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# COMPREHENSIVE HYDROLOGICAL STUDIES OF MALAPRABHA AND GHATAPRABHA REPRESENTATIVE BASINS

**Summary, Conclusions and Recommendations**

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# PREFACE

Representative basins are basins, which are selected as representative of a hydrological region within which hydrological similarity is presumed. They are used for intensive investigation of specific problems of the hydrological cycle. A representative basin takes the more specific role representing a broad area to which the data can be transferred. Hard rocks (crystalline rocks) such as granites, gneisses, basalt, and indurated pre-Cambrian sediments cover approximately 75 per cent of the total area of the India. Due to the complex nature of the hard rock region, it is quite necessary to have a through study of the hydrological problems existing in this region. However, it is impossible to cover whole area at a stretch, therefore it is decided to select two representative basins in this region for extensive research. For this purpose, the Hard Rock Regional Center, in consultation with the State and other Central Govt. Departments selected Malaprabha catchment upto Khanapur and Ghataprabha catchment upto Daddi as a Representative Basins.

During the thirteen years of establishment of Hard Rock Regional Centre of National Institute of Hydrology, a nos. of hydrological studies has been carried out in the Malaprabha and Ghataprabha Representative Basins. Therefore, in the meeting of Regional Co-ordination Committee, which comprises of the field engineers from different State/Central Government organisations within the region, it is decided to carry out the comprehensive studies for these experimental representative basins, in order to standardize and develop the methodologies for providing solutions for understanding and solving various hydrological problems of the entire hard rock region.

In present report, an effort has been made to compile the studies on various hydrological problems carried out so far in these representative basins. This report has been compiled by Mr. Dilip G. Durbude, Scientist 'B, and assisted by Mr. P. R. S. Rao under the guidance of Mr. C. P. Kumar, Scientist 'E1' and Head, Regional Center, National Institute of Hydrology, Belgaum. I hope that the conclusions brought out in this report will be useful for the user agencies. It is expected that this document would prove to be very good reference source for academic community as well as field engineers dealing the above problems in the hard rock region.

**(Dr. K. S. Ramasastri)**

**Director**

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# 1.0 Introduction

With the growing demand on revealing all available water resources and analysis of hydrological conditions in a comprehensive way, a landmark appears in the science of hydrology, that is the contents and interrelation of hydrological activities under go a radical change. A new means of research is being established in a growing number and within the scope of comprehensive investigations extending to large regions the network of representative areas is formed (Szesztay, 1965). Thus, the aim of hydrological research is not only the collection of data, but rather than an interpretation of these data for use in solution of various management problems such as:

Flood forecasting and management of floods; prediction and estimation of surface water; prediction and estimation of ground water; understanding the system of hydrological cycle and the water balance nature under different regions; how does the variability of the topography, soil, vegetation, geology and climate etc.influence the hydrological cycle within different region and how a small change within a system can effect the entire hydrological system of a region etc.

Thus newly emerged concepts of representative basin study is being widely recognised to solve various management problems because:

- principle objectives of hydrological research in representative basin are the prediction and quantitative estimation of various components of the hydrological cycle;
- representative basin studies are useful for detailed studies of the hydrological cycle and provide an insight into the characteristics of the area, which they represent;
- a representative basin takes the more specific role of representing a broad area to which the data can be transformed;
- it is the representative basin study by which a holistic model of hydrological system could be developed which defines that how a small change in parameters of the system individually and the entire hydrological system as a whole;
- a holistic model derived from a representative basin study helps in the prediction of various hydrological parameters such as overland flow, channel run-off, evaporation, infiltration, groundwater storage, flooding, sheetwash erosion, channel erosion and sedimentation etc;

- prediction of estimation of various hydrological parameters based on a representative studies help planners, decision makers, farmers and engineers to formulate their plans and to execute their plans for different purposes;
- representative basin study is the most useful in reducing time and effort required for studies of large area, and it permits the formulation of rapid approximations and because time is saved it enables more detailed observation to be made and a greater number of variable to be considered.

Several analytical framework, or for approach to Organisation of hydrological studies have been suggested in recent years and the term representative basin experimental basin and other associated nomenclature such as benchmark basin, vigil basin, barometer basin and paired catchments and multiple catchments etc.

According to the Australian Water Resource Council (1969) a representative basin, which contains within its boundaries a complex of land forms, geology, landuse and vegetation, which can be recognized in many other catchments of a similar size throughout a particular region. Recently Toebes and Ouryvaeu (1970) have defined the representative basins as follows.

"Representative basins are basins, which are selected as representative of a hydrological region, i.e. region within which hydrological similarity is presumed". They are used for intensive investigations of specific problems of the hydrological cycle (or part thereof) under relatively stable, natural conditions. Thus a sparse network of representative basin may reflect general hydrological features of a given region and their variations over large natural zones.

The hydrological parameters (or responses/outputs) are the functions of energy inputs provided by the climate above the surface and the endogenic processes below the earth surface To understand the hydrological cycle in general and hydrological system, in particular in different hydrological regions, the relationships among the energy inputs and hydrological outputs is required. A drainage basin is excellent example of open system wherein the input-output relationships can be obtained most precisely. It is widely recognised as a fundamental unit in the hydrological mileu.

The selection of representative basins depends upon the purpose of the study. However, Toebes and Ouryvaev (1970) have emphasised on the following points while selecting representative basins

- Representativeness

- Basin divide
- Consistency of conditions
- Deep percolation and channel infiltration
- Quality of flow measuring stations
- Access
- Size of representative basin

A brief account of these points based on Toebes and Ouryvaev (1970) is given below.

- The type and range of climate, vegetational , geomorphological, pedagogical and geological characteristics of the selected representative basin should be compared with those of the hydrological region.
- The water divide of the selected representative basin should be as distinct as possible for the exact determination of a basin boundary and area. If a basin is suitable in all aspects but the basin divide is not clear, an artificial divide can be constructed by means of small dams or walls.
- The cultural changes in land use, land management streamflow utilization etc. should be minimal during the period of study and, where they are inevitable, should be carefully recorded. The loss of subsurface flow by deep percolation, or the gain of this flow from neighboring basins must be as small as possible.

It is essential that stage discharge relation is relatively constants. For this purpose, the site for a gauging station should have a natural control or, if this is not available an artificial control should be constructed. Access of the gauging station should be available for every stream flow condition. Access in the representative basin should be such that precipitation and other climatic observations can be carried out. The size of the representative basin depends on the purpose for which the basin is being established. In general the representative basin should be so small that its sensitivity to high intensity rainfalls of short duration is not suppressed by channel characteristics.

Since, the hydrological studies are generally carried out on basin scale, in order to develop and standardize the methodologies for providing solutions for understanding and solving various hydrological problems, it is necessary to carry out the comprehensive studies for typical basins located in different regions of the country.

During the thirteen years of establishment of Hard Rock regional Centre of National Institute of Hydrology, a nos. of hydrological studies has been carried out in the Malaprabha and Ghataprabha Representative basins. In this report, an affort have been made to compile the various studies carried out so far in these representative basins.

## 2.0 Malaprabha and Ghataprabha Representative Basin

Malaprabha and Ghataprabha are the tributaries of river Krishna. The Malaprabha river is a right bank tributary, while Ghataprabha is one of the southern tributary (Figure 1). The Malaprabha river originates from the Chorla ghats, a section of western ghats, at an elevation of about 792 m about 35 m south-west of Belgaum district in Karnataka. The river flows east and the north-west and joins the Krishna at Kapila Sangam in the Bijapur district at an elevation of about 488 m. It traverses a length of 306 km before meeting the river Krishna. The Bennihalla and the Hirehalla are the principle tributaries of the river Malaprabha. To harness the water of the Malaprabha River, a dam is constructed at Naviluteerth, Belgaum district to impound 1377 MCM water.

The river Ghataprabha rises from the western ghats at an altitude of 884 m, flow eastwards for a length of 283 km before joining the Krishna at Kudalisangam about 35 km north-east of Kaladgi at an elevation of 500m. The river flows for about 60 km in the Ratnagiri and Kolhapur districts of Maharashtra before entering the Belgaum district of Karnataka. It enters Karnataka and flows for about 283 km covering parts of Belgaum and Bijapur districts and joins the Krishna at Kudalisangam at an elevation of 500m, about 16 km from Almatti. Its principle tributaries are the Tamraparni, the Hiranyakeshi and the Markandeya.

The Tamraparni rising in Maharashtra flows in Maharashtra for 26 km and after a run of another 26 km in village in Sindhudurg district of Maharashtra flows in Kartnataka for 63 km, forms the boundary between Maharashtra and Karnataka for 63 km and after a run of 19 km in Karnataka, joins the Ghataprabha on the left bank. The Markandeya in Maharashtra flows in Maharashtra 8 km and after a run of 66 km in Karnataka, joins the Ghataprabha on the right bank. A dam is constructed at Hidkal in Hukkeri taluka of Belgaum district of Karnataka to impound 2202 MCM water running two canals on either bank and coupled with weirs and lift irrigation schemes on the foreshores.

### 2.1 Malaprabha Representative Basin

#### 2.1.1 Location

The Malaprabha representative basin lies in the extreme western part of the Krishna basin. It extends in between $74^0$ 20' and $74^0$30' E longitudes, and $15^0$ 20' and 15 $^0$40' N latitudes and encompasses an area of 540 Sq. km of the Belgaum district in the Karnataka state. Two major roads run through the Malaprabha representative basin are Belgaum-Goa (N 4A) and

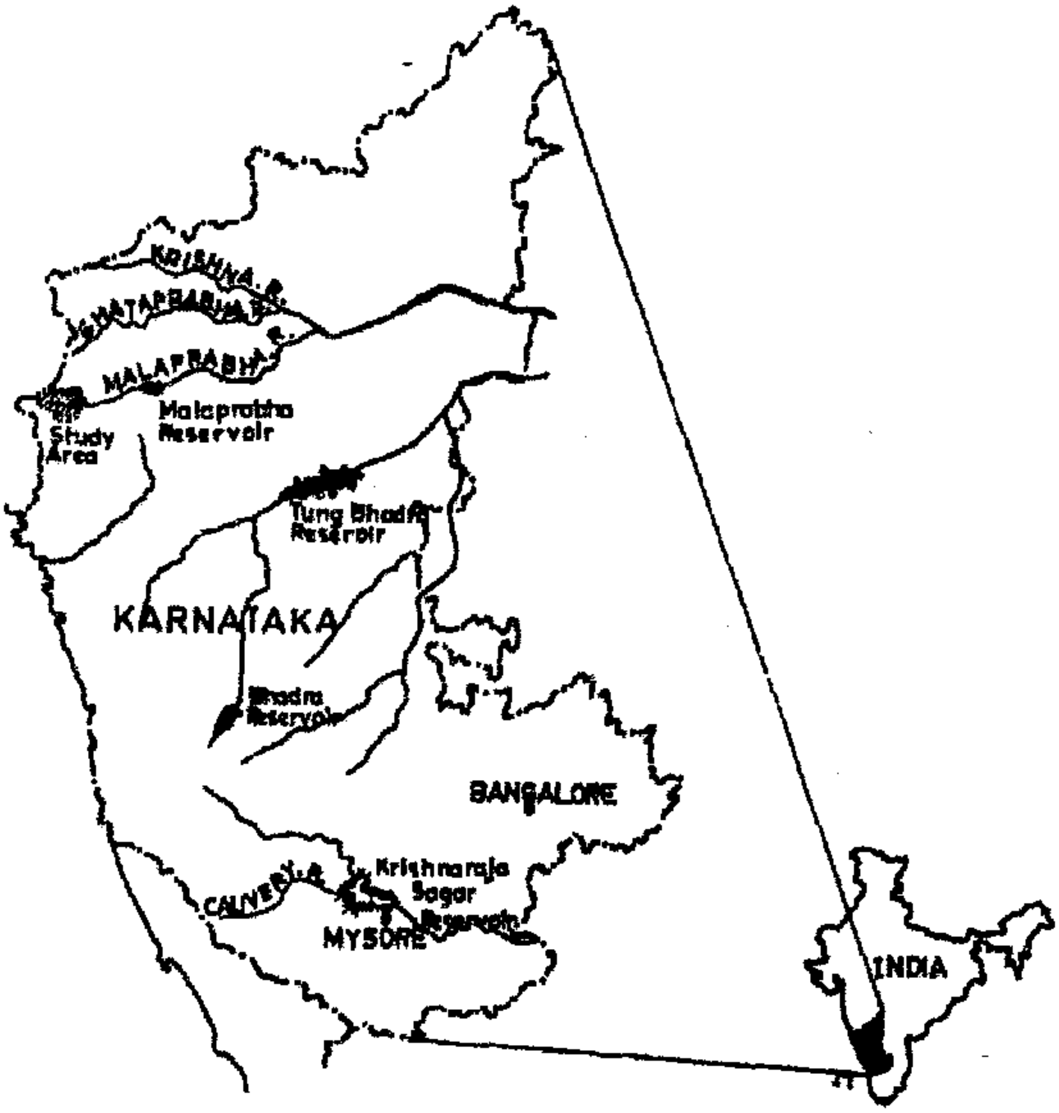


**Figure1. Location Map of the Representative Basins**

Belgaum - Mapusa state high way. This representative basin is the major source of water yield for the Naviluteerth Dam constructed at 35-45 km downstream of its mouth. This dam impounds about 1377mcm water and provides water for irrigation approximately for 2.17 lakh ha lands. The catchment area of the sub-basin District-wise break-up of the area of the catchment is given in the table 1 below.

**Table 1. District-Wise break-up of the Catchment area of Malaprabha Catchment**

| State | District | Area of the district falling in the catchment (Sq. km.) | Percentage of the area of district within the catchment |
|---|---|---|---|
| Karnataka | Belgaum | 3880 | 33.6 |
| | Bijapur | 1950 | 16.9 |
| | Dharwar | 5499 | 47.6 |
| | Raichur | 220 | 1.9 |
| | Total | 11549 | 1000 |

### 2.1.2 Hydrometeorological Network

There are five raingauge stations and two hydrometeorological stations consisting of stevension screen (to record temperature and humidity), pan evaporimeter, anemometer, windvane, self recording raingague and ordinary raingauges different places in the Malaprabha representative basin. Figure 2 depicts the distribution of hydrometeorological network of the Malaprbha representative basin and details of these hydrometeorological stations are presented in table 2.

The representative basin is gauged at its mouth viz., Khanapur by WRDO Karnataka.

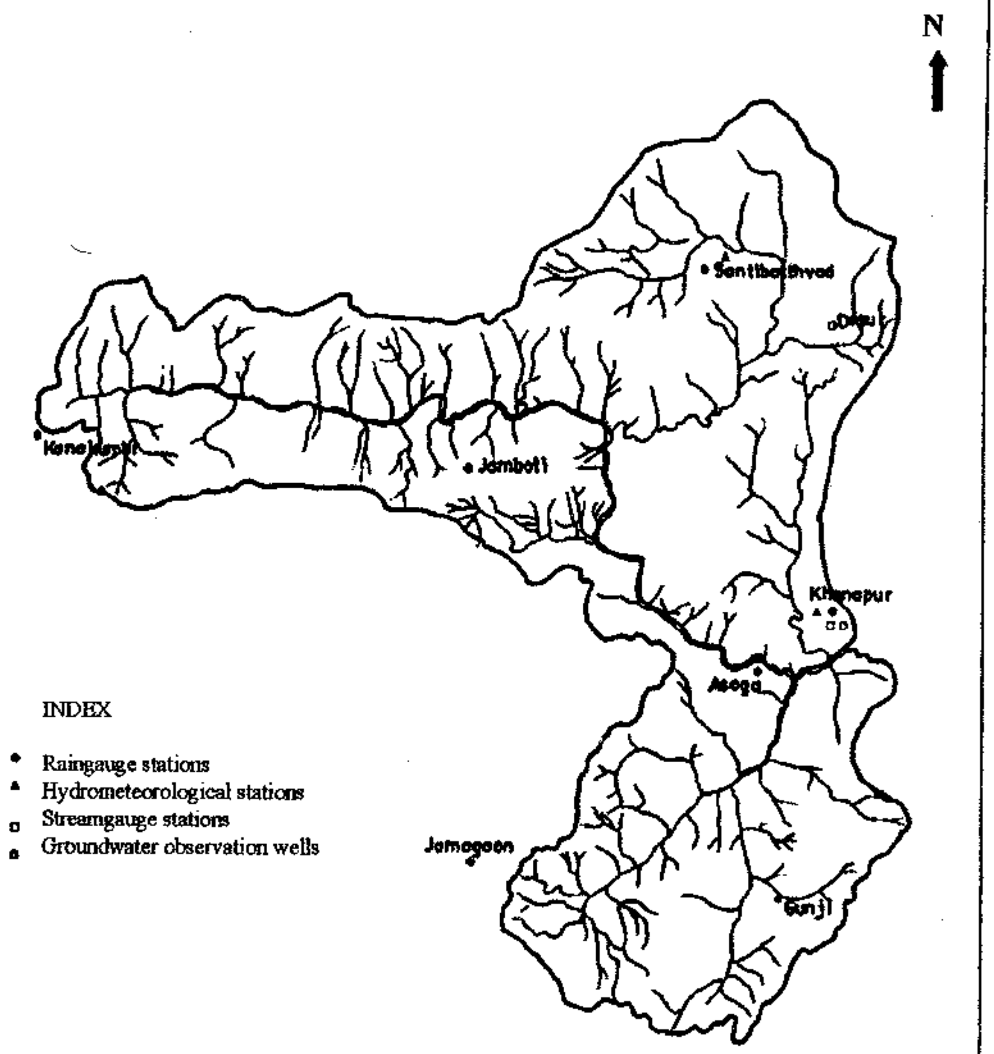


**Figure 2. Location of the Hydrometeorological Stations in Malaprabha Representative Basin**

**Table 2. Details of the hydrometeorological stations in the Malaprabha representative basin**

| Type of station | Location | parameters recording | data recorded since | Maintained by |
|---|---|---|---|---|
| Hydrometeorological stations | Khanapur | Water discharge | June, 1972 | WRDO |
| | | sediment discharge | June, 1975 | WRDO |
| Hydrometeoro-logical stations | Khanapur | Rainfall | January, 1975 | WRDO |
| | | Maximum temp. | Dec., 1975 | WRDO |
| | | Minimum temp. | Dec., 1975 | WRDO |
| | | Evaporation | Dec., 1975 | WRDO |
| | | Wind velocity | Dec., 1975 | WRDO |
| | | Wind direction | Dec., 1975 | WRDO |
| | | Humidity | Dec., 1975 | WRDO |
| | | Vapour pressure | Dec., 1975 | WRDO |
| | Santibastwad | Rainfall | Oct., 1985 | WRDO |
| | | Maximum temp. | Apr.,1986 | WRDO |
| | | Minimum temp. | Apr.,1986 | WRDO |
| | | Evaporation | Apr.,1986 | WRDO |
| | | Wind velocity | Apr.,1986 | WRDO |
| | | Wind direction | Apr.,1986 | WRDO |
| | | Humidity | Apr.,1986 | WRDO |
| | | Vapour pressure | Apr.,1986 | WRDO |
| Raingauge stations | Jamboti | Rainfall | January, 1972 | WRDO |
| | Kankumbhi | Rainfall | January, 1972 | WRDO |
| | Gunji | Rainfall | January, 1972 | WRDO |
| | Desur | Rainfall | January, 1972 | WRDO |
| | Asoga | Rainfall | January, 1972 | WRDO |
| Groundwater observation wells | Khanapur | Monthly water level | 1986 | GWD, Karnataka |
| | Gunji | Monthly water level | 1986 | |
| | Desur | Monthly water level | 1986 | |

### 2.1.3 Basin Characteristics

A brief description of the Malaprabha representative basin characteristics, i.e., geology, soils, land use pattern and geomorphological parameters are given below.

**Geology**

Geologically the Malaprabha representative basin comprises of two main geological formations (i) Tertiary basalts, (ii) Sedimentary Formations of Pre-Cambrian age (Table 3).

**(i) Tertiary Basalts**

As shown in figure 3, a major parts (96%) of the representative basin is covered by Tertiary basalts. The hydrology of basalt is different from that other type of hard rocks. One of the main differences is that the various basalt flow units can form a multi-aquifer system some what similar to a sedimentary rock sequence, having alternate pervious and impervious horizons.

**(ii) Sedimentary Rocks**

The sedimentary formation is of Pre-Cambrian age. This type of rocks are confined in the south eastern part of the study area. Sedimentary rock generally acts as a good aquifer if it is not interrupted by intertrappean clays and other impermeable rocks.

**Soils**

Pedagogically speaking, the basin rocks are covered by thin (0.5 m) to thick (10 m) layer of soils, which are divisible into two major groups (Figure 4). These are red loamy soils and medium black soils (Table 4).

**(i) Red Loamy Soils**

The upper reaches of the basin, i.e., on crest and gently sloping mid-crest regions, viz., pediplains are characterized by red loamy soils. The top soil texture varies between sandy loam to clay loam underlain by gravel and sandy loam, sub-soil horizon, About 80 % area of the Malaprabha representative basin is covered by red loamy soils.

