United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

Global Hydrogeological Solutions

# Significance of Geomorphic Analysis of Watershed for Optimization of Recharge Structures


*Editors:*
*D.K. Chadha*
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**UNESCO, New Delhi**

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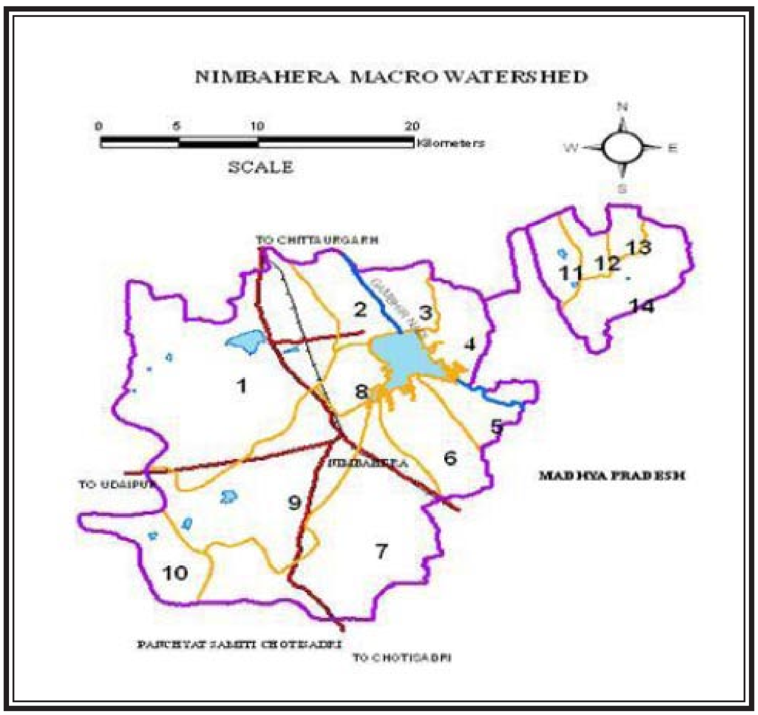


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United Nations
Educational, Scientific and
Cultural Organization

ISBN : 978-81-89218-40-9
First Impression : 2011
Published by : UNESCO, New Delhi
Printed at : Bal Vikas Prakashan Pvt. Ltd.

# FORWARD

Traditional wisdom has it that dire consequences result from continuously ignoring repeated cries for help by 'mother earth'. If not handled with care, land suffers from serious degradation and becomes acutely vulnerable to desertification that does not allow even a blade of grass to grow. Serious attention is never paid to these warning signs until consequences become too grave to ignore attention. This phenomenon is currently one of the most significant global environmental problems. It has life-threatening irreversible effects in the form of rendering land completely unproductive to sustain lives and livelihood.

Nearly 92% of the area in arid y is now affected by desertification. Such extreme conditions make everyday survival a challenge for the people in the region. Aridity and desertification threaten to worsen the present state of conditions.

As part of the Water for Life International Decade for Action 2005-2015, UNESCO has placed increasing emphasis on the urgent need for alternative sources of water in the arid regions around. Rainwater harvesting, in providing a source of water at the point of consumption, offers a number of solutions. Through its International Hydrological Programme (IHP) and for at least three decades, the organization has been involved in research, capacity building and partnership development in the field of rainwater harvesting. The Global Water and Development Information for Arid and Semi-Arid Areas (GWADI) initiative under the IHP, have explored possible applications of rainwater harvesting, and soil and water conservation technologies. Towards this, UNESCO has produced material for training and institutional capacity building, prepared policy briefs, and developed viable strategies for the successful promulgation of rainwater harvesting across the developing world.

UNESCO is publishing this book "Significance of Geomorphic Analysis of Watershed for the Optimization of Recharge Structures" under the GWADI initiative as an attempt to integrate geomorphic analysis and stream ordering into the rainwater harvesting initiative. The book presents technique for optimum utilization of the available runoff at different locations within the watershed based on stream ordering and geomorphic analysis of the drainage area. Aimed at prompting policy review and research as well as developing future strategies for implementing measures for water harvesting programmes, this book will be useful, both as a reference manual and a guidebook, for programme managers, students and field workers working on soil and water conservation or water resources development projects.

I would like to express my appreciation to the authors of the book for their scientific contribution and academic coordination.

United Nations
Educational, Scientific and
Cultural Organization

**Armoogum Parsuramen**

Director and UNESCO Representative to
Bhutan, India, Maldives and Sri Lanka

# PREFACE

The continuous increasing demand of water resources for various user sectors particularly for the irrigation, the ground water (which is the main contributor) development has reached to more than 230 BCM per year (2004) which has resulted in the decline of water table in about 15 % of the country's geographical area. The availability of non-committed monsoon run off in various river basins, amounting to 864 BCM, has encouraged the utilization of the surplus water for water conservation & recharge to ground water using various techniques & methods. The geomorphology of the area is the overall reflection of climate, geological formations, tectonic history of the area and other man made alterations over the area. The water conservation practices in hilly areas with different geomorphology & geological formations is mainly done by constructing cement plugs, check dams, anicuts etc across the different order of streams. India has ushered upon an era of water conservation/artificial recharge so as to overcome the water scarcity in many of the watersheds. These structures in many of the watershed areas have not been properly designed considering the various input parameters of the watershed. The Physiography & drainage play a vital role in identifying the realistic & effective number of conservation structures, locations, spacing & storage capacity of each structure. The geomorphic analysis has now become a useful tool in management of water resources in a watershed as it defines the type of water conservation & recharge structures which can be constructed across different order of streams.

The geomorphic analysis is used in many of the successful implementation of water shed management programs ; five case studies where the drainage characteristic & geomorphic analysis were taken into consideration for construction of check dams, anicuts, recharge to the ponds etc. are also given.

The present publication is a step towards disseminating the knowledge on the geomorphic analysis of a micro watershed so as to properly design and locate the conservation structures. This further helps in controlling the silt content in surface runoff resulting into longer life of harvesting structures. The categorization of stream order in to first, second, third orders etc. indicate the process of erosion and quantum of silt content in water. The run off potential; the bifurcation ratio indicates geomorphic control on the development of drainage pattern. The first few chapters cover the basic of the geomorphic analysis & the calculations made thereof for different type watersheds with different drainage density & shape. The book will be a good ready reckoned for those who are implementing the water conservation projects & also for those who are in teaching & conduct awareness programs on water conservation practices.

Dr. D.K. Chadha
Dr B. R. Neupane

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## Chapter 4: Conclusion

CHAPTER

1

# Introduction

## 1.1 Introduction

The demand of water resources continuously increases to maintain the food security that meets the demand of the population's domestic and industrial requirements. The existing water resources are not adequate to meet the demand. However, there is surplus monsoon runoff which can be harnessed for creating surface and sub-surface storages by constructing different structures along the different drainage lines. It thus becomes essential to study the regional characteristics of a watershed to calculate the potential runoff. The availability of non-committed runoff in the macro/micro watersheds and designing the conservation/recharge structures as per the order of drainage system (streams) need to be further ascertained. The construction of structures according to stream ordering and drainage area helps in optimum utilization of the available runoff at different locations within the watershed.

Topographical, geomorphological, hydrogeological, geological and hydrological conditions play an important role in the planning and implementation in the watershed development programme for water conservation and recharge. In order to combine the utilization of total runoff potential, location and construction of different types of water conservation recharge structures, the geomorphic analysis becomes imperative.

## 1.2. Watershed and Classification

A watershed is a natural hydrological topographic entity from which surface runoff flows to a defined drain, channel, stream or river at a particular point. It is also defined as a topographically delineated area that is drained by streams by a common outlet through which excess overload flow collected within the watershed is drained out.

Viewed from another angle a watershed is a natural unit of land, which collects water and drains through a common point by a system of drains. Hence it comprises a Catchment area (Recharge Zone), a Command area (Transition Zone) and a Delta area (Discharge Zone). Therefore a watershed is the area encompassing the catchments, command and delta area of a stream. The topmost portion of the watershed is known as the "ridge" and a line joining the ridge portions along the boundary of the watershed is called a "ridgeline". A watershed is thus a logical unit for planning optimal development of its soil, water and biomass resources. A watershed can be defined as the area of land that drains to a particular point along a stream. Each stream has its own watershed. Topography is the key element affecting this area of land. The boundary of a watershed is defined by the highest elevations surrounding the stream. A drop of water falling outside the boundary will drain to another watershed. Watersheds could be classified into several groups depending on the mode of classification.

## 1.2.1 Watershed

Watershed management is an integrated approach to natural resources management that aims at securing the livelihoods in the community. These approaches were pursued for the development of drought-prone areas, desert areas and for increasing food production in the rain-fed areas. For the past 25 years, watershed management has been promoted for natural resources management by the government (Union and State), non-government organizations (NGOs), bilateral donor agencies and international aid and lending agencies (FAO, UNDP and World Bank).

The need for watershed development arises owing to the poor performance of the agricultural front resulting in rampant poverty and unemployment in the rural areas. Watershed projects are a favorable alternative as most of the unskilled rural masses could be drawn into various activities leading to the improved agricultural scenario.

## 1.2.2 Importance of Macro Watershed Development

Macro watershed development involves development of land and water resources, improvement in the economic status of people and optimal resources use, and sustainable development of resources.

The main focus of development strategy is to minimize the risk to the farmers and to provide them with area-specific technological packages, inputs and services. Hence, the emphasis should be on small area improvement taking the macro watershed as a unit of development. The development measures undertaken in the macro watershed include soil and moisture conservation, land-shaping, bunding, construction of water harvesting structures; ground water recharges, structures and drainage line treatment structures. Development of water storage structures provides life-saving irrigation during moisture stress. It also helps in raising the water table to protect and enhance drinking water sources and to provide protective irrigation for at least one crop.

The Significance of Geomorphic Analysis of Watershed for Optimization of Recharge Structures

## 1.2.3 Nimbahera Watershed and Classification

On the basis of size and runoff volume the rates increase as the watershed size increases. The calculation of the peak rate of runoff is essential for designing erosion control structures and channels to carry maximum runoff.

### 1.2.3.1 According to Size Classification

| Region | Area (m ha) | Area (sq km) |
|---|---|---|
| 1. Water Resources Region | 55 | 5.5 lakhs |
| 2. Basin | 9.5 | 95,000 |
| 3. Catchment | 3.0 | 30,000 |
| 4. Sub catchments | 0.7 | 7,000 |
| 5. Watershed | 0.1 | 1,000 |
| 6. Large watershed | more than 2000 ha | 20 |
| 7. Mini (macro) watershed | 500 ha to 2000 ha | 5 to 20 |
| 8. Micro watershed | not more than 500 ha | < 5 |

### 1.2.3.2 Based on Drainage Classification

A watershed is broadly related to its drainage pattern, stream density and drainage density. The stream density of a watershed is the number of streams per unit area. Drainage density indicates the drainage efficiency of the basin

High stream density = high undulation terrain

High drainage density = well developed network and high runoff

Low drainage density = mode of low runoff and high permeable terrain.

### 1.2.3.3 Based on Shape Classification

Long and narrow watersheds are likely to have a longer time for flow of water in downstream areas and lower rates of transport of sediments as well as water while a rectangular shape will have a shorter time period.

Fan-shaped (near circular)

Fern-shaped (elongation)

The shape of a watershed is important because it controls the time for the run off. The runoff water to travel from the further point of a watershed to the outlet is known as the time of concentration (Tc).

The Significance of Geomorphic Analysis of Watershed for Optimization of Recharge Structures.

Watersheds may also be classified in several categories --

- Hilly or flat watershed
- Humid watershed
- Aried watershedh
- Red soil watershed
- Black soil watershed

According to the watershed point of view: Watersheds can be divided into three types on the basis of land use pattern .

1. First Type - located at high elevation of river catchments consisting predominant of forest.

2. Second Type - such watersheds are largely inhabited by tribal communities. The management aspects will have to focus on an optimum development of land use.

3. Third Type - watershed lands are under settled cultivation.

On the basis of upper specification Nimbahera macro watershed falls under these categories

**Size** - area -- 72846 ha (large watershed)

**Shape** - Each tributary is different and the discharge at the outlet is distributed over a long period (elongation watershed)

**Drainage** - moderate to low runoff and high permeable terrain (low drainage density)

**Soil and terrain** - hilly and flat watershed.

**Land use pattern** - tribal community (second type)

CHAPTER

2

# Drainage Classification

## 2.1 Drainage Classification

Geomorphologists and hydrologists often view streams as being part of drainage basins. A drainage basin is the topographic region from which a stream receives runoff, through flow, and groundwater flow. Drainage basins are divided from each other by topographic barriers called a watershed .A watershed represents all the stream tributaries that flow to some location along the stream channel. The number, size, and shape of the drainage basins found in an area vary with the scale of examination. Drainage basins are arbitrarily based on the topographic information available on a map.

Trellised drainage patterns tend to develop where there is strong structural control on streams because of geology. In such situations, channels align themselves parallel to structures in the bedrock with minor tributaries coming in at right angles. Areas with tectonic faults or bedrock joints can cause streams to take on a grid-like or rectangular pattern. Parallel drainage patterns are often found in areas with steep relief or where the flow is over non-cohesive materials. Dendritic patterns are typical of adjusted systems on erodable sediments and uniformly dipping bedrock. Deranged drainage patterns are found in areas recently disturbed by events like glacial activity or volcanic deposition. Over time, the stream will adjust the topography of such regions by transporting sediment to improve the flow and channel pattern.

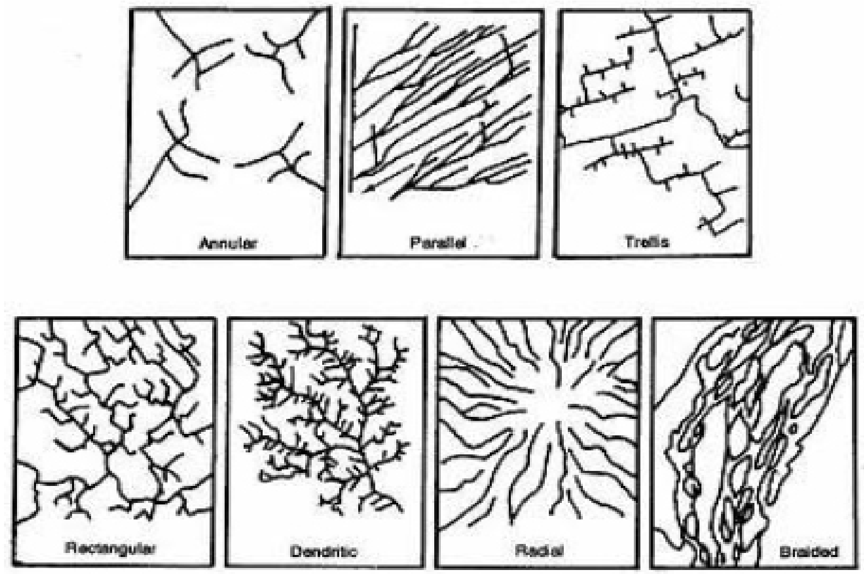



**Figure 1:** General Classification of Drainage Pattern Types in a Watershed

| Classification of Drainage Patterns | Significance |
|---|---|
| Dendritic | Horizontal sediments or uniformly resistant crystalline rocks; gentle regional slope at present or during drainage inception |
| Parallel | Moderate to steep slopes; also in areas of parallel elongate landforms |
| Trellis | Dipping or folded sedimentary, volcanic, or low-grade met sedimentary rocks; areas of parallel fractures |
| Rectangular | Joints and/or faults at right angles; streams and divides lack regional continuity |
| Radial | Volcanoes, domes, and residual erosion features |
| Annular | Structural domes and basins, diatremes, and possibly stocks |

**Table 1:** Classification of Drainage Patterns and Significance

## 2.2 Geomorphologic Features of Macro Watershed

Recurrence of drought conditions, limited water resources and soil erosion are the main environmental hazards in the area. Soil erosion is mostly from rivers and nullahs during the rainy season. The nature of soil erosion varies from erosion to gully erosion.

The ground water potential of Nimbahera indicates the area is over exploited or critical both in the command and non command areas. The ground water scenario at present has no scope for development unless remedial measures are taken on a large scale.

In order to combat this impact on environmental hazards, soil and water conservation measures like contour bunding and graded bunding, construction of

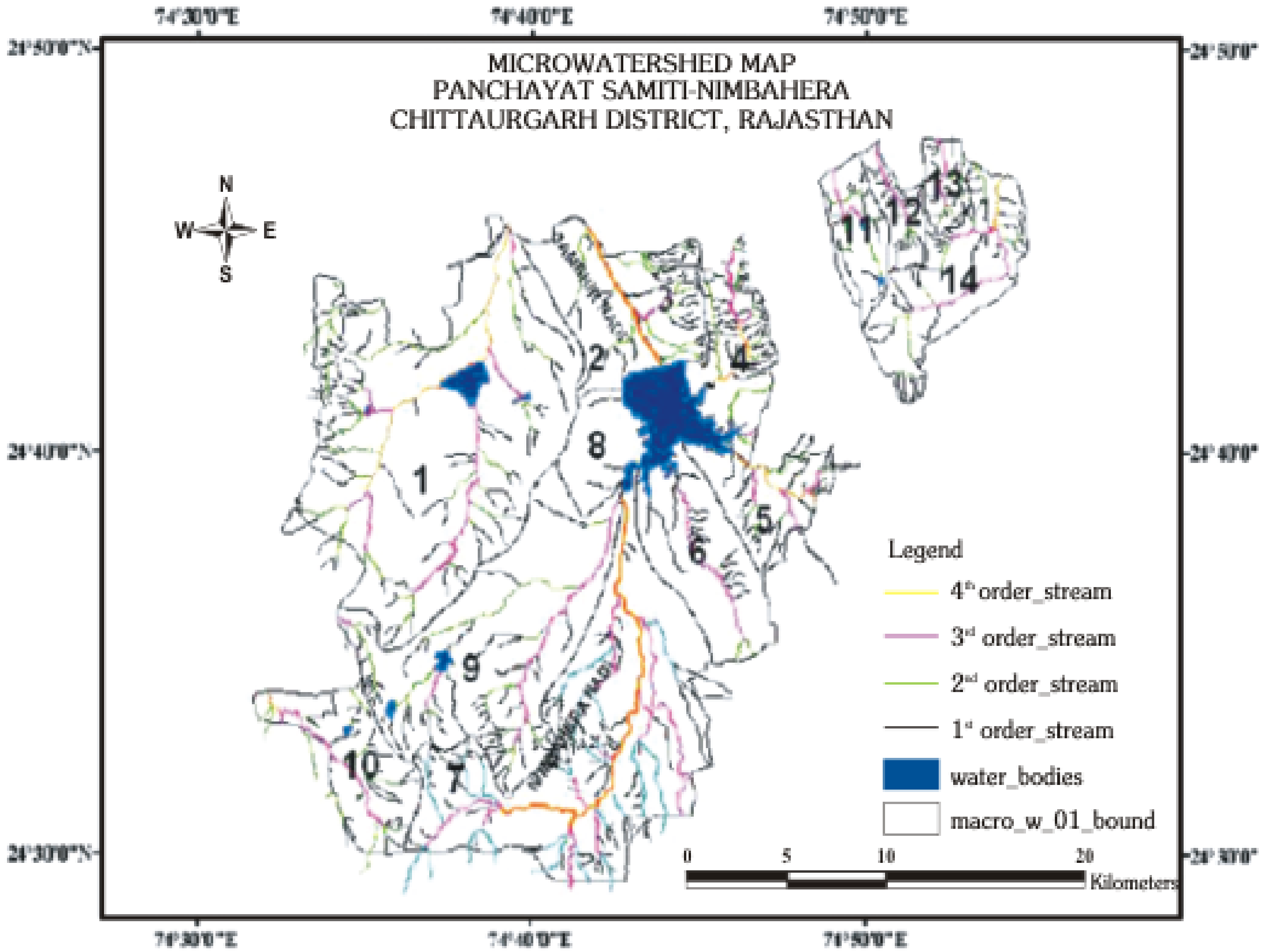



**Figure 2:** Drainage Map of Nimbahera Watershed

irrigation and drainage outlets, pasture development, terracing, land levelling, construction of irrigation channels and check dams were initiated.

### 2.2.1 Drainage Basin

The geometry of a basin is formed by continuous discharge through stream courses over a period of time. The stream flow is a function of the channel length, shape and size of the drainage basin, slope of the basin, stream slope, channel roughness, infiltration capacity of the basin and other parameters. The above mentioned parameters are all geometrically oriented and may be broadly classified as:

### 2.2.2 Linear Aspects

The basin characteristics falling under the linear category have been taken up for evaluation, viz. stream order, bifurcation ratio, elongation ratio, form factor and circulatory ratio.

#### A. Stream Order

The first step in drainage basin analysis is to designate the order of streams. There are two systems of assigning order (a) European system and (b) American.

The European system designates the main stream or trunk segment as first order and extreme tributaries as the highest order, whereas in the American system the finger tip tributaries are designated as first order and the trunk segment as the highest order. In this study, the American system has been followed in designating the stream order, as this has an added advantage because the order number is directly proportional to the size of the basin, channel dimensions and to stream discharge at that place in the system.

Small finger tip tributaries are classified as order No.1. Those streams which have branches only of the first order are classified as second order. In other words a second order stream is formed when two first order streams meet. The third streams are those which have branches of only second and lower orders. In other words, when two streams of second order join; a third order stream is formed (Fig. 3).

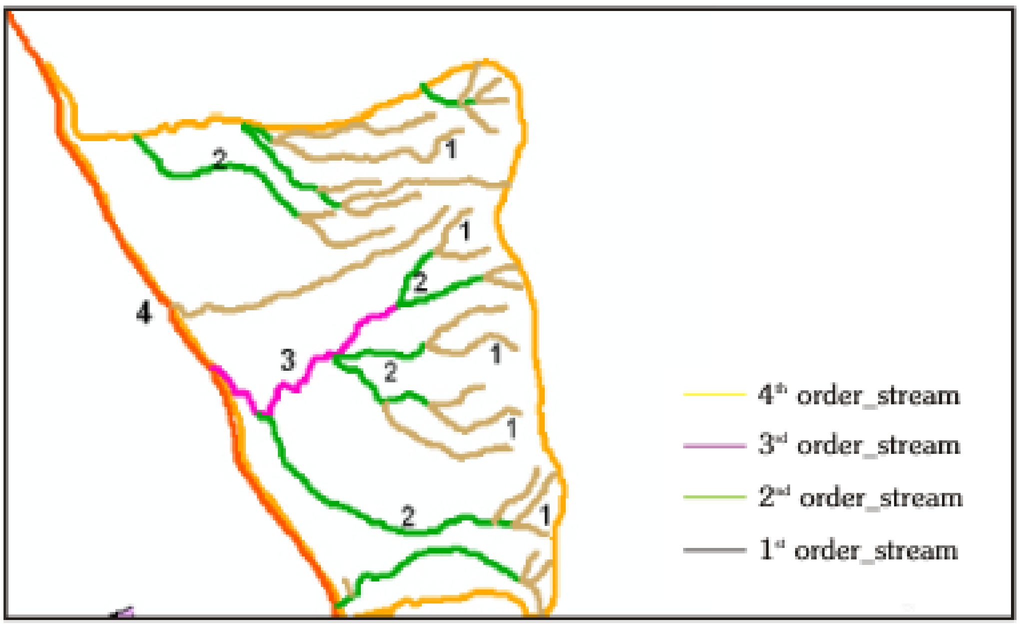



**Figure 3:** Stream Order Classification in a Micro Watershed.

### B. Bifurcation Ratio ($R_b$)

The ratio between the numbers of stream segments of a given order ($N_u$) to the number of the next highest order ($N_u$ +1) is termed as bifurcation ratio. Thus

$$R_b = N_u / N_u+1$$

This parameter gives us an idea of the shape of the basin and also helps us to know the runoff behaviour. The bifurcation ratio will not be exactly the same from one order to the next because of the possibility of the change in watershed geometry, but will tend to be a constant throughout the series. In Table 4 each macro watershed gives the bifurcation ratio worked out on the arithmetic averages.

Bifurcation ratios characteristically range between 3 and 5 for watersheds in which geological structure does not distort the drainage pattern. If the bifurcation ration is more than 5, it suggests structural control on development of drainage pattern. In the micro watershed area the bifurcation rated of more than 5 was not observed in any of the micro watersheds suggesting that the geological structure has no control over the development of drainage pattern. The theoretical minimum possible value (assuming that a hypothetical basin has 2 first order streams and 1 second order stream to give a bifurcation ratio of 2 .0) (Figure 4).

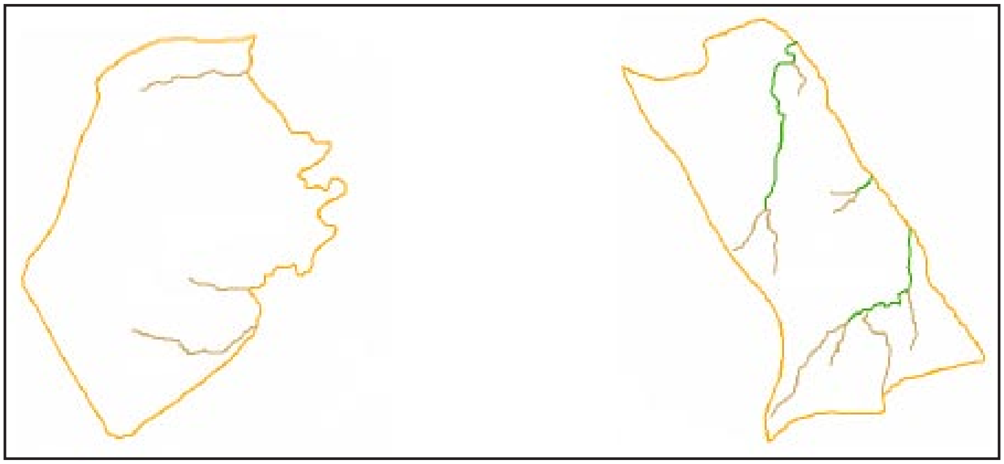


**Figure 4:** Bifurcation Ratios in Micro Watersheds

### *2.2.3 Areal Aspects*

**A. Stream Frequency (F)**

A drainage basin is defined as the number of stream segments per unit area, thus

$$F = N_s / Au$$

Where $N_s$ is the total number of streams

$A_u$ is the catchments area in kmss$^2$

Both drainage density and stream frequency measure the texture of the drainage net. Low drainage density indicates relatively long overland travel of surface water and possibilities of high recharge and low surface runoff. The high drainage density is a remarkable characteristic feature of the impermeable sub-surface material. It also indicates sparse vegetation, high mountainous relief and low ground water recharge. The areas having lower drainage density is favourable to take up artificial recharge schemes. It reflects the hydro geological characteristics of underlying rock formation. A small number of relatively longer stream length suggest that rock formation is permeable, while a large number of small stream lengths suggest that the area is not permeable and not feasible for recharge. In such areas water harvesting structures are feasible.

**B. Elongation Ratio ($R_e$)-**

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum length.

$$R_e = (2 \sqrt{A_u} / \pi / Lbmax$$

Where $A_u$ is the area in kms$^2$

Lbmax is the basin length in kmss

The ratio generally ranges from 0.6 to 1.0. The basins with the values of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes, whereas the values in the range of 0.8 to 1.0 are typical of regions with low relief.

**C. Drainage Density ($D_d$ )**

The drainage density ($D_d$) is defined as the average length of streams per unit area within the basin. It is an indicator for structural framework of underlying formations. It is also an indicator for the time of travel of runoff. The low drainage density indicates more seepage, and less runoff.

Thus $(D_d) = \Sigma L / A_u$

Where $\Sigma L$ is the total length of streams in kmss

$A_u$ is the area of the drainage basin in kmss$^2$

### D. Circulatory Ratio ($R_c$)

It is defined as the ratio of the basin area ($A_u$) to the area of the circle having the same perimeter as the basin.

$$R_c = 4 \Pi A_u / P2$$

Where $A_u$ is the area in $kmss^2$

P is the perimeter in kmss

The shape of a drainage basin mainly governs the rate at which water is supplied to the main stream as it flows along its course from the source to the mouth. Long and narrow basins with a high bifurcation ratio are expected to have low discharges over a long time, whereas round basins with a low bifurcation ratio would be expected to have sharp peaked flood discharge.

### E. Form Factor ($R_f$)

It is defined as the ratio of area ($A_u$) of the basin to the square of the basin length (Lb), thus

$$R_f = A_u / L_b^2$$

## 2.3 Analytical Parameters of Macro Watershed

### 2.3.1 Stream Order

We can count the number of stream and number of structures on stream. For stream length we use the Alto meter. And measure the length in $kms^2$ unit.

### 2.3.2 Area

Using data of watershed.

### 2.3.3. Perimeter

Using the Alto meter we measure perimeter length in $kms^2$ unit.

### 2.3.4 Flow Direction (slope)

Slope calculates using contour interval and distance.

For example :—

Contour interval = 20 m

Distance = 12 kms

Then, 12 kms = 20 m slope

1 kms = 20/12 = 1.6 m i.e. 1 kms /1.6 m

### 2.3.5 Bifurcation Ratio ($R_b$)

The ratio between the numbers of stream segments of a given order ($N_u$) to the number of the next highest order ($N_u$ +1) is termed as bifurcation ratio. Thus $Rb = N_u / N_u+1$

Find out value :—

N1/N2 = No. of stream, first order/ No. of stream, second order

N2/N3 = No. of stream, second order/ No. of stream, third order

N3/N4 = No. of stream, third order/ No. of stream, fourth order

N1 + N2 + N3

N2 N3 N4

Avg = 3

Now using for each micro watershed Bifurcation ratio formula $Rb = N_u / N_u+1$ and put value.

Example:-In macro watershed No.1 there are 24 micro watersheds in which 68 first order stream, 30 second order streams, 10 third order streams and 2 fourth order streams and Average Bifurcation ratio is 2.82.

### 2.3.6. Stream Length Ratio

2/1 = second order stream length/first order stream length

3/2 = third order stream length/second order stream length

4/3 = fourth order stream length/third order stream length

2 + 3 + 4

1 2 3

Avg =

3

Example:-In macro watershed No.1 there are 24 micro watersheds in which 81.5 first order stream length, 33.5 second order stream length, 34.65 third order stream length and 17.0 fourth order stream length and average stream length ratio is. 0.86.

### 2.3.7. Drainage Density ($D_d$)

$D_d = \Sigma L / A_u$

Where $\Sigma L$ is the total length of streams in kmss

$A_u$ is the area of the drainage basin in kmss$^2$

1 (Dd) = L Au = 2.5/1.5 =1.6

2 (Dd) = L Au = 2.0/2.42 = 0.8

3 (Dd = L Au = 2.5/2.10 = 1.1

4 (Dd = L Au = 0/3.4 = 0.0

5 (Dd) = L Au = 5.0/4.92 = 1.01

6 (Dd) = L Au = 6.5/2.72 = 2.38

7 (Dd) = L Au = 6.75/4.40 = 1.53

8 (Dd) = L Au = 4.4/3.12 = 1.41

9 (Dd) = L Au = 17.5/12.80 = 1.36

10(Dd) = L Au = 6.0/8.72 = 0.68

11(Dd) = L Au = 24.0/13.60 = 1.76

12(Dd) = L Au = 8.0/5.72 = 1.39

13(Dd) = L Au = 10.0/3.2 = 3.12

14(Dd) = L Au = 3.0/3.6 = 0.83

15(Dd) = L Au = 0.0/3.07 = 0.0

16(Dd) = L Au = 1.5/2.52 = 0.59

17(Dd) = L Au = 6.0/3.17 = 1.89

18(Dd) = L Au = 1.0/3.47 = 0.28

19(Dd) = L Au = 17.0/6.28 = 2.70

20(Dd) = L Au = 8.5/6.55 = 1.29

21(Dd) = L Au = 8.0/13.40 = 0.59

22(Dd) = L Au =3.0/4.40 = 0.68

23(Dd) = L Au = 11.0/8.65 =1.27

24(Dd) = L Au = 8.5/8.87 = 0.95

### 2.3.8. Stream Frequency (F)

$F = N_s / Au$

Where $N_s$ is the total number of streams

$A_u$ is the catchments area in kms

1 F = Ns Au = 2/1.5 =1.3

2 F = Ns Au = 2/2.42 = 0.8

3 F = Ns Au = 2/2.10 = 0.9

4 F = Ns Au = 0/3.40 = 0.0

5 F = Ns Au = 4/4.92= 0.8

6 F = Ns Au = 4/2.72 = 1.47

7 F = Ns Au = 5/4.40 = 1.13

8 F = Ns Au = 4/3.12 = 1.28

9 F = Ns Au = 14/12.80 = 1.09

10 F = Ns Au = 3/8.72 = 0.34

11 F = Ns Au = 18/13.60 = 1.32

12 F = Ns Au = 5/5.72 = 0.87

13 F = Ns Au= 10/3.2 = 3.1

14 F = Ns Au = 1/3.6 = 0.27

15 F = Ns Au = 0/3.07 = 0.0

16 F = Ns Au = 2/2.52 = 0.79

17 F = Ns Au = 6/3.17 = 1.98

18 F = Ns   Au = 1/3.47 = 0.28

19 F = Ns   Au = 6/6.28 = 0.95

20 F = Ns   Au = 2/6.55 = 0.30

21 F = Ns   Au = 8/13.40 = 0.59

22 F = Ns   Au = 1/4.40 = 0.22

23 F = Ns   Au = 5/8.65 = 0.57

24 F = Ns   Au = 4/8.87 = 0.45

### 2.3.9. Form Factor ($R_f$)

It is defined as the ratio of area ($A_u$) of the basin to the square of the basin length (Lb), thus

$$R_f = A_u / L_b^2$$

1 Rf = Au   Lb2 = 1.5/3.65*3.65 = 0.12

2 Rf = Au   Lb2 = 2.42/2.65*2.65 = 0.38

3 Rf = Au   Lb2 = 2.10/3.3*3.3 = 0.05

4 Rf = Au   Lb2 = 3.40/3.75*3.75 = 0.27

5 Rf = Au   Lb2 = 4.92/4.1*4.1 = 0.30

6 Rf = Au   Lb2 = 2.72/3.6*3.6 = 0.22

7 Rf = Au   Lb2 = 4.40/3.4*3.4 = 0.48

8 Rf = Au   Lb2 = 3.12/2.8*2.8 = 0.49

9 Rf = Au   Lb2 = 12.80/9.25*9.25 = 0.15

10 Rf = Au   Lb2 = 8.72/6.3*6.3 = 0.24

11 Rf = Au   Lb2 = 13.60/7.5*7.5 = 0.32

12 Rf = Au   Lb2 = 5.72/7.5*7.5 = 0.21

13 Rf = Au   Lb2 = 3.2/4.0*4.0 = 0.2

14 Rf = Au   Lb2 = 3.6/3.75*3.75 = 0.29

15 Rf = Au   Lb2 = 3.07/3.5*3.5 = 0.19

16 Rf = Au   Lb2 = 2.52/2.5*2.5 = 1.12

17 Rf = Au   Lb2 = 3.17/3.7*3.7 = 0.35

18 Rf = Au   Lb2 = 3.47/4.5*4.5 = 0.38

19 Rf = Au   Lb2 = 6.28/8.0*8.0 = 0.11

20 Rf = Au   Lb2 = 6.55/6.0*6.0 = 0.18

21 Rf = Au   Lb2 = 13.40/4.0*4.0 = 0.83

22 Rf = Au   Lb2 = 4.40/4.25*4.25 = 0.21

23 Rf = Au   Lb2 = 8.65/9.5*9.5 = 0.13

### 2.3.10. Circulatory Ratio ($R_c$)

$$R_c = 4\ \Pi\ A_u / P2$$

Where $A_u$ is the area in $kms^2$

P is the perimeter in kms

1 Rc = 4 II Au   P2 = 4*3.14*1.5/7.0*7.0 = 0.38

2 Rc = 4 II Au   P2 = 4*3.14*2.42/4.50*4.50 = 1.50

3 Rc = 4 II Au   P2 = 4*3.14*2.10/5.0*5.0 =1.05

4 Rc = 4 II Au   P2 = 4*3.14*3.40/8.0*8.0 = 0.66

5 Rc = 4 II Au   P2 = 4*3.14*4.92/10.0*10.0 = 0.61

6 Rc = 4 II Au   P2 = 4*3.14*2.72/8.5*8.5 = 0.47

7 Rc = 4 II Au   P2 = 4*3.14*4.40/9.0*9.0 = 0.68

8 Rc = 4 II Au   P2 = 4*3.14*3.12/5.65*5.65 = 1.29

9 Rc = 4 II Au   P2 = 4*3.14*12.80/20.05*20.05 = 0.39

10 Rc = 4 II Au   P2 = 4*3.14*8.72/8.0*8.0 = 1.71

11 Rc = 4 II Au   P2 = 4*3.14*13.60/24.0*24.0 = 0.29

12 Rc = 4 II Au   P2 = 4*3.14*5.72/18.0*18.0 = 0.20

13 Rc = 4 II Au   P2 = 4*3.14*3.2/11.0*11.0 = 0.33

14 Rc = 4 II Au   P2 = 4*3.14*3.6/10.0*10.0 = 0.45

15 Rc = 4 II Au P2 = 4*3.14*3.07/9.5*9.5 = 0.42

16 Rc = 4 II Au P2 = 4*3.14*2.52/6.5*6.5 = 0.74

17 Rc = 4 II Au P2 = 4*3.14*3.17/13.0*13.0 = 0.23

18 Rc = 4 II Au P2 = 4*3.14*3.47/10.0*10.0 = 0.43

19 Rc = 4 II Au P2 = 4*3.14*6.28/20.0*20.0 = 0.19

20 Rc = 4 II Au P2 = 4*3.14*6.55/16.0*16.0 = 0.32

21 Rc = 4 II Au P2 = 4*3.14*13.40/12.0*12.0 = 1.16

22 Rc = 4 II Au P2 = 4*3.14*4.40/12.5*12.5 = 0.35

23 Rc = 4 II Au P2 = 4*3.14*8.65/21.0*21.0 = 0.24

24 Rc = 4 II Au P2 = 4*3.14*8.87/16.5*16.5 = 0.40

### 2.3.11. Elongation Ratio ($R_e$)

$R_e = (2 \sqrt{A_u}/\pi / Lbmax)$

Where $A_u$ is the area in kmss$^2$

Lbmax is the basin length in kmss

1 Re = (2 Au / Lbmax = (2 1.5/3.14/3.65 = 0.37

2 Re = (2 Au / Lbmax = (2 2.42/3.14/2.65 = 0.66

3 Re = (2 Au / Lbmax = (2 2.10/3.14/3.3 = 0.49

4 Re = (2 Au / Lbmax = (2 3.40/3.14/3.75 = 0.55

5 Re = (2 Au / Lbmax = (2 4.92/3.14/4.1 = 0.61

6 Re = (2 Au / Lbmax = (2 2.72/3.14/3.6 = 0.51

7 Re = (2 Au / Lbmax = (2 4.40/3.14/3.4 = 0.69

8 Re = (2 Au / Lbmax = (2 3.12/3.14/2.8 = 0.71

9 Re = (2 Au / Lbmax = (2 12.80/3.14/9.25 = 0.43

10 Re = (2 Au / Lbmax = (2 8.72/3.14/6.3 = 0.51

11 Re = (2 Au / Lbmax = (2 13.60/3.14/7.5 = 0.55

12 Re = (2 Au / Lbmax = (2 5.72/3.14/7.5 = 0.34

13 Re = (2 Au / Lbmax = (2 3.2/3.14/4.0 = 0.50

14 Re = (2 Au / Lbmax = (2 3.6/3.14/3.75 = 0.57

15 Re = (2 Au / Lbmax = (2 3.07/3.14/3.5 = 0.56

16 Re = (2 Au / Lbmax = (2 2.52/3.14/2.5 = 0.71

17 Re = (2 Au / Lbmax = (2 3.17/3.14/3.7 = 0.54

18 Re = (2 Au / Lbmax = (2 3.47/3.14/4.5 = 0.46

19 Re = (2 Au / Lbmax = (2 6.28/3.14/8.0 = 0.35

20 Re = (2 Au / Lbmax = (2 6.55/3.14/6.0 = 0.47

21 Re = (2 Au / Lbmax = (2 13.40/3.14/4.0 = 1.03

22 Re = (2 Au / Lbmax = (2 4.40/3.14/4.25 = 0.55

23 Re = (2 Au / Lbmax = (2 8.65/3.14/9.5 = 0.34

24 Re = (2 Au / Lbmax = (2 8.87/3.14/7.5 = 0.44

## 2.3.12. Basin Length

Using the Alto meter we measure the maximum basin length in sq kms unit.

## *2.3.13. Relief Aspects*

**A. Relief**

Relief is the elevation difference between any two reference points. Maximum relief within a region of a given boundary is simply the elevation difference between the highest and the lowest points.

**B. Elevation**

Mean elevation is equal to $a_i e_i / a_u$

Where "$a_i$" is the area between the two contours in $kmss^2$

"$e_i$" is the average elevation of the area "$a_i$" in m

"$A_u$" is the total area of the drainage in $kmss^2$

**C. Slope of the Channel**

The slope of a stream between any two points is taken as the total fall divided by the stream length. The elevations of the originating point and outlet point of the stream have been determined.

All these parameters determine the characteristics of the area based on which different water conservation / artificial recharge to groundwater structures need to be planned. As the type of the structures like gabion structure, contour bunding, and different types of check dams depends upon the stream collecting the drainage of all the six basins have been classified with different stream ordering and their total length determined for developing a groundwater management plan.

The water development plan depends on the aquifer's sustainability and quantity of run off potential for conservation in different macro watersheds.

## 2.4. Characteristics of Macro Watershed

In order to plan the construction of different types of recharge and conservation structures, it is important to study the characteristics of the watershed and undertake the drainage basin analysis. Each individual watershed has a number of distinct characteristics, which affects its functioning with respect to receiving and disposal of water. The principal factors influencing watershed operations are:

## 2.4.1. Physiography

**A. Shape**

Long and narrow watersheds are likely to have a longer time for flow of water in downstream areas and lower rates of transport of sediments as well as water while a rectangular shape will have a shorter time period.

**B. Size**

The size of the watershed is an important parameter in determining the peak rate of runoff. Both runoff and volume rates are higher as the watershed size increases. The calculation of peak rate of runoff is essential for designing structures, erosion control and channels to carry maximum runoff.

**C. Land slope**

The speed and extent of runoff depend on the slope of land .The greater the slope the greater is the velocity of runoff water.

D. Geology and Soils

The type of soils and geology influences the amount of water, which will be absorbed by the soil. The soil character also determines the amount of silt, which will be washed down in water harvesting structures and the valleys below.

E. Rainfall

The amount and time of precipitation is a most important factor, which determines the fate of the watershed.

H. Drainage Density and Pattern

Refers to the design of the stream courses and their tributaries. It is influenced by the slope of the land, lithology and structure. It affects the runoff pattern. If there is high drainage density then the runoff water will drain quickly. Thus it will have less opportunity to soak into the soil.

In order to demonstrate the usefulness of the Geomorphic Analysis, Nimbahera watershed has been identified for understanding the stream ordering, delineating macrowatershed, their drainage area, runoff potential and number of artificial recharge structures to be constructed.

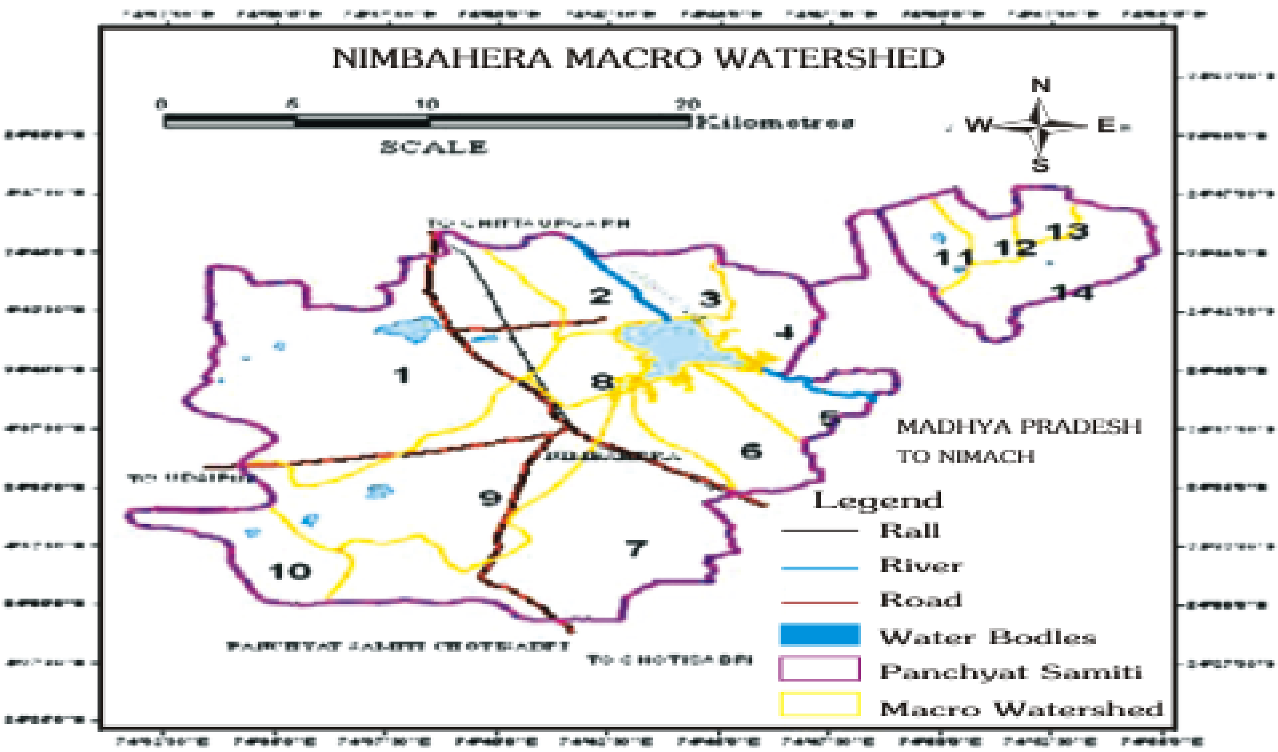



**Figure 5:** Delineation of Different Macro Watersheds

F. Vegetation Cover

The type and quality of vegetative cover on watershed land influences the infiltration rates, erosion and sediment production and rate of evapotranspiration.

G. Land Use

The land use affects rates of runoff infiltration, types and quality of the vegetation cover.

Nimbahera watershed consists of 14 macro watersheds (Figure 5). These macro watersheds are further divided into 125 micro watersheds.

To show on a drainage map macro watersheds and numbering of micro watersheds on one of the macro watersheds. Macro watershed No.1 with 24 micro watersheds and calculating different parameters and detailed morphometric analyses of the watersheds are as separate chapter.

CHAPTER

# 3

# Morphometric Analyses Of The Watersheds

## 3.1 Macro Watershed No. 1

This is one of the largest watersheds with an area of 132.15 sq kmss. It comprises 24 micro watersheds with an average area of 5.64 sq kmss (564 Ha). There are 68 first order streams, 30 second order streams, 10 third order streams and 2 fourth order streams with a total length of 81.5, 33.5, 34.65, and 17.0 kmss respectively. The average bifurcation ratio of stream order is 0.70. The drainage density is 1.21 with stream frequency of 0.86. The total length of watershed is 22.5 kms, while the periphery is 52.5 kms. The average slope is 1.33 m/kms. The elongation ratio is 0.53 while the form factor is 0.30 and the circulatory ratio is 0.60. Considering average catchment, the total catchment yield of surface water is 13.7 mcm, while harvesting potential is 10.27 mcm (75 per cent of total yield). Details of the micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 2 and 3 and Figure 6.

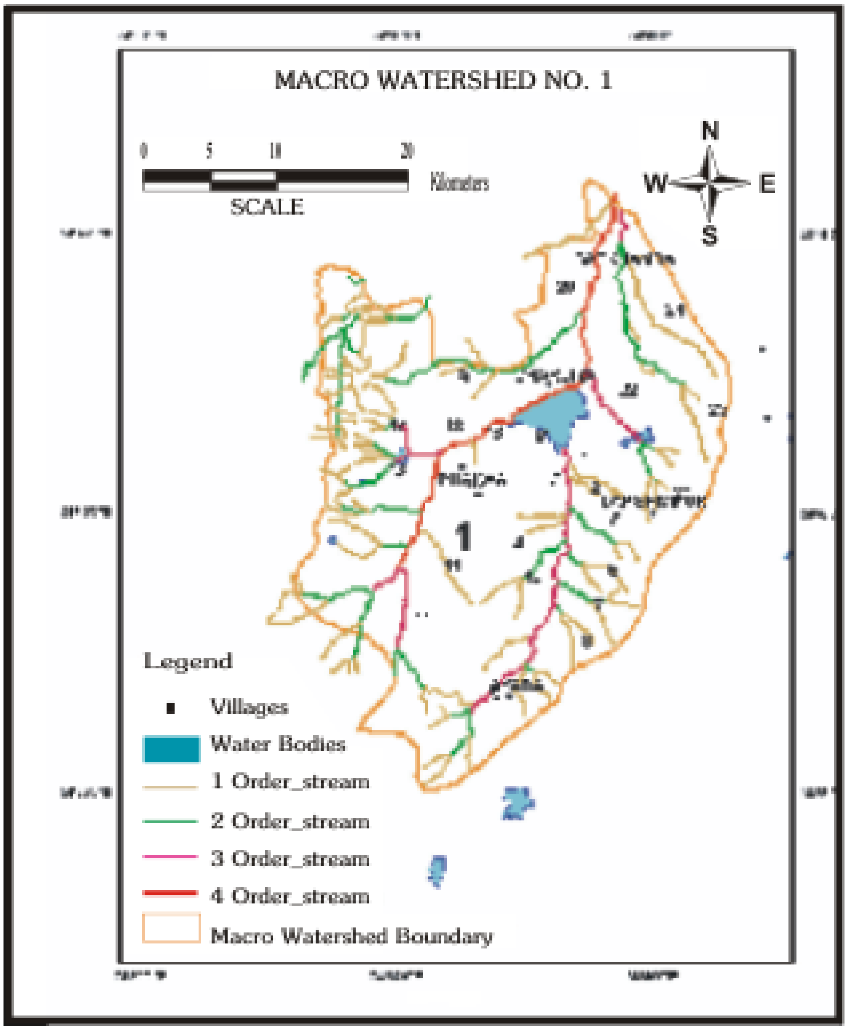



**Figure 6:** Drainage Classification of Macro Watershed No.1

## Classification Based on Shape :—

Morphological Characteristics of Watershed 1

| | | |
|---|---|---|
| Size [area] | - | 132.15 sq kms |
| Geology | - | Quartzite, Khardeola sandstone, Bhagwanpura limestone, Sava sandstone, Parli sandstone, Kalmia sandstone, Binota shale, Jircon and Bari (Nimbahera) shale. |
| Runoff | - | 13.70 mcm |
| Vegetation | - | very high |
| Land use | - | high |
| Shape | - | polygon shape |

**Table 2:** Morphometric Analysis of Macro Watershed No.01

| Micro Watershed No. | Ist order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms$^2$ | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 1 | 2 | - | - | Co.9 | 0.5 | - | - | 1.5 | 7 | NW |
| 2 | 1 | 1 | - | - | Co.9 | 1 | - | - | 2.42 | 4.5 | NW |
| 3 | 2 | 2.5 | 1 | 4.5 | - | - | - | - | 2.1 | 5 | N |
| 4 | - | - | - | - | - | - | - | - | 3.4 | 8 | NE |
| 5 | 2 | 2 | 1 | 2 | Co.9 | 1 | - | - | 4.92 | 10 | NW |
| 6 | 2 | 3 | 1 | 1 | Co.9 | 2.5 | - | - | 2.72 | 8.5 | NW |
| 7 | 3 | 4 | 1 | 2 | Co.9 | 0.75 | - | - | 4.4 | 9 | NWW |
| 8 | 2 | 3 | 1 | 0.5 | Co.9 | 0.9 | - | - | 3.12 | 5.65 | NW |
| 9 | 10 | 10.5 | 3 | 3 | 1 | 4 | - | - | 12.8 | 20.05 | NE |
| 10 | 2 | 3.5 | 1 | 2.5 | 1 | 2 | - | - | 8.72 | 8 | NE |
| 11 | 10 | 10 | 5 | 7.5 | 2 | 4.5 | 1 | 2 | 13.6 | 24 | N |
| 12 | 4 | 2.5 | 1 | 3 | - | - | Co.11 | 2.5 | 5.27 | 18 | N |
| 13 | 7 | 5.5 | 2 | 3 | 1 | 1.5 | - | - | 3.2 | 11 | NE |
| 14 | 1 | 3 | - | - | - | 1 | 1 | 1.5 | 3.6 | 10 | NW |
| 15 | - | - | - | - | - | - | - | - | 3.07 | 9.5 | NE |
| 16 | - | - | - | - | - | - | Co.11 | 1.5 | 2.52 | 6.5 | NE |
| 17 | 4 | 4 | 2 | 0.5 | 1 | 1.5 | - | - | 3.17 | 13 | SE |
| 18 | 1 | 1 | - | - | - | - | - | - | 3.47 | 10 | SE |
| 19 | 4 | 4 | 8 | 1 | 1 | 2 | Co.11 | 5 | 6.28 | 20 | NNE |
| 20 | 1 | 4 | - | - | - | - | Co.11 | 4.5 | 6.55 | 16 | NE |
| 21 | 5 | 5 | 2 | 2.5 | 1 | 0.5 | - | - | 13.4 | 12 | NW |
| 22 | - | - | - | - | - | 3 | - | - | 4.4 | 12.5 | NW |
| 23 | 4 | 5 | - | - | 1 | 6 | - | - | 8.65 | 21 | NW |
| 24 | 2 | 6 | 1 | 0.5 | 1 | 2 | - | - | 8.87 | 16.5 | NW |
| TOTAL | 68 | 81.5 | 30 | 33.5 | 10 | 34.65 | 2 | 17 | 132.15 | 285.7 | |

Co = Continuous stream

**Table 3: Geomorphic Analysis of Macro Watershed No.1**

| Micro watershed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drainage density in kms/$kms^2$ | Frequency/ kms2 | Form-factor | Circulatory ratio | Elongation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 1.5 | 1 | 2.5 | - | - | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 1.3 | 0.12 | 0.38 | 0.37 | 3.65 |
| 2 | 2.42 | 1 | 2.0 | - | - | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.38 | 1.50 | 0.66 | 2.65 |
| 3 | 2.10 | 3 | 7.0 | - | - | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.95 | 0.05 | 1.05 | 0.49 | 3.3 |
| 4 | 3.40 | - | - | - | - | - | - | 0.0 | 0.0 | 0.0 | 0.0 | - | - | 0.27 | 0.66 | 0.55 | 3.75 |
| 5 | 4.92 | 3 | 5.0 | 2.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.5 | 0.0 | 0.5 | 1.01 | 0.81 | 0.30 | 0.61 | 0.61 | 4.1 |
| 6 | 2.72 | 3 | 6.5 | 2.0 | 1.0 | 0.0 | 1.0 | 0.3 | 2.5 | 0.0 | 0.9 | 2.38 | 1.47 | 0.22 | 0.47 | 0.51 | 3.6 |
| 7 | 4.40 | 4 | 6.75 | 3.0 | 1.0 | 0.0 | 1.3 | 0.5 | 0.3 | 0.0 | 0.2 | 1.53 | 1.13 | 0.48 | 0.68 | 0.69 | 3.4 |
| 8 | 3.12 | 3 | 4.4 | 2.0 | 1.0 | 0.0 | 1.0 | 0.1 | 1.8 | 0.0 | 0.6 | 1.41 | 1.28 | 0.49 | 1.29 | 0.71 | 2.8 |
| 9 | 12.80 | 14 | 17.5 | 3.33 | 3.0 | 0.0 | 2.11 | 0.2 | 1.3 | 0.0 | 0.5 | 1.36 | 1.09 | 0.15 | 0.39 | 0.43 | 9.25 |
| 10 | 8.72 | 4 | 8.0 | 2.0 | 0.0 | 0.0 | 0.66 | 0.1 | 0.0 | 0.0 | 0.2 | 0.68 | 0.34 | 0.24 | 1.71 | 0.51 | 6.5 |
| 11 | 13.60 | 18 | 24 | 2.0 | 2.5 | 2.0 | 2.16 | 0.7 | 0.6 | 0.4 | 0.5 | 1.76 | 1.32 | 0.32 | 0.29 | 0.55 | 7.5 |
| 12 | 5.27 | 5 | 8.0 | 4.0 | 0.0 | 0.0 | 1.33 | 1.2 | 0.0 | 0.0 | 0.4 | 1.51 | 0.9 | 0.21 | 0.20 | 0.34 | 7.5 |
| 13 | 3.2 | 10 | 10 | 3.5 | 2.0 | 0.0 | 1.83 | 0.5 | 0.5 | 0.0 | 0.3 | 3.12 | 3.12 | 0.2 | 0.33 | 0.50 | 4.0 |
| 14 | 3.6 | 2 | 5.5 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.83 | 0.27 | 0.29 | 0.45 | 0.57 | 3.75 |
| 15 | 3.07 | - | - | - | - | - | - | 0.0 | 0.0 | 0.0 | 0.0 | - | - | 0.19 | 0.42 | 0.56 | 3.5 |
| 16 | 2.52 | - | 1.5 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.59 | 0.79 | 1.12 | 0.74 | 0.71 | 2.5 |
| 17 | 3.17 | 7 | 6.0 | 2.0 | 2.0 | 0.0 | 0.66 | 0.1 | 3.0 | 0.0 | 1.04 | 1.89 | 1.89 | 0.35 | 0.23 | 0.54 | 3.7 |
| 18 | 3.47 | 1 | 1.0 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.28 | 0.28 | 0.38 | 0.43 | 0.46 | 4.5 |
| 19 | 6.28 | 13 | 12 | 4.0 | 0.0 | 0.0 | 1.33 | 2.0 | 0.0 | 0.0 | 0.6 | 2.70 | 0.95 | 0.11 | 0.19 | 0.35 | 8.0 |
| 20 | 6.55 | 1 | 8.5 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 1.29 | 0.30 | 0.18 | 0.32 | 0.47 | 6.0 |
| 21 | 13.40 | 8 | 7.5 | 2.5 | 2.0 | 0.0 | 1.5 | 0.5 | 0.2 | 0.0 | 0.2 | 0.59 | 0.59 | 0.83 | 1.16 | 1.03 | 4.0 |
| 22 | 4.40 | - | 3.0 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.68 | 0.22 | 0.21 | 0.35 | 0.55 | 4.25 |
| 23 | 8.65 | 5 | 11.0 | 0.0 | 0.0 | 0.0 | - | 0.0 | 0.0 | 0.0 | 0.0 | 1.27 | 0.57 | 0.13 | 0.24 | 0.34 | 9.5 |
| 24 | 8.87 | 4 | 8.5 | 2.5 | 1.0 | 0.0 | 1.0 | 0.08 | 4.0 | 0.0 | 1.3 | 0.95 | 0.45 | 0.12 | 0.40 | 0.44 | 7.5 |
| TOTAL | 132.15 | 110 | 166.15 | | | | 16.88 | | | | | 29.36 | 20.82 | 7.34 | 14.49 | 12.94 | 119.2 |

## 3.2 Macro Watershed No. 2

This watershed having an area of 21.17 sq kms. comprises 4 micro watersheds with an average area of 5.32 sq kms. There are 9 first order streams; 4 second order streams, no third and fourth order streams with a total length of 21 and 6 kms respectively. The average bifurcation ratio of stream order is 2.25. The drainage density is 0.95 with stream frequency of 0.61. The total length of watershed is 8.5 kms, while the periphery is 21.5 kms. The average slope is 1.88 m/kms. The elongation ratio is 0.65, while the form factor is 0.41 and the circulatory ratio is 0.59. Considering average catchment, the total catchment yield of surface 3.2 Macro Watershed No. 2

This watershed having an area of 21.17 sq kms. comprises 4 micro watersheds with an average area of 5.32 sq kms. There are 9 first order streams; 4 second order streams, no third and fourth order streams with a total length of 21 and 6 kms respectively. The average bifurcation ratio of stream order is 2.25. The drainage density is 0.95 with stream frequency of 0.61. The total length of watershed is 8.5 kms, while the periphery is 21.5 kms. The average slope is 1.88 m/kms. The elongation ratio is 0.65, while the form factor is 0.41 and the circulatory ratio is 0.59. Considering average catchment, the total catchment yield of surface water is 2.20 mcm; while the harvesting potential is 1.65 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 4 and 5 and Figure 7.

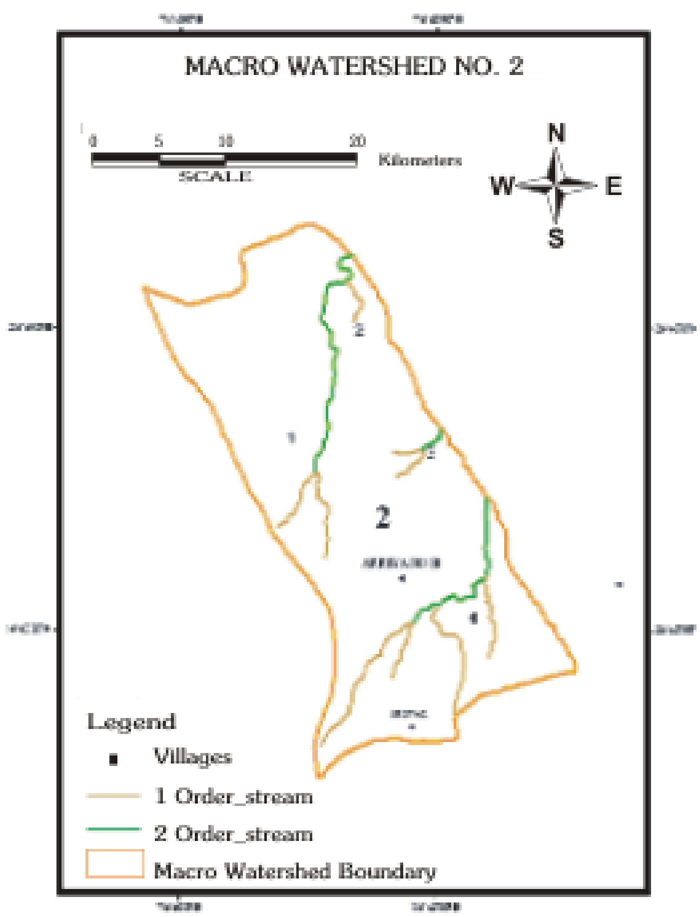



**Figure 7:** Drainage Classification of Macro Watershed No.2.

### Classification Based on Shape :-

Morphological Characteristics of Watershed-2

Size [area] – 21.17 sq kms

Geology – Nimbahera limestone and Suket shale

Runoff – 2.20 mcm

Vegetation – low Land use – low

Shape – rectangular shape

**Table 4:** Morphometric Analysis of Macro Watershed No.2

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in $kms^2$ | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 2 | 2.5 | 1 | 3 | - | - | - | - | 7.35 | 17 | N |
| 2 | 1 | 1 | - | - | - | - | - | - | 1.4 | 4 | N |
| 3 | 2 | 10 | 1 | 0.5 | - | - | - | - | 4.22 | 11 | NE |
| 4 | 4 | 7.5 | 2 | 2.5 | - | - | - | - | 8 | 13 | NE |
| TOTAL | 9 | 21 | 4 | 6 | | | | | 21.17 | 45 | |

Co = continuous stream

**Table 5:** Geomorphic Analysis of Macro Watershed No. 2

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/$kms^2$ | Frequ-ency/ kms2 | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 7.55 | 3 | 5.5 | 2.0 | - | - | 2.0 | 1.2 | - | - | 1.2 | 0.79 | 0.39 | 0.22 | 0.32 | 0.53 | 5.8 |
| 2 | 1.40 | 1 | 1.0 | - | - | - | - | - | - | - | - | 1.78 | 0.71 | 0.35 | 1.09 | 0.44 | 2 |
| 3 | 4.22 | 3 | 10.5 | - | - | - | - | - | - | - | - | 0.71 | 0.71 | 0.46 | 0.43 | 0.77 | 3 |
| 4 | 8.0 | 6 | 10.0 | 2.0 | - | - | 2.0 | 0.3 | - | - | - | 0.52 | 0.75 | 0.61 | 0.59 | 0.88 | 3.6 |
| TOTAL | 21.17 | 13 | 27.0 | | | | 4.0 | | | | 1.2 | 3.8 | 2.56 | 1.64 | 2.43 | 2.62 | 14.4 |

## 3.3 Macro Watershed No. 3

This watershed having an area of 22.65 sq kms. comprises 3 micro watersheds with an average area of 7.55 sq kms. There are 28 first order streams, 8 second order streams and 1 third order stream with a total length of 27.5, 13.0 and 2.0 kms respectively. The average bifurcation ratio of stream order is 3.5. The drainage density is 0.65 with stream frequency of 1.49. The total length of watershed is 7.5 kms, while the periphery is 20.0 kms. The average slope is 1.33 m/kms. The elongation ratio is 0.71 while the form factor is 0.40 and the circulatory ratio is 0.78. Considering average catchment, the total catchment yield of surface water is 2.35 mcm; while harvesting potential is 1.76 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 6 and 7 and Figure 8.

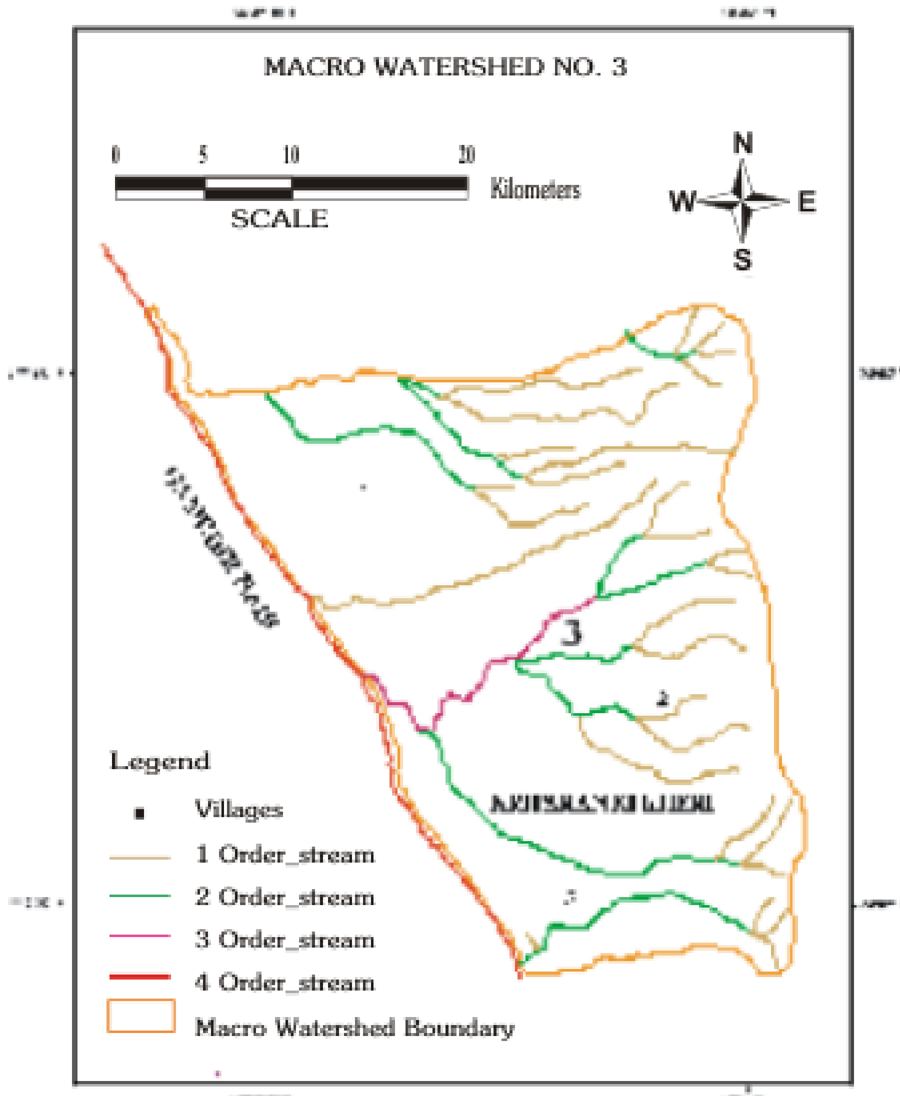



**Figure 8:** Drainage Classification of Macro Watershed No. 3.

### Classification Based on Shape :-

Morphological Characteristics of Watershed 3

Size [area] – 22.65 sq kms

Geology – Kamur sandstone and Suket shale.

Runoff – 2.35 mcm

Vegetation – very high

Land use – low

Shape – polygon shape

**Table 6:** Morphometric Analysis of Macro Watershed No.3

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms² | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 12 | 15.5 | 4 | 5 | - | - | - | - | 11.5 | 11 | NW |
| 2 | 12 | 11 | 3 | 5.5 | 1 | 2 | - | - | 7.65 | 11.5 | W |
| 3 | 4 | 1 | 1 | 2.3 | - | - | - | - | 3.5 | 11 | W |
| TOTAL | 28 | 27.5 | 8 | 13 | 1 | 2 | | | 22.65 | 33.5 | |

Co = continuous stream

**Table 7:** Geomorphic Analysis of Macro Watershed No. 3

| Micro water-shed No. | Area (kms²) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/kms² | Frequ-ency/kms2 | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 11.5 | 16 | 11.5 | 3.0 | - | - | 3.0 | 0.3 | - | - | 0.32 | 0.43 | 1.39 | 0.46 | 1.19 | 0.76 | 5.0 |
| 2 | 7.65 | 17 | 7.65 | 4.0 | 3.0 | - | 3.5 | 2 | 0.36 | - | 0.43 | 0.52 | 2.09 | 0.47 | 0.79 | 0.78 | 4.0 |
| 3 | 3.50 | 5 | 3.5 | 4.0 | - | - | 4.0 | 0.5 2.5 | - | - | 2.5 | 1.0 | 1.42 | 0.28 | 0.36 | 0.60 | 3.5 |
| TOTAL | 22.65 | 38 | 22.65 | | | | 10.5 | | | | 3.25 | 1.95 | 4.48 | 1.21 | 2.34 | 2.14 | 12.5 |

## 3.4 Macro Watershed No. 4

This watershed having an area of 24.23 sq kms. comprises 4 micro watersheds with an average area of 6.06 sq kms. There are 37 first order streams, 9 second order streams and 3 third order streams and 1 fourth order stream with a total length of 34.5, 11.5, 7.5 and 6.0 kms respectively. The average bifurcation ratio of stream order is 3.9. The drainage density is 0.85 with stream frequency of 1.6. The total length of watershed is 7.0 kms, while the periphery is 23.0 kms. The average slope is 1.71 m/kms. The elongation ratio is 0.61, while form factor is 0.31 and circulatory ratio is 0.57. Considering average catchment, the total catchment yield of surface water is 2.52 mcm; while harvesting potential is 1.89 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 8 and 9 and Figure 9.

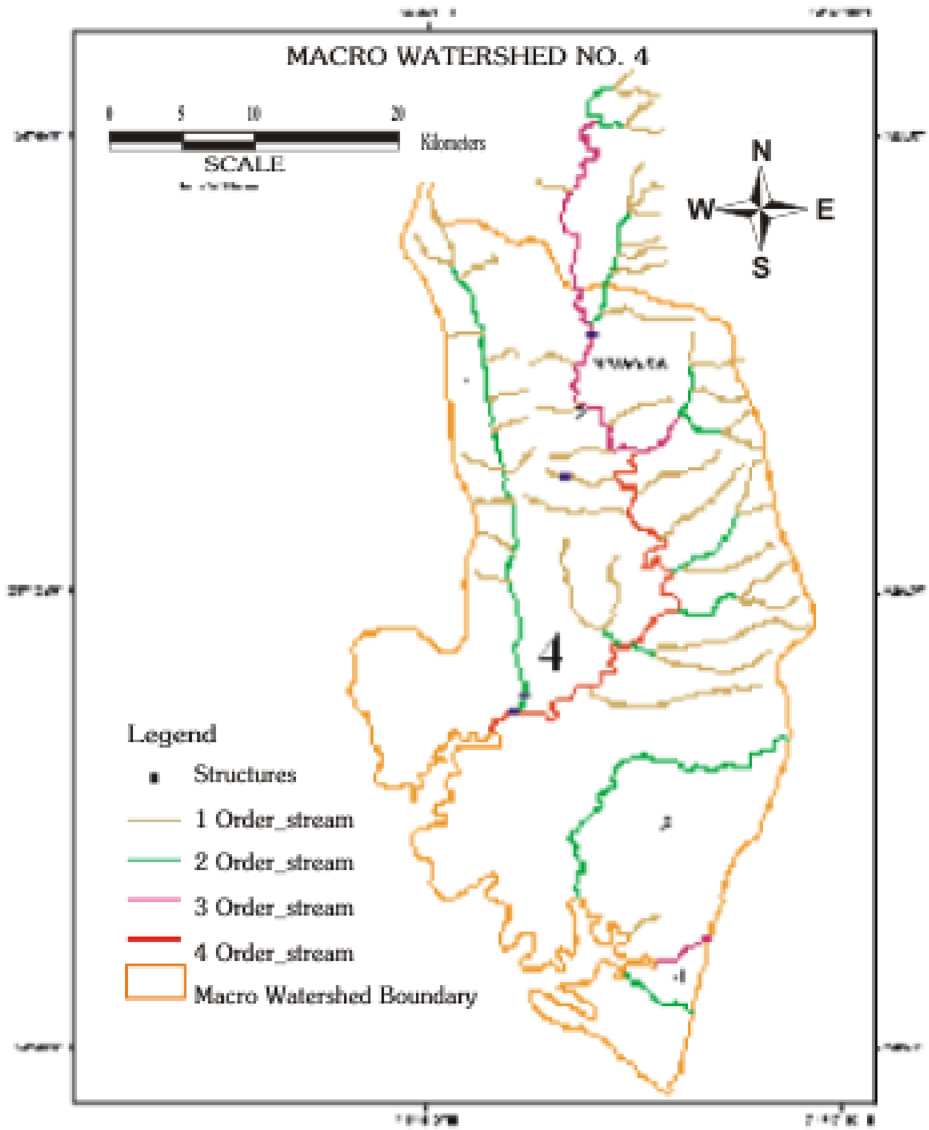



**Figure 9:** Drainage Classification of Macro Watershed No. 4.

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 4

Size [area] – 24.23 sq kms

Geology – Kamur sandstone and Suket shale

Runoff – 2.52 mcm

Vegetation – medium

Land use – medium to high

Shape – fern leaf- shape

**Table 8:** Morphometric Analysis of Macro Watershed No.4

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in $kms^2$ | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 12 | 12 | 1 | 5 | - | - | - | - | 5.5 17 | 17 | S |
| 2 | 24 | 22 | 7 | 5 | 2 | 2.5 | 1 | 6 | 10.98 | 13 | SW |
| 3 | - | - | - | - | 1 | 5 | - | - | 5.7 | 8.5 | SW |
| 4 | 1 | 0.5 | 1 | 1.5 | - | - | - | - | 2.05 | 9 | W |
| TOTAL | 37 | 27.5 | 9 | 13 | 3 | 7.5 | 1 | 6 | 24.23 | 47.5 | |

Co = continuous stream



**Table 9:** Geomorphic Analysis of Macro Watershed No. 4

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/ $kms^2$ | Frequ-ency/ kms2 | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 5.5 | 12 | 17 | 12.0 | - | - | 12.0 | 0.41 | - | - | 0.41 | 0.95 | 2.36 | 0.2 | 0.23 | 0.50 | 5.25 |
| 2 | 10.98 | 34 | 29.5 | 3.4 | 3.5 | 2.0 | 2.97 | 0.22 | 0.5 | 2.4 | 1.04 | 0.54 | 3.09 | 0.30 | 0.81 | 0.62 | 6.0 |
| 3 | 5.7 | 1 | 5.0 | 1.0 | - | - | 1.0 | - | - | - | - | 0.61 | - | 0.46 | 0.99 | 0.76 | 3.5 |
| 4 | 2.05 | 2 | 2.0 | - | - | - | - | - | - | - | - | 1.31 | 0.97 | 0.28 | 0.31 | 0.59 | 2.7 |
| TOTAL | 24.23 | 50 | 53.5 | | | | 15.97 | | | | 1.45 | 3.41 | 6.42 | 1.24 | 2.34 | 2.47 | 17.45 |

## 3.5 Macro Watershed No. 5

This watershed having an area of 23.99 sq kms. comprises 3 micro watersheds with an average area of 8.01 sq kms. There are 20 first order streams, 6 second order streams 3 third order streams and 1 fourth order stream with a total length of 18.0, 6.0, 4.5 and 8.0 kms respectively. The average bifurcation ratio of stream order is 1.38. The drainage density is 2.09 with stream frequency of 1.08. The total length of watershed is 7.0 kms, while the periphery is 20.0 kms. The average slope is 1.43 m/kms. The elongation ratio is 1.67, while the form factor is 1.25 and circulatory ratio is 0.61. Considering average catchment, the total catchment yield of surface water is 2.50 mcm; while the harvesting potential is 1.88 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 10 and 11 and Figure 10.

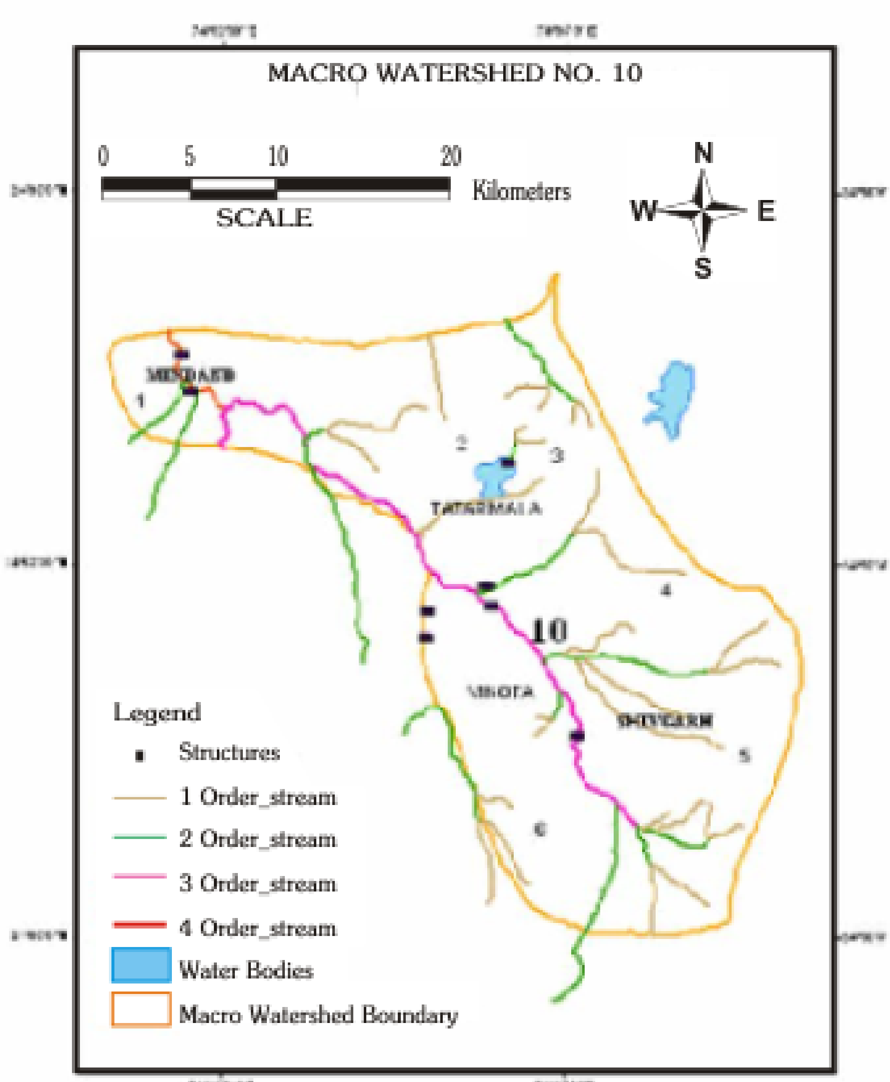



**Figure 10:** Drainage Classification of Macro Watershed No. 5.

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 5

Size [area] – 23.99 sq kms

Geology, rock and soil – Nimbahera limestone and Suket shale

Runoff – 2.50 mcm

Vegetation – medium

Land use – very low

Shape – triangular shape

**Table 10:** Morphometric Analysis of Macro Watershed No.5

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in $kms^2$ | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 2 | 3 | - | - | - | - | Co3 | 4 | 6.27 | 13 | NE |
| 2 | 8 | 4.5 | 2 | 2 | 1 | 1.25 | Co3 | 1 | 6.72 | 10 | NE |
| 3 | 10 | 10.5 | 4 | 4 | 2 | 3.25 | 1 | 3 | 11.05 | 16 | N |
| TOTAL | 20 | 18 | 6 | 6 | 3 | 4.5 | 1 | 8 | 23.09 | 39 | |

Co = continuous stream



**Table 11:** Geomorphic Analysis of Macro Watershed No. 5

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/$kms^2$ | Frequ-ency/$kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 6.27 | 2 | 7.0 | - | - | - | - | - | - | - | - | 1.11 | 0.31 | 1.29 | 0.46 | 1.28 | 2.2 |
| 2 | 6.72 | 11 | 8.75 | 4.0 | 2.0 | - | 2.0 | 0.44 | 0.62 | 0.8 | 0.62 | 1.30 | 1.63 | 0.30 | 0.84 | 0.62 | 4.7 |
| 3 | 11.05 | 17 | 20.75 | 2.5 | 2.0 | 2.0 | 2.16 | 0.38 | 0.81 | 0.92 | 0.70 | 3.86 | 1.53 | 2.18 | 0.54 | 0.54 | 2.2 |
| TOTAL | 23.99 | 30 | 36.5 | | | | 4.16 | | | | 1.32 | 6.27 | 3.47 | 3.77 | 1.84 | 3.12 | 9.1 |

## 3.6 Macro Watershed No 6

This watershed having an area of 31.14 sq kms comprises 6 micro watersheds with an average area of 5.22 sq kms. There are 14 first order streams, 4 second order streams and no third order stream with a total length of 18.5, 5.0 and 12.0 kms respectively. The average bifurcation ratio of stream order is 1.5. The drainage density is 1.23 with stream frequency of 0.74. The total length of watershed is 11.5 kms, while the periphery is 26.0 kms. The average slope is 1.30 m/kms. The elongation ratio is 0.38, while the form factor is 0.22 and circulatory ratio is 0.82. Considering average catchment, the total catchment yield of surface water is 3.26 mcm; while the harvesting potential is 2.44 mcm (75per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 12 and 13 and Figur

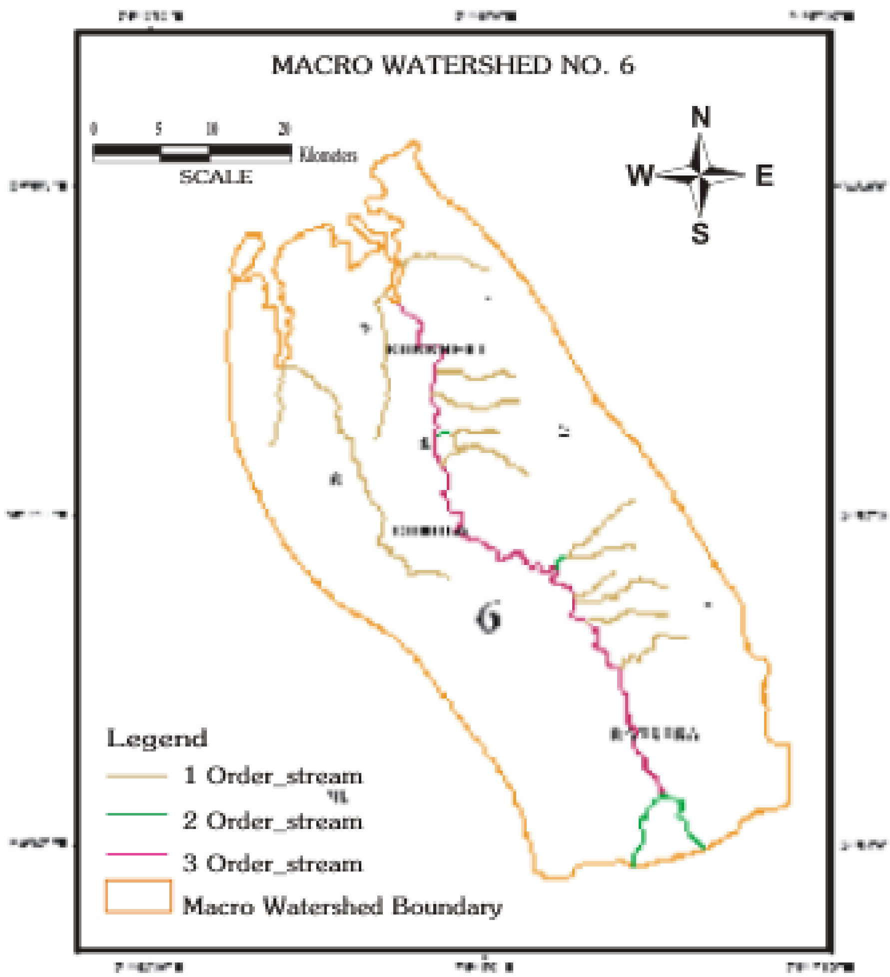



**Figure 11:** Drainage Classification of Macro Watershed No.6

### Classification Based on Shape :-

Morphological Characteristics of Watershed-6

Size [area] – 31.14 sq kms

Geology – Bari (Nimbahera) shale and Nimbahera limestone

Runoff – 3.26 mcm

Vegetation – medium

Land use – very low

Shape – rectangular shape

**Table 12:** Morphometric Analysis of Macro Watershed No. 6

| Micro Watershed No. | 1st order stream | | $2^{nd}$ order stream | | $3^{rd}$ order stream | | $4^{th}$ order stream | | Area in $kms^2$ | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 1 | 2.5 | - | - | Co.3 | 4.5 | Co.3 | - | 2.55 | 5 | NW |
| 2 | 4 | 5 | 1 | 0.5 | Co.3 | 3 | Co.3 | - | 5.5 | 8 | NW |
| 3 | 6 | 4.5 | 2 | 2 | - | 4.5 | 1 | - | 9.2 | 1.5 | - |
| 4 | - | - | - | - | - | - | - | - | 1.2 | 5 | - |
| 5 | 1 | 2.5 | - | - | - | - | - | - | 5.27 | 7.5 | N |
| 6 | 2 | 5 | 1 | 2.5 | - | - | - | - | 7.42 | 17 | N |
| TOTAL | 14 | 18.5 | 4 | 5 | | 12 | | | 31.14 | 57.5 | |

Co = continuous stream

**Table 13:** Geomorphic Analysis of Macro Watershed No. 6

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/$kms^2$ | Frequ-ency/$kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 2.55 | 1 | 6.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.35 | 0.39 | 0.102 | 1.281 | 0.508 | 2.0 |
| 2 | 5.50 | 5 | 8.5 | 4.0 | 0.0 | 0.0 | 4.0 | 0.1 | 6.0 | 0.0 | 3.0 | 1.54 | 0.90 | 0.085 | 1.079 | 0.597 | 2.5 |
| 3 | 9.20 | 8 | 11.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.4 | 2.2 | 0.0 | 1.3 | 2.06 | 0.86 | 0.040 | 0.513 | 0.371 | 5.2 |
| 4 | 1.20 | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | - | 0.048 | 0.602 | 0.232 | 3.0 |
| 5 | 5.27 | 1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.47 | 0.189 | 0.093 | 1.176 | 0.395 | 3.7 |
| 6 | 7.42 | 3 | 7.5 | 2.0 | 0.0 | 0.0 | 2.0 | 0.5 | 0.0 | 0.0 | 0.5 | 1.01 | 0.40 | 0.025 | 0.322 | 0.216 | 8.0 |
| TOTAL | 31.14 | 18 | 35.5 | | | | 9.0 | | | | 4.8 | 7.43 | 2.73 | 0.393 | 4.95 | 2.29 | 24.4 |

## 3.7 Macro Watershed No 7

This watershed having an area of 124.20 sq kms. comprises 32 micro watersheds with an average area of 3.97 sq kms. There are 84 first order streams, 25 second order streams, 7 third order and 3 fourth order streams with a total length of 70, 49, 11 and 16 kms respectively. The average bifurcation ratio of stream order is 3.08. The drainage density is 1.32 with a stream frequency of 0.94. The total length of watershed is 821.0 kms, while the periphery is 62.5 kms. The average slope is 0.95 m/kms. The elongation ratio is 0.34, while the form factor is 0.29 and circulatory ratio is 0.41. Considering average catchment, the total catchment yield of surface water is 11.92 mcm; while the harvesting potential is 8.94 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 14 and 15 and Figure 12.

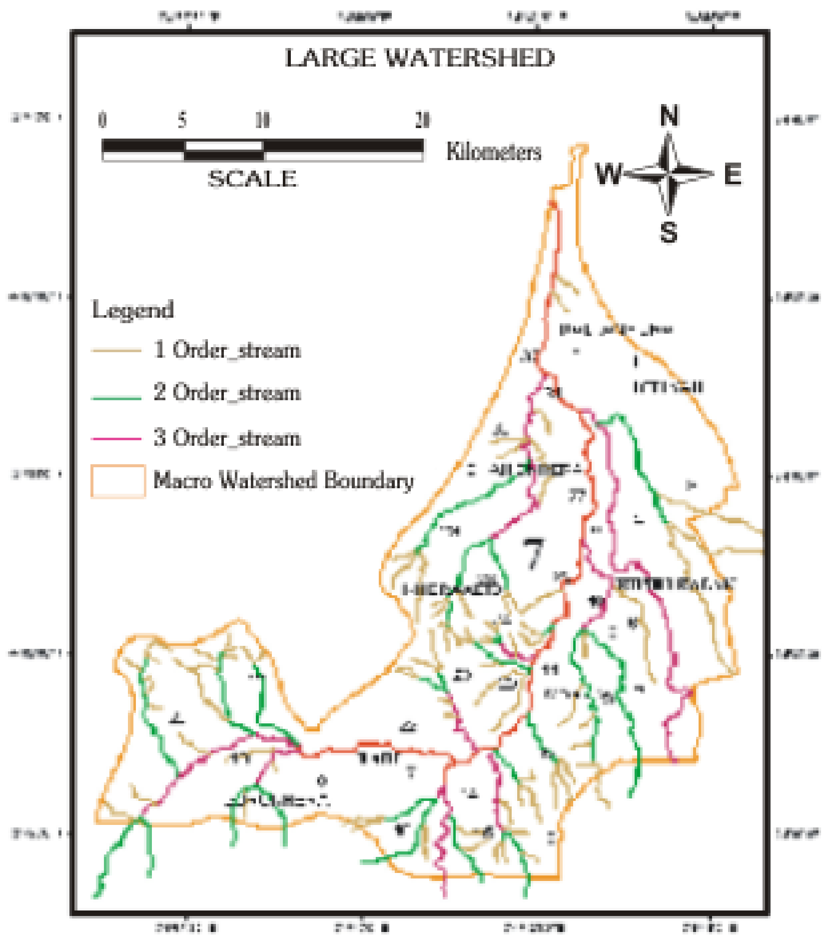



**Figure 12:** Drainage Classification of Large Watershed

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 7

Size [area] – 124.20 sq kms

Geology – Nimbahera limestone, sandstone, Bari (Nimbahera) shale, Sava sandstone, Binote shale, Khardeola sandstone, Kalmia sandstone and Parlia sandstone.

Runoff – 11.92 mcm

Vegetation – high

Land use – high to very high

Shape – fern leaf- shape

**Table 14:** Morphometric Analysis of Macro Watershed No. 7

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms² | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 1 | 1 | - | - | - | - | Co.14 | 5 | 8.05 | 26 | N |
| 2 | 1 | 0.5 | Com.3 | 1 | Com.4 | 1 | Co.14 | 4.5 | 3 | 9.5 | NW |
| 3 | 3 | 7.5 | 1 | 4.5 | - | - | - | - | 11.25 | 20 | N |
| 4 | - | - | - | - | 1 | 12 | - | - | 9.08 | 21 | N |
| 5 | - | - | - | - | - | - | - | - | 1.1 | 9.5 | N |
| 6 | 1 | 5.5 | - | - | - | - | - | - | 1.65 | 4.5 | N |
| 7 | 1 | 1 | 1 | 3 | - | - | - | - | 3.55 | 10 | N |
| 8 | - | - | Com.7 | 1.5 | - | - | - | - | 0.5 | 5.5 | N |
| 9 | 5 | 5 | 1 | 3.5 | - | - | - | - | 4.6 | 10.5 | N |
| 10 | - | - | - | - | 1 | 2 | - | - | 1.46 | 5.5 | N |
| 11 | - | - | - | - | - | - | Co.14 | 3.5 | 1.75 | 10 | N |
| 12 | 3 | 3 | 1 | 1.5 | - | - | Co.14 | 5.5 | 2.4 | 17.5 | N |
| 13 | 8 | 5 | 3 | 3.5 | 1 | 2.5 | - | - | 5.25 | 10.5 | NNW |
| 14 | - | - | - | - