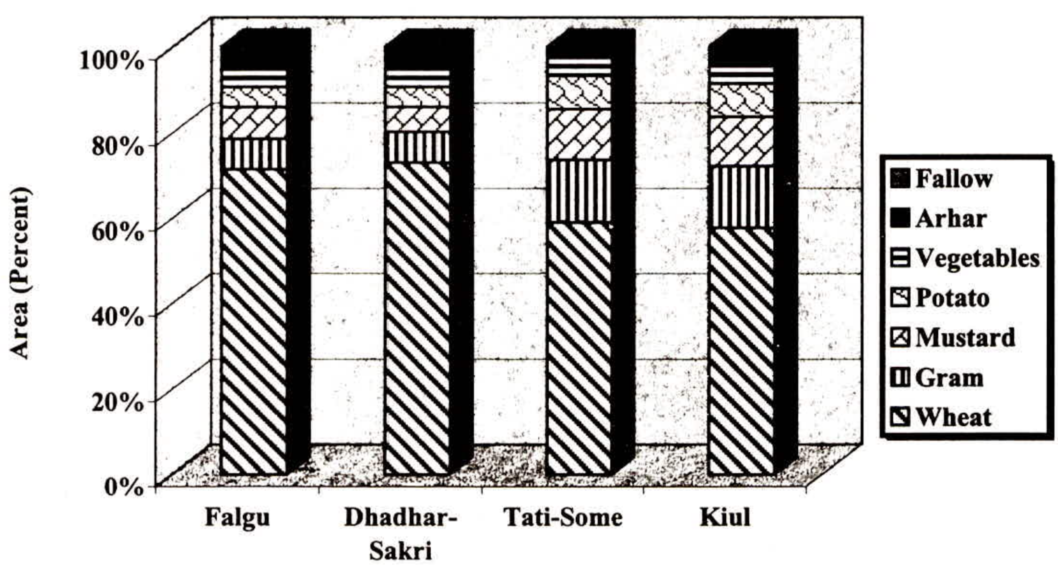


Table 7.6: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 20% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	24.85	46.74	100.51	330.99	94.50	87.69	149.62	167.07	104.01	23.46	1129.46
Dhadhar-Sakri	23.16	43.55	93.65	308.41	88.05	82.70	140.34	156.16	96.28	22.25	1054.56
Tati-Some	4.69	8.82	18.96	62.81	17.90	56.15	97.10	112.01	74.99	16.20	469.64
Kiul	12.64	23.78	51.15	169.41	48.29	68.98	119.29	137.61	92.12	19.90	743.17
Tal Area	9.54	17.94	38.43	121.68	36.23	53.14	92.61	104.22	66.61	13.62	554.02

Table 7.7: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	1136.20	1058.68	98.51	399.52	399.38
Maize	224.25	208.95	19.44	78.85	32.13
Vegetables	44.85	41.79	3.89	15.77	6.89
Arhar	89.70	83.58	7.78	31.54	20.66
Rabi Season					
Wheat	843.18	785.65	590.53	727.48	450.71
Gram	210.80	196.41	147.63	181.87	112.68
Mustard	168.64	157.13	118.11	145.50	90.14
Potato	112.42	104.75	78.74	97.00	60.09
Vegetables	70.27	65.47	49.21	60.62	37.56
Total Area, km^2	2900.30	2702.42	1113.84	1738.14	1210.24
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	194.00	194.00	112.28	139.72	130.84

7.3.3.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.19**. It is observed that in kharif season, out of a total area of 1062 km^2, 602.94 km^2 remains waterlogged, while in rabi season, only 290.16 km^2 remains waterlogged. The increase in waterlogging (over case II outlined in section 7.3.2) in the Tal in kharif season, is due to the inflow of at least 30% which is allowed into the Tal area. Again, as a result of high inflow into the Tal in kharif season (i.e. 30%), the water availability in the upstream catchment decreases. The water release from the upstream catchment to the Tal in rabi season, in addition to the water available from tubewells, is thus not sufficient to meet the crop water requirements in the Tal. Hence, the additional water requirement in the Tal in rabi season is met by a part of the excess water in the Tal at the end of kharif season which is not allowed to flow into the river Ganga. This may be achieved by construction of appropriate sluice gates. This obstruction of a part of the excess water increases the waterlogging in the Tal in rabi season (over case II outlined in section 7.3.2). **Figures 7.20 and 7.21** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 57% of the Tal area remains waterlogged in kharif season and only 27% in rabi season.

7.3.3.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.7. **Figures 7.22 and 7.23** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 86.93% and 57.74% of the total cultivable area in Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. However, in Falgu and Dhadhar-Sakri sub-basins, the total cultivable area remains under cropping in kharif as well as rabi season inspite of a minimum outflow of 30% into the Tal area.

Figure 7.19: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area

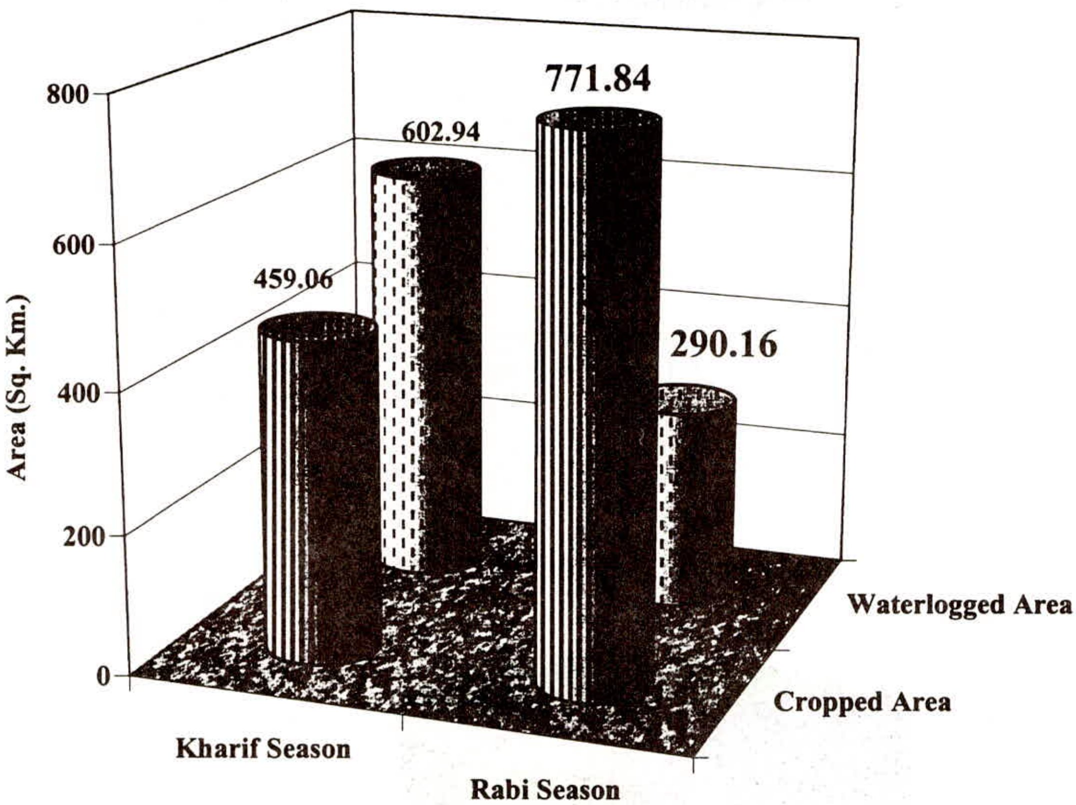


Figure 7.20: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area

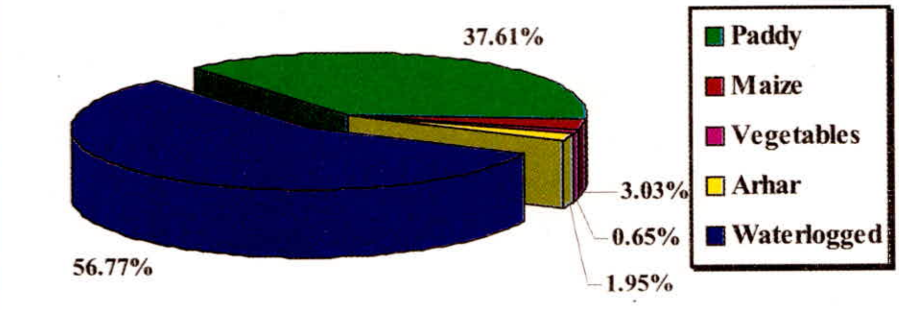


Figure 7.21: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area

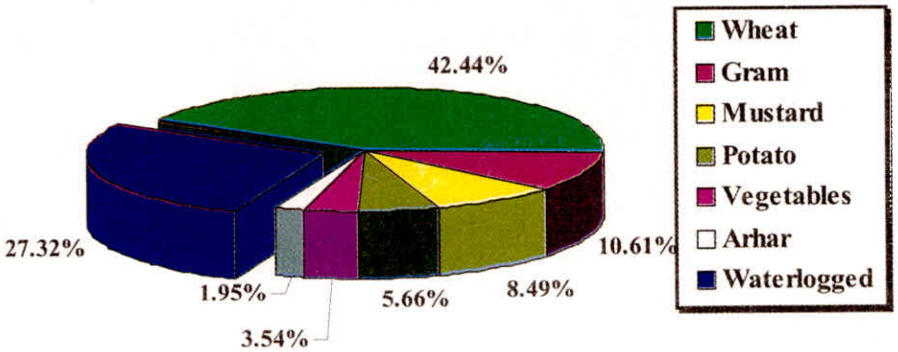


Figure 7.22: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area

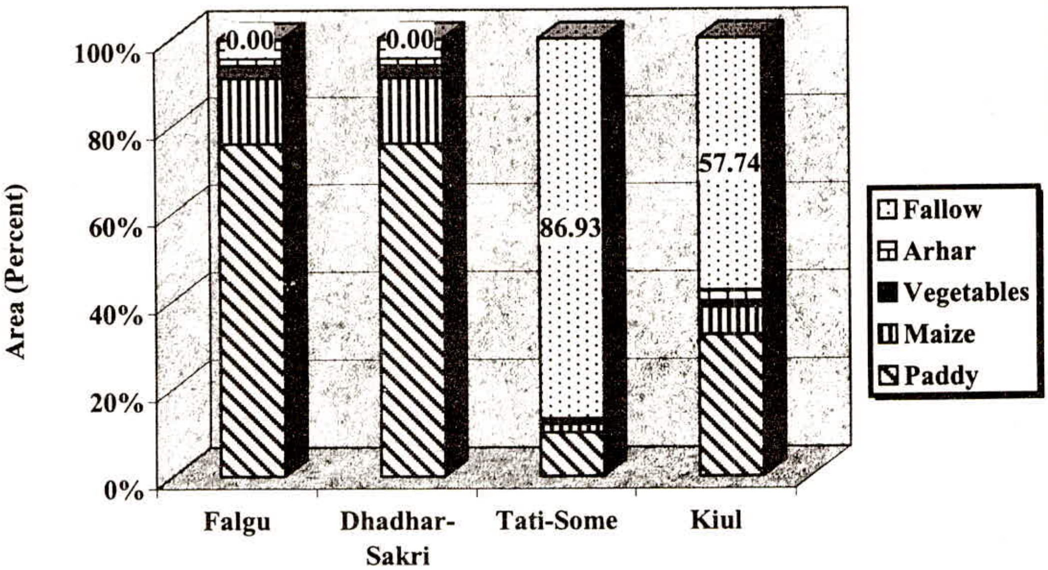
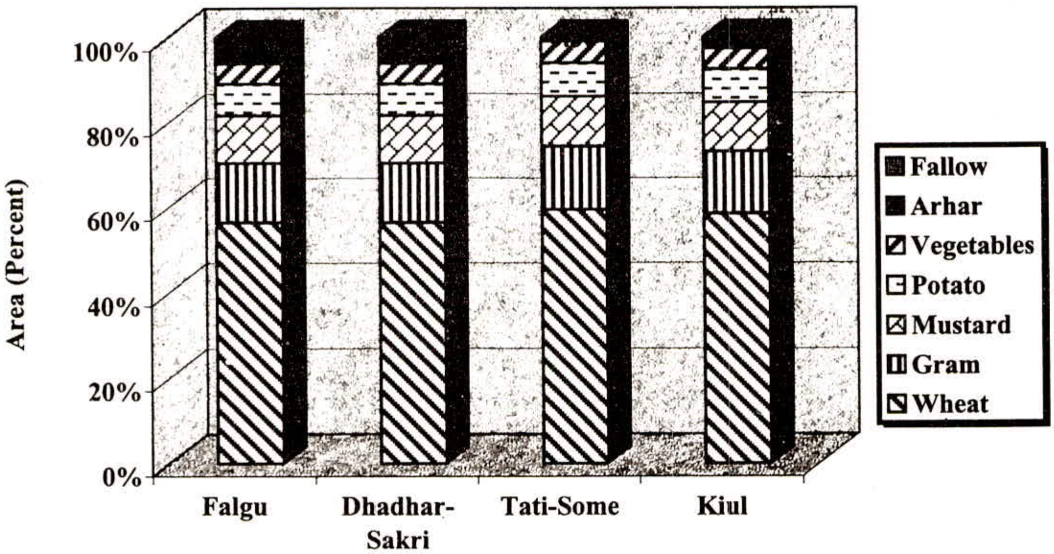


Figure 7.23: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area



7.3.3.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.8**. In addition to the 30% inflow into the Tal (i.e., 30% of the runoff values from various sub-basins, as mentioned in table 6.7), the reservoirs in the Falgu sub-basin should release 89.54 km^2m of water in rabi season to the Tal area; and those of the Dhadhar-Sakri sub-basin should release 49.57 km^2m of water in rabi season to the Tal area, so as to meet the crop water requirements in the Tal area. In rabi season, the water available from tubewells is also used for irrigation in the Tal area. Further, at the end of kharif season, 980 km^2m of water is to be drained out from the Tal while 130 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season.

7.3.4 Case IV - Minimum outflow being forty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 40% inflow into the Tal are presented in **table 7.9**. The maximised value of the objective function is obtained as 8,772.04 km^2.

7.3.4.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.24**. It is observed that in kharif season, out of a total area of 1062 km^2, 659.17 km^2 remains waterlogged, while in rabi season, only 405.6 km^2 remains waterlogged. The increase in waterlogging (over case III outlined in section 7.3.3) in the Tal in kharif season, is due to the inflow of at least 40% which is allowed into the Tal area. Again, as a result of high inflow into the Tal in kharif season (i.e. 40%), the water availability in the upstream catchment decreases to an extent that there is no water release from the upstream catchment to the Tal in rabi season. Hence, the water requirement in the Tal in rabi season, is met by a part of the excess water in the Tal at the

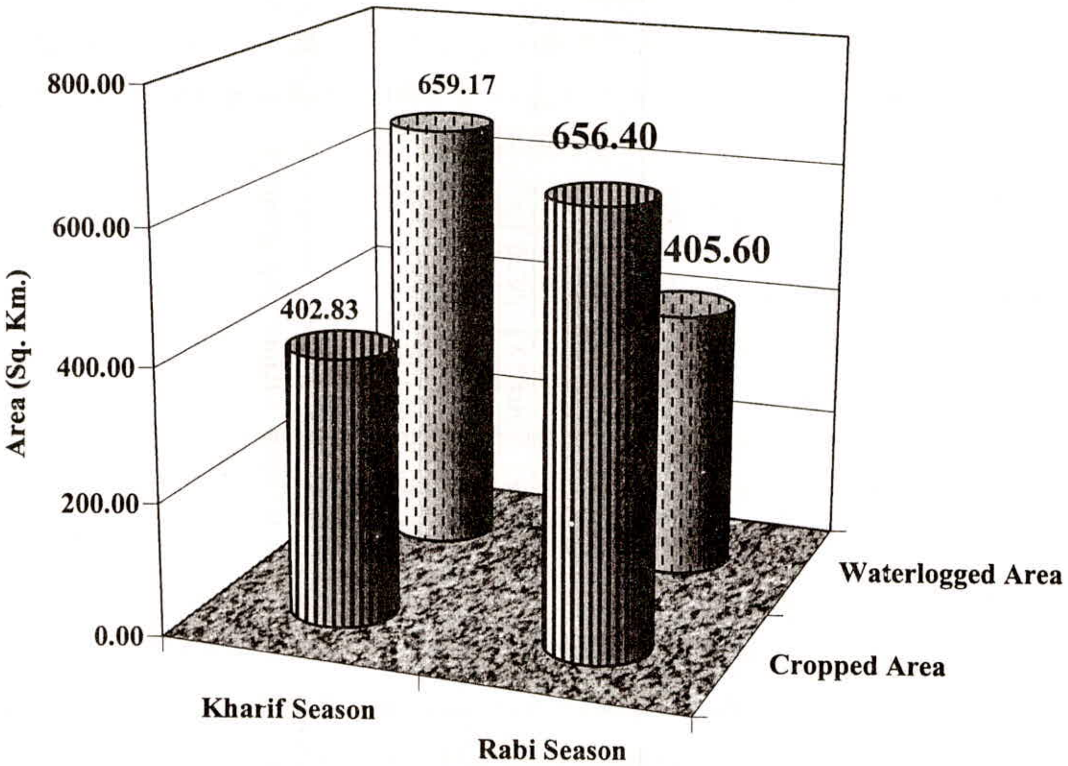
Table 7.8: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 30% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	24.37	45.83	98.58	326.53	93.07	80.95	139.99	161.49	108.11	23.36	1102.29
Dhadhar-Sakri	22.71	42.71	91.85	304.25	86.72	75.42	130.44	150.47	100.73	21.76	1027.08
Tati-Some	2.11	3.97	8.55	28.31	8.07	56.69	98.05	113.10	75.72	16.36	410.93
Kiul	8.57	16.12	34.66	114.82	32.73	69.84	120.78	139.33	93.27	20.15	650.27
Tal Area	8.57	16.11	34.50	109.25	32.53	43.27	74.83	86.32	57.79	12.49	475.66

Table 7.9: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	1038.62	882.86	0	209.54	350.46
Maize	204.99	174.25	0	41.36	28.20
Vegetables	41.00	34.85	0	8.27	6.04
Arhar	82.00	69.70	0	16.54	18.13
Rabi Season					
Wheat	847.80	793.98	577.92	736.47	382.96
Gram	211.95	198.50	144.48	184.12	95.74
Mustard	169.56	158.80	115.58	147.29	76.59
Potato	113.04	105.86	77.06	98.20	51.06
Vegetables	70.65	66.17	48.16	61.37	31.91
Total Area, km^2	2779.60	2484.96	963.20	1503.17	1041.10
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	185.93	178.39	97.10	120.83	112.55

Figure 7.24: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area



end of kharif season (in addition to the water available from tubewells) which is not allowed to flow into the river Ganga. This obstruction of a part of the excess water increases the waterlogging in the Tal in rabi season (over case III outlined in section 7.3.3). **Figures 7.25 and 7.26** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 62% of the Tal area remains waterlogged in kharif season and only 38% in rabi season.

7.3.4.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.9. **Figures 7.27 and 7.28** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 8.59%, 16.61%, 100% and 77.84% of the total cultivable area in Falgu, Dhadhar-Sakri, Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. Again, 2.9% of the total cultivable area in Tati-Some sub-basin remains fallow in rabi season.

7.3.4.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.10**. In kharif season, 40% of the inflow (i.e., 40% of the runoff values from various sub-basins, as mentioned in table 6.7), is allowed to flow to the Tal area. There is no release of water from the upstream catchment to the Tal in rabi season. At the end of kharif season, 859 km^2m of water is to be drained out from the Tal while 359 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

Figure 7.25: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area

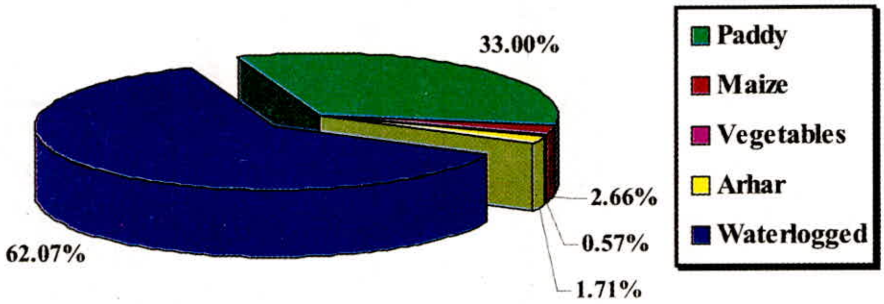


Figure 7.26: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area

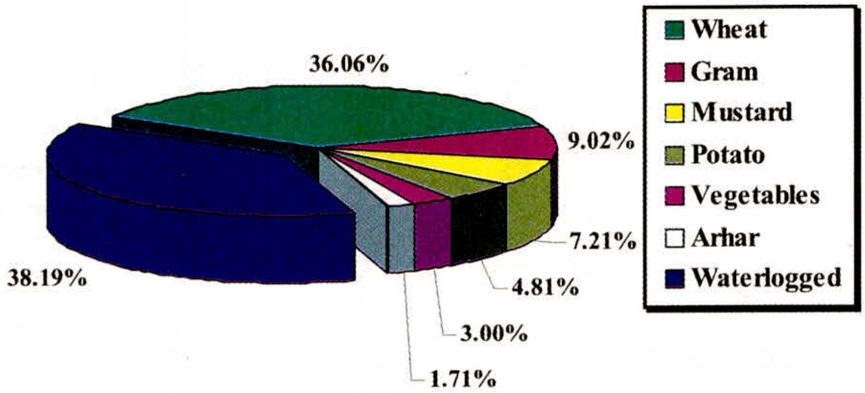


Figure 7.27: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area

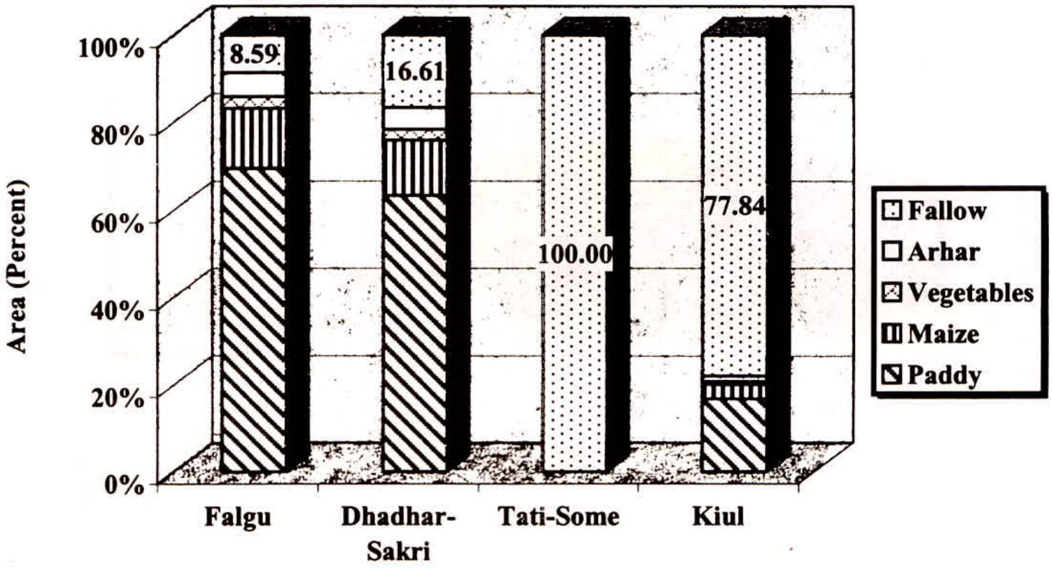


Figure 7.28: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area

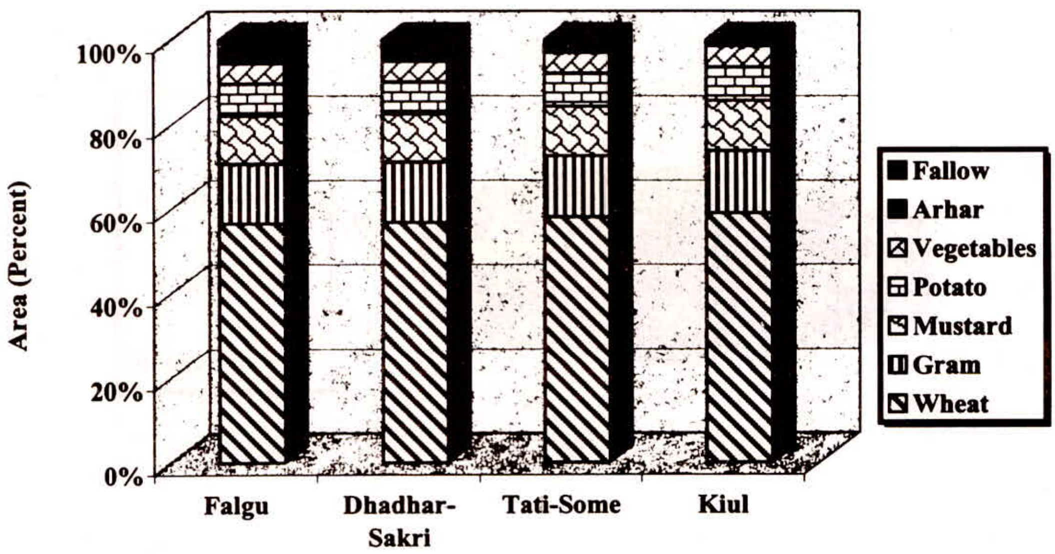


Table 7.10: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 40% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	22.28	41.90	90.11	298.49	85.08	81.39	140.76	162.38	108.70	23.49	1054.57
Dhadhar-Sakri	18.94	35.61	76.60	253.72	72.32	76.22	131.82	152.07	101.80	22.00	941.11
Tati-Some	0	0	0	0	0	55.48	95.95	110.69	74.10	16.01	352.23
Kiul	4.49	8.45	18.18	60.22	17.17	70.70	122.28	141.06	94.43	20.40	557.38
Tal Area	7.52	14.14	30.28	95.87	28.55	36.77	63.58	73.35	49.10	10.61	409.75

7.3.5 Case V - Minimum outflow being fifty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 50% inflow into the Tal are presented in **table 7.11**. The maximised value of the objective function is obtained as 7,478.99 km^2.

7.3.5.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.29**. It is observed that in kharif season, out of a total area of 1062 km^2, 715.41 km^2 remains waterlogged, while in rabi season, only 408.13 km^2 remains waterlogged. Thus, the waterlogged area in rabi season remains nearly the same as in case IV outlined in section 7.3.4. The reasons for the increase in waterlogging in kharif season are same as those described in section 7.3.4.1. **Figures 7.30 and 7.31** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 67% of the Tal area remains waterlogged in kharif season and only 38% in rabi season.

7.3.5.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.11. **Figures 7.32 and 7.33** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 40.22%, 46.91%, 100% and 97.93% of the total cultivable area in Falgu, Dhadhar-Sakri, Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. Again, 19.09% of the total cultivable area in Tati-Some sub-basin remains fallow in rabi season.

7.3.5.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and

Table 7.11: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	679.18	562.10	0	19.57	301.54
Maize	134.05	110.94	0	3.86	24.26
Vegetables	26.81	22.19	0	0.77	5.20
Arhar	53.62	44.38	0	1.54	15.60
Rabi Season					
Wheat	864.83	809.17	481.60	745.47	382.96
Gram	216.21	202.29	120.40	186.37	95.74
Mustard	172.97	161.83	96.32	149.09	76.59
Potato	115.31	107.89	64.21	99.40	51.06
Vegetables	72.07	67.43	40.13	62.12	31.91
Total Area, km^2	2335.04	2088.22	802.66	1268.20	984.86
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	156.19	149.91	80.91	101.95	106.47

Figure 7.29: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area

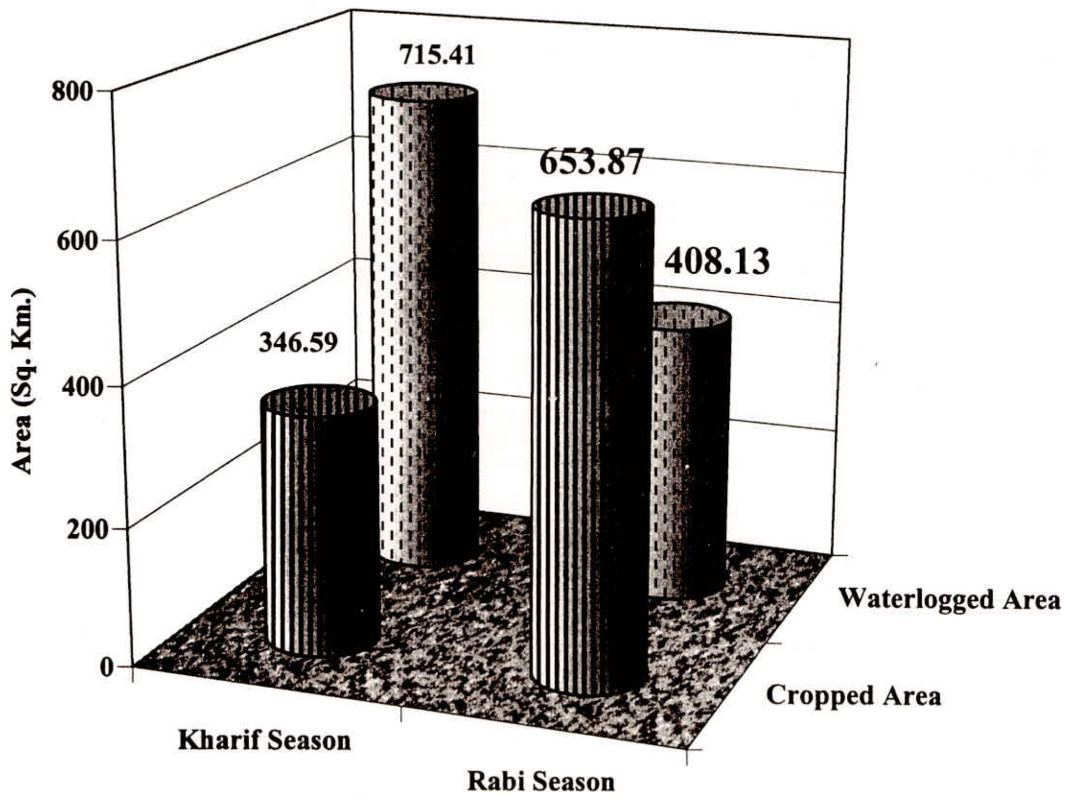


Figure 7.30: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area

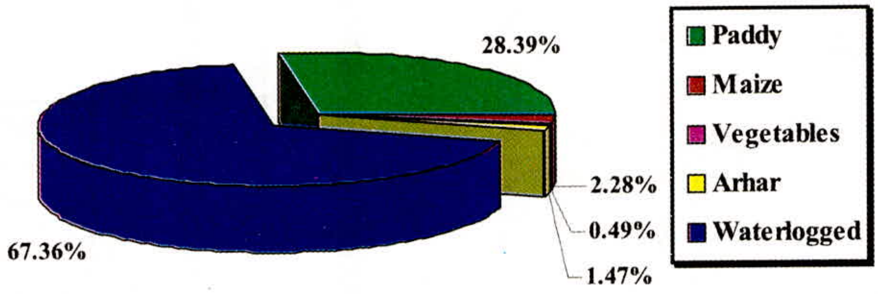


Figure 7.31: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area

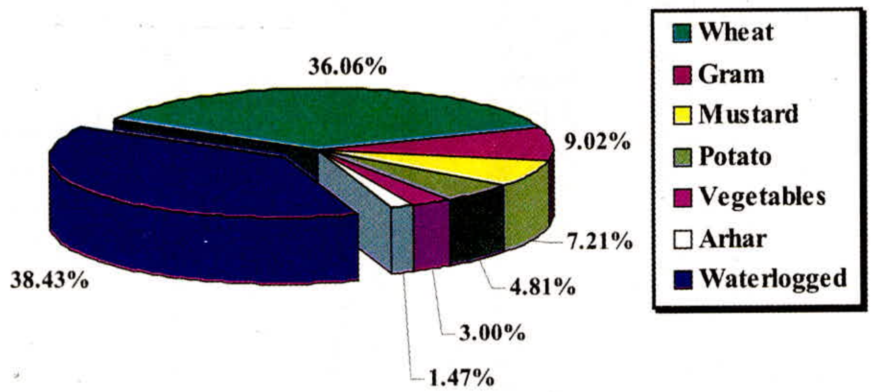


Figure 7.32: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area

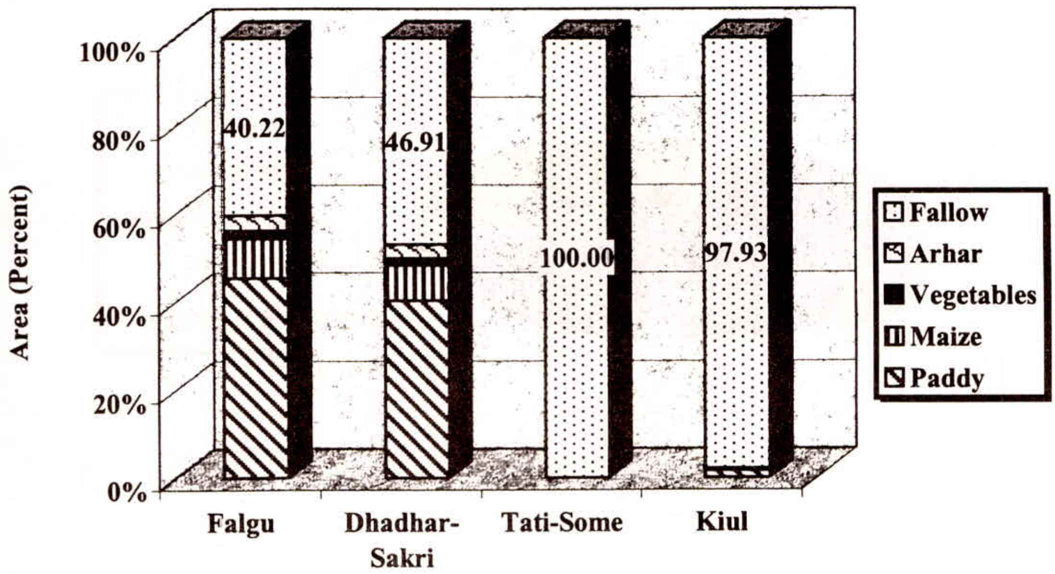
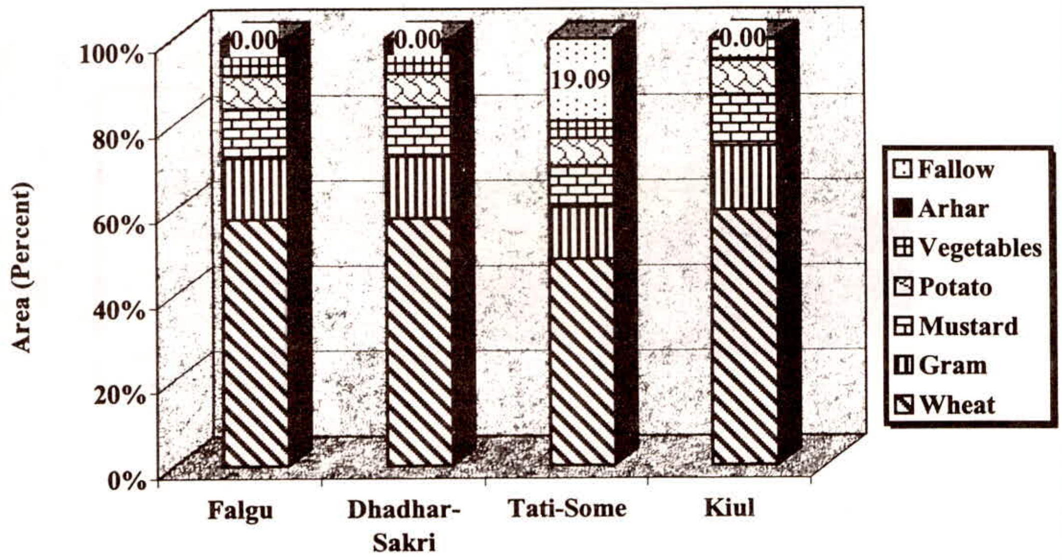


Figure 7.33: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area



Tal area are presented in **table 7.12**. In kharif season, 50% of the inflow (i.e., 50% of the runoff values from various sub-basins, as mentioned in table 6.7), is allowed to flow to the Tal area. There is no release of water from the upstream catchment to the Tal in rabi season. At the end of kharif season, 1299 km^2m of water is to be drained out from the Tal while 362 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

7.3.6 Case VI - Minimum outflow being sixty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 60% inflow into the Tal are presented in **table 7.13**. The maximised value of the objective function is obtained as 6,168.84 km^2.

7.3.6.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.34**. It is observed that in kharif season, out of a total area of 1062 km^2, 771.64 km^2 remains waterlogged, while in rabi season, only 410.66 km^2 remains waterlogged. Thus, the waterlogged area in rabi season remains nearly the same as in case V outlined in section 7.3.5. The reasons for the increase in waterlogging in kharif season are same as those described in section 7.3.4.1. **Figures 7.35 and 7.36** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 73% of the Tal area remains waterlogged in kharif season and only 39% in rabi season.

7.3.6.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.13. **Figures 7.37 and 7.38** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that 71.86%, 77.20%, 100% and 100% of the total cultivable

Table 7.12: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 50% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	14.57	27.40	58.93	195.19	55.64	83.03	143.59	165.64	110.88	23.96	878.81
Dhadhar-Sakri	12.06	22.68	48.77	161.54	46.05	77.68	134.35	154.98	103.75	22.42	784.26
Tati-Some	0	0	0	0	0	46.23	79.96	92.24	61.75	13.34	293.52
Kiul	0.42	0.79	1.70	5.62	1.60	71.57	123.77	142.78	95.58	20.65	464.48
Tal Area	6.47	12.16	26.05	82.48	24.56	36.77	63.58	73.35	49.10	10.61	385.14

Table 7.13: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area, km².

Crop	Area Allocated in Different Sub-Basins (km²)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	319.74	241.33	0	0	252.61
Maize	63.11	47.63	0	0	20.33
Vegetables	12.62	9.53	0	0	4.36
Arhar	25.24	19.05	0	0	13.07
Rabi Season					
Wheat	881.85	824.37	385.28	609.68	382.96
Gram	220.46	206.09	96.32	152.42	95.74
Mustard	176.37	164.87	77.06	121.94	76.59
Potato	117.58	109.92	51.37	81.29	51.06
Vegetables	73.49	68.70	32.11	50.81	31.91
Total Area, km²	1890.47	1691.49	642.13	1016.13	928.63
Total Cultivable Area, km²	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	126.45	121.43	64.73	81.68	100.39

Figure 7.34: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area

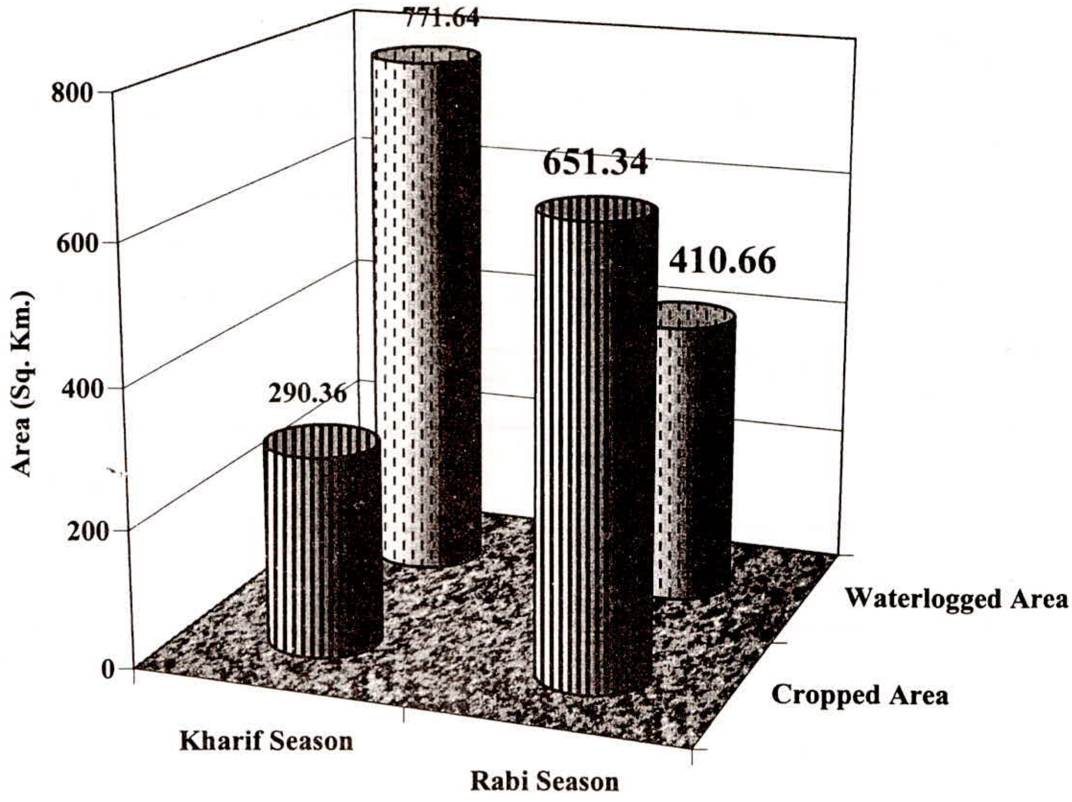


Figure 7.35: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area

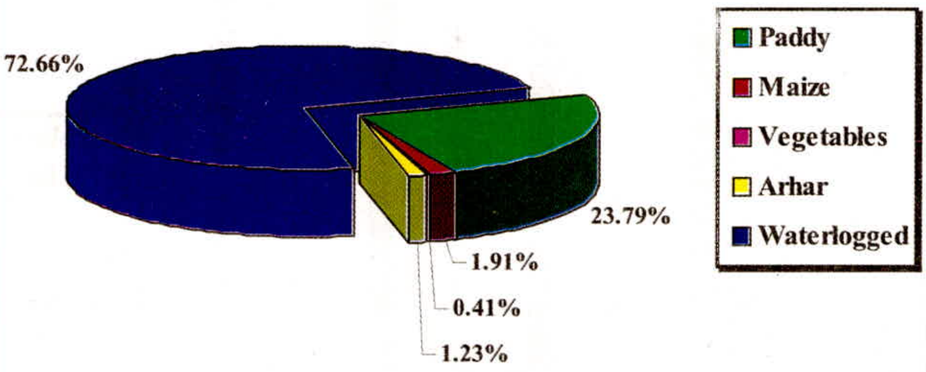


Figure 7.36: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area

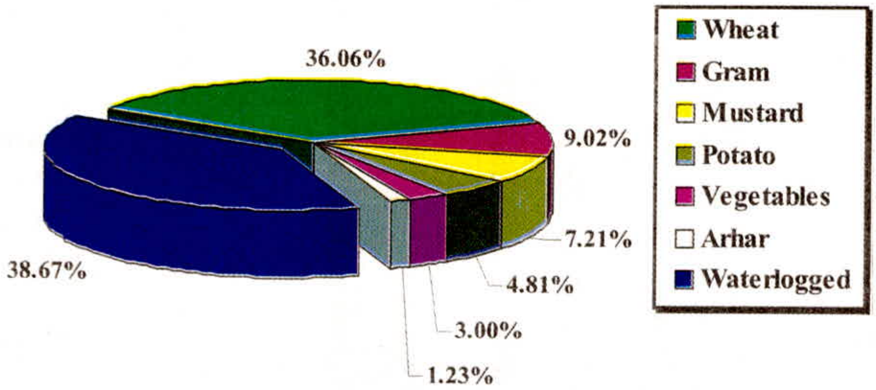


Figure 7.37: **Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area**

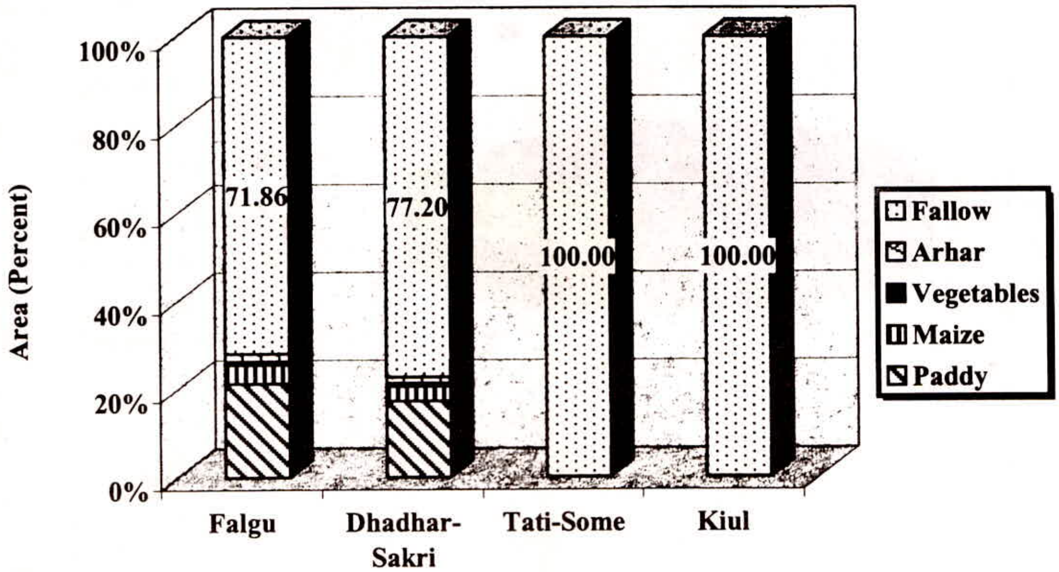
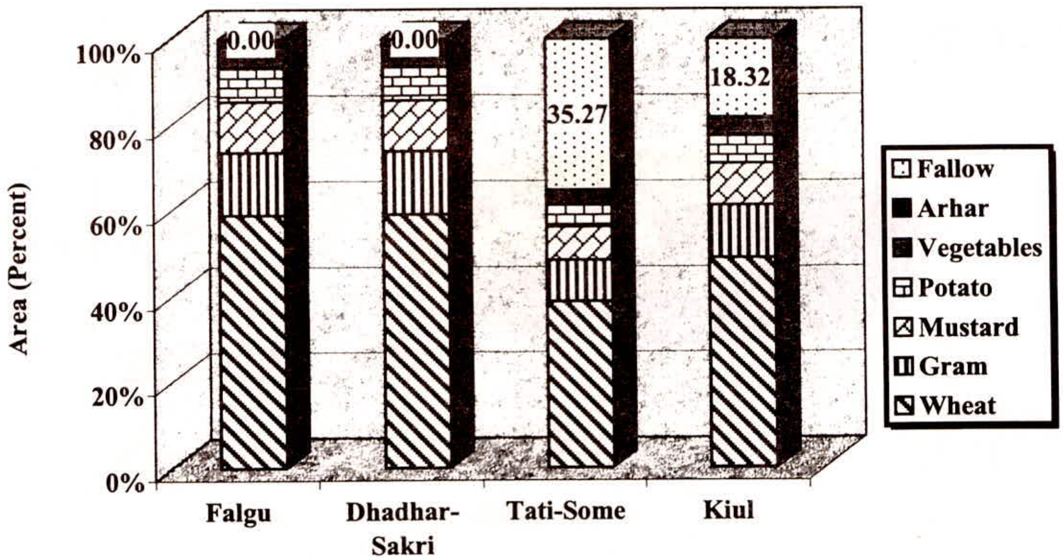


Figure 7.38: **Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area**



area in Falgu, Dhadhar-Sakri, Tati-Some and Kiul sub-basins respectively, remain fallow in kharif season. Again, 35.27% and 18.23% of the total cultivable area in Tati-Some and Kiul sub-basins respectively, remain fallow in rabi season.

7.3.6.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.14**. In kharif season, 60% of the inflow (i.e., 60% of the runoff values from various sub-basins, as mentioned in table 6.7), is allowed to flow to the Tal area. There is no release of water from the upstream catchment to the Tal in rabi season. At the end of kharif season, 1641 km^2m of water is to be drained out from the Tal while 365 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

7.3.7 Case VII - Minimum outflow being seventy percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 70% inflow into the Tal are presented in **table 7.15**. The maximised value of the objective function is obtained as 4,848.45 km^2.

7.3.7.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.39**. It is observed that in kharif season, out of a total area of 1062 km^2, 824.21 km^2 remains waterlogged, while in rabi season, only 413.03 km^2 remains waterlogged. Thus, the waterlogged area in rabi season remains nearly the same as in case VI outlined in section 7.3.6. The reasons for the increase in waterlogging in kharif season are same as those described in section 7.3.4.1. **Figures 7.40 and 7.41** show the percentage area of different crops and waterlogging in Mokama group

Table 7.14: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 60% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	6.86	12.90	27.74	91.89	26.19	84.66	146.41	168.90	113.07	24.43	703.05
Dhadhar-Sakri	5.18	9.74	20.94	69.35	19.77	79.14	136.87	157.89	105.70	22.84	627.41
Tati-Some	0	0	0	0	0	36.99	63.97	73.79	49.40	10.67	234.82
Kiul	0	0	0	0	0	58.53	101.22	116.77	78.17	16.89	371.58
Tal Area	5.42	10.19	21.82	69.10	20.58	36.77	63.58	73.35	49.10	10.61	360.52

Table 7.15: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	0	0	0	0	206.88
Maize	0	0	0	0	16.65
Vegetables	0	0	0	0	3.57
Arhar	0	0	0	0	10.70
Rabi Season					
Wheat	865.15	772.06	288.96	457.26	382.96
Gram	216.29	193.02	72.24	114.31	95.74
Mustard	173.03	154.41	57.79	91.45	76.59
Potato	115.35	102.94	38.53	60.97	51.06
Vegetables	72.10	64.34	24.08	38.10	31.91
Total Area, km^2	1441.91	1286.77	481.60	762.10	876.06
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	96.45	92.37	48.55	61.26	94.71

Figure 7.39: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area

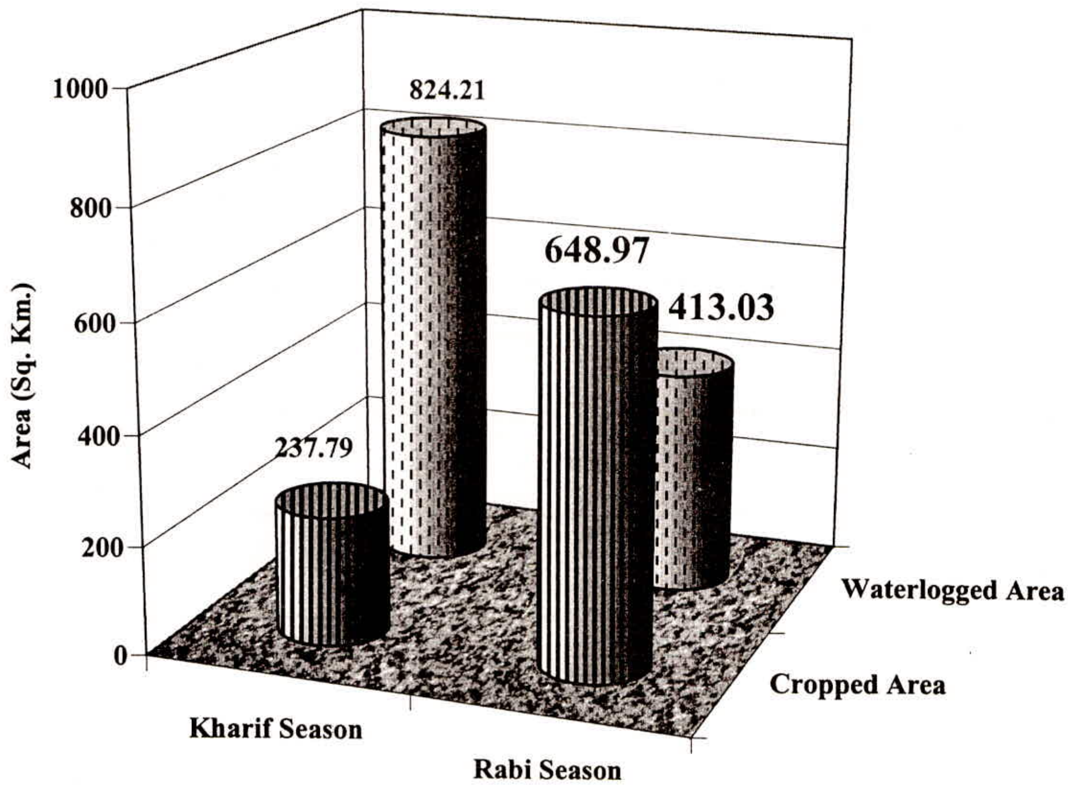


Figure 7.40: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area

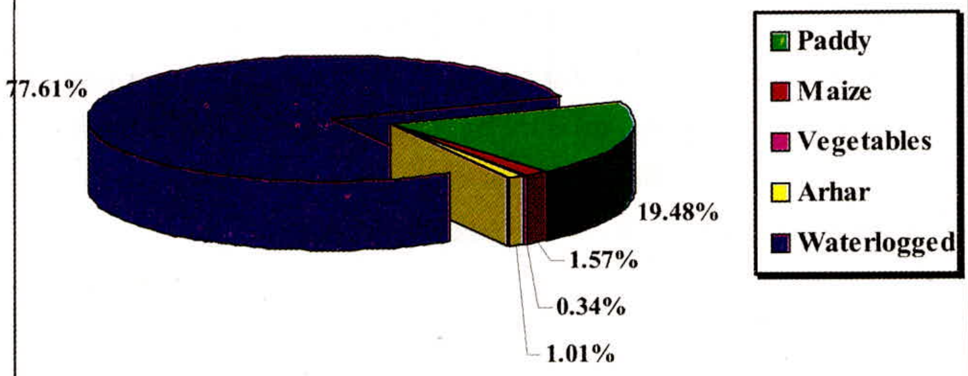
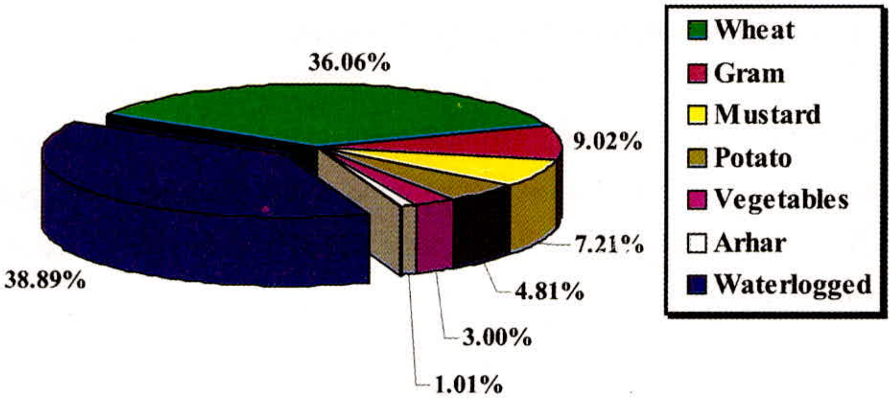


Figure 7.41: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area



of Tals in kharif and rabi season respectively. It is observed that approximately 78% of the Tal area remains waterlogged in kharif season and only 39% in rabi season.

7.3.7.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.15. **Figures 7.42 and 7.43** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that the total cultivable area in all the sub-basins remain fallow in kharif season, while 3.55%, 7.63%, 51.45% and 38.74% of the total cultivable area in Falgu, Dhadhar-Sakri, Tati-Some and Kiul sub-basins respectively, remain fallow in rabi season.

7.3.7.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.16**. In kharif season, 70% of the inflow (i.e., 70% of the runoff values from various sub-basins, as mentioned in table 6.7), is allowed to flow to the Tal area. There is no release of water from the upstream catchment to the Tal in rabi season. At the end of kharif season, 2301 km^2m of water is to be drained out from the Tal while 368 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

7.3.8 Case VIII - Minimum outflow being eighty percent

The area allocated to different crops in Kharif and Rabi season, in various sub-basins of the upper catchment and Tal area, under the objective of maximisation of cropped area with at least 80% inflow into the Tal are presented in **table 7.17**. The maximised value of the objective function is obtained as 3,504.70 km^2.

Figure 7.42: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area

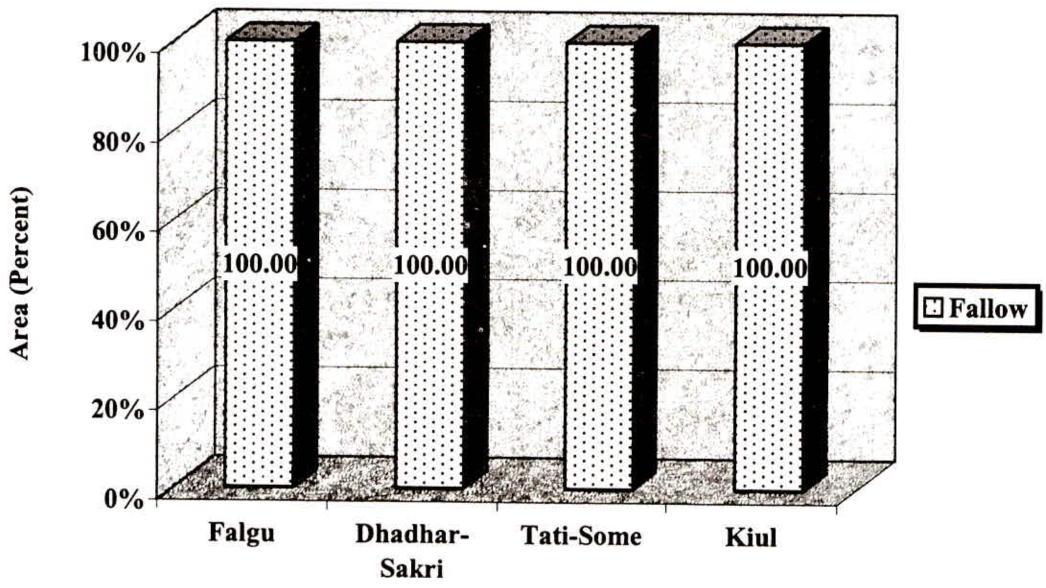


Figure 7.43: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area

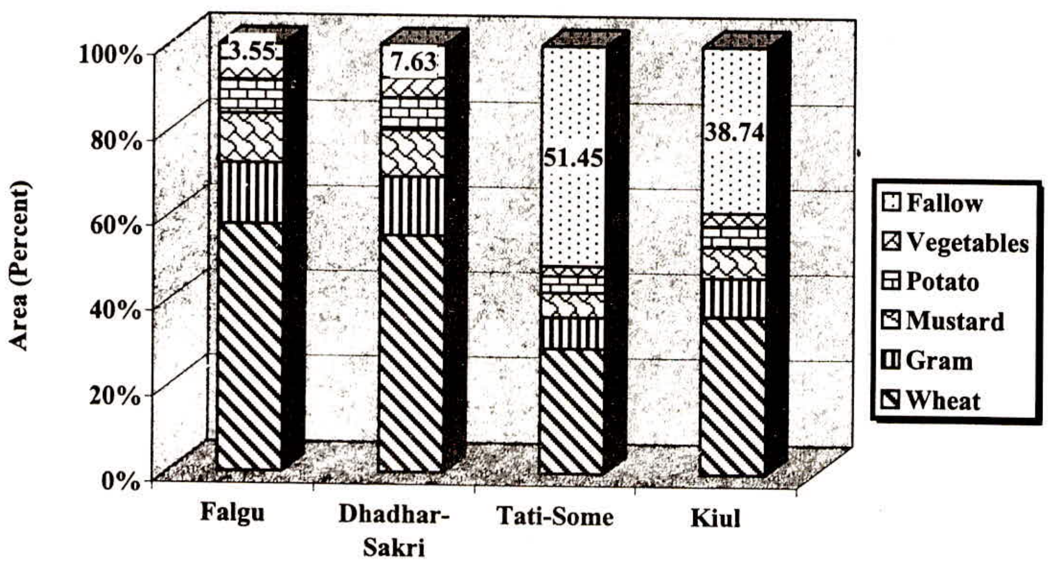


Table 7.16: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 70% Inflow into the Tal Area, km^2m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^2m.									
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	0	0	0	0	0	83.06	143.64	165.70	110.93	23.97	527.29
Dhadhar-Sakri	0	0	0	0	0	74.12	128.18	147.87	98.99	21.39	470.56
Tati-Some	0	0	0	0	0	27.74	47.98	55.34	37.05	8.00	176.11
Kiul	0	0	0	0	0	43.90	75.92	87.58	58.63	12.67	278.69
Tal Area	4.44	8.35	17.87	56.59	16.85	36.77	63.58	73.35	49.10	10.61	337.51

Table 7.17: Crop Area Allocation in Various Sub-Basins under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area, km^2.

Crop	Area Allocated in Different Sub-Basins (km^2)				
	Falgu	Dhadhar-Sakri	Tati-Some	Kiul	Tal Area
Kharif Season					
Paddy	0	0	0	0	189.81
Maize	0	0	0	0	15.27
Vegetables	0	0	0	0	3.27
Arhar	0	0	0	0	9.82
Rabi Season					
Wheat	576.76	514.71	192.64	304.84	382.96
Gram	144.19	128.68	48.16	76.21	95.74
Mustard	115.35	102.94	38.53	60.97	76.59
Potato	76.90	68.63	25.69	40.65	51.06
Vegetables	48.06	42.89	16.05	25.40	31.91
Total Area, km^2	961.27	857.85	321.07	508.07	856.44
Total Cultivable Area, km^2	1495.00	1393.00	992.00	1244.00	925.00
Cropping Intensity, Percent	64.30	61.58	32.37	40.84	92.59

7.3.8.1 Cropped and waterlogged area in Mokama group of Tals

The cropped and waterlogged areas in Mokama group of Tals in both kharif as well as rabi season are shown in **figure 7.44**. It is observed that in kharif season, out of a total area of 1062 km^2, 843.83 km^2 remains waterlogged, while in rabi season, only 413.91 km^2 remains waterlogged. Thus, the waterlogged area in rabi season remains nearly the same as in case VII outlined in section 7.3.7. The reasons for the increase in waterlogging in kharif season are same as those described in section 7.3.4.1. **Figures 7.45 and 7.46** show the percentage area of different crops and waterlogging in Mokama group of Tals in kharif and rabi season respectively. It is observed that approximately 79% of the Tal area remains waterlogged in kharif season and only 39% in rabi season.

7.3.8.2 Cropped area in the various sub-basins of the upper catchment

The area allocated to different crops in various sub-basins in both kharif and rabi season are shown in Table 7.17. **Figures 7.47 and 7.48** show the percentage of total cultivable area allocated to different crops in various sub-basins in kharif and rabi season respectively. It is observed that the total cultivable area in all the sub-basins remain fallow in kharif season, while 35.70%, 38.42%, 67.63% and 59.16% of the total cultivable area in Falgu, Dhadhar-Sakri, Tati-Some and Kiul sub-basins respectively, remain fallow in rabi season.

7.3.8.3 Water release schedule

The monthly crop water requirements (including conveyance losses), which serve as guidelines for the water release schedule of the reservoirs, in various sub-basins and Tal area are presented in **table 7.18**. In kharif season, 80% of the inflow (i.e., 80% of the runoff values from various sub-basins, as mentioned in table 6.7), is allowed to flow to the Tal area. There is no release of water from the upstream catchment to the Tal in rabi season. At the end of kharif season, 2451 km^2m of water is to be drained out from the Tal while 368 km^2m of water is to be stored in the Tal so as to meet the crop water requirements in the Tal in rabi season. In rabi season, the water available from tubewells is also used for irrigation in the Tal area.

<u>Figure 7.44</u>: Cropped and Waterlogged Area in Mokama Group of Tals under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area

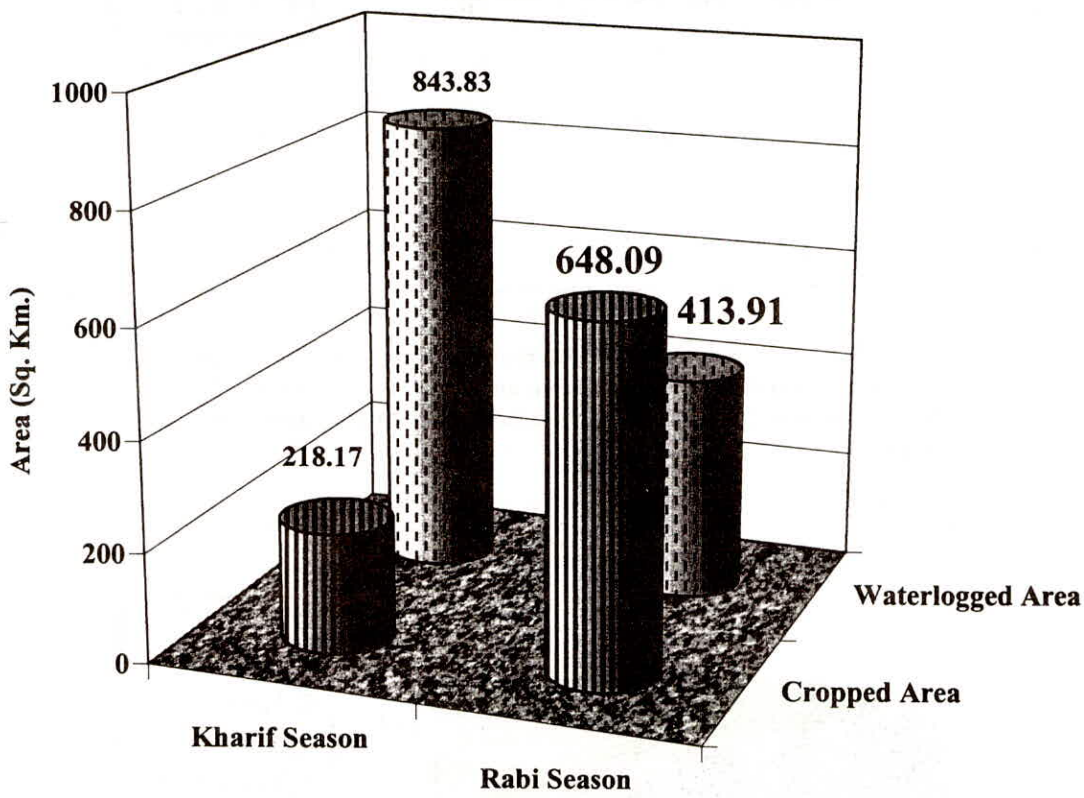


Figure 7.45: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area

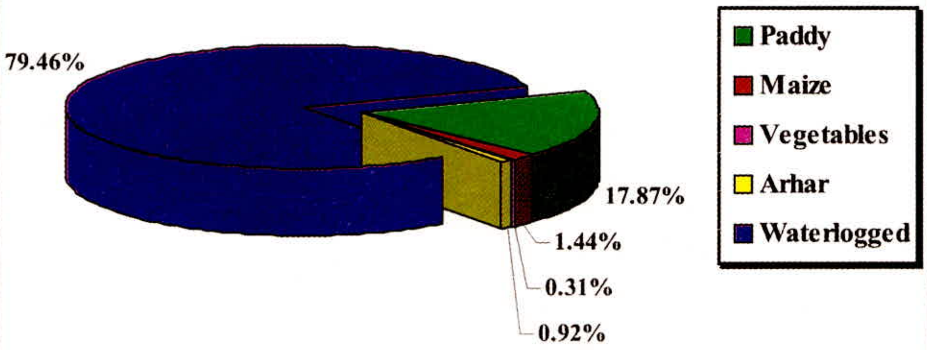


Figure 7.46: Percentage Area of Different Crops and Waterlogging in Mokama Group of Tals in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area

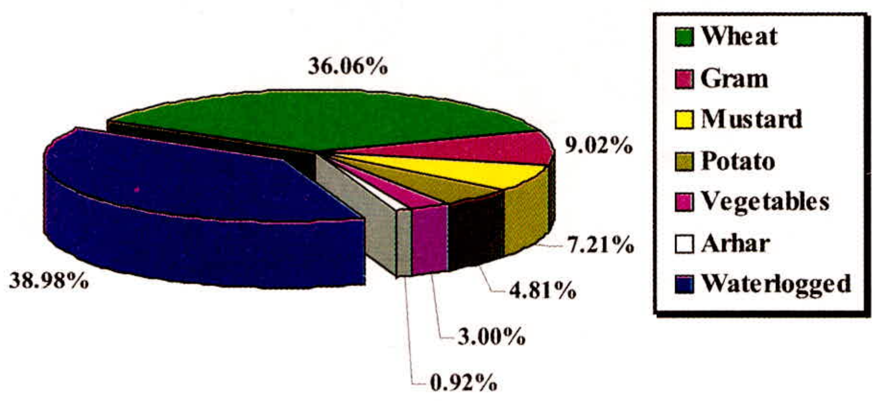


Figure 7.47: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of the Upper Catchment in Kharif Season under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area

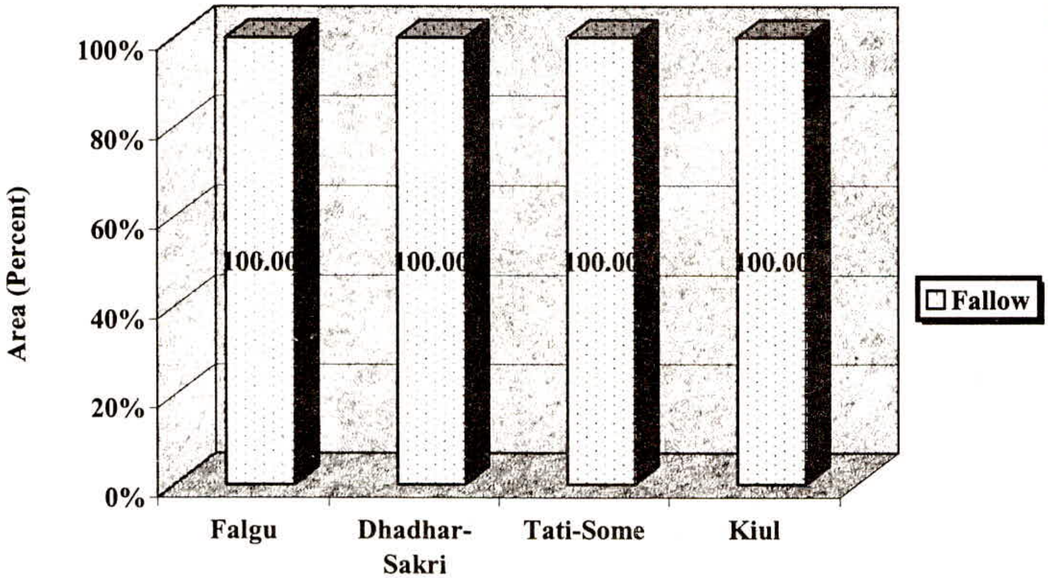


Figure 7.48: Percentage of Cultivable Area under Different Crops in Various Sub-Basins of Upper Catchment in Rabi Season under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area

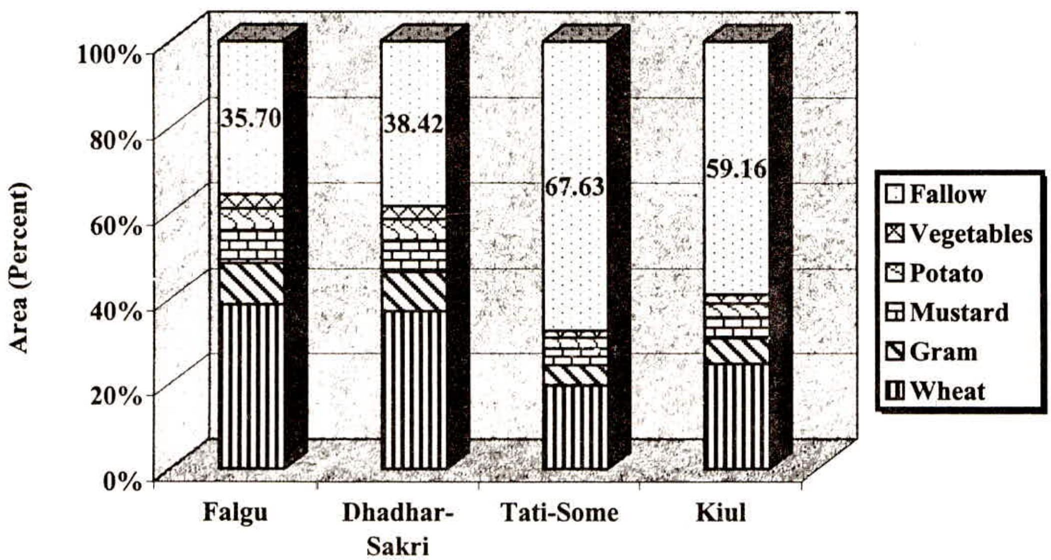


Table 7.18: Monthly Crop Water Requirements in various Sub-Basins and Tal Area (including conveyance losses) under the Objective of Maximisation of Cropped Area with at Least 80% Inflow into the Tal Area, km^{2}m.

Sub-Basins	Monthly Crop Water Requirements (Including Conveyance losses), km^{2}m.										
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Falgu	0	0	0	0	0	55.37	95.76	110.47	73.95	15.98	351.52
Dhadhar-Sakri	0	0	0	0	0	49.41	85.46	98.58	65.99	14.26	313.70
Tati-Some	0	0	0	0	0	18.49	31.98	36.90	24.70	5.34	117.41
Kiul	0	0	0	0	0	29.27	50.61	58.39	39.09	8.44	185.79
Tal Area	4.07	7.66	16.40	51.92	15.46	36.77	63.58	73.35	49.10	10.61	328.92

7.4 Effect of Varying Outflow on the Waterlogging Conditions in the Tal

The extent of waterlogged area in the Tal for different minimum percentage of inflow into the Tal are plotted as shown in **figure 7.49** for both kharif as well as rabi season. It is observed from figure 7.49 that in kharif season, the waterlogged area in the Tal is minimum for the case when there is no constrained inflow into the Tal (i.e, for the case outlined in section 7.2). However, there is a gradual increase in the extent of waterlogged area in the Tal with increase in the minimum percentage of inflow into the Tal from 0 to 80%. The rate of increase, however, is higher when the minimum percentage of inflow into the Tal increases from 0 to 10%. This may be attributed to the topography of the Tal area. It is also observed from figure 7.49 that in rabi season, the waterlogged area in the Tal is minimum for the case when there is no constrained inflow into the Tal (i.e, for the case outlined in section 7.2) and remains constant even when the percentage inflow increases from 0 to 20%. This constancy is due to the fact that the excess water at the end of kharif season is drained out into the river Ganga making the Tal area free from waterlogging. However, as the percentage inflow increases from 20% to 40%, the extent of waterlogging in the Tal gradually increases. This is because with increase in percentage inflow there is a decrease in water storage in the upstream catchment and hence the release of water from the upstream catchnment to the Tal area in rabi season also decreases. Hence, the water deficiency in the Tal in rabi season is compensated by storing a part of the excess water at the end of kharif season. This leads to an increase in the waterlogged area in the Tal in rabi season. The increasing trend continues till the percentage of inflow reaches 40% when the water availability in the upstream catchment decreases to an extent that there is no water release from the upstream catchment to the Tal in rabi season. Hence, the water requirement in the Tal in rabi season, is met by a part of the excess water in the Tal at the end of kharif season in addition to the water available from tubewells. Thereafter with further increase in the percentage inflow, the waterlogged area in the Tal in rabi season remains a constant. The corresponding variation of cropped area in the Tal with varying percentage of inflow is shown in **figure 7.50** for both kharif as well as rabi season.

Figure 7.49: Variation of Waterlogged Area with Different Percentages of Inflow in Mokama Group of Tals

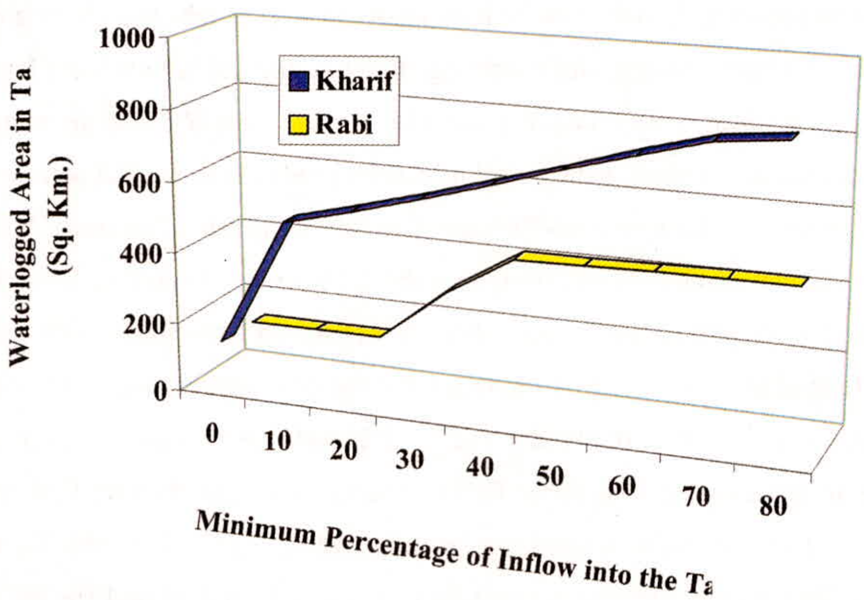
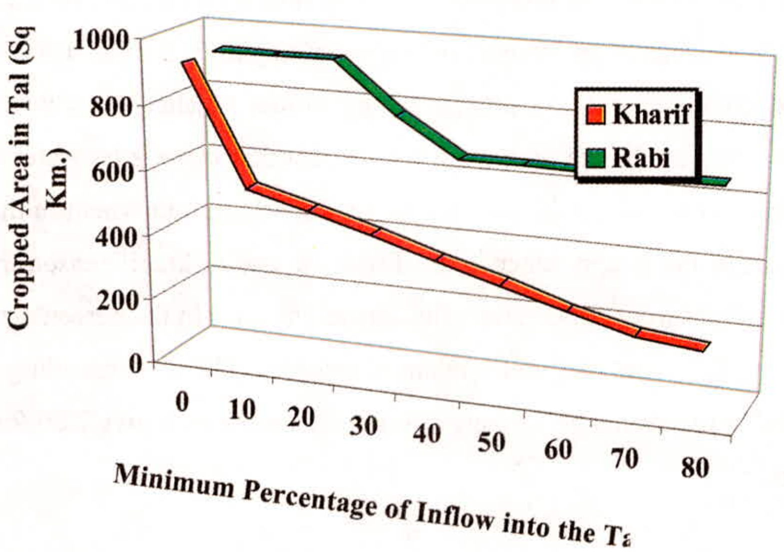


Figure 7.50: Variation of Cropped Area with Different Percentages of Inflow in Mokama Group of Tals



7.5 Effect of Varying Outflow on the Cropping Conditions in Upstream Catchment

Figure 7.51 shows the variation of cropped area in various sub-basins with different percentages of inflow into the Tal in kharif season. It is observed from figure 7.51, that the cropping area in Tati-Some and Kiul sub-basins decrease with increase in percentage inflow. The cropping area becomes zero for Tati-Some sub-basin when the percentage inflow increases to 40% while it becomes zero for Kiul sub-basin when the percentage inflow increases to 60%. However, for Falgu and Dhadhar-Sakri sub-basins, the cropped area remains unaffected till the percentage inflow increases to 30% and thereafter it decreases and becomes zero when the inflow increases to 70%. This shows that the water availability in Tati-Some and Kiul sub-basins is less in comparison to those of Falgu and Dhadhar-sakri. **Figure 7.52** shows the variation of cropped area in various sub-basins with different percentages of inflow into the Tal in rabi season. It is observed from figure 7.52 that the cropping areas in all the sub-basins remain unaffected till the percentage inflow increases to 40%. Thereafter the cropping area in Tati-Some sub-basin starts decreasing. The corresponding values of inflow after which the cropping areas in Kiul, Falgu and Dhadhar-Sakri sub-basins start decreasing are 60%, 70% and 70% respectively. It is interesting to note from figures 7.51 and 7.52 that the cropping areas in the various sub-basins in rabi season start decreasing only when the corresponding cropping areas in kharif season becomes zero. This implies that the available water is used on a prioity basis for rabi season. This is obviously justified because wheat which is a major rabi crop requires less water than paddy which is a major kharif crop and hence the available water is allocated to wheat on a priority basis so as to increase the cropped area since the objective is to maximise the cropped area.

Figure 7.51: Variation of Cropped Area with Different Percentages of Inflow in Various Sub-Basins of the Upper Catchment in Kharif Season

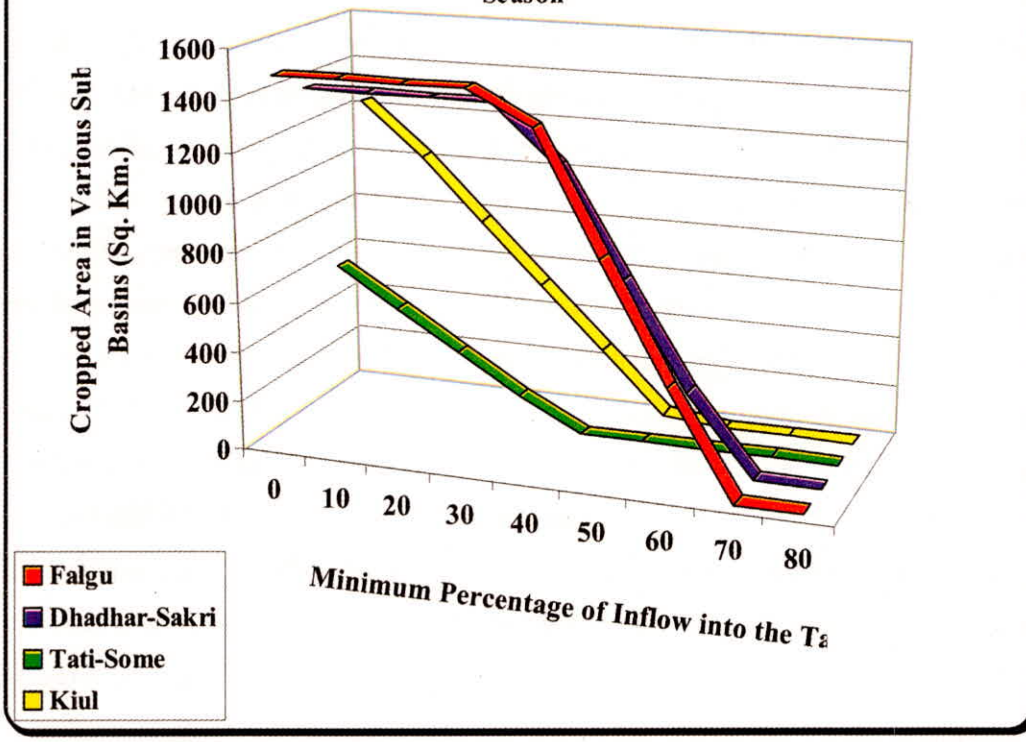
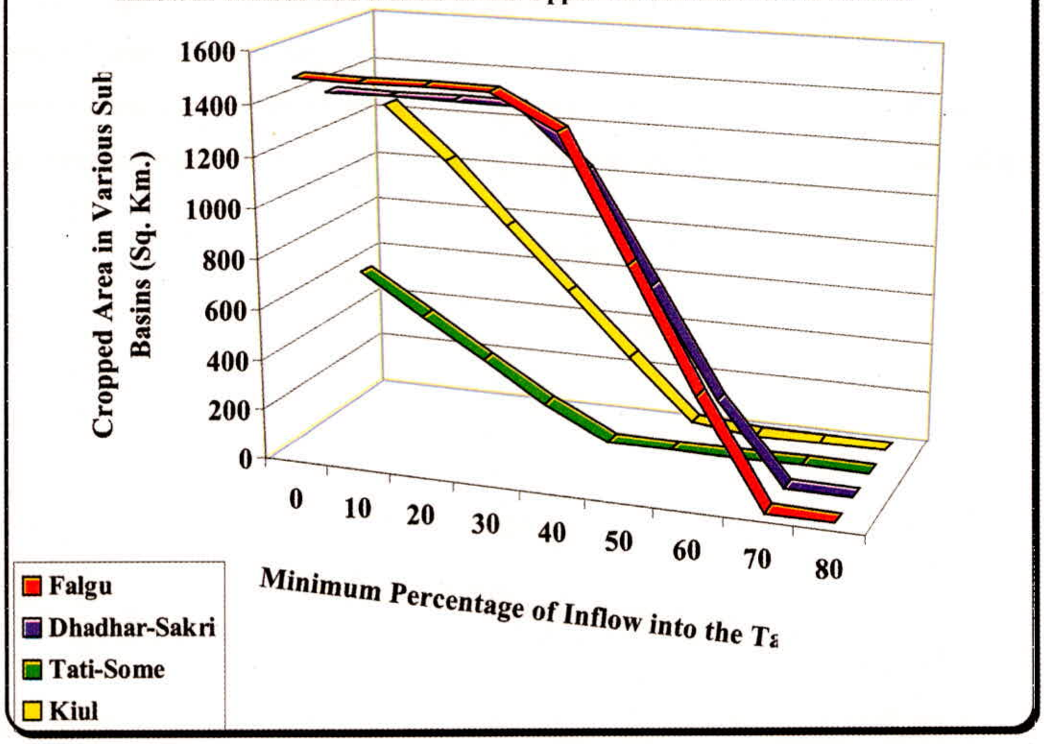


Figure 7.52: Variation of Cropped Area with Different Percentages of Inflow in Various Sub-Basins of the Upper Catchment in Rabi Season



8.0 CONCLUSIONS

Based on the analysis of the hydrological characteristics and data, following conclusions are drawn:

- The problem in the Mokama Group of Tals can be regarded as surface waterlogging/ blockage of water for a period of 4-5 months (June - October).
- The hydrology of the catchment from which Tal area receives its inflow, reveals that at the end of monsoon a dimensionally opposite problem persists in terms of availability of water, for instance, at the end of monsoon, the upstream catchment experiences scarcity of water while tail end (Tal area) has surplus water. Thus, it is basically a management problem oriented towards waterlogging and drainage.
- A management model with objective to maximize the cropped area to obtain the optimum Tal area free from surface waterlogging, under the constraints of check over inflows, storage, area, water requirement, affinity and cropping pattern has been considered for solution.
- The area capacity relationship of the Tal area shows an agreement of 6^{th} order polynomial, while other constraints have linear relationship, thus the model reveals a nonlinear optimization model.

Considering different input alternatives, model performance has been worked out, and following are found the best alternatives in terms of benefit.

- **Benefits in the Tal Area**

1. At present, out of the total Tal area of 1062 km^2, only 30 % is cultivated and the balance 70% remains waterlogged in kharif season. Similarly, in rabi season, around 65% of the Tal area is cultivated and the rest 35% remains waterlogged. This is the case when around 30% of the total monsoon inflow from the upstream catchment is utilised for meeting the crop water requirements in the upstream catchment.
2. By implementing the results of the non-linear optimization model, the area under cropping can be substantially increased to 87% in both the kharif as well as rabi season, thus reducing the waterlogged area to a bare minimum of 13%. The non-linear optimization model thus

minimizes the waterlogged area in the Mokama group of Tals by judiciously using the water in the upstream catchment as well as in the Tal area and also storing a part of it in the upper catchment.

3. The management model is also solved with a range of additional storage values (i.e in addition to the 30% of the total monsoon inflow which is already being stored and utilised in the upstream catchment) i.e. varying from 10 to 57%. The effect of varying storage in the upstream catchment on the waterlogging conditions in the Tal in kharif as well as rabi season is extensively studied and the results are presented in following table. These results are expected to be a vital input to the decision making process.

Table: Decreasing Waterlogged Area in Mokama Group of Tals with Increasing Percentage of Water Storage in the Upstream Catchment

Additional Percentage of Water Storage in the Upstream Catchment	Waterlogged Area in Mokama Group of Tals in			
	Kharif Season		Rabi Season	
	Sq. km.	Percent	Sq. km.	Percent
10	716.32	67.45	342.81	32.28
20	693.27	65.28	332.72	31.33
30	659.17	62.07	320.72	30.20
37	602.94	56.78	290.16	27.32
44	550.72	51.86	137.00	12.90
49	501.96	47.27	137.00	12.90
57	137.38	12.90	137.00	12.90

- **Benefits in the upstream catchment**

By restricting the incoming flows, the irrigation potential in the upstream catchment (having a total areal extent of 16,303 km^2) can be substantially increased. At present the total area under cultivation in various sub-basins of the upper catchment in kharif and rabi season is 2879.90 km^2 and 1231.39 km^2 respectively. By implementing the results of the non-linear optimization model, the area under kharif cropping can be substantially increased to 4735.52 km^2 and that under rabi cropping to 4898.30 km^2.

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Appendix-I

Monthly and Annual Normal Rainfall at Raingauge Stations in Kiul-Harohar and its Adjacent Basin Maintained by IMD

Sl. No.	Raingauge Station	June (mm)	July (mm)	August (mm)	Sept. (mm)	Oct. (mm)	Total (mm)
1	Patna	158.0	276.1	340.4	237.7	54.6	1066.8
2	Bihar Sharif	138.2	283.0	305.8	185.7	42.9	955.6
3	Barh	140.2	238.8	265.4	185.4	43.9	873.7
4	Hilsa	120.1	248.4	310.6	188.5	37.1	904.7
5	Islampur	128.0	285.2	293.6	193.8	32.3	932.9
6	Asthanwan	129.3	249.2	236.8	179.8	43.7	888.8
7	Ekangersarai	85.1	221.2	214.9	157.0	32.0	710.2
8	Bakhtiarpur	125.7	294.6	351.8	224.3	49.3	1045.7
9	Sarmera	135.9	289.6	319.3	204.5	60.5	1009.8
10	Badalpur (Khagole)	75.7	206.8	249.4	160.0	31.5	723.4
11	Silao	108.2	268.5	266.2	167.6	38.9	849.4
12	Chandi	122.7	305.1	302.0	204.0	44.5	978.3
13	Gaya	140.5	331.0	366.5	197.1	48.8	1083.9
14	Nawada	123.7	267.7	308.6	176.8	47.2	924.0
15	Jehanabad	130.8	283.0	325.9	213.6	38.9	992.2
16	Sherghati	128.3	297.4	362.5	213.1	52.8	1054.1
17	Rajauli	139.9	308.1	350.8	213.1	55.4	1067.3
18	Pukribarawan	117.3	227.3	379.7	176.3	48.5	849.4
19	Baradwati	121.4	324.6	377.9	209.0	50.5	1083.4
20	Begusarai	178.1	271.3	324.9	243.8	57.1	1075.2
21	Munger	174.0	263.4	324.9	212.3	55.4	1030.0
22	Jamui	160.0	292.6	292.9	216.4	59.4	1021.3
23	Sheikhpura	165.3	277.1	312.2	199.4	51.6	1005.6
24	Chakaibanda	193.3	300.2	305.1	227.6	87.6	1113.8
25	Gidhaur	200.1	327.1	317.1	233.4	85.9	1164.2
26	Hazaribagh	194.3	321.8	349.0	219.7	79.5	1164.3
27	Barhi	183.4	334.5	365.8	201.2	80.3	1165.2
28	Chatra	73.2	360.9	385.1	229.1	61.0	1209.3
29	Kodarma	175.5	305.6	342.7	210.3	70.6	1104.7
30	Hunterganj	151.4	380.7	388.6	231.9	60.2	1212.8
31	Satgawan	113.0	288.5	325.6	186.4	49.3	962.8
32	Dhanwar	166.4	326.4	303.5	197.9	82.5	1076.7

"Water"

The rain is plenteous but, by God's decree,
Only a third is meant for you and me;
Two-thirds are taken by the growing things
Or vanish Heavenward on vapour's wings:
Nor does it mathematically fall
With social equity on one and all.
The population's habit is to grow
In every region where the water's low:
Nature is blamed for failings that are Man's,
And well-run rivers have to change their plans.

by Sir Alan Herbert

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