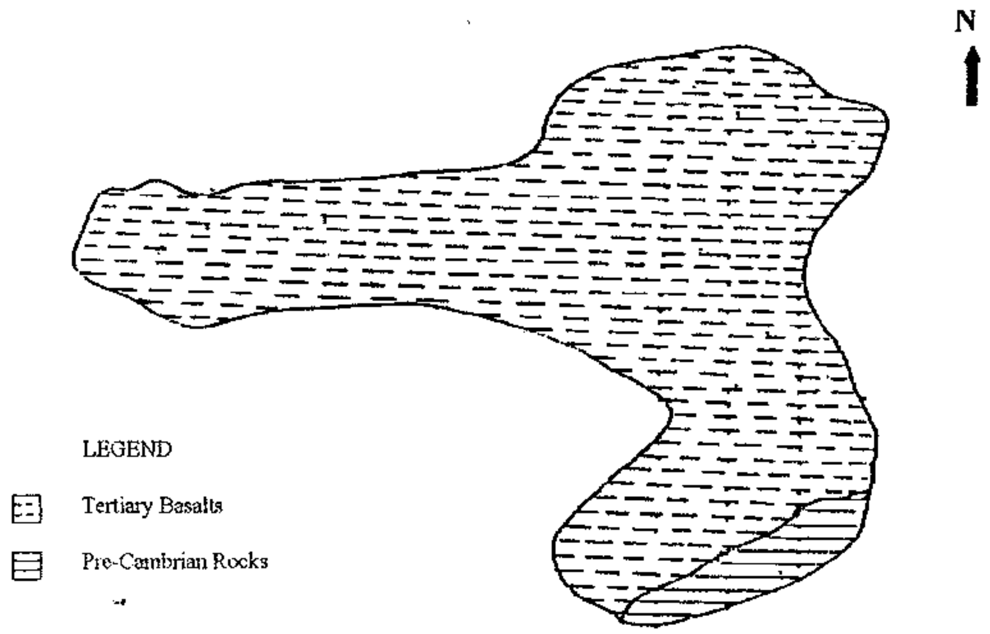


**Figure 3. Geological Map of the Malaprabha Representative Basin**

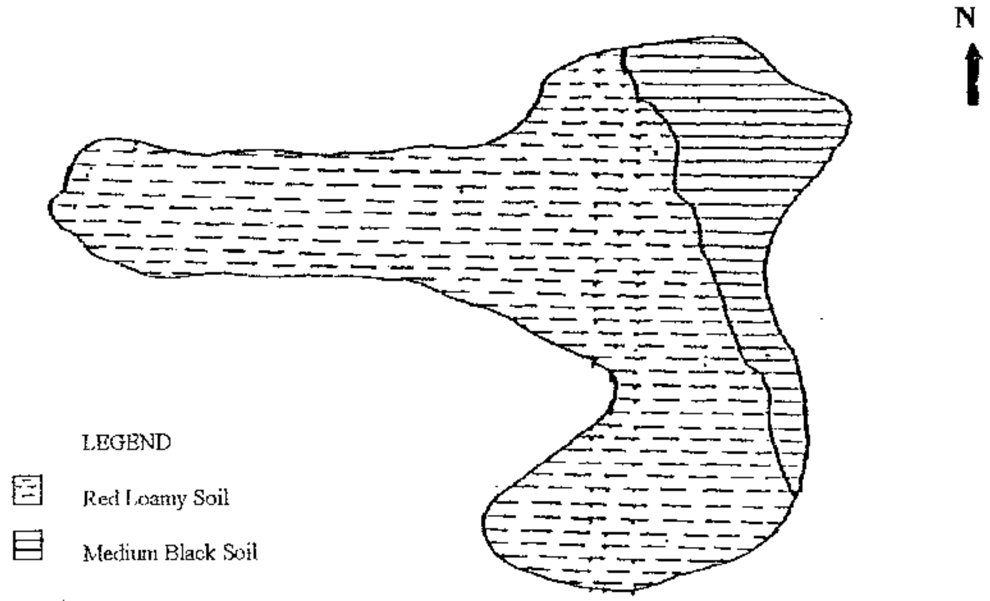


**Figure 4. Soil Types in the Malaprabha Representative Basin**

**(ii) Medium Black Soils**

This type of soils occur extensively in parts of Khanapur taluk. Soils are moderately depth to very dark greyish brown, dark reddish brown or black in colour, usually calcareous cracking and clayey. These are moderately well drained with low permeability.

**Landuse Pattern**

Land use pattern of the Malaprabha representative basin is very complex comprising of forest, agriculture, shrubs and barren land (Figure 5). Area under different category of land is presented in table 5. A brief description of the different land use based on IRS-1A-LISS-II imageries and subsequent field check is presented below.

**(I) Forests**

About 62.65 per cent of the Malaprabha representative basin in Kankumbi, Jamboti and Gunji areas are covered by dry tropical forests. The major species are covered by teak wood, rosewood, jack wood, Bamboo etc. The ground of these forest is covered by shrubs (2-4 m high) and grasses.

**(ii) Shrubs**

The eastern facing watersheds of the area having steep slope (20-30) are covered by shrubs and small trees and bushes (3-5 m high). The most important feature of this class of land is that these are relatively shallow soil areas. About 19.3 % area of the basin is covered by shrubs.

**(iii) Agriculture Land**

The gentle slopes and level valley bottom areas, where the most fertile soil is confined, have been occupied by man for the cultivation of various cereal (paddy, ragi etc.) and cash crops (cotton, sugarcane). About 16.85 % of the total basin area falls under agricultural land.

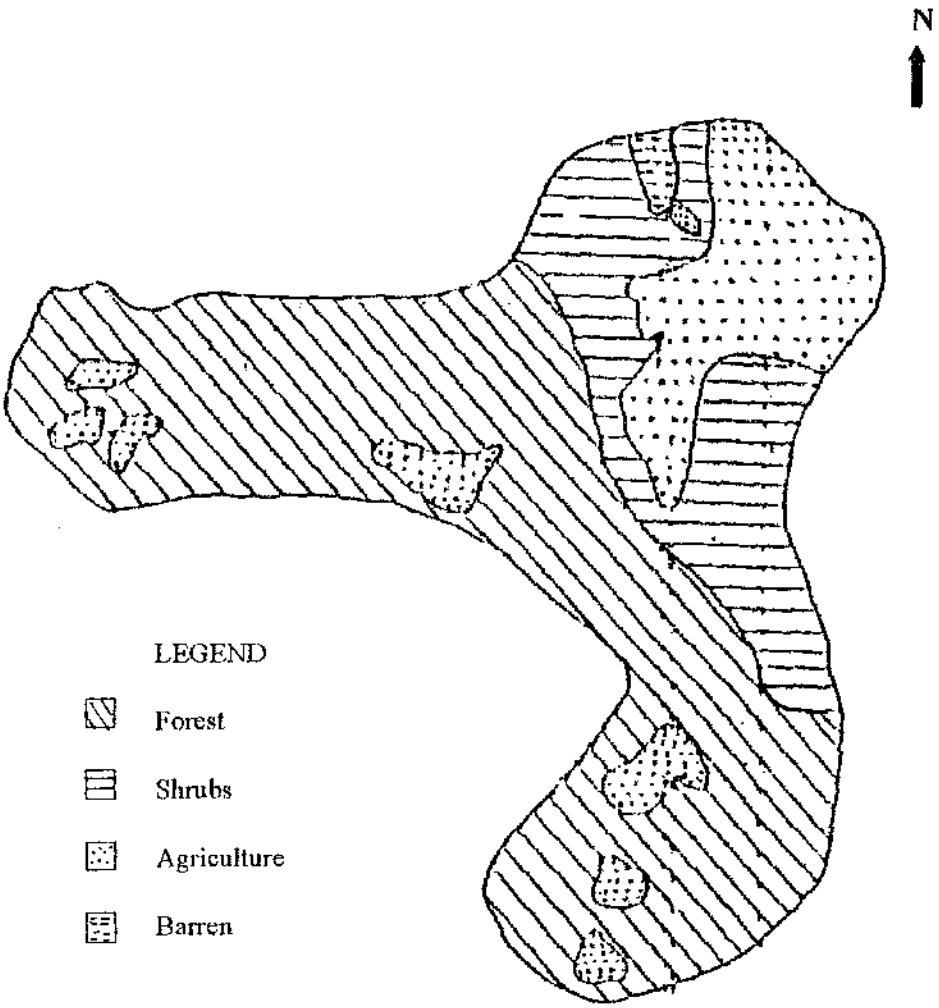


**Figure 5. Land use Pattern in the Malaprabha Representative Basin**

(iv) Barren Land

About 1.15 % of the area is in the form of small patches, on steep slopes and on the gentle slopes having very thin film of soil, is in the form of barren land. This land is used for the grazing purpose of cattles.

**Table 3. Distribution of area under different rock formations in the Malaprabha representative basin upto Khanapur**

| Rock Formation | Area in sq. km | Area in % |
|---|---|---|
| 1. Tertiary Basalts | 518.4 | 96 % |
| 2. Sedimentary Rocks | 21.6 | 4 % |
| | 540.00 | 100 % |

**Table 4. Distribution of area under different soil groups in the Malaprabha Representative Basin upto Khanapur**

| **Soil Groups** | **Area in sq. km** | **Area in %** |
|---|---|---|
| 1. Red loamy soil | 432.0 | 80.0 |
| 2. Medium Black soil | 108.0 | 20.0 |
| **Total** | **540.00** | **100.00** |

**Table 5. Distribution of area under different land use type in the Malaprabha Representative Basin upto Khanapur**

| **Sl. No.** | **Land Use Type** | **Area in sq. km** | **Area in %** |
|---|---|---|---|
| 1. | Forests | 338.58 | 62.65 |
| 2. | Shrubs | 104.22 | 19.35 |
| 3. | Agriculture | 90.99 | 16.85 |
| 4. | Barren | 6.21 | 1.15 |
| | **Total** | **540.0** | **100.00** |

## Geomorphology

### i) Morphology regions

The relief of the Malaprabha representative basin varies between 668 and 1038 m from the mean seal level. The contour map (Figure 6) depicts the morphological characteristics. The pattern closely spaced contours on the water divides indicates that the cress and mid-crest have convexo-concave slope, and the widely spaced contours in the valley bottom indicate gentle and flat valley bottoms. Thus, the basin is divisible into three distinct morphological zones.

These are

i) Convex hill summit (more than 900m)

ii) Concave and gentle mid-crest and (800 - 900 m)

iii) Flat valley bottom (less than 800 m)

This change in morphological character from hill crest to valley bottom of the basin is largely responsible in the change in behavior of water flow between hillslope and foot slope. Further detailed geomorphological studies are required to understand the change in behavior of the hydrological processes form hill slope to foot slope.

The 800m contour line divides the area into the hillslope. Above this contour line there is convexo-concave hillslope which has completely erosional environment. This is the zone of maximum overland flow and the minimum infiltration. The area below the 800 m contour line encompassing an area of 86.5 % of the total basin, the gentle and flat slope has depositional environment. This is the maximum recharge zone of the basin as is made up of colluvial materials.

### ii) Altitudinal zone

The entire basin is divisible into as many as six altitudinal zones ranging from less than 700 m to more than 100 m. The spatial distribution of these altitudinal zones is depicted in figure 7. Table 6 contains that a large part, i.e., 86.5 of the basin area falls under less than 800 m relief group and a small part falls under more than 1000 m. Area under other altitudinal zones, i.e., between 800 m and 900 m and 900 m to 1000 m stands at 12 % and 1.5 % . respectively.

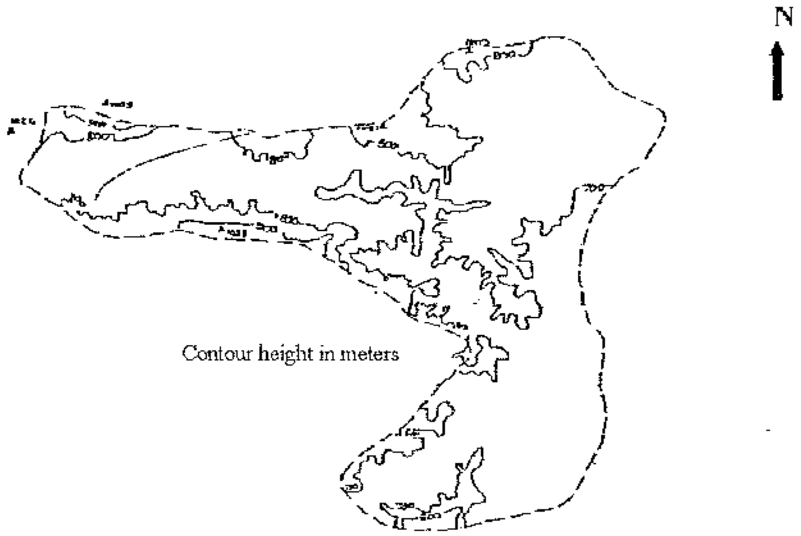


**Figure 6. Contour Map of the Malaprabha Representative Basin**

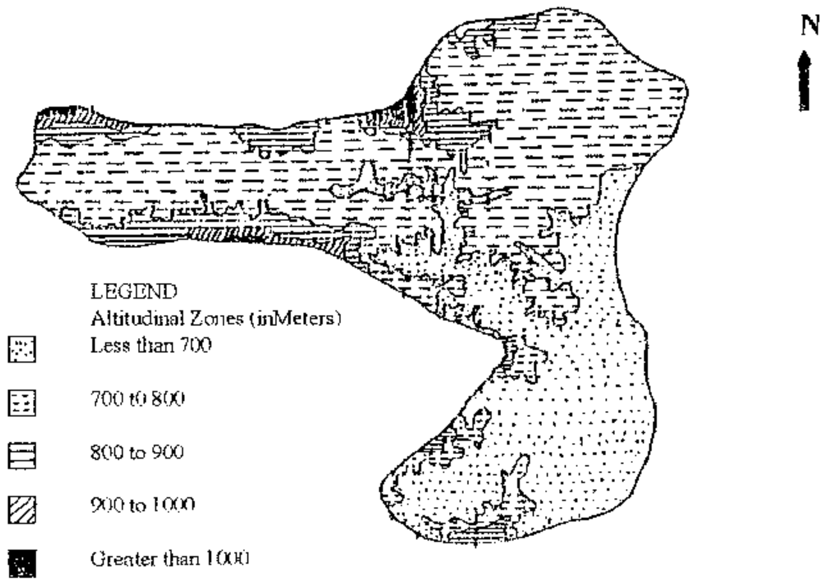


**Figure 7. Altitudinal Zonesof the Malaprabha Representative Basin**

**iii) Hypsometric Analysis**

Relationship of horizontal cross-sectional basin area was obtained and the Hypsometric curve (Strahler, 1952) for the Malaprabha representative basin was developed (Figure 8). The Hypsometric curve indicate that the Malaprabha representative basin is passing through mature stage of geomorphic development.

**iv) Drainage Density**

The drainage density based on topographic map varies between less than 0.5 km/sq. km on flat low lying depositional areas and more than 2.5 km/sq.km on covex hill crests in southern part of the basin, composed of relatively less resistant rocks of Pre-Cambrian age. The drainage network and the spatial distribution of different drainage density regions (Table 7) of the Malaprabha representative basin are depicted in figure 9 and figure 10.

**v) Stream ordering**

As per Horton (1932) stream hierarchy modified by Strahler (1952) , there are as many as 784 first order, 198 second order, 50 third order, 8 fourth order and 2 fifrfth order streams are there in the Malaprabha representative basin (Table 8).

**vi) Stream Length**

The total length of the drainage network of Malaprabha stands at 1186.03 km. The distribution of this total length under different stream order segment is presented in the table 8, which reveals that a large part of stream length (82.7 %) is covered by the first and second order streams and a small part (4.3 %) by the large streams, i.e., fifth (.4.01 %) and sixth order stream (0.2 %). The remaining part is covered by medium size streams, i.e., third (8.2 %) and fourth (4.9 %) order streams.

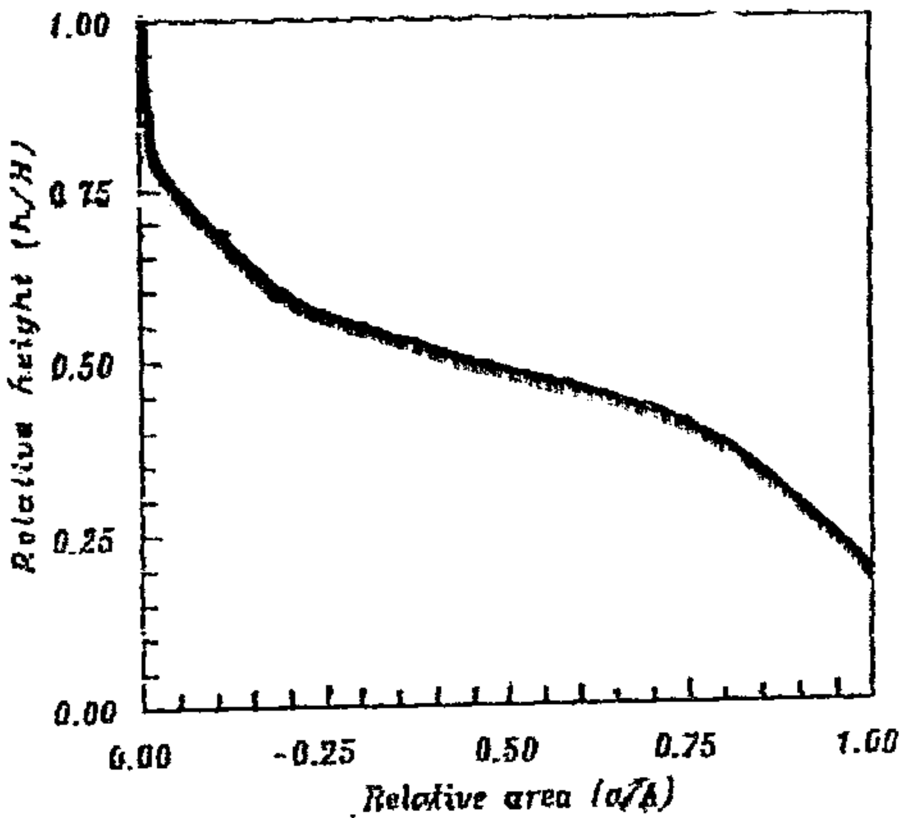


Figure 8. Hypsometric Curve of Malaprabha Representative Basin

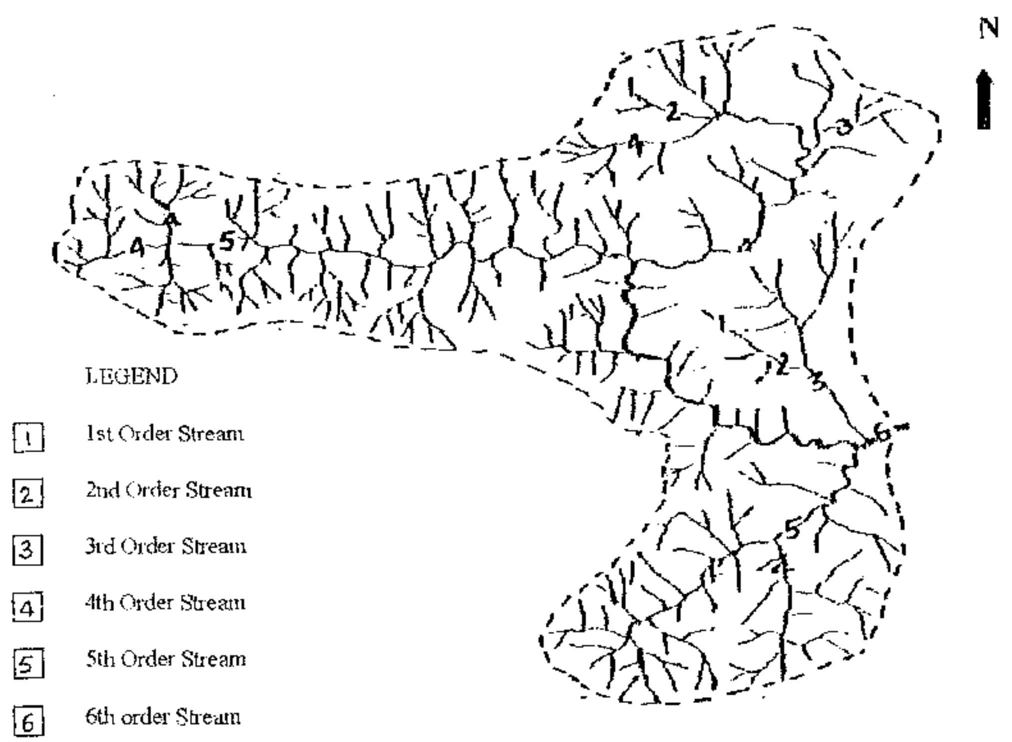


**Figure 9. Drainage Network of the Malaprabha Representative Basin**

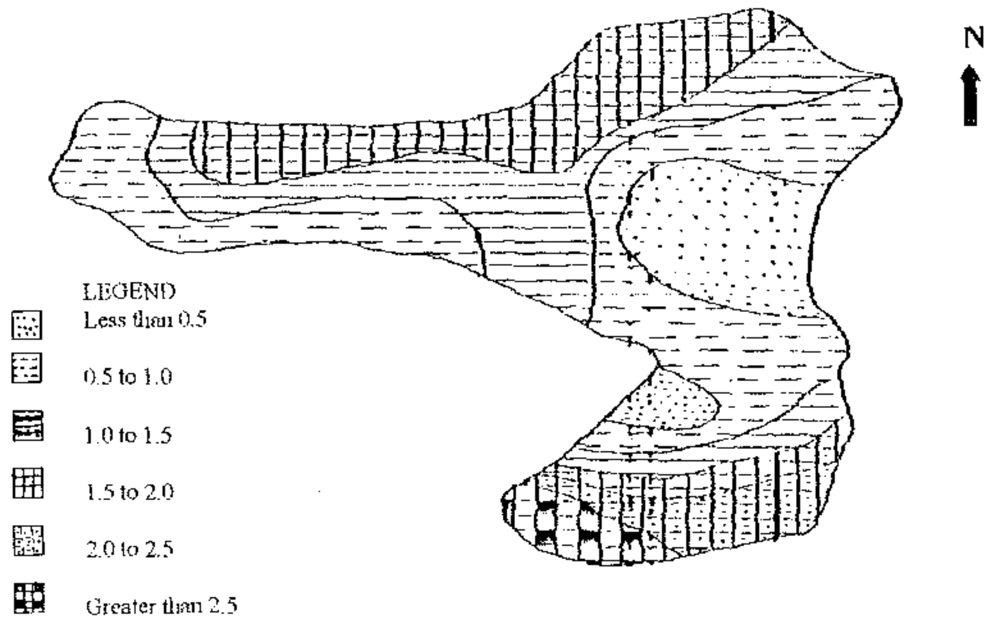


**Figure 10. Drainage Density in the Malaprabha Representative Basin**

**Table 6. Distribution of Area under different altitudinal zones of the Malaprabha representative basin**

| Sl No | Altitudinal zones in m | Area in sq. km | Area in % |
|---|---|---|---|
| 1 | < 700 | 216.00 | 40.0 |
| 2 | 700 – 800 | 251.10 | 46.5 |
| 3 | 800 – 900 | 64.80 | 12.0 |
| 4 | 900 – 1000 | 8.10 | 1.50 |

**Table 7. Area under different drainage density groups in the Malaprabha representative basin**

| Sl. No. | Drainage density groups km/sq.km) | Area in sq. km | Area in % |
|---|---|---|---|
| 1 | Less than 0.5 | 65.88 | 12.0 |
| 2 | 0.5 - 1.0 | 184.68 | 34.2 |
| 3 | 1.0 - 1.5 | 105.30 | 19.5 |
| 4 | 1.5 - 2.0 | 122.04 | 22.6 |
| 5 | 2.0 - 2.5 | 38.88 | 7.2 |
| **6** | **Greater than 2.5** | **23.22** | **4.3** |

**Table 8. Drainage morphometry of the Malaprabha representative basin**

| Stream order | No. streams | Bifurcation ratio | T.S.L* | M.S.L** | S.L.R*** |
|---|---|---|---|---|---|
| 1 | 784 | 3.96 | 651.16 | 0.83 | - |
| 2 | 198 | 3.96 | 329.3 | 1.66 | 2.0 |
| 3 | 50 | 6.25 | 97.46 | 1.95 | 1.17 |
| 4 | 8 | 4.0 | 58.14 | 7.27 | 3.73 |
| 5 | 2 | 2.0 | 47.62 | 23.81 | 3.27 |
| 6 | 1 | - | 2.35 | 2.35 | 0.10 |

* T.S.L - Total stream length in km  ** M.S.L - Mean Stream Length in km  *** S.L.R.- Stream Length Ratio

## Basin Input Parameters

A brief account of the basin input parameters i.e. temperature, rainfall and humidity is presented below.

## Air temperature

Table 9 contains the average 5 years (1987-1992) monthly temperature recorded at Santibastwad in the Malaprabha representative basin. On the basis of these data following salient characteristics of the air temperature may be deduced.

The maximum temperature in the Malaprabha representative basin varies between 35.0 $^{0}$C in the month of April and 26.0 $^{0}$C in the month of January. The average annual temperature stands at 24.4 $^{0}$C, which varies in between 35$^{0}$C and 14.6$^{0}$C. April is the hottest month and January is the coldest month in the year.

**Table 9. Monthly average maximum and minimum temperature observed at Santibastwad (1987-1992) in the Malaprabha Representative Basin**

| Sl. No. | Months | Temperature ($^{0}$C) | |
|---|---|---|---|
| | | Maximum | Minimum |
| 1 | January | 28.5 | 14.6 |
| 2 | February | 31.0 | 15.7 |
| 3 | March | 32.6 | 18.9 |
| 4 | April | 35.0 | 21.0 |
| 5 | May | 34.5 | 21.5 |
| 6 | June | 28.7 | 21.0 |
| 7 | July | 26.0 | 20.8 |
| 8 | August | 26.0 | 20.7 |
| 9 | September | 27.6 | 21.0 |
| 10 | October | 29.0 | 20.6 |
| 11 | November | 28.5 | 18.1 |
| 12 | December | 27.4 | 16.3 |
| | Annual Mean | 29.6 | 19.2 |

**Rainfall**

Table 10 contains the average monthly rainfall data recorded at different localities of the Malaprabha representative basin.

**Table 10. Average Monthly rainfall at 3 different stations in the Malaprabha Representative Basin (Years- 1979-1992)**

| Sl. No. | Months | Rainfall in (mm) | | | |
|---|---|---|---|---|---|
| | | Stations | | | |
| | | Khanapur | Kankumbhi | Jamboti | Average |
| 1 | June | 367.9 | 1363.4 | 415.3 | 715.5 |
| 2 | July | 616.2 | 2115.9 | 898.3 | 1210.1 |
| 3 | August | 412.8 | 1709.2 | 598.4 | 904.8 |
| 4 | September | 127.7 | 439.4 | 198.0 | 251.0 |
| 5 | October | 69.1 | 175.7 | 65.5 | 44.4 |
| 6 | November | 44.4 | 45.4 | 39.7 | 43.2 |
| 7 | December | 4.5 | 0.0 | 0.0 | 1.6 |
| 8 | January | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | February | 0.3 | 0.0 | 0.0 | 0.1 |
| 10 | March | 3.2 | 2.4 | 6.9 | 4.2 |
| 11 | April | 24.8 | 23.0 | 20.1 | 22.6 |
| 12 | May | 58.8 | 62.4 | 48.9 | 56.7 |
| | Average | 144.4 | 494.73 | 190.92 | 271.68 |

The mean annual rainfall of three different stations is 1113 mm. The average total annual rainfall for the catchment is high often exceeding 3300 mm. The rainfall is not evenly distributed throughout the year as well as throughout the basin. The basin receives maximum rain of 36.5% of the total annual rainfall in the month July and 27.3% of the rainfall during August, which is the second important month. About 21.6% of the rain is received during the early part of the southwest monsoon season i.e. in June (Table 11).

**Table 11. Monthly Budget of rainfall in the Malaprabha Representative Basin**

| Sl. No. | Months | Rainfall | |
|---|---|---|---|
| | | Rainfall in mm | % of the annual rainfall |
| 1 | June | 715.5 | 21.6 |
| 2 | July | 1210.1 | 36.5 |
| 3 | August | 904.8 | 27.3 |
| 4 | September | 251.0 | 7.7 |
| 5 | October | 44.4 | 3.1 |
| 6 | November | 43.2 | 1.3 |
| 7 | December | 1.6 | 0.05 |
| 8 | January | 0.0 | 0.0 |
| 9 | February | 0.1 | 0.03 |
| 10 | March | 4.2 | 0.12 |
| 11 | April | 22.6 | 0.70 |
| 12 | May | 56.7 | 1.70 |

**Humidity**

The mean relative humidity is high during the south west monsoon season and comparatively low during the non-monsoon period. In summer, the weather is dry and the humidity is low (Table 12).

**Table 12. Relative Humidity observed at Santibastwad in the Malaprabha Representative Basin**

| Sl.No. | Months | Average Relative Humidity (1987- 1992) |
|---|---|---|
| 1 | January | 84 |
| 2 | February | 88 |
| 3 | March | 91 |
| 4 | April | 90 |
| 5 | May | 91 |
| 6 | June | 91 |
| 7 | July | 92 |
| 8 | August | 92 |
| 9 | September | 91 |
| 10 | October | 92 |
| 11 | November | 90 |
| 12 | December | 88 |
| | Average | 90 |

## Basin Responses or Outputs

Among various basin response parameters of basin observations are available only for water discharge (1971-92) and sediment flow (1987-88) recorded by WRDO. A brief account of these parameters is given below.

## Water Discharge

Table 13 contains the yearwise per day monthly water discharge of the Malaprabha stream recorded at the mouth of the representative basin, viz., Khanapur, reveals that

i) Malaprabha is a rainfed stream.

ii) The stream flow is confined mainly to the rainy period.

iii) The stream has influent nature that is why it becomes dry during nonrainy season.

iv) The stream is not receiving water from its permanent ground water table throughout the basin area, hence it becomes dry during nonrainy season.

**Table 13. Monthly Water Discharge (Cumecs) At Khanapur In The Malaprabha Representative Basin**

| Years | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1979-80 | 743.9 | 1619.0 | 5831.9 | 632.2 | 247.9 | 236.2 | - | - | - | - | - | - |
| 1980-81 | 1616.4 | 6076.3 | 4580.7 | 816.0 | 105.6 | - | - | - | - | - | - | - |
| 1981-82 | 330.9 | 4259.5 | 4761.1 | 763.5 | 221.8 | 111.2 | 46.4 | 16.9 | 6.7 | - | - | - |
| 1982-83 | 615.5 | 3978.3 | 5805.1 | 764.2 | 236.0 | 124.3 | - | - | - | - | - | - |
| 1983-84 | 2075.2 | 3326.9 | 3727.8 | 938.6 | 272.6 | 87.6 | - | - | - | - | - | - |
| 1984-85 | 965.0 | 3929.3 | 2075.5 | 715.3 | 331.4 | - | - | - | - | - | - | - |
| 1985-86 | 555.3 | 1634.5 | 2854.0 | 320.2 | 611.9 | 100.1 | - | - | - | - | - | - |
| 1986-87 | 1093.8 | 2133.7 | 2818.8 | 274.9 | 120.4 | - | - | - | - | - | - | - |
| 1987-88 | 195.9 | 2252.3 | 1207.2 | 823.0 | 858.7 | 104.8 | - | - | - | - | - | - |
| 1988-89 | 171.7 | 3673.4 | 2204.2 | 1629.4 | 530.1 | 82.1 | - | - | - | - | - | - |
| 1989-90 | 1090.2 | 2036.6 | 1841.0 | 780.6 | 290.0 | 86.4 | 22.1 | - | - | - | - | - |
| 1990-91 | 350.7 | 3595.0 | 3229.4 | 1314.5 | 301.9 | 149.3 | 27.9 | - | - | - | - | - |
| 1991-92 | 582.6 | 3694.7 | 5028.4 | 1533.3 | 1013.0 | 159.2 | 24.2 | - | - | - | - | - |
| **Average** | **799.0** | **3246.9** | **3535.8** | **869.7** | **395.5** | **95.5** | **9.3** | **1.3** | **0.5** | - | - | - |

Hydrograph (Figure 11) based on 13 years data of the Malaprabha stream reveals the following salient characteristics.

i) June is the month of approaching segment of the water discharge.

ii) July is the month, which corresponds with rising segment graph.

iii) August is the month of peak water discharge.

iv) September is the month of gradual recession segment.

v) October is the month of rapid recession segment.

Table 14 contains the monthwise budget of water discharge from the Malaprabha representative basin. It reveals that,

i) The water generating capacity of land to channels approaches upto 6.5 cumecs/sq.km./day in the month of August and drops almost zero in the month of March, April, may.

ii) July is the second important month for which the water generating capacity of land to stream stands at 6 cumecs/sq.km./day.

iii) June and September are third important months when the water generating capacity of land to channel stand at 1.5 and 1.6 cum/sq.km/day respectively.

iv) In the months of October, November, December, January and February, this capacity stands at0.73, 0.17,0.01, 0.002 and 0.0009 cumec/sq.km./day respectively.

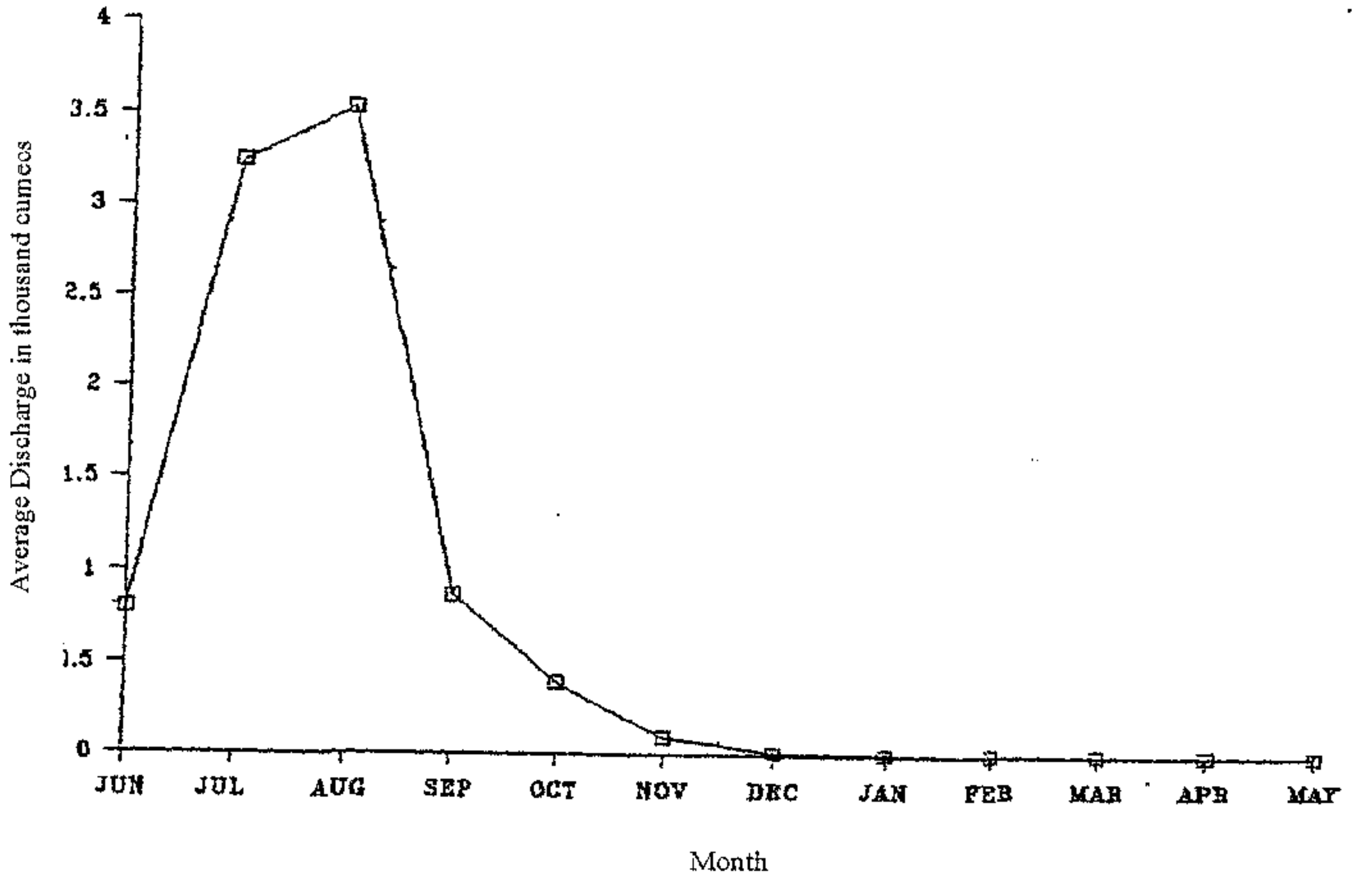


**Figure 11. Hydrograph of the Malaprabha Representative Basin recorded at Khanapur (1979-1992)**

**Table 14. Monthly Budget of Water Discharge (%) in the Malaprabha Representative Basin (Recorded at Khanapur)**

| Sl. No. | Months | Average monthly water discharge | % contribution (Monthwise) |
|---|---|---|---|
| 1 | June | 799.0 | 8.9 |
| 2 | July | 3247.0 | 36.3 |
| 3 | August | 3535.8 | 39.5 |
| 4 | September | 869.7 | 9.7 |
| 5 | October | 395.5 | 4.4 |
| 6 | November | 95.5 | 1.07 |
| 7 | December | 9.3 | 0.10 |
| 8 | January | 1.3 | 0.02 |
| 9 | February | 0.5 | 0.006 |
| 10 | March | - | - |
| 11 | April | - | - |
| 12 | May | - | - |

**Sediment Flow**

Sediment flow recorded at Khanapur reveals the following salient characteristics

i) In Malaprabha channels erosion occurs during the months of June to October.

ii) In other months of the year the channel erosion is negligible or approaches zero.

Monthly budget of the sediment flow from the Malaprabha representative basin which reveals the following facts

i) About 53.05% of the total annual sediment flow and equivalent to a flow of 826.9 metric tonnes/day flows in a single month of the year i.e. July. The sediment flow rate approaches upto 4130 metric tonnes/day and drops to 86 metric tonnes/day in this month.

ii) August, September and October are other important months when 12.67 %, 11.06% and 20.02% respectively of the total annual sediment is discharged from the basin.

The Malaprabha drainage network have a capacity to ganerate about 48.32 metrictonnes of annual sediment load at the average rate of 132.4 metric tonnes/sq.km./day. Using the value of total annual sediment yield of the basin (i.e. 48.32 metric tonnes), the rate of erosion may be extrapolated by using the following formulae as

Rate of Denudation = (Total Load / Area (sq. km.))*Specific gravity
(mm/thousand yrs)

Using above formulae, it can be extrapolated that the rate of erosion in the Malaprabha representative basin stands at 0.026 mm/year.

## 2.2 Ghataprabha Representative Basin

### 2.2.1 Location

The study area of Ghataprabha representative is considered upto Daddi, which is the first gauge-di-scharge site on the stream. The catchment area of the sub basin lies between latitude $15^0 50'$ and $16^0 40'$ and longitude $74^0 08'$ and $74^0 30'$. A dam is constructed at Hidkal (which is about 20 to 25 kms from Daddi) in Hukkeri taluk. A road connecting Belgaum - Vengurla passes through the catchment. The government has planned for irrigation to an extent of about 10 lakh acres to augment food production. The total command area of the reservoir is 3,17,430 hectares.

### 2.2.2 Hydrometeorological Network

Various hydrological Parameters like rainfall, temperature, evaporation, relative humidity, wind velocity, vapour pressure, soil temperature and soil Moisture are observed at hydrometeorological observatories. There are two hydrometeorological stations within the representative basin, i.e. one at Halkarni, maintained by NIH and one at Tarewadi maintained by Irrigation department, Maharashtra (Table 15). Hydrometeorological stations and hydrological stations are shown in figure 12. There are six raingauge stations maintained by State and Central Organisations. There is a G and D site in Daddi maintained by Central Water Commission. The discharge data are computed on the basis of current meter reading taken at 0.6 times the depth of flow from the water surface.

### 2.2.3 Basin Characteristics

A brief description of the Malaprabha representative basin characteristics, i.e., geology, soils, land use pattern and geomorphological parameters are given below.

#### Geology

The geological formations met within the representative basin are i) Deccan trap of tertiary age, and ii) Sedimentary formations known as "Kaladagi group" comprising lime stone, shale and quartzite (Figure 13 and Table 16).

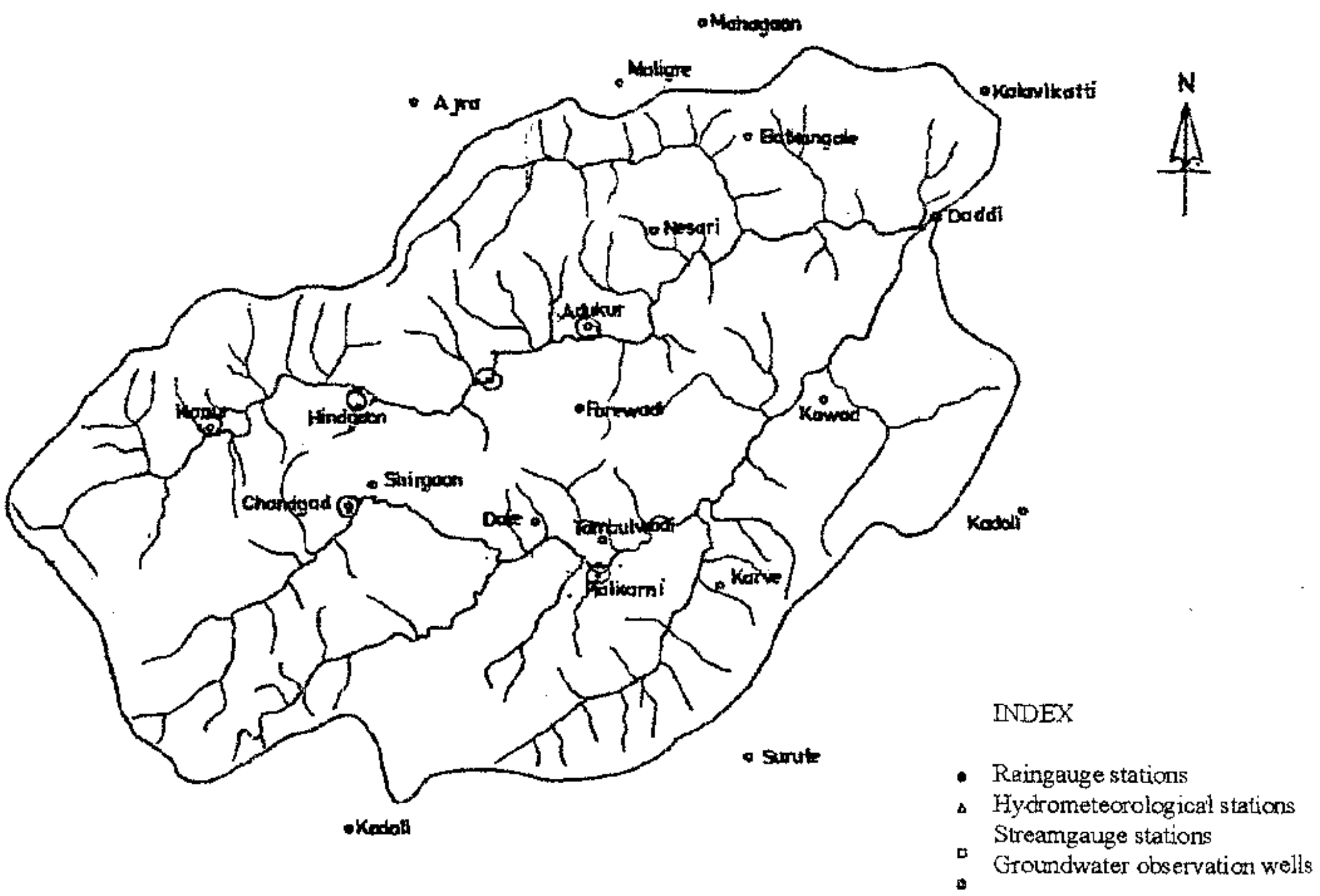


**Figure12. Hydrometeorological Network in the Ghataprabha Representative Basin**

**Table 15. Details of stations in the Ghataprabha representative basin**

| Type of stations | Location | Parameters | Data recording since | Maintained by |
|---|---|---|---|---|
| Streamgauge station | Daddi | Water discharge | Dec., 1978 | CWC |
| Hydrometeorological station | Halkarni | Rainfall | June, 1989 | NIH |
| | | Max. temp | July, 1989 | NIH |
| | | Min. temp. | Jan., 1990 | NIH |
| | | Evaporation | Nov., 1989 | NIH |
| | | Wind velocity | July, 1989 | NIH |
| | | Wind direction | July, 1989 | NIH |
| | | Humidity | July, 1989 | NIH |
| | | Soil temp. | April, 1991 | NIH |
| Raingauge stations | Chandgad | Rainfall | August, 1990 | NIH |
| | Nesari | -do- | Sept., 1990 | NIH |
| | Mahagaon | -do- | June, 1990 | NIH |
| | Daddi | -do- | Jan., 1975 | WRDO |

**Soil**

**i) Lateritic soils**

Lateritic soils includes both coarse shallow and medium deep soil (Figure 14 and Table 17). These soils.are found on undulating, rolling plain and gently slopping topography occupying areas in parts of Kolhapur district coming under the dry agro-climatic region.

**ii) Coarse shallow black soils**

These type of soils are found on undulating ridges in the Deccan hard rock region. These type of soils are widely distributed in north and eastern part of the representative basin

**Land use**

Land use is an important aspect for determining the various hydrological phenomena like infiltration, overland flow, evaporation and interception etc. Land use pattern has a significant influence on the quality and quantity of runoff available from it. The spatial distribution of' landuse in Ghataprabha representative basin is shown in figure 15, which reveals that there are four different types of land uses in the Ghataprabha representative basin (Table 18). These are

i) Agricultural land

ii) Barren/Fallow land

iii) Shrubs

iv) Forests

**i) Agriculture land**

Agriculture land covers about 42.15 % of the total catchment. Generally the type of land use is governed by social, and socioeconomic and characteristics of soil. Here except in the western part of the basin other parts are known for agricultural production.

**ii) Barren/'Fallow land**

A total of 8.3 % of the catchment, remains as barren/ fallow land. This is formed due to the lack of water supply either by rainfall or irrigation. Fallow can be brought under irrigation by providing small irrigation tanks or by exploring the groundwater available in the region.

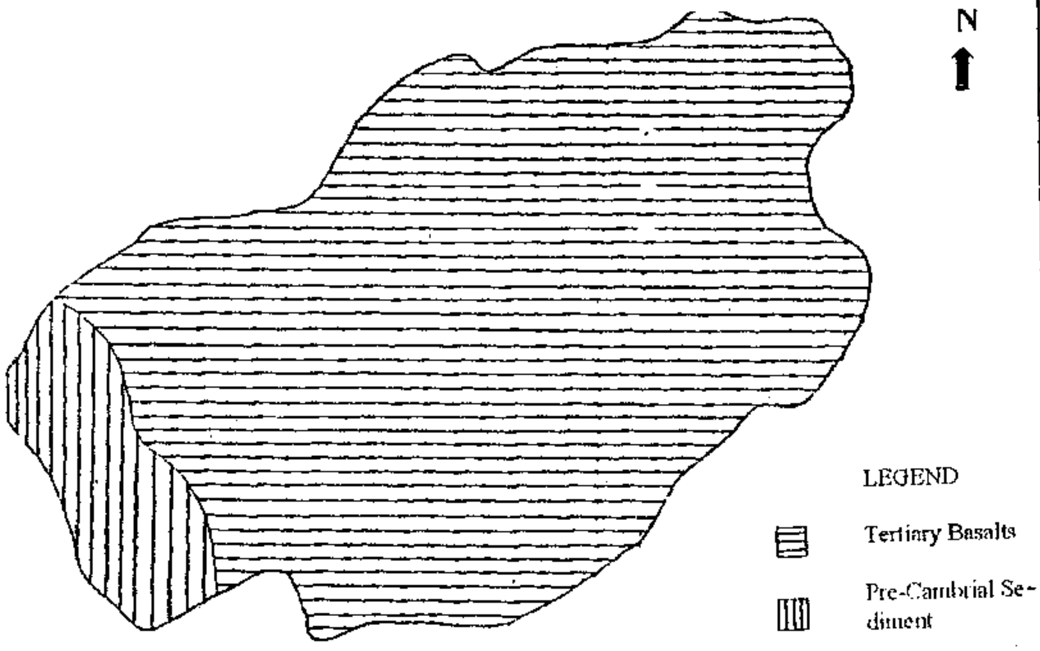


**Figure 13. Geological map of the Ghataprabha Representative Basin**

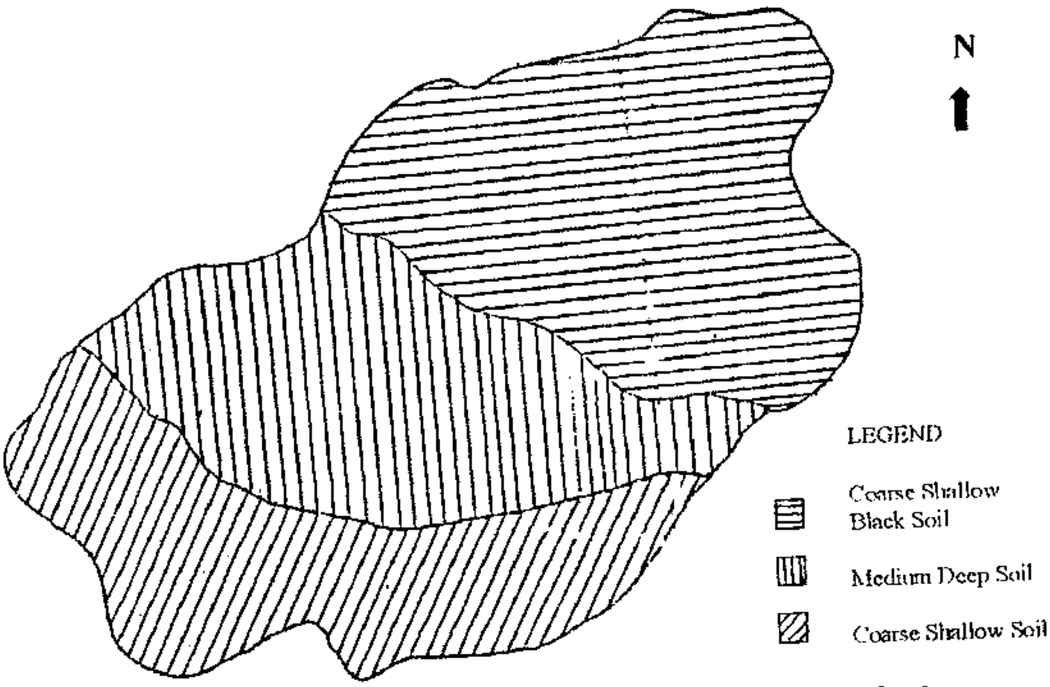


**Figure 14. Soil Types in the Ghataprabha Representative Basin**

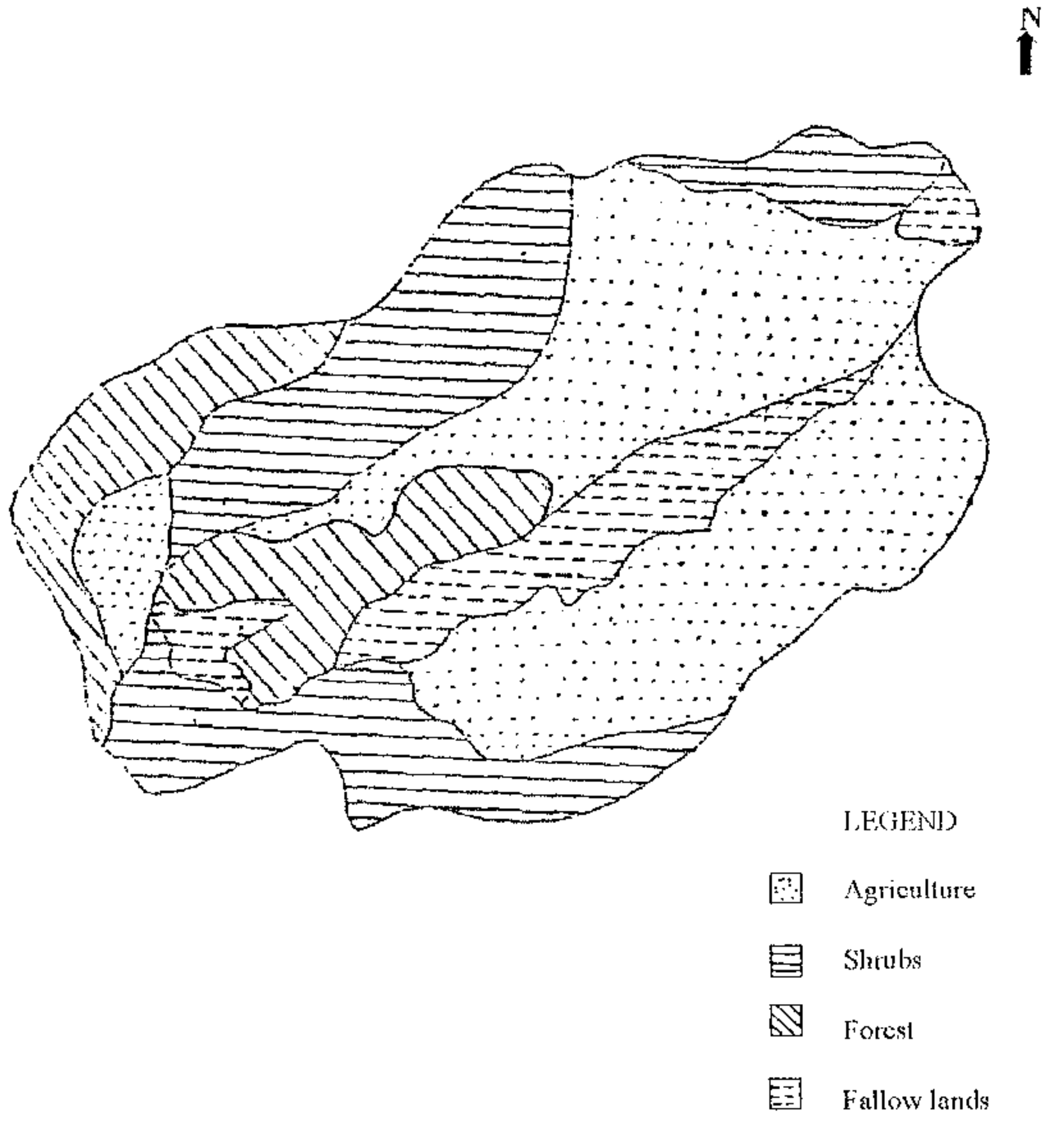


**Figure 15. Land Use Pattern in the Ghataprabha Representative Basin**

**Table 16. Distribution of area under different rock formations in the Ghataprabha representative basin upto Daddi**

| Rock Formation | Area in sq. km | Area in % |
|---|---|---|
| 1. Tertiary Basalts | 1023.34 | 97 % |
| 2. Pre-Cambrial Sediment | 31.65 | 3 % |
| | 1054.99 | 100 % |

**Table 17. Distribution of area under different soil groups in the Ghataprabha representative basin upto Daddi**

| Soil Groups | Area in sq. km | Area in % |
|---|---|---|
| 1. Coarse Shallow Black Soil | 422.99 | 40.0 |
| 2. Medium Deep Soil | 316.0 | 30.0 |
| 3. Coarse Shallow Soil | 316.0 | 30.0 |
| **Total** | **1054.99** | **100.00** |

**Table 18. Distribution of area under different land use type in the Ghataprabha representative basin upto Khanapur**

| Sl. No. | Land Use Type | Area in sq. km | Area in % |
|---|---|---|---|
| 1. | Forests | 145.79 | 13.80 |
| 2. | Shrubs | 376.67 | 35.75 |
| 3. | Agriculture | 444.78 | 42.15 |
| 4. | Barren | 87.75 | 8.30 |
| | **Total** | **1054.99** | **100.00** |

**iii) Shrubs**

Shrubs are widely distributed in Chandgad and Gadhinglaj talks and covers 35.75 % area of the basin. This class of land is used intensively through establishment of reseeded and high yielding pastures. Its most important features are relatively shallow soils with less than 30 % gravels and slopes not exceeding 25 - 30 %.

**iv) Forests**

The forest cover of the catchment is 13. 8 %. The wet deciduous forests occur in the west zone of the Kolhapur and Sindhudurg districts of Maharashtra. The main species in the forest are Teak wood, Rose wood, Jack fruit, trees, bamboo etc. Most of the notified forests have been degraded partially due to irregular rainfall and climatic aberrations

**Geomorphology**

**i) Morphological regions**

Geomorphologically the catchment is relatively flat and gently undulating with isolated hillocks intervened by valleys. The catchment is somewhat oval in shape. The, relief of the basin varies between 682 m and 1039 m. Very steep contours (Figure 16) are observed towards the western side of the representative basin. The high basin relief observed in the Ghataprabha catchment is an indication of the higher potential energy available to move water and sediment downstream regions, i.e. the region in and around Daddi. However, in the northern part of the basin they are not as steep as in the south and western part of the basin. This part (southwestern part) may easily be subjected to erosion due to its higher relief.

**ii) Altitudinal Zones**

The entire basin is divided into as many as 5 divisions ranging from < 700 to > 1000m. The spatial distribution of these zones are shown in figure 17 and table 19, which shows the percentage distribution of different altitudinal zones. It is found that a total of 686.3sq. km. (65.05%) area is lying within 700-800 m contour line. A small part of type catchment falls under higher altitudinal groups.

**iii) Hypsometric Analysis**

The Hypsometric analysis shows the various stages of geomorphological development. This is indicated in the figure 18 shows that Ghataprabha river has reached mature stage of development. The field studies carried out in this region also gives a clear-cut indication of its maturity.

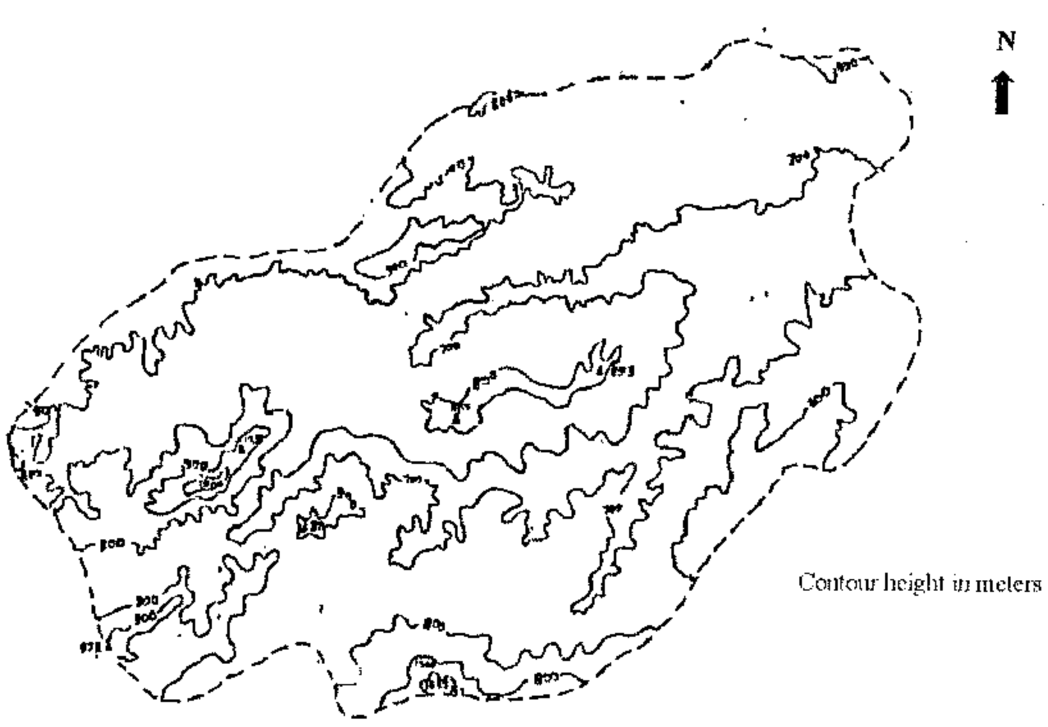


**Figure 16.Contour Map of the Ghataprabha Representative Basin**

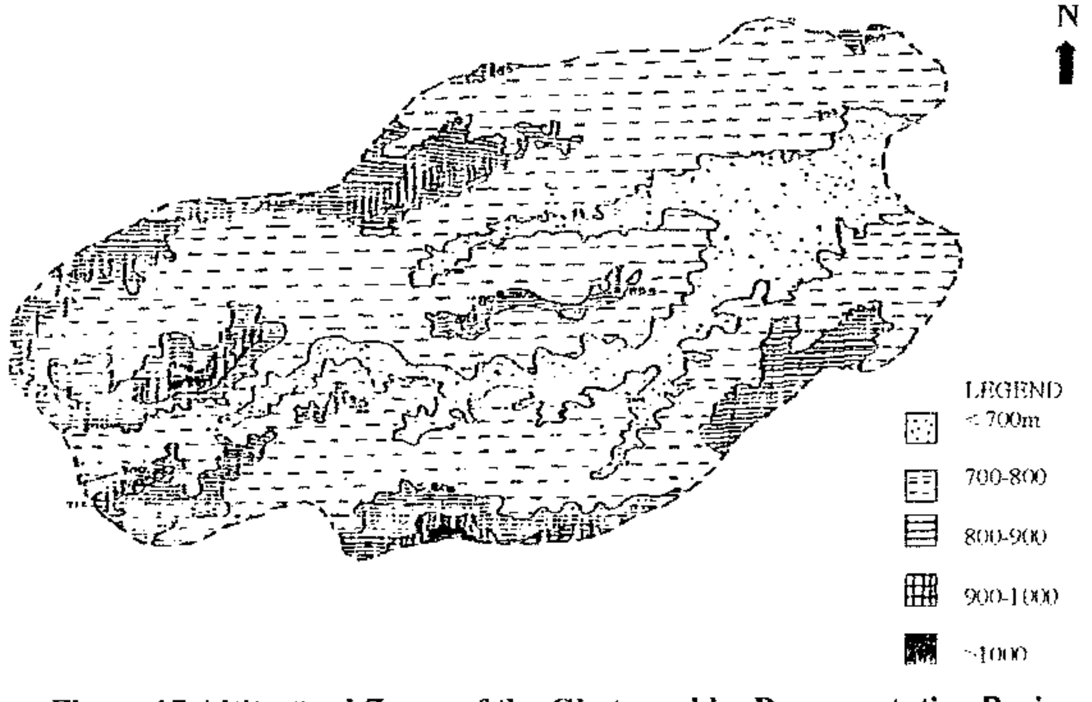


**Figure 17.Altitudinal Zones of the Ghataprabha Representative Basin**

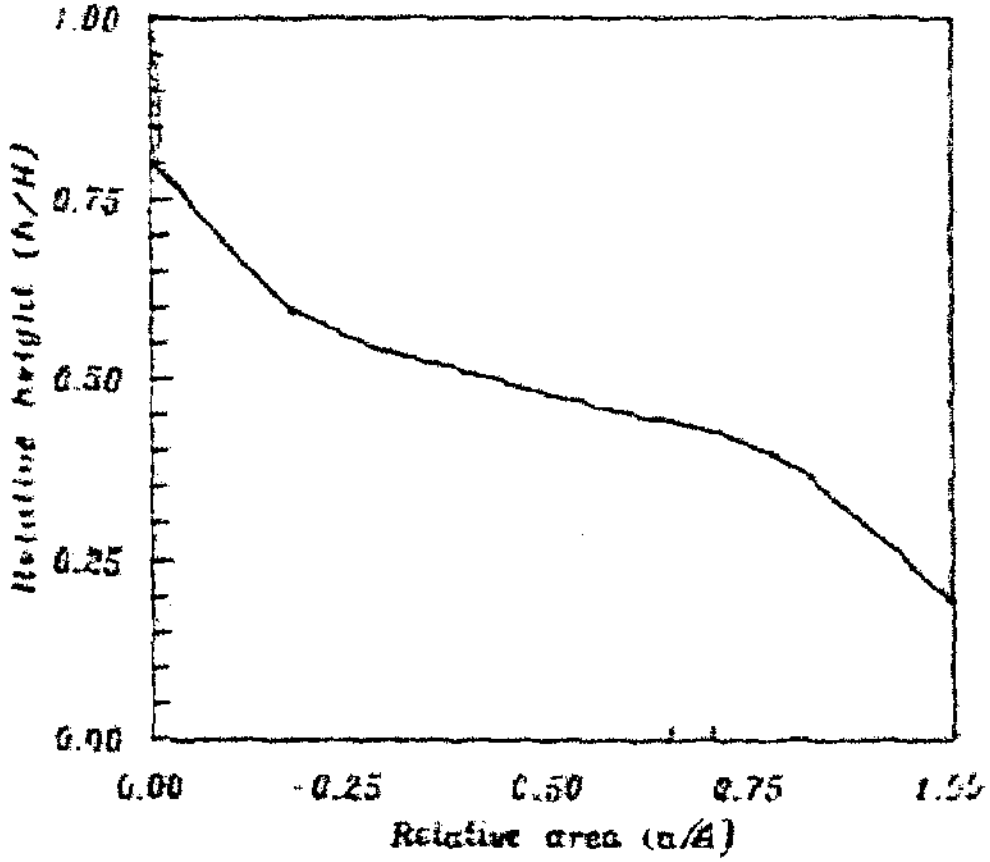


Figure 18. Hypsometric Curve of Ghataprabha Representative Basin

**iv) Drainage density**

Density of the drainage network varies widely between 0.5 km/sq. km. to 2.5 km/sq.km. It is observed that (Figure 19) the less resistant rocks confined in the western part of the catchment has higher values of drainage density than that of the flat areas in the central part. The areal distribution of various drainage density groups are given in table 20.

**v) Stream ordering**

Table 21 shows the various geomorphological parameters of the Ghataprabha representative basin. These are 1402 first order, 284 second order, 82 third order, 15 fourth order, 4 fifth order and one six order streams in the representative basin.

**vi) Stream Length**

The total stream length of Ghataprabha representative basin is 1102 km. Stream length covered by different order streams are given in table 18. As in the case of Malaprabha, here also a large part of the stream length is covered by first and second order stream, which is followed by third and fourth order streams. Only a very small percentage is covered by higher order stream (Table 21)

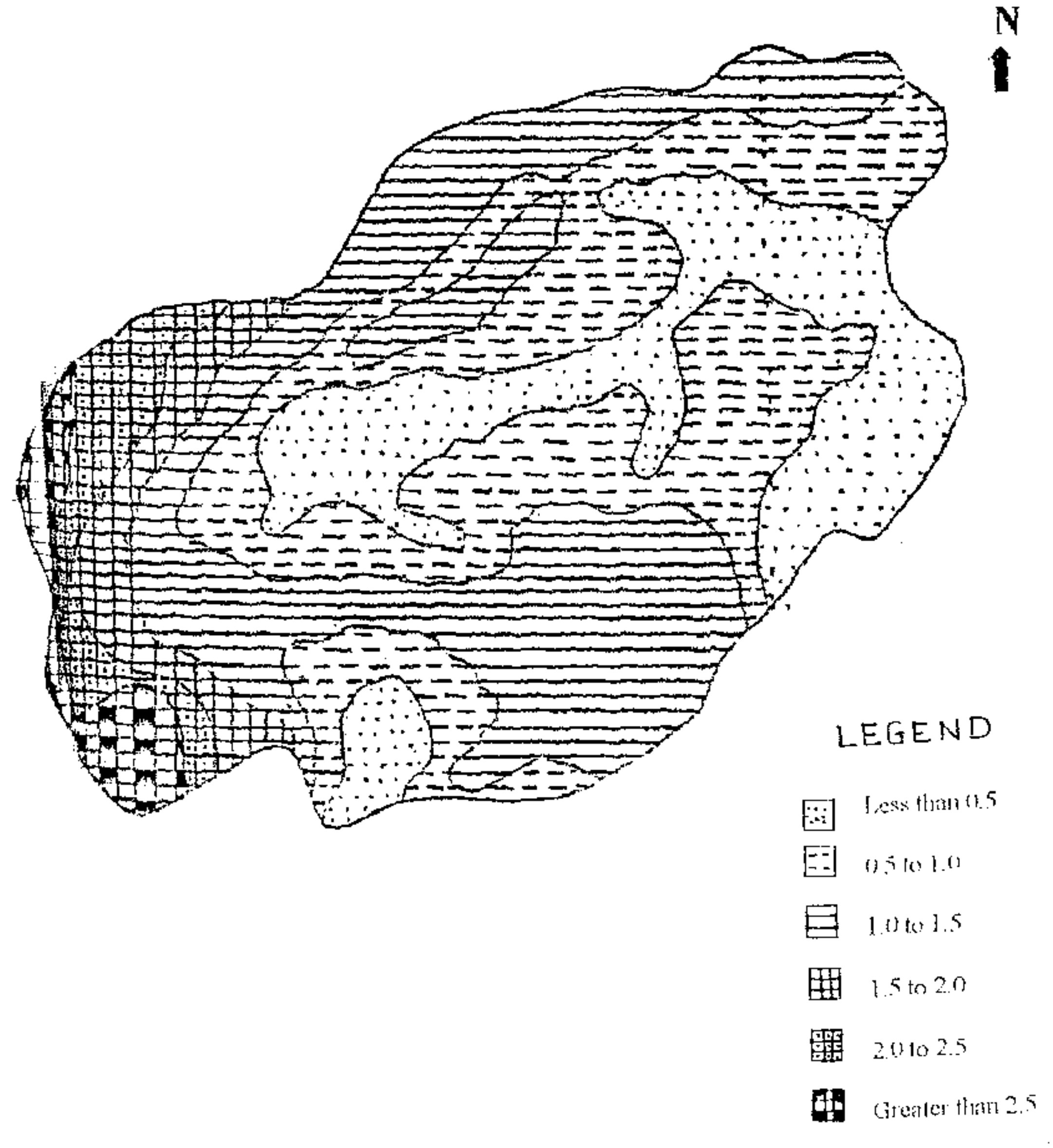


**Figure 19. Drainage Density in the Ghataprabha Representative Basin**

**Table 19. Distribution Of Area Under Different Altitudinal Zones Of The Ghataprabha Representative Basin**

| Sl. No. | Altitudinal Zones (in meters) | Area in sq. km. | Area in % |
|---|---|---|---|
| 1 | < 700 | 169.85 | 16.1 |
| 2 | 700-800 | 686.28 | 65.05 |
| 3 | 800-900 | 183.04 | 17.35 |
| 4 | 900-1000 | 14.24 | 1.35 |
| 5 | >1000 | 1.58 | 0.15 |

**Table 20. Area under different Drainage Density groups in the Ghataprabha Representative Basin**

| Sl. No. | Drainage density (Kms. /sq.km.) | Area in sq. km. | Area in % |
|---|---|---|---|
| 1 | <0.5 | 242.65 | 23.0 |
| 2 | 0.1- 1.0 | 316.50 | 30.0 |
| 3 | 1.0 -1.5 | 284.85 | 27.0 |
| 4 | 1.5- 2.0 | 82.30 | 7.8 |
| 5 | 2.0- 2.5 | 84.40 | 8.0 |
| 6 | >2.5 | 44.30 | 4.2 |

**Table 21. Geomorphological Parameters of the Ghataprabha Representative Basin**

| Sl. No. | Nos. of streams | Bifurcation Ratio | T.S.L.* | M.S.L.** | S.L.R.*** |
|---|---|---|---|---|---|
| 1 | 1402 | 4.9 | 753 | 0.54 | - |
| 2 | 284 | 3.5 | 293 | 1.03 | 1.9 |
| 3 | 82 | 5.5 | 152 | 1.85 | 1.79 |
| 4 | 15 | 3.7 | 81 | 5.40 | 2.91 |
| 5 | 4 | 4.0 | 86 | 21.50 | 3.98 |
| 6 | 1 | - | 37 | 37.0 | 1.72 |

*T.S.L.- Total stream length, **M.S.L.- Mean stream length

*** S. L.R.-Stream length ratio

**Basins Input Parameters**

The available basin input parameters of the Ghataprabha representative basin are presented below.

**Air temperature**

The data on temperature (average of three years) shows that April is the hottest month (34.4 $^0$C) and January is the coldest month 14 $^0$C (Table 22). The average maximum temperature in the catchment is 34.4$^0$C and average minimum temperature is 18.6$^0$C. With the onset of Monsoon there is an appreciable drop in the day temperature, but the nights are generally warm.

**Table 22. Monthly Average Maximum and Minimum Temperature Observed at Halkarni in the Ghataprabha Representative Basin**

| Sl No. | Months | Temperature Maximum (°C) | Temperature Minimum (°C) |
|---|---|---|---|
| 1 | January | 30.2 | 14.0 |
| 2 | February | 31.9 | 14.7 |
| 3 | March | 33.9 | 17.3 |
| 4 | April | 34.4 | 20.0 |
| 5 | May | 32.3 | 20.8 |
| 6 | June | 26.8 | 20.6 |
| 7 | July | 24.7 | 20.5 |
| 8 | August | 24.5 | 22.1 |
| 9 | September | 27.0 | 19.9 |
| 10 | October | 28.3 | 19.4 |
| 11 | November | 28.8 | 19.1 |
| 12 | December | 28.2 | 15.2 |
| | **Annual Mean** | **29.6** | **18.6** |

**Rainfall**

The average monthly rainfall in the Ghataprabha representative basin, at stations Chandgad, Halkarni and Daddi are given in table 23. It is observed that, the maximum rainfall occurred in the month of July (37.7% of the total rainfall) and minimum is observed during February (0.05 %) (Table 23), which is quite negligible. The average maximum rainfall is noted at Chandgad, 3011 mm and minimum is 885.7 mm recorded at Daddi.

**Table 23. Average Monthly Rainfall in the Ghataprabha Representative Basin Stations**

| Months | Chandgad | Halkarni | Daddi | Average |
|---|---|---|---|---|
| January | 509.0 | 463.1 | 180.9 | 384.3 |
| February | 1286.0 | 499.3 | 245.0 | 723.4 |
| March | 749.0 | 385.9 | 189.8 | 441.6 |
| April | 216.0 | 106.6 | 129.5 | 150.7 |
| May | 117.0 | 71.2 | 52.5 | 80.2 |
| June | 45.0 | 9.9 | 21.6 | 25.5 |
| July | 6.0 | 0.1 | 2.2 | 2.8 |
| August | 0.0 | 0.1 | 4.4 | 0.1 |
| September | 2.0 | 0.0 | 0.6 | 0.9 |
| October | 8.0 | | 13.8 | 7.3 |
| November | 40.0 | 19.9 | 20.1 | 26.7 |
| December | 93.0 | 74.4 | 48.1 | 71.8 |
| **Total** | **3011.0** | **1753.3** | **885.7** | **1916.7** |

### Humidity

The relative humidity is high during the southwest monsoon period and low during the non-monsoon period. In summer the weather is dry and the humidity is low. The maximum relative humidity is noticed in the month July and minimum in the month of March 953.7%). The average relative humidity from 1989-1992 is 71% observed at Halkarni observatory (Table 24).

### Wind Velocity

Maximum wind velocity is experienced during the month of July (15.3km/hr), (Table 25). During the south-west monsoon period, the wind blows mainly from south-west and west. In November and December, it experiences NE-easterly wind. South westernlies and westernlies appear in January and generally from February onward, the easterlies decrease in frequency. The average minimum wind speed is recorded in the month of October.

**Table 24. Monthly Average Relative Humidity data (1989-1992) of the Halkarni Observatory Located in the Ghataprabha Representative Basin**

| Sl.No. | Months | Relative Humidity |
|---|---|---|
| 1 | January | 57.8 |
| 2 | February | 53.7 |
| 3 | March | 57.5 |
| 4 | April | 63.6 |
| 5 | May | 71.6 |
| 6 | June | 83.1 |
| 7 | July | 85.6 |
| 8 | August | 84.7 |
| 9 | September | 80.7 |
| 10 | October | 75.9 |
| 11 | November | 68.3 |
| 12 | December | 69.2 |
| | Average | 71.0 |

**Table 25. Average monthly Wind Speed Observed at Halkarni Observatory**

| Sl.No. | Months | Wind Speed(km/hr) |
|---|---|---|
| 1 | January | 6.0 |
| 2 | February | 10.4 |
| 3 | March | 9.0 |
| 4 | April | 2.4 |
| 5 | May | 2.4 |
| 6 | June | 2.4 |
| 7 | July | 3.6 |
| 8 | August | 3.8 |
| 9 | September | 1.9 |
| 10 | October | 2.3 |
| 11 | November | 2.2 |
| 12 | December | 2.6 |

**Basin Output**

**Water Discharge**

Table 26 shows the monthly water discharge of the Ghataprabha river recorded at the month of the representative basin viz., Daddi.

i) The stream is rainfed stream

ii) The stream is influent in nature

iii) The base flow is negligible

Hydrograph (Figure 20) based on 10 years data of the Daddi site explains the following facts.

i) Discharge increases from June (8.9%) to August (39.5%) and decreases thereafter. From November onwards the discharge are negligible and March and April are seems to be the dry months. The percentage contribution of discharge is shown in table 27.

ii) The average discharge (1979-1989) is 23034.8 cumecs each year which approaches 30740.2 cumecs in 1980-1981 and dropped to 12341.22 cumecs in 1987-1988.

Water generating capacity of basin to its stream was calculated based on the water discharge data (Table 26) and presented in table 27. It shows that,

i) On an average the water generating capacity of the catchment to its stream is 2.96 cumecs/sq.km./day.

ii) The maximum water generating capacity is observed during July and August months and it recedes slowly and approaches to zero during February, March and April months. The corresponding values are shown in table 27.

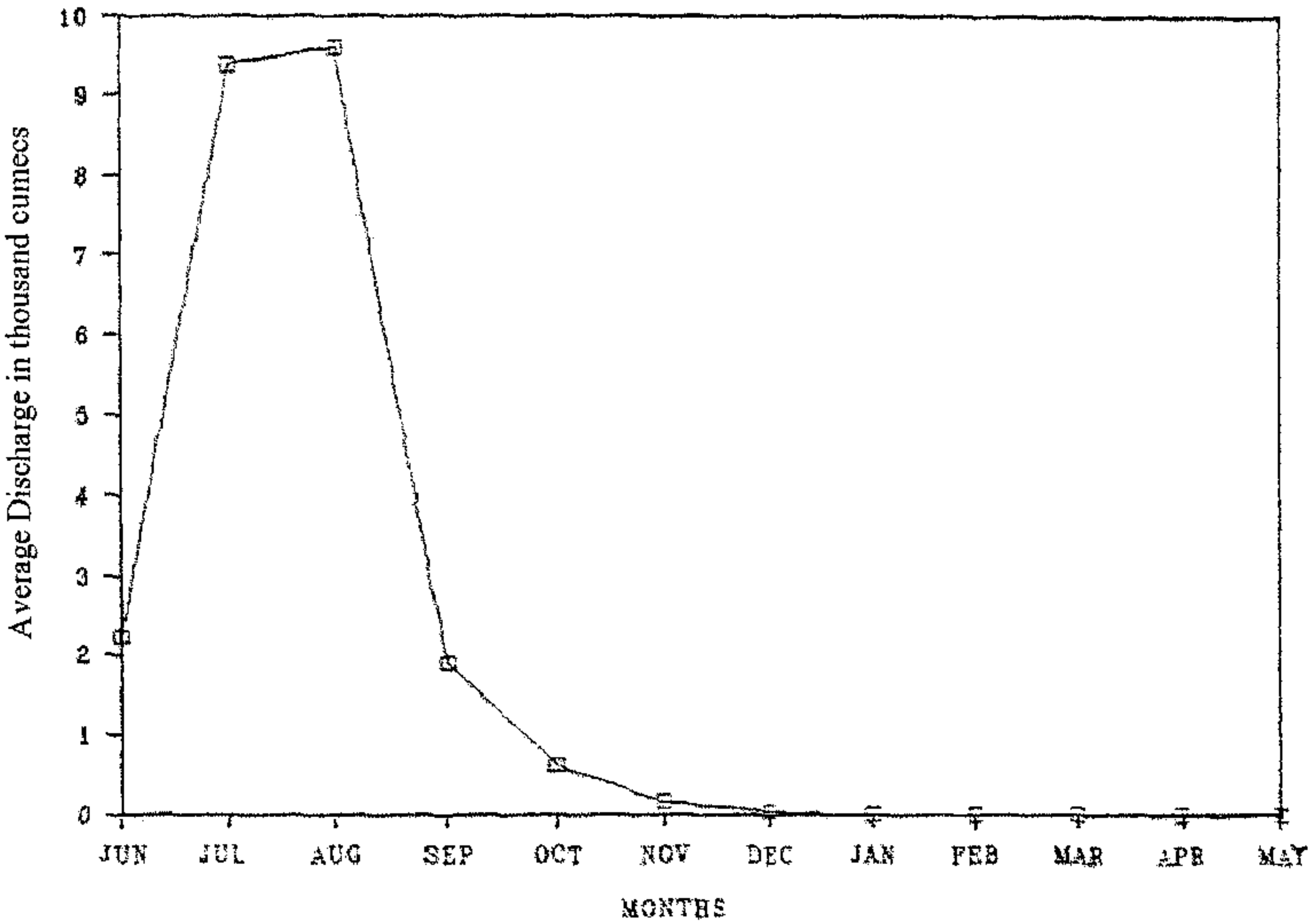


**Figure 20. Hydrograph of the Ghataprabha Representative Basin Recorded at Daddi (1979 to 1989)**

Table 26. Monthly water discharge (in Cumecs) recorded at Daddi in the Ghataprabha Representative Basin

| Year | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1979-80 | 1890.8 | 6151.0 | 14167.0 | 1792.0 | 744.9 | 305.9 | 102.7 | 16.0 | 1.8 | nil | Nil | Nil |
| 1980-81 | 3691.0 | 12572.6 | 11261.3 | 2327.3 | 736.2 | 112.5 | 37.0 | 2.3 | - | - | - | - |
| 1981-82 | 1348.1 | 10454.7 | 12870.3 | 2337.6 | 556.4 | 159.2 | 36.2 | - | - | - | - | 68.8 |
| 1982-83 | 1359.8 | 10736.6 | 12454.4 | 1421.9 | 398.5 | 281.2 | 37.3 | - | - | - | - | - |
| 1983-84 | 4737.5 | 10132.2 | 10113.8 | 2932.0 | 714.8 | 162.3 | 51.3 | - | - | - | - | - |
| 1984-85 | 2130.8 | 11711.0 | 6417.1 | 1606.0 | 684.0 | 120.6 | 32.5 | - | - | - | - | - |
| 1985-86 | 3040.6 | 6765.7 | NA | 948.2 | 0 | 0.0 | 31.0 | - | - | - | - | - |
| 1986-87 | 2805.7 | 6863.0 | 7431.2 | 578.1 | 262.2 | 205.8 | 18.4 | - | - | - | - | - |
| 1987-88 | 486.0 | 5944.1 | 3159.2 | 1566.4 | 969.2 | 150.0 | 37.3 | - | - | - | - | - |
| 1988-89 | 835.1 | 12504.7 | 8571.9 | 4111.3 | 1095.3 | 56.9 | - | - | - | - | - | - |
| Average | 2232.5 | 9383.6 | 9605.1 | 1910.0 | 616.1 | 155.4 | 38.4 | 1.92 | 0.23 | - | - | 6.9 |

**Table 27. Water Generating Capacity of land to channels in the Ghataprabha Representative Basin**

| Sl.No. | Months | Water generating capacity (Cumec/sq.km/day) |
|---|---|---|
| 1 | June | 2.1 |
| 2 | July | 8.9 |
| 3 | August | 9.1 |
| 4 | September | 1.8 |
| 5 | October | 0.6 |
| 6 | November | 0.15 |
| 7 | December | 0.04 |
| 8 | January | 0.002 |
| 9 | February | 0.0002 |
| 10 | March | - |
| 11 | April | - |
| 12 | May | - |

## 3.0 Data Processing and Hydrological Analysis

The hydrometeorological variables such as rainfall, temperature, humidity, wind speed, etc. are measured from the field as a time series data. Many of these hydrological variables recorded are not directly used for purpose of hydrological modelling and analysis. These data are subjected to preliminary and secondary processing in order to ensure the quality of data and also bring them in the appropriate form required for the purpose of hydrological modelling. The data, which are required for hydrological modelling may be classified as: the time series data, spatial data and location specific data. The time series data are fed on the computer and softwares are available for the processing of such data. During such processing, various computations like areal estimates of the data, stastistical analysis including correlation and regression analysis are generally utilised. Spatial information may be stored in two or three dimensional grid systems and necessary quality control test is performed on them. For the processing of the spatial and location specific data, digitisation may be achieved manually by digitising tables or by automated or semi automated digitising equipment. The conversion process can be checked by computer plotting of the data into overlap and comparing with the original traces.

In order to provide the specific contents for the water year book, the hydrological year book for Ghataprabha representative basin up to Daddi and Malaprabha representative basin up to Khanapur was prepared. In this hydrological year book, the time series data of the rainfall and runoff were included for the year 1988 in addition to some physical features.

### 3.1 Hydrological Year Book

Planning and management of various water resources projects requires vast amount of hydrological data. This hydrological data is collected and maintained by various organisations like Central Water Commission, Central Ground Water Board, Indian Meteorological Department and various State Government Organisations. To make the data readily available to users for various purposes, it is desirable to have all the data in a consolidated form at one place.

This hydrological yearbook for representative basin contains description of the river basin, present status of water resources development and existing network of hydrological stations. A number of maps like index map showing location of representative basin area and map showing location of hydrometeorological stations. It also includes monthly rainfall data, monthly climatological data, daily gauge discharge data and ground water level data for the period of 1988.

The preparation of this yearbook is an attempt to bring all the possible information relative to representative basin area together. The same book can be extended for number of years also.

The contents of an ideal hydrological year book have been prepared keeping in mind the objective of the year book.

For details of the study, the reader may refer NIH Report No. TR 149 and TR 151.

**Remarks**

The hydrometeorological and hydrological data are subjected to preliminary and secondary processing in order to ensure the quality of data and also bring them in the appropriate form required for the purpose of hydrological modelling. The data, which are required for hydrological modelling may be classified as: the time series data, spatial data and location specific data. The time series data are fed on the computer and softwares are available for processing of such data. During such processing, various computations like aerial estimates of data, statistical analysis including correlation and regression analysis are generally utilised. Spatial information may be stored in two or three dimensional grid systems and necessary quality control test is performed on them. For the processing of the spatial and location specific data, digitisation may be achieved manually by digitising tables or by automated or semi-automated digitising equipment. The conversion process can be checked by computer plotting of the data into overlap and comparing with the original traces.

To provide the specific contents for the water year book, the hydrological year book for Ghataprabha and Malaprabha representative basin up to Khanapur was prepared for the year 1988 only. Therefore, it is necessary to prepare such hydrological book for the various years.

The studies like rating curves development for the gauging sites located within basin area, processing of hydrological time series data using HYMOS software, methodology and computational step of the physical-statistical method to determine representative area per stream gauging station, guidelines for selection of stream gauging sites as well as spatial disaggregation of rainfall data to disaggregates the hydrological variables from larger temporal scale to smaller scale etc., should be carried out for investigation of the hydrological, hydrometeorological and physical characteristics of the representative basin.

# 4.0 Field and laboratory Investigation

## 4.1 Field Investigations

The main objective of the field investigation activity was to improve the knowledge about soil parameter values based on measurement campaign carried at different locations in the catchment, which in turn would reduce the uncertainty about input parameters in the model application.

### 4.1.1. Infiltrometer Tests

Infiltration is one of the important phenomena of the hydrological cycle. This deserves a special place in hydrologic study, which enables us to estimate the amounts of runoff more effectively. The in-si-tue infiltrometer tests were conducted at various sites using double ring cylindrical infiltrometer. The representative value of final infiltration rate at each site was taken as the asymptotic infiltration rate at 24 hours after the test started. This is obtained by extrapolating the actual time vs. infiltration curve. This best linear fit curve is plotted on a double log scale. The final infiltration rate thus calculated corresponds to the value obtained from linearised equation at time 24 hours.

**Infiltration studies carried out in the Representative Basins**

Knowledge of infiltration characteristics of the basin helps in estimating the quantity of rainfall excess resulting from a stream. In watershed management studies, infiltration indices obtained from soils under various types of plant cover and land use are helpful in providing a basis for judgement so as to optimise watershed conditions for water yield and soil erosion. Infiltration is also considered to be the basic criterion in the design of surface irrigation as well as ground water irrigation.

A number of Infiltration tests have been conducted in the Malaprabha and Ghataprabha Representative Basin to understand the infiltration characteristics of the basin. Figure 21 shows the test site at Asoga village in Khanapur taluka of Belgaum district, which is a part of Malaprabha representative basin. The test was carried out on a natural terrace. It is found that the average infiltration rate in the Malaprabha representative basin stands at 2.7 cm/hr, which varies between 0.9 cm/hr and 5.1 cm/hr. In the Ghataprabha representative basin the average rate of infiltration is 5.9 cm/hr, which varies between 0.9 cm/hr and 16.5 cm/hr. The

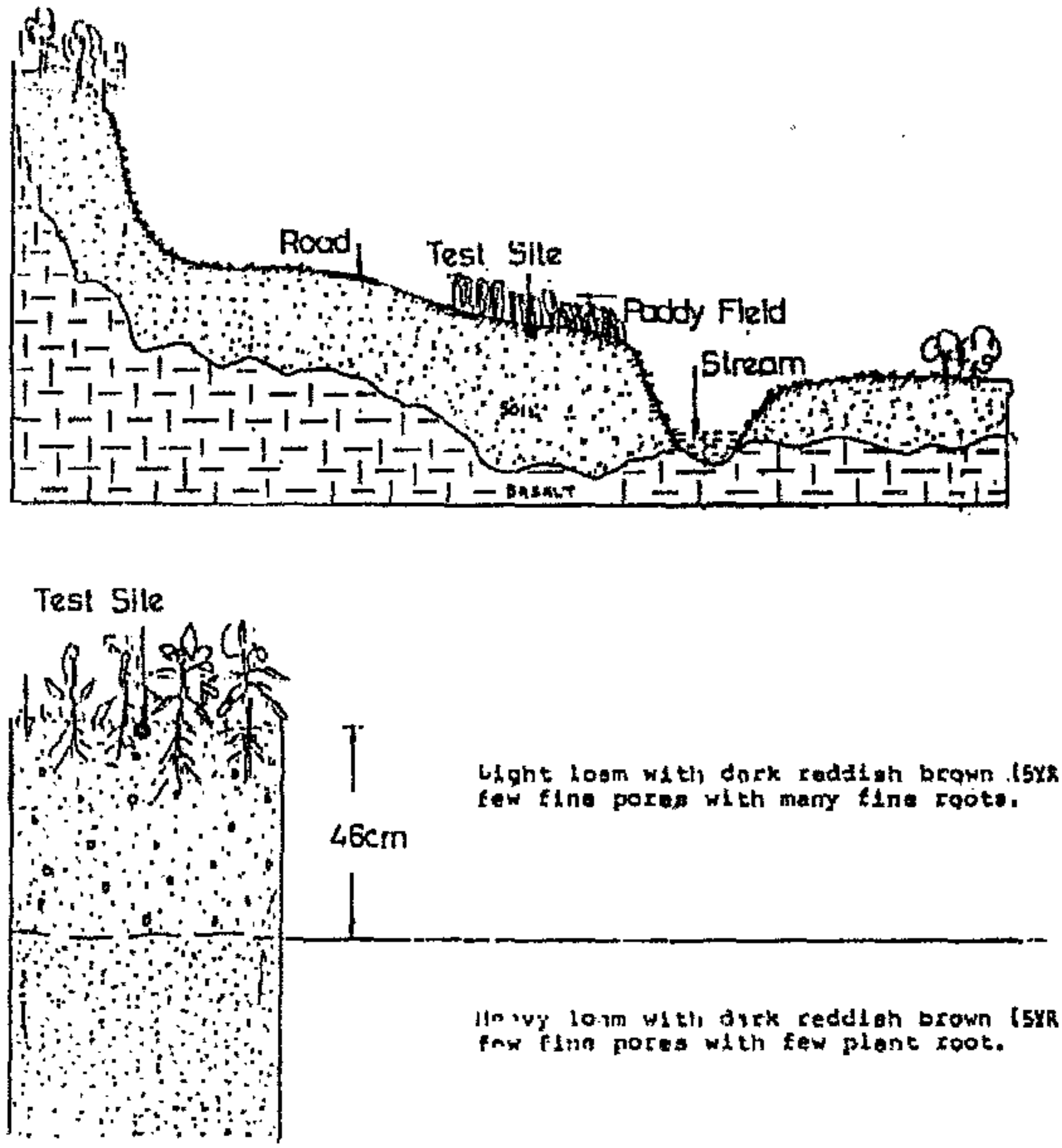


**Figure 21. Cross Section showing the location and environment near site at Asoga (above) and soil profile at test site (below) in the Malaprabha Representative Basin**

infiltration rate under different soils and land use pattern varies widely. The average rate of infiltration in the light loam soil of the Malaprabha representative basin is 3.8 cm/hr. In the case of Ghataprabha representative basin variation is between 4.8 cm/hr and 8.4 cm/hr. Under medium loam condition the rate of infiltration stands at 2.3 cm/hr in Malaprabha and 6.3 cm/hr in Ghataprabha representative basins. If soil texture is heavy loam the rate of infiltration is 1.8 cm/hr in Malaprabha and 4.8 cm/hr in the Ghataprabha representative basins.

The rate of infiltration observed under different landuse pattern varies significantly. A forest land in Malaprabha representative basins has an infiltration rate of 3.3 cm/hr, whereas in the case of Ghataprabha representative basin it goes upto 13.2 cm/hr. The infiltration rate on the agricultural land stands at 2.7 cm/hr and 3.9 cm/hr for Malaprabha and Ghataprabha representative basin respectively. On barren lands the rate of infiltration observed in Malaprabha representative basin is 2.2 cm/hr and in Ghataprabha representative basin it is 9 cm/hr. Due to the topographic variation and water yield in these basins, there is prominent difference in the infiltration rate that the infiltration rate of Ghataprabha representative basin is more than double that the Malaprabha representative basin.

For the detail of the study reader may refer the NIH Report No. CS 105.

Also, the Infiltration studies were carried out by using the CSIRO Disc permeameter. The CSIRO Disc Permeameter, developed in the CSIRO Centre for Environmental Mechanics, Canberra, Australia, is designed to measure the in-si-tue hydraulic properties of the field soils. It enables rapid measurement of hydraulic conductivity, sorptivity, macroscopic capillary length and characteristics pore size with minimal soil disturbance. The tests sites were fixed by taking into consideration, the geology, soil type and land use pattern of the region. Depending on the rate of infiltration, soils of the command area were classified.

For details of the study reader may refer the NIH Report no. CS (AR) 145.

### 4.1.2 Land use and Soil Maps

Based upon the field survey conducted, the land use and soil maps were prepared. The average value of infiltration rates under different soil texture and land uses/cover of the Malaprabha representative basin are presented in the Table 28.

**Table 28. Infiltration rate in different types of landuse and soil type.**

| Sr. No. | Stations | Land use | Soil type | Infiltration rate (cm/hr) |
|---|---|---|---|---|
| 1 | Asoga | Agricultural land | Heavy loam | 3.0 |
| 2 | Jamboti | Barren land | Light loam | 2.4 |
| 3 | Kankumbi | Barren land | Sandy loam | 3.3 |
| 4 | Kankumbi | Forest land | Sandy loam | 5.1 |
| 5 | Jamboti | Agricultural land | Medium loam | 3.3 |
| 6 | Bamanvadi | Agricultural land | Heavy loam | 0.9 |
| 7 | Santibastwad | Barren land | Clayey | 1.2 |
| 8 | Unchod cross | Forest land | Clayey | 3.9 |
| 9 | Kusmoli | Shrubi land | Heavy loam | 3.6 |
| 10 | Gangoli | Forest land | Light loam | 3.0 |
| 11 | Gunji | Agricultural land | Heavy loam | 1.8 |
| 12 | Manturgi | Agricultural land | Medium loam | 1.2 |

### 4.1.3 Hydrological soil parameters

The various parameters considered in this study are field saturated hydraulic conductivity, Theta-Psi relationship and soil texture. Guelph permeameter has been used for the measurement of field saturated hydraulic conductivity in different types of soil group. For the determination of Theta-Psi relationship, ceramic pressure plate apparatus has been used. Particle size analysis has been carried out by using sieves and hygrometer.

**Measurement of Surface-Soil Hydraulic Properties of Malaprabha Basin**

For a complete evaluation of soil water system, it is necessary to know the state of water and its movement. Forces of adhesion, cohesion, and surface tension regulate the retention and movement of water in soils. Water movement is controlled by the rate of water flow known as the soil hydraulic conductivity, and also by the driving forces, which is the difference between the water potentials at two locations in the soil. Hence, in order to analyse the retention and movement of water through the unsaturated soil zone, it is essential to have an idea about the properties of this zone. Major properties to be evaluated includes soil texture and structure, pore characteristics, infiltration rate, conductivity, soil moisture and its retention capacity.

The experimental studies were conducted to estimate surface soil properties for Malaprabha command area, which lies in Dharwad, Bijapur and Belgaum districts of Karnataka. Field experiments were conducted using CSIRO Disc Permeameter to estimate infiltration, sorptivity, saturated hydraulic conductivity, and pore characteristics. Pipette analysis used to derive the soil moisture retention curve.

For the details of the study reader may refer the NIH Report No. CS (AR)-26/96-97.

### 4.1.4 River Cross Section

Information of the river cross-section is necessary for the analysis related to river and its flood plains. The river- cross section of the Malaprabha River at the upstream end and gauging point are surveyed and provided for the future reference.

For details of the study, the reader may refer NIH Report No. CS(AR)- 30/98-99.

## 4.2 Laboratory investigation of Soil samples

The main thrust of the field programme particularly in respect to soil parameters and relationship was concentrated on the evaluation of the following,

i) Unsaturated zone saturated hydraulic conductivity (for vertical flow);

ii) Unsaturated zone moisture content/hydraulic conductivity relationship;

iii) Unsaturated zone moisture content/tension relationship

iv) Saturated zone hydraulic conductivity (for vertical flow)

v) Soil depth and profile

vi) Root zone depth

The field tests were carried out in several locations in the Malaprabha and Ghataprabha representative basins. The various soil parameters were analysed are 1) particle size analysis, 2) Field saturated hydraulic conductivity and 3) Soil moisture retention curve.

### 4.2.1 Particle size analysis

For determination of percentage particle size of various soil groups, samples were collected from various locations of the basins. The distributed samples were oven dried. Since the soil in this area consist of both coarse and fine grains, sieve analysis as well as hydrometer analysis were used. The samples were collected from 20 to 40 cm depth. 500 gm of oven dried soil sample was washed through 75 micron size sieve. The material retained on the sieve were used for sieve analysis after oven drying. The proportion of soil samples retained on each sieve was weighted and the percentage was calculated on the basis of total weight of dried soil samples taken. The material passing through 75micron sieve size was used for hydrometer analysis by 152 H hydrometer. The percentage of Gravel, sand, silt and clay were ascertained, as given in the Table 29.

**Table 29. Particle Size Analysis of Soil Samples in Ghataprabha Representative Basin**

| Sr. No. | Locations | % of gravel | % of sand | % of silt | % of clay |
|---|---|---|---|---|---|
| 1 | Hidkal dam | 12.50 | 72.50 | 6.20 | 8.80 |
| 2 | Belgaum | 5.00 | 18.43 | 29.57 | 47.00 |
| 3 | Ramdurg | 0.60 | 53.40 | 14.50 | 31.50 |
| 4 | Raibag | 22.60 | 18.34 | 37.31 | 21.75 |
| 5 | Jamkhandi | 2.70 | 30.62 | 11.68 | 55.00 |
| 6 | Mudhol | 4.50 | 51.65 | 26.35 | 17.50 |
| 7 | B D Tank | 8.10 | 44.40 | 21.25 | 26.25 |
| 8 | Badami | 0.20 | 88.77 | 3.03 | 8.00 |

The particle size analysis of the Malaprabha region shows that, sand is the predominating constituent at Asoga, Ramdurg and Badami. It is also evident that the grain size distribution in these regions follow a good sorting trend.

For details of the study reader may refer the NIH Report No. TR 130.

### 4.2.2 Soil Moisture Retention Curve

In order to evaluate completely the condition of water in soil, one must know the energy of the water, the amount of water in the soil and how these conditions varies in space and time. The plant response to the water appears to be more closely related to the water potential, although the velocity of movement of water to the absorbing root is an important consideration. The movement rate is strongly related to the potential. There is a relation between the amount of water in a soil and the potential energy of the water in the soil system.

When the pressure head of the soil changes the water content of the soil changes. The graph representing the relationship between the pressure head and water content is generally referred as the soil moisture retention curve or soil moisture characteristics curve. Pressure plate apparatus (Ceramic plates) has been used for the determination soil moisture characteristics curve. The soil moisture retention curve drawn for the soil samples of Malaprabha representative basion indicates that there are mainly three types of soils, i) loamy sands ii) sandy clay loam's and iii) clays. Table 30 shows the soil moisture content at various pressures.

**Table 30. Soil moisture characteristics curve at Malaprabha and Ghataprabha Basins**

| Locations | Soil moisture at different pressure (Bar) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.10 | 0.33 | 0.50 | 0.70 | 1.00 | 3.00 | 5.00 | 10.00 | 15.00 |
| Asoga (Khanapur) | 22.46 | 14.03 | 11.05 | 11.79 | 10.14 | 9.26 | 8.63 | 7.64 | 7.73 |
| B. D. Tank | 28.26 | 20.66 | 20.02 | 19.37 | 17.33 | 16.06 | 15.09 | 14.21 | 13.53 |
| Bagalkot | 54.22 | 45.44 | 39.23 | 36.46 | 34.42 | 34.09 | 30.73 | 23.6 | 21.55 |
| Belgaum | 37.48 | 29.43 | 25.91 | 26.57 | 24.42 | 23.65 | 23.65 | 19.59 | 22.27 |
| Gokak | 48.90 | 40.39 | 35.26 | 36.84 | 30.94 | 28.67 | 28.67 | 23.16 | 21.13 |
| Hidkal dam | 13.36 | 7.93 | 6.42 | 6.14 | 5.95 | 5.28 | 5.28 | 3.99 | 4.20 |
| Jamkhandi | 42.07 | 33.59 | 30.15 | 13.41 | 27.89 | 25.88 | 26.81 | 18.32 | 21.22 |
| Ramdurg | 27.17 | 18.54 | 16.40 | 16.61 | 14.31 | 13.41 | 14.07 | 10.25 | 11.05 |
| Raibag | 42.04 | 33.20 | 30.02 | 28.29 | 24.26 | 23.79 | 21.56 | 19.40 | 19.13 |
| Ron | 42.96 | 24.00 | 28.50 | 28.42 | 24.71 | 24.03 | 20.94 | 17.76 | 19.50 |

Loamy sands are found in the upper reaches. The textural analysis of the soil samples indicates a very high percentage of (61.2%) sands with intermittent silts (13.75%) and clays (16.25%). The percentage of gravel is found to be 8.8%. The wilting point observed for this soil is 7.6% and the field capacity is found to be 22.46%. Sandy clay loam's are found in downstream of Asoga. In this region, the percentage of clay is very less. It varies between 26.25% to 31.5%. The percentage of sand is comparatively high (44.4% to 53.4%) and silt content varies between 14.5% to 21.25%. The wilting point for this group of soil varies widely between 10.2% and 14.2%. The field capacity varies between 27.17% and 28.26%. Clayey soils are distributed in the downstream. The percentage of clay is comparatively more (52%). The wilting point observed for the clay samples is 17.76% and the field capacity is measures as 42.96%.

The soil moisture curve of the Ghataprabha command area shows three distinct group of soils, i.e. i) sandy loam's, ii) Clays and iii) loamy soils. In sandy loam soils, the percentage of the clay is very less (8.8%) and sand content is very high (72.5%). The wilting point observed

is very minimum (3.99%). The field capacity is comparatively very less (13.36%). Clay distribution is very common in the basin. The percentage of clay increases towards the downstream region (53.75% to 58%). The wilting point varies between 18.32% and 23.6% depending upon the clay content.

For the details of the study, reader may refer the NIH Report No. TR-130.

### 4.2.3 Saturated hydraulic Conductivity

The hydraulic conductivity of the soil depends on various of physical parameters like porosity, particle size distribution, shape of the particles and other related factors. In general, for consolidated porous media, the hydraulic conductivity varies with particle size. The clayey material exhibits low values of hydraulic conductivity, where as, sands and gravels display high values.

The value of field saturated hydraulic conductivity are shown in table 31.

Table 31. **Field Saturated Hydraulic Conductivity (cm/sec)**

| Sr. No. | Locations | Kfs cm/hr |
|---|---|---|
| 1 | Badami | $45.25 \times (10)^{-4}$ |
| 2 | Ramdurg | $3.62 \times (10)^{-4}$ |
| 3 | Belgaum | $2.46 \times (10)^{-4}$ |
| 4 | Hidkal dam | $2.37 \times (10)^{-4}$ |
| 5 | Mudhol | $0.484 \times (10)^{-4}$ |
| 6 | Jamkhandi | $0.438 \times (10)^{-4}$ |
| 7 | Raibag | $0.106 \times (10)^{-4}$ |
| 8 | B. D. Tank | $0.025 \times (10)^{-4}$ |

**Remarks**

The correct and detailed information about soil properties is very crucial input for a physically based distributed model. Field investigation activities like infiltration test, land use and soil mapping, hydrological soil parameter estimation as well as river cross section were carried out by the Institute with a view to improve the information about soil parameter values based on measurement campaign carried out at different locations in the representative basins. Which in turns would reduce the uncertainty about input parameters and consequently about the results of simulation models. The laboratory investigations like particle size analysis, field saturated hydraulic conductivity and soil moisture retention curve analyses were carried out based on the data acquired from field investigation.

## 5.0 Hydrological.Modelling

Development and application of computer based mathematical models for solving the various problems have increased significantly during last two decades. A mathematical model provides a quantitative mathematical description of the processes through a collection of mathematical equations, logical statements, boundary conditions and initial conditions expressing relationships between inputs, variables and parameters.

A large number of hydrological models exist. However, many of the models function in basically the same way. A model represents the physical/chemical/biological characteristics of the catchment and simulates the natural hydrological processes. It is not an end in itself but is a tool in a large process, which is usually a decision problem. A model aids in making decisions, particularly where data or informations are scarce or there are large numbers of options to chosen from. It is not a replacement for field observations. Its value lies in its ability, when correctly chosen and adjusted, to extract the maximum amount of information from the available data, so as to aid in decision making process.

The hydrological modelling required not only for estimating the water yield and design parameters but also for understanding and evaluating the effects of developmental and other activities on hydrological regime of a river basin. The challenging task of preparing developmental plans for managing the limited resources of river basins for their optimal use necessitates application of multi-disciplinary approach system engineering for comprehensive planning of water resources projects. The use of physically based distributed modelling approach can provide such information and could also incorporate scenarios of proposed/ likely land use changes in the river basin for use in planning/operation of water resources projects.

In the area of hydrological modelling significant amount of studies were carried out by the Institute to deal with calibration, validation and simulation of lumped conceptual model (event based as well as continuous) and physically based models.

The modelling processes and the development of understanding are closely related in that a comparison of model predictions with measurements is commonly used to test hypotheses about the operation of the system being modeled. Where the measurements are taken during carefully formulated and closely controlled experiments, such comparison is part of the standard scientific method. For field systems the method is fraught with difficulties. Hydrological quantities measured in the field tend to be either integral variables (e.g., stream discharge, which reflects an integrated catchment response) or point estimates of variables that are likely to exhibit marked spatial and/or temporal variation (e.g., soil hydraulic conductivity). The result is that the scientific problem of identifying the mechanisms giving rise to observed catchment responses is poorly posed. Yet, in spite of these difficulties, pseudophysical models of catchment dynamics provide the only vehicle for testing hypotheses in catchment hydrology, i.e., the only way to make comparisons between theory (model predictions) and observations.

The conceptual models are selected and used for the specific purposes. The use of conceptual model often involves three major issues. Firstly, the conceptual base of the model should 'capture' the major hydrological processes of the catchment. A calibrated model may reasonably reproduce observed patterns of streamflow at the calibration stage even though the basins major hydrological processes can be different from those assumed in the model. the common amount of detail desired and the type of data available. The second issue is whether the time steps used in the model are sufficiently small to represent the rate of change of the process. This problem can be particularly important in arid region where the rainfall intensity can change quickly over relatively short time scale, resulting in a sharp rise in the surface runoff. The third issue concerns model calibration. The implementation of this type of hypothesis-testing procedure in catchment hydrology is further complicated by the fact that at least some parameters in the conceptual models of catchments cannot be measured independently of inflow-outflow data, but must be fitted using the very data available for the test itself. The generally accepted way around this dilemma is to use one portion of the period of record to 'calibrate' the model and a second portion to 'validate' the model so defined.

The variable contributing area concept was introduced by Hewlett in 1961, and further clarified by Dunne and Black in 1970. Subsurface flow was gradually recognized as a major storm-flow-generating processes, by itself as 'return flow' contributions to overland flow and by its strong influence on saturation overland flow. More recent research have been oriented towards the integration of all these concepts in a continuum of subsurface processes. Increasing the complexity of conceptual perception with respect to hydrological processes appeared to be an adequate answer to an enlarged need for accurate hydrological modelling of a land management impacts, water quality or climatic change assessments. Although lumped conceptual rainfall-runoff models claim to incorporate in their structures most of the process of the hydrological cycle, they do not provide a sound scientific basis for analysing the above mentioned modelling problems. Many parameters are required if all the processes involved are to be represented. However, most of these parameters cannot be related successfully to physical catchment characteristics and must be estimated by calibration using observed hydrographs. Therefore most models show serious drawbacks in parameter identification because of their conceptual structure and the data used for calibration.

The hydrological modelling efforts of the Institute using Representative basin data are summarised below:

## 5.1 Rainfall-Runoff Modelling

The water yield is an integration of discharges as a function of time for a specified duration and reflects the volumetric relationship between rainfall and runoff. The estimation of water yield is required for solution of water resources problems such as design of storage facilities, water availability for agriculture, industrial or drinking purpose, dependable water supply for power generation, planning irrigation operation and design of irrigation projects. However most of the time, the estimation of water yield is either under estimated or over estimated for any of the purposes mentioned above. In other words to say that, a proper tool to estimate the water yield for ungauged catchments is required. In this regard regional hydrologic analysis which comprises the study of hydrologic phenomena with an aim of developing mathematical relations to be used in regional context. The mathematical relations are developed so that information from gauged or long-record catchments can be readily transferred to neighbouring ungauged or catchments of similar hydrologic characteristics. The prospects for the successful solution of the problem of parametric estimation is an urgent requirement for water yield estimation. Perhaps the regionlisation of data and parameters are the only reasonable approach to the present problem.

Keeping in this view, the effort has been made to develop a regional conceptual water balance model parameters which can be used to estimate the water yield from ungauged catchments located in the same region. The regionalised parameters of the catchment water balance model have been obtained by developing relationship between model parameters such as wetting potential, vapourisation potential, initial abstraction coefficient of baseflow and surface flow either mean annual rainfall, and vegetation cover of the basin. However, coefficient of determination between vegetation cover and the model parameters found to be very high and where as the relationship between mean annual rainfall and model parameters is very low. The regional parameters obtained are compared with calibrated parameters and found to be within the tolerable limits. Water balance components are simulated using both regionalised and calibrated parameters of the model. The variation between the simulated using both regionalised and calibrated parameters of the model. The variation between the simulated values are within 10 per cent. Therefore it is suggested that model parameters can be obtained from the established relationship between vegetation cover of the basin and the model parameters.

For details of the study reader may refer the NIH Report No. CS (AR) -31/98-99.

#### 5.1.1 Application of Rainflo Model

Flood forecasting, reservoir design, watershed and comprehensive water resources projects generally utilize some form of routing technique. RAINFLO is a comprehensive hydrologic computer software system to model rainfall runoff process to forecast real time flood in complex watersheds and river basin. RAINFLO model is used to predict the temporal and spatial variations of a flood wave as it traverses a river reach or reservoir based on rainfall data in a real time. The RAINFLO model has been applied as an initial application to Indian hard rock stream, namely, Malaprabha basin upstream of Khanapur. The effort has been made to simulate the daily hydrograph and monthly discharge of a wet month. The sensitiveness of set of parameter values such as SCS curvenumber coefficient, slope, velocity, curve numbers, and Manning's 'n' have been selected and tested in the model. The sensitiveness of each parameter has been discussed and the error of the observed flow series and estimated flow series is within acceptance limit and found to be around 10 per cent.

For details of the study reader may refer the NIH Report No. TR 179.

### 5.1.2 Application of Catchment Water Balance Model

The conceptual model of a catchment water balance is based on the sequential two step separation of annual precipitation into surface runoff and wetting, and wetting into baseflow and vaporisation. A given set of model parameters, the model can separate annual precipitation into three major components: surface runoff, baseflow, and vapourisation. It is used to characterized baseflow and runoff coefficient as a function of climate. The runoff and baseflow functions are derived and analyzed: (1) runoff and baseflow coefficients vs annual precipitation and (2) baseflow and runoff gains vs annual precipitation. The conceptual model of water balance is also used to simulate changes in baseflow and runoff with annual precipitation.

The conceptual water balance model is applied to the Malaprabha river basin upstream of Khanapur, Karnataka. The wetting and vapourisation potentials, and surface runoff and baseflow initial abstraction coefficients have been calibrated. For a given annual precipitation, a set of surface flow and baseflow initial abstraction coefficients, and wetting and vapourisation potentials are used to separate precipitation into surface runoff, wetting, vapourisation, runoff coefficients, baseflow coefficients, and runoff gains and baseflow gains have been simulated by the model. Yield scenario of the catchment is established with the variation of annual rainfall. With given set of model parameters, this model can separate annual precipitation into its three major components surface runoff, baseflow and vapourisation. This model can be used to estimate the annual water yield in different biogeographical regions and climatic settings.

For the details of the study reader may refer NIH Report No. CS (AR) 149.

### 5.1.3 Application of ARNO Model

In the recent years, the water has become the scarce commodity. The country like India, where the demand for the water is increasing very day. The quantification of the water at the basin level is an urgent need for the proper management and distribution of water for different uses. To solve such problems, the hydrological modelling of catchement is one of the scientific tools. The hydrological modelling not only quantify the amount of water, but can also be used for the flood warning system and to predict the stream flows.

In the present report one such attempt is made to simulate the daily flows using ARNO, distributed function rainfall and runoff model for the river Malaprabha. The advantage of the conceptual distributed function model over other conceptual model is that, the model accounts the present soil moisture condition over the basin and also considers the non-linear variations of the drainage and the percolation into groundwater regime.

The results obtained from the analysis using ARNO rainfall-runoff model, it is observed that, ARNO model predicts the rise and fall of the flood peaks and the magnitude of the high flows in the basin appreciably. It also calculates the low flows more accurately in the catchment. Hence therefore, the model is best suited for the Malaprabha basin.

For details of the study, the reader may please refer unpublished NIH report of the year 1997 entitled "Application of ARNO, A Distributed Rainfall - Runoff Model To Malaprabha Catchment"

### 5.1.4 Application of Tank Model

Different rainfall runoff models are in use in India for simulation of daily runoff. Tank model is a simple conceptual rainfall runoff model developed in Japan by Sugawara. It has the capability to simulate both flood and daily runoff. This model for daily analysis has been used to simulate streamflow of Malaprabha representative basin. Using daily observed flow data for the period 1981 to 1984, the model has been calibrated. The input rainfall data are based on the observed daily rainfall at Kankumbi, Gunji, Desur and Khanapur. The calibration of the model was carried out by simulation of observed flows in 1981 and 1982. The simulation was good, the fit of 1982 being better than that of 1981. The calibrated model has been used to simulate daily streamflows during 1984 and 1985 which were found to be within 10% of the observed streamflows. The model was calibrated using data of 1979 and 1980. The tank model has been tested with independent data of a984 and 1985. In first and last week of July 1984 flows was under estimated but performance of the model in general was satisfactory. Good fit of the computed Hydrograph was observed except first week of Oct. in 1985. The model performed well for peak flows as well as lien season flows.

For the details of the study reader may refer the NIH Report No. TR-68.

## 5.2 Application of TOPMODEL

The TOPMODEL (TOPography MODEL) is a variable contributing area conceptual model in which the predominant factors determining the formation of runoff are presented by the topography of the basin and a negative exponential law linking the transmissivity of the soil with the vertical distance from the ground level. Though the TOPMODEL is a conceptual model, i.e. one in which the physical reality is represented in a simplified manner, the TOPMODEL is frequently described as being "Physically Based", in the sense that its parameters can be measured directly in situ.

TOPMODEL represents catchment topography by means of a topographic index, $\ln(a/\tan\beta)$, where 'a' is the area draining through a grid square per unit length of contour and '$\tan\beta$' is the average outflow gradient from the grid square. The topographic index is calculated from a Digital Terrain Map (DTM) across a grid covering the catchment. The grid must be sufficiently fine to resolve important characteristics and slope formations. A high index value usually indicates a wet part of the catchment, which can arise either from a large contributing drainage area or from very flat slopes. Areas with low index values are usually drier, resulting from either steep slope or a small contributing drainage area. Grid squares with the same index values are assumed to behave in a hydrologically similar manner. As a result of this assumption, the catchment topography may be summarised by the distribution of the index values.

The TOPMODEL has been applied to Malaprabha catchment in Karnataka to simulate the daily flows at Khanapur. The model uses topographic index for the formation of runoff. The topographic index for Malaprabha catchment was derived by developing a Digital Elevation Model (DEM) by interpolating the contours in the basin at 300 m grid size.

The result indicates that the model can be used to simulate the flows in the catchment quite accurately (the efficiency of the model is 0.89 and 0.79 respectively in calibration and validation run). Also, model is able to simulate the timing and magnitude of the peak flows satisfactorily.

For details of the study, the reader may please refer NIH Report No. CS (AR)– 3/97-98.

## 5.3 Application of Watbal, Watsed and Wepp Model

Soil erosion is a complex phenomenon governed by a large number of factors such as rainfall erosity, soil erodibility, slope, land use and conservation measures. As a natural process, soil erosion is credited with the formation of the most fertile valleys and flood plains in the world. This natural and creative process involves displacement of some 10 billion tons of soil per year. The rate of soil erosion is however, greatly enhanced due to man's intervention. This accelerated erosion due to deforestation and expansion of agricultural activities to steep and marginal lands, is believed to be about 2.5 to 5 times higher than the natural rate. Therefore, it is a fact that soil erosion is one of the most serious environmental threat to the mankind in various parts of the world.

Modelling soil erosion is the process of mathematically describing soil particle detachment, transport, and deposition on land surfaces. Though, efforts were made nearly a decade ago to estimate soil erosion in India through available information on soil loss from small runoff plots, small and large watersheds, and reservoirs, by land resource region. Various soil erosion models have also been applied to predict the soil erosion rates in many parts of the country. WATBL, WATSED and WEPP models has been executed for 10 years period for a representative element. The Watershed Response Model for Forest Management (WATBAL) was developed (Patten, 1989) to respond to these issues and concerns. The main objective is to estimate water yields in response to cumulative watershed development and vegetative manipulation and recovery over time. The program currently is designed to simulate the potential and most likely effects of primary forest management practices (timber harvest, road development, and fire) on the responses of watershed and water resource systems with regard to stream flow and sediment regimes.

WATSED model, which is a modified WATBAL model predicted an yield of 50 per cent. WEPP model data was executed for the whole Malaprabha representative basin which, predicted an yield of 45 per cent. The sediment yield predicted using WATBL model is only 8 tons / sq. miles / year whereas WATSED model has predicted a sediment yield of 68 tons / sqmi / yr. WEPP model estimated the sediment yield as 48 kg / sq. m /yr. This is the average soil loss calculated by using 45 years data. WEPP has estimated a very high value when compared to other models. The estimates given by WEPP is comparable with the reported values for the study area.

For detailed of the study the reader may please refer the unpublished report of the year 1999-2000 entitled "Soil erosion studies for the forested watersheds".

**Remarks**

Application of computer based mathematical models for solving various hydrological problems have increased significantly during last two decades. A large number of hydrological models exist. However, many of the models function in basically the same way. A model represents the physical/chemical/biological characteristics of the catchment and simulate the natural hydrological processes. It is not an end in itself but is a too in a larger process which is usually a decision problem. A model aids in making decision, particularly where data or information are scarce or there are large numbers of options to chosen from. It is not a replacement for field observations. Its value lies in its ability, when correctly chosen and adjusted, to extract the maximum amount of information from the available data, so as to aid in decision making process. The hydrological modelling is required not only for estimating the water yield and design parameters but also for understanding and evaluating the effect of developmental and other activities on hydrological regime of the river basin. The challenging task of preparing developmental plans for managing the limited resources of the river basins for their optimal use necessitates application of multi-disciplinary approach system engineering for comprehensive planning of water resources projects. The use of physically based distributed modelling approach can provide such information and could also incorporate scenarios of proposed/likely land use changes in the river basin for use in planning/operation of water resource projects.

A number of studies were carried out for the Malaprabha and Ghataprabha representative basins describing the calibration, validation and simulation of conceptual models as well as physically based models.

## 6.0 Flood and Drought Studies

The main objectives of hydrological studies of flood is to develop appropriate procedures in order to arrive a desired design variable for the particular structure to be safe under extremes of floods without leading to over design and consequent increase in cost. One of the common methods of estimating the design flood for the design of bridges and culverts especially in small catchment is by the use of frequency analysis of annual peak flood data recorded at site under consideration. The flood frequency analysis procedures are based on general statistical and probabilistic concept and the data used in such analysis has to satisfy the criteria of homogeneity, independence, randomness and time invariance. Flood frequency analysis for a river basin site with a long record can be based almost exclusively on that record alone. Unfortunately many of the streams in small catchments have not been gauged or very scanty data are available at the site. When only short records or no records are available, the need for procedure for augmenting site-specific hydrologic information with regional information arises in order to improve upon or stabilize site-specific estimates or to make inference at un-gauged river basin sites. The need for such procedures is particularly great in the estimation of extreme hydrologic events where a combination of limited site data and need for inference in the tails of probability distributions unite to destabilize such estimates. The regional analysis approach can provide estimate of floods for a limited data and un-gauged locations, through appropriate regional multiple regression relationships of statistical parameters of the flood series and cathchment characteristics. The choice of catchment, morphometric characteristics depends on the (1) Judgement of the likely predictive success of variables, and (2) Numerical calculations of regression equations and the interpretation of their coefficients. However, these characteristics are of 10 dodged by correlation, resulting in interdependence amongst independent parameters.

Whenever the river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable estimates of design flood, water availability and other hydrological variables directly. In such situation, the regional approach are the alternative methods, which provide these estimates. Although a large number of hydrological simulation models have been developed in the past decades, yet often simplified modelling approaches are being used for predicting the hydrological behaviour of various catchments. The main problem in applying the advance hydrological modelling approaches viz.

physically baesd or conceptual models in a developing country like India is non availability of adequate data for various catchments. Hydrologist face difficulties in calibration of complex models for different spatial and temporal scales, applying values on one scale computed from a population of parameters of another scales, adopting the limits of the applicability of physically based simulation models for different spatial scales when data uncertainity is considered. Hydrologist are concerned, how can model parameters of one scale be derived from the knowledge of the lower scale if the mathematical approach changes with scale. According to these questions the main tasks in regionalisation can be characterised as: (i) developing the regional approaches for estimation of the hydrological variables for the ungauged catchments, (ii) considering spatial variability within a given scale, (iii) deriving effective or representative parameters for an aggregated area (upscaling) and (iv) disaggregating information on a larger scale (downscaling). In addition to these tasks the regional transpossibility is also one of the main research interests. In order to be able to apply models to ungauged catchments, it is indispensable to develop tools for deriving model parameters from catchments characteristics like soil, geomorphology, geology, landuse and the climatological characteristics etc. Regionlisation has been employed for solving many hydrological problems; prominent among these are regional flood frequency analysis, regional unit hydrograph derivation and regional flow duration curves. Regional flood frequency study has been carried out using the data of Malaprabha and Ghataprabha represnetaive basins are described here.

## 6.1 Regional Flood Frequency Studies

Regional flood study has been carried out using Index- flood and EV-I, GEV and Wakeby Distribution. The gauging sites at different locations having a various catchment area are considered as test sites to verify the developed regional flood formulae under different cases namely, i) medium catchment, ii) large catchment and iii) considering the basin as a unit. The gauging records of the various test sites were used to compute the parameters of Index-flood, PWM based EV-I distribution, GEV distribution and Wakeby distribution. The relationship between catchment area, mean annual peak flood and the return period of the flood were obtained.

The flood values obtained from these methods (independently applied on the data of test sites) were compared with those values computed for test sites using the developed regional flood formulae. It is observed that the flood estimated using the relationship developed between $Q_T$ and catchment area (A) using Index-flood method and PWM based extreme value type-I distribution for the medium catchments and the case of considering the basin as a unit yielded very good result. The ratios of absolute difference between observed and estimated using the regional parameters is very low for those methods compared to the ratios obtained by other two methods for most of the cases. It is concluded that for the basins having catchment area below 5000 $km^2$, the following equation can be used for the estimation of quantiles quite accurately,

Also, the study reveals that, the size of the catchment plays an important role in developing the regional flood formula. For the basin having catchment area of 5000 $km^2$ and above the relation could not be established, as there are few gauging stations in the basin, which falls in this category.

For more details the reader may refer unpublished NIH report of the year 1999-2000 entitled "Regional Flood Frequency Analysis for Krishna Basin".

### 6.2 Drought Studies

The frequent occurrence of severe drought in past gew decades in the country have drawn the attention of planners and administrators. In view of the poor documentation and less understanding of the hydrological aspects associated with drought, the Drought Studies Division of the Institute has conducted studies on hydrological aspects of drought in the 36 districts in India. These studies were started from 1985-86. The major objective of these studies was to document the impacts of drought from hydrologiocal point of view.

In order to study the hydrological aspects of drought the hydrometeorologiocal data were subjected to various kinds of analysis including rainfall departure, probability analysis, dry spell analysis, groundwater fluctuation analysis and analysis of change in availability of water storage in reservoirs. Available models were also applied to identify the probable periods for onset and termination of drought and to make the estimate of drought intensity. Districtwise drought analysis is presented in the NIH published reports.

For more details the reader may refer NIH report No. CS 59

**Remarks**

Most of the regional flood studies are based n the USGS approach and with RDSO data. There is a need for taking up systematic regional flood studies using large data base collected by different organisations and agencies. This would enables pulling together of vast informations for use hydrologic analysis and design. In addition to the regional flood frequency studies, regional unit hydrograph derivation and regional flow duration curves studies should be carried out for estimation of unit hydrographs for the basin.

In these representative basin the entire Belgaum district, which covers most of part of these basin have been considered as drought prone and study has been carried out using the relevant data of this district. The major objective of this study was to document the impacts of drought from hydrological point of view. For studying the hydrological aspects of drought the hydrometeorological data were subjected to various types of analysis including rainfall departure, probability analysis, dry spell analysis, groundwater fluctuation analysis and analysis of change in availability of water storage in reservoirs. Analysis of groundwater regime indicated a falling trend in groundwater levels over the yeara as a result of rainfall deficiency.

## 7.0 Ground Water Studies

Groundwater is a major source of water supply for a large portion of the world population. The evaluation, rational development and management of ground water resources, which is very essential to feed the growing population, requires a through knowledge of the subsurface environment and an understanding of the hydrological processes that governs the occurrence, movement and yield of ground water.

As per the National Water Policy, the development of ground water resources is to be limited to the utilisation of the renewable part of the naturally occurring ground water. The present development policy does not envisage utilisation of secular reserve ( static ground water resource) which is many times the dynamic ground water resource.

During the past four decades, there has been phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resources backed by liberal funding in availability of power and diesel, good quality seeds, fertilisers, government subsidies, etc. Further additional dependance is being laid on the resources during drought periods. Ground water development has, therefore, occupied an important place because of its role in stabilising Indian agriculture and as means for drought management.

The earlier practice of planning surface irrigation without much consideration of ground water status has often been resulted in waterlogging and salinity problems in the command areas after a time due to gradual rise of ground water. The impact of surface water development on the existing ground water regime therefore needs to be studied for judicious use of surface water and ground water to derive optimal benefits.

### 7.1 Ground Water Balance

Groundwater balance for the Ghataprabha representative basin has been estimated by water table fluctuation method, which is based on recommendation of the Groundwater Estimation Committee, Ministry of Irrigation, Govt. of India. Using the available monthly groundwater level data, groundwater level contours have been drawn for pre and post monsoon seasons for the period 1989-93. Nearabout monthly groundwater levels of 15 wells for 5 years were used for the estimation. Water table fluctuation between pre-monsoon (April/May) and post-monsoon (September) periods were calculated for each well and for each year. These values will only represents the fluctuation in the area surrounding each well. For getting an average value of the fluctuation for the study area, suitable weights have been allocated to each well, by drawing Theissen polygon. It is found that the five year average water level fluctuation for the area varies from 5.10 to 6.78 m.

By analysing the weighted pre-monsoon and post-monsoon groundwater levels for the basin, it can be seen that the general tendency of the groundwater situation in the study area is encouraging, since it is showing an increase trend, the reason for which may be the increase in the draft rate in pre-monsoon period over the years (1989-93). Further groundwater fluctuation also shows an increasing trend, which indicates that the long term availability of groundwater resources is increasing.

Analysis for individual wells falling within the basin also shows that the water level increases over the study period, except for Nesari, where it shows a decreasing trends.

For details of the study, the reader may please refer NIH Report No. CS (AR) 176.

### 7.2 Ground Water Quality Studies

Quality of water is an important factor in classifying the water for various purpose such as domestic, irrigation or industrial purposes. Main objective of the study will be to wee suitability of water for various uses. For the above study 10 stations have been selected within the Malprabha reservoir catchment (Kanakumbi, Jamboti, Khanapur, Bidi, M.K.Hubli, Bailhongal, Belavadi, Soundati, Naviluteerth, Desur). Few samples from the river basin has been collected in order to know the quality of groundwater. Similar process will be continued during post-monsoon and pre-monsoon periods. Trace element analysis will be carried out as the trace elements are the actual carriers of pollution.

Sources of contamination can be divided basically into two groups, natural and cultural (those caused by man). The source can be further classified as either point or diffuse (non point) source of pollution. Point sources enter the pollution transport routes as discrete, identifiable locations and can be measured directly or otherwise quantified, and their impact can be evaluated directly. Major point sources include effluent from industrial and sewage treatment plants, and effluent from farm buildings or solid waste disposal sites. The non-point sources include, effluents from agriculture activity, urban runoff mining activities etc.

Groundwater pollution studies in general deal with problem of identifying pollution sources and contaminant of pollutant spreading from known sources or elimination of stress conditions. Groundwater quality varies from place to place as well as strata to strata. Pollution from diffuse sources can be related to weathering of minerals, erosion of virgin lands and forest, including residues of natural vegetation, or artificial or semiartificial sources. The last can be related directly to human activities such as fertilizer application or use of agricultural chemicals controlling insects, erosion of soil materials from agricultural farming areas and animals feedlots, construction sites, transportation, strip mining and others.

Since pollution is the addition of substances to ground waters above their natural quality, pollution by non-point sources is caused mostly by man and his activities and should be distinguished from water quality contributions, sometimes called "background pollution", caused by the contact of water with rocks; undisturbed soils and geological formations; natural erosion and elutriation of chemical and biochemical components from forest litter; migration of salt water into estuaries; or other natural sources.

In addition, the quality of groundwater and its temperature may undergo change due to influence of man. Some times there are slow changes in quality due to the movement of groundwater induced by operation of well fields. More frequently, in the vicinity of waste disposal sites (including wells), the leachate which is a complex fluid responsible for quality deterioration is the focus of monitoring.

In view of noticeable changes taking place in agricultural, industrial and domestic fields, need was felt for monitoring water quality of groundwater for taking necessary measures to protect it from contamination.

Sampling is one of the most important and foremost step in collection of representative water samples for ground water quality studies. Moreover, the integrity of the sample must be maintained from the time of collection to the time of analysis. Factors involved in the proper selection of sampling sites depend upon the objectives of the study, accessibility, chemical source locations, manpower, and facilities available to conduct the study. Further more, the hydrologist must be aware of the locations of point and non point sources of chemical and physical constituents, such as industrial complexes, sewage out falls, agricultural wastes etc. The use of a few strategic locations and enough samples to define the results in terms of statistical significance is usually much more reliable than using many stations with only a few samples from each.

The quantity of samples to be collected varies with the extent of laboratory analysis to be performed. A sample volume between two and three litres is normally sufficient for a fairly complete analysis. The total number of samples will depend upon the objectives of the monitoring programme. To achieve the objectives of the study, fifty one samples representing the groundwater were collected from the study area by dip (or grab) sampling method during post-monsoon season in the year 1998. The location of groundwater sampling stations is shown in fig.11. The samples were collected from both open and bore wells, which are being extensively used for drinking and other domestic purposes. The depth of the water in the respective wells was also measured with Hand held Water level indicator.The samples were collected in clean polyethylene containers fitted with screw caps. One container of 500 ml sample was acidified with nitric acid for analysis of metal ions. Some parameters like pH and temperature were measured in the field at the time of sample collection using portable kits and the other chemical parameters were analysed in the laboratory. The chemical properities and the constituents of water analysed are pH, specific conductance (EC), Temperature, Total Dissolved Solids, Alkalinity (Carbonates, bicarbonates), hardness, Fluoride and major cations and anions.

In the ground water of Malaprabha catchment pH values are mostly confined within the range 7 to 9.4 except in few post-monsoon cases. The maximum pH values are observed for open wells. In the bore well waters the maximum value observed is 8.75. The temperature of water is one of the most important characteristics which determine the trends and tendencies of changes in its quality. The shifting of various dynamic equilibria such as concentration of carbonates, sulfides, or degree of alkalinity or electrical conductivity are affected by temperature changes. In the present study temperature of the samples varies from 25°C to 28°C

In the present study conductivity varies from 60 μmhos/cm to 3510 μmhos/cm during pre-monsoon season and from 36 μmhos/cm to 3800 μmhos/cm during post-monsoon season. The mean value varies between 901.80 μmhos/cm and 1092.30 μmhos/cm.Median value varies from 398μmhos/cm to 616 μmhos/cm and standard deviation varies berween 991.40 μmhos/cm and 1061.60 μmhos/cm. In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. The determination of dissolved solids does not give a clear picture of the kind of pollution. In the present study TDS varies between 36 mg/l and 2100 mg/l during pre-monsoon and 21.60 mg/l and 2280 mg/l during post-monsoon period. The mean value of TDS varies between 540 mg/l and 674 mg/l. The mean value is higher than the general acceptable limit of 500 mg/l. The standard deviation varies between an average of 594 mg/l and 660 mg/l. Carbonates are commonly absent in most of the samples especially when pH is below 8.5. Content of carbonate is closely related with pH value. Carbonate content varies between 6.96 mg/l and 69.6 mg/l. Highest value of carbonate is observed where the pH is above 9.6. Open wells show higher values when compared to bore wells.

Bicarbonate content varies between 28.3 mg/l and 495.3 mg/l during pre-monsoon and 35 mg/l and 764 mg/l during post-monsoon. The mean value during pre-monsoon season is 167.46 mg/l and 278.64 mg/l during post-monsoon. Median value varies from 106 to 212 and standard deviation varies between 135 mg/l and 198 mg/l during the two seasons. The chloride content of groundwater may be due to the presence of soluble chlorides from rocks, saline intrusion, connate and juvenile water. In the zone of actual circulation the chloride ion concentration is normally relatively small. The chloride concentration in the study area during pre-monsoon varies between 7.1 and 759 mg/l. The mean chloride concentration varies between 150.67 mg/l and 160.4 mg/l during the study period.Standard deviation varies from

197.12 mg/l to 213.8 mg/l during pre-monsoon and post-monsoon season. The maximum chloride concentration is observed at Holehosur in a black cotton soil terrain. Desur also shows high content of chloride.

The sulphate content by atmospheric precipitation is 2 mg/l, but a wide range in sulphate content in groundwater is made possible through reduction by precipitation solution and concentration, as the water traverses through strata of rocks. It is reported that in arid and semi arid region, particularly it is found in higher concentration due to the accumulation of soluble salts in soil and shallow aquifers. Rain water has quite high concentration of sulphate particularly in the areas of high atmospheric pollution. The sulphate content in the catchment area varies from 36.5 mg/l to 415 mg/l. Sulphate content is very high in Desur, Ugargol and Gunji (exceeds 400 mg/l). Holehosur also shows a comparatively high value of sulphate (260-275 mg/l). In groundwater, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks, but contrary to the relative solubilities of their salt. Magnesium carbonate is more soluble in water containing sodium salts compared to calcium carbonate. The variation of calcium is between 8 mg/l to 460 mg/l which is quite higher than the permissible limit of 75 mg/l. Excessive calcium is observed at Holehosur, Desur and Belwadi. In the upstream part of the stream the calcium content is quite normal. The mean of calcium concentration is 87.52 mg/l during pre-monsoon and 116.38 mg/l during post-monsoon. Standard deviation varies between 118.91mg/l and 121.40 mg/l. The magnesium concentration varies from 0.5 mg/l to 59.5 mg/l during pre-monsoon and 3.43 mg/l to 79 mg/l in the post-monsoon season. The increase of magnesium is quite proportionate with calcium, the correlation coefficient between the two ions is 0.95.

Although sodium and potassium is abundant in igneous and metamorphic rocks, but concentration of sodium and potassium is found only in waters with low mineral content. Sodium content in groundwater ranges from about 1 ppm in humid and snow-fed region to over 100,000 ppm in brines. Groundwater in well drained areas with good amounts of rainfall usually has less than 10 to 15 ppm of sodium. The sodium concentration varies between 3.9 mg/l to 200 mg/l. The mean value of sodium is 50.88 mg/l. Median of the sodium concentration is 27 mg/l and standard deviation is 56.1488 mg/l. During the post-monsoon season the sodium concentration increases heavily especially in the downstream portion of the river. The concentration of potassium in groundwater varies between 0.6 mg/l and 236 mg/l and from 1 mg/l to 195 mg/l. The mean concentration varies between 41 mg/l and 50 mg/l during pre-monsoon and post-monsoon season respectively. The standard deviation is 71 mg/l. Potassium content is very high in the downstream area. The concentration of fluoride in groundwater does not exceed 10 mg/l. But water for drinking purposes containing 1 mg/l to 0.5 mg/l may cause mottled tooth enamel in children and adults. Concentration of fluoride is very high in the study area. The mean value of fluoride varies between 1.48 mg/l and 1.64 mg/l during pre-monsoon and post-monsoon. Standard deviation varies between 0.85 mg/l and 0.89 mg/l. In the study area, the groundwater show very high content of fluoride. There is a low level correlation between Potassium and fluoride.

For more details reader may refer unpublished NIH report of the year 2000-2001, entitled " Groundwater quality studies in Malaprabha Sub-basin".

### 7.3 Ground Water Modelling Studies

Use of Numerical models for Groundwater flow modelling in specific, has acquired lots of momentum in recent times. The reasons are manifold but two basic reasons are 1) Groundwater is no more a safe /unlimitted resource and 2) Upgradation of Computer Technology along with well documentation of Groundwater Models. Three Dimensional Finite Difference code MODFLOW generated by USGS is month best world wide.

Ghataprabha sub-basin of Krishna River basin in peninsular India is facing various ground water development problems. In some places water table is going down drastically due to unsafe exploitation of groundwater resources and on the other hand some places are becoming water logged due to faulty irrigation practices and lack of knowledge about ground water conditions. These problems have always been looked upon as isolated local problems in past which could yield a very limited solution.

Therefore a two layered Finite difference domain has been conceptualised and then calibrated and validated through 3 D-USGS model MODFLOW. The calibrated model has been successfully testified for various applications. Hence the model has been recommended as a useful tool for giving guidelines to various groundwater development activities and solution to hydrological problems in Ghataprabha sub-basin.

For more details reader may refer NIH Report No. CS(AR)-31/1996-97.

**Remarks**

Groundwater balance study carried out in Ghataprabha representative basin shows that the general tendency of the groundwater situation in this area is encouraging, since it is showing an increase trend, the reason for which may be the increase in the draft rate in pre-monsoon period over the years (1989-93). Further groundwater fluctuation also shows an increasing trend, which indicates that the long term availability of groundwater resources is increasing. Analysis for individual wells falling within the basin also shows that the water level increases over the study period, except for Nesari, where it shows decreasing trends.

Precipitation, which is the purest of natural waters, is the most dominant source of ground water recharge. The chemical composition of precipitation is, therefore, of considerable importance in understanding the chemistry of ground water. Substantial increase in concentration of dissolved salts may be brought about in the soil zone due to high evaporation rate. In general, a progressive change in the chemical character of the ground water is noticed from the point of recharge to point of discharge. During the prolonged contact of ground water with the reservoir rocks, physico-chemical processes lead towards attainment of equilibrium between the mobile constituents of the rock minerals and solutes in the ground water. The most striking change in the composition of ground waters, especially in semi-arid to arid regions is brought about by evaporation. Evaporation of ground water, in areas where the capillary fringe intercepts the land surface, cause salinisation of soils and formation of saline crusts, accompanied by concentration of dissolved solids. Progressively salts are precipitated in the reverse order of solubilities. Which of these will be precipitated is dependent upon the initial concentration of the salts and duration of evaporation and climatic factors. However, to conclude the reasons for salinisation, a detailed study is required.

Use of Numerical models for Groundwater flow modelling in specific, has acquired lots of momentum in recent times. A two layered Finite difference domain has been conceptualised and then calibrated and validated through 3 D-USGS model MODFLOW. The calibrated model has been successfully testified for various applications and found as a useful tool for giving guidelines to various groundwater development activities and solution to hydrological problems in this sub-basin.

## 8.0 Application of Remote Sensing and GIS Techniques

Watershed characteristics is a foremost task in any water resources development project. The conventional methods of watershed characterisation through ground based survey and aerial photographs are time consuming and costly. Also, it is difficult to get recent information from such surveys. Spatial variations of watershed parameters generate uncertainties about the point data collected by conventional method. Remote sensing which is an advance stage of development is becoming a versatile tool for such studies because of the accelerated speed, better accuracy, repeated measurements and synoptic coverage and finally an integrated data base. The synoptic view provided by satellite imagery gives information for the identification of broad geomorphic features, land use and water spread area. Since the data is repetitive it is possible to update the existing data base and base maps for use in various hydrologic purposes. Also, it is possible to study the integrated effects of various aspects of ecosystem and it is often possible to correlate the cause and effect of changes which are being monitored. These information could be suitably used as input to various hydrologic studies such as stream flow estimation.

It transpires from these stated advantages that remote sensing data provide an unique platform to study the land and water resources of a particular area region / catchment in its totality and as anentity. It helps to analyse the cause and effect relationship of land water resources management problems. As such, remote sensing data form a very viable data base for the various problems of hydrology, wherein a multidisciplinary approach is the essential pre-requisite.

In the field of water resources, satellite images are being routinely used in the identification/mapping of surface water bodies, monitoring their spread, preparation of hydro geomorphological maps leading to ground water prospect maps, identification of sites for rain water harvesting structures/recharges sites, water logged areas in the command areas etc. Lastly, remote sensing lends itself beautiful as a powerful, common visible input media representing the faithful reproduction of the natural features in the photographs and imagery and thereby encompassing the process of multi-disciplinary approach for assessment and planning of natural resources for integrated development.

With the above advantages of the remote sensing applications, numbers of related studies were undertaken in the Malaprabha and Ghataprabha representative basins, which are described below:

### 8.1 Hydrological – land use mapping

Knowledge of hydrologic land use pattern of any basin is very important because a record of surface cover characteristics can be used to define estimates of the quantity and quality of the water yield in response to a particular precipitation event or watershed treatment. The land use pattern in any basin is of dynamic nature and it influence to a greater extent the hydrological system of the basin. In general, the land use pattern is mainly depends upon physical attributes such as topography, soils and vegetation. In this study, IRS -1A images were used to map the land utilization pattern in these basins from the hydrological point of view. The visual interpretation technique is used for the analysis.

For details of the study reader may refer NIH Report No. CS 85.

### 8.2 Geomorphology

It is a well known fact that the climate and geomorphological characteristics of a basin affect its response to a considerable extent. Thus, linking of geomorphological parameters with hydrological characteristics of a basin provides a simple way to understand their hydrological behaviour. Quantitaive study of geomorphological parameters is pre-requisite for taking up hydrological simulation studies using these parameters. Various geomorphological parameters which have mostly been used by various investigator scan be broadly classified as those describing (1) Linear Aspect of channel system (2) Areal Aspect of channel system and (3) Relief Aspect of the basin. It is observed from the geomorphological parameters based on linear aspects that the Ghataprabha basin is more compact and well shaped as compared to Malaprabha basin. The low wandering ratio of Ghataprbha shows the travel time of runoff is less compared to Malaprbah basin. The lower values of watershed eccentricity for Ghataprabha indicate the greater compactness of the watershed and higher flood peaks are attained earlier than Malprabha for any given event of rainfall. The areal aspects found from the study reveal that constant of channel maintenance, which provides a quantitative expression of the minimum limiting area required to form unit length of the channel is very high for Ghataprabha basin and is about 50% more than that for Malaprabha. This indicates that the channel capacities of Ghataprabha should be large enough to carry higher discharges resulting from the bigger drainage areas. The equality of elongation ratios for both the basins and higher circularity ration for the Ghataprabha also indicate the larger amounts of flows in Ghataprabha than in Malaprabha. The parameters based on relief, which are most important in influencing the runoff and other hydrological process, indicates that the Ghataprabha catchment is steeper than the Malaprbha. The high basin relief of Ghataprabha is a measure of the higher potential energy available to move water and sediment downstream.

For detailed of the study reader may refer NIH Report No. CS-53.

**Remarks**

Knowledge of hydrologic land use pattern and geomorphological characteristics of any basin are very important for developing the hydrological models to simulate hydrological response of the basin. Such models are very useful and are being widely used for simulating hydrological response of ungauged basin or basin with limited data. Modern technique like remote sensing and GIS can provide useful information for hydrological modeling and monitoring. The model like USLE can be integrated in GIS and results can be produced in map form. Different scenarios can be applied and their effects can be analysed.

## 9.0 Recommendations

The followings are the some of the important recommendations based on the studies carried out in the representative basins and further requirements,

1. The hydrometeorological variables such as rainfall, temperature, humidity, wind speed etc. are measured from the field as a time series data. Many of these hydrological variables recorded are not directly used for purpose of hydrological modelling and analysis. These data are subjected to preliminary and secondary processing in order to ensure the quality of data and also bring them in the appropriate form required for the purpose of hydrological modelling. Therefore, to investigate the hydrological, hydrometeorological and physical characteristics of the basin for the purpose of hydrological modelling, it is necessary to carried out the studies like rating curves development for the gauging sites, processing of hydrological time series data using HYMOS software, methodology and computational step of the physical-statistical method to determine representative area per stream gauging station, guidelines for selection of stream gauging sites as well as spatial disaggregation of rainfall data to disaggregates the hydrological variables from larger temporal scale to smaller scale etc.

In order to provide the specific contents for the water year book, it is required to prepare the hydrological year book for both representative basins for number of years.

2. Hydrologic network serves an important and fundamental role in the scientific management of water resources. Ideally the network should themselves be designed as scientifically as possible. Network design for hard rock area requires a special attention, as the hydrological variations are quite drastic from place to place. For economic and optimum utilization of water resources, a determination of extent and availability of surface and ground water is the first requisite and this in term requires adequate hydrological and hydrometeorological data. Therefore, it is an essential to design the hydrological network for the hydrological data acquisition.

3. The correct and detailed information about soil properties is very crucial input for a physically based distributed model. Field investigation activities like infiltration test, land use and soil mapping, hydrological soil parameter estimation as well as river cross section were

carried out by the Institute with a view to improve the information about soil parameter values based on measurement campaign carried out at different locations in the representative basins. Which in turns would reduce the uncertainty about input parameters and consequently about the results of simulation models. The laboratory investigations like particle size analysis, field saturated hydraulic conductivity and soil moisture retention curve analyses were carried out based on the data acquired from field investigation. In addition to this, Land capability classification should be carried considereing several soil characteristics and associted land features. This will be very useful for further studies as well as this information will be useful for various government agencies and researchers working in this area.

4. Whenever the river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable estimates of design flood, water availability and other hydrological variables directly. In such situation, the regional approach are the alternative methods, which provide these estimates. Although a large number of hydrological simulation models have been developed in the past decades, yet often simplified modelling approaches are being used for predicting the hydrological behaviour of various catchments. The main problem in applying the advance hydrological modelling approaches viz. physically baesd or conceptual models in a developing country like India is non availability of adequate data for various catchments. In order to be able to apply models to ungauged catchments it is indispensable to develop tools for deriving model parameters from catchments characteristics like soil, geomorphology, geology, landuse and the climatological characteristics etc. Regionlisation has been employed for solving many hydrological problems. Regional flood frequency study has been carried out using the data of represnetaive basins. In addition to this, the regional unit hydrograph derivation and regional flow duration curves studies should be carried out for estimation of unit hydrographs for the basin.

5. Failure of open and borewells in many parts of the hard rock region are common phenomenons. This problem usually arises, either because of the over abstraction in existing wells or due to the failure in identifying the exact water bearing zones. As in the hard rock region water mainly exists in fracture and joint, locating such zones and predicting the flow processes is a difficult process. Hence, it is necessary to carried out such studies in thses

representative basins of hard rock region to investigate the hydrological failure of open and bore well.

6. Precipitation, which is the purest of natural waters, is the most dominant source of ground water recharge. The chemical composition of precipitation is, therefore, of considerable importance in understanding the chemistry of ground water. Substantial increase in concentration of dissolved salts may be brought about in the soil zone due to high evaporation rate. In general, a progressive change in the chemical character of the ground water is noticed from the point of recharge to point of discharge. During the prolonged contact of ground water with the reservoir rocks, physico-chemical processes lead towards attainment of equilibrium between the mobile constituents of the rock minerals and solutes in the ground water. The most striking change in the composition of ground waters, especially in semi-arid to arid regions is brought about by evaporation. Evaporation of ground water, in areas where the capillary fringe intercepts the land surface, cause salinisation of soils and formation of saline crusts, accompanied by concentration of dissolved solids. Progressively salts are precipitated in the reverse order of solubilities. Which of these will be precipitated is dependent upon the initial concentration of the salts and duration of evaporation and climatic factors. However, to conclude the reasons for salinisation, a detailed study is required in these representative basins.

7. Modern technique like remote sensing and GIS can provide useful information for hydrological modeling and monitoring. The model like USLE can be integrated in GIS and results can be produced in map form. In the field of water resources, satellite images are being routinely used in the identification/mapping of surface water bodies, monitoring their spread, preparation of hydro geomorphological maps leading to ground water prospect maps, identification of sites for rain water harvesting structures/recharges sites, water logged areas in the command areas etc. Hence, it is recommended to take studies based on remote sensing and GIS.

APPENDIX - I

**LIST OF TECHNICAL REPORTS BROUGH OUT BY THE INSTITUTE ON VARIOUS AREAS ON THE BASIS OF STUDIES CONDUCTED ON MALAPRABHA AND GHATA PRABAHA RIVER SUB BASINS.**

1. DATA PROCESSING AND ANALYSIS

   1. Hydrology Year Book Of Malaprabha Representative Basin (TR 144)
   2. Hydrology Year Book Of Ghataprabha Representative Basin(TR 151)

2. FIELD AND LABORATORY INVESTIGATIONS

   1. Infiltration Studies For The Representative Basin (CS 105)
   2. Infiltration Studies For Belgaum District (CS (AR) 145)
   3. Representative Basin Studies (Malaprabha upto Khanapur and Ghataprabha upto Daddi) (TR 178)
   4. Estimation of Surface Soil Properties In Malaprabha Command Area (CS (AR) 26)
   5. Computation of Water Surface Profiles Using HEC-River Analysis System (CS (AR) 30)

3. HYDROLOGICAL MODELLING

   1. Rainfall- Runoff Modelling of Western Ghat region of Karnataka (CS (AR) 31/98-99)
   2. Application of Rainflo Model in Malaprabha Catchment upstream Khanapur (TR 179)
   3. Application of Catchment Water Balance Model to the Malaprabha Basin, Karnataka (CS (AR 149)
   4. Application of ARNO, a Distributed Rainfall-Runoff Model to Malprabha Catchment ( Unpublished)
   5. Application of TOPMODEL to Malaprabha Catchments (CS (AR) 3/97-98)
   6. Soil Erosion Studies for the Forested Watersheds (Unpublished)

4. GROUNDWATER ANALYSIS, MODELLING AND WATER QUALITY ANALYSIS

1. Representative Basin Studies - Part 2:Estimation Of Groundwater Balance For Ghataprabha Basin (CS (AR) 176)
2. Groundwater Quality Studies in malaprabha Sub-basin (Unpublished)
3. Groundwater Modelling Of Ghataprabha Basin of Krishna River Basin (CS (AR 31/96-97)

5. FLOOD and DROUGHT STUDIES

1. Development of Regional Flood Formulae for Krishna Basin (Unpublished)
2. Hydrological Aspects of Drought up to 1998-99- a Case Study in Karnataka (CS 59)

6. APPLICATION OF REMOTE SENSING, GIS AND GEOMORPHOLOGY

1. Landuse Mapping Of Malaprabha And Ghataprabha Catchments ( CS 85/92-93)
2. Geomorphological Characteristics of Western Ghats, Part II: Ghataprabha and Malaprabha Basins (CS 53)

**LIST OF TECHNICAL PAPERS PUBLISHED/ACCEPTED FOR PUBLICATION/SENT FOR PUBLICATION BASED ON STUDIES CONDUCTED ON MALAPRABHA AND GHATA PRABAHA RIVER REPRESENTATIVE BASINS.**

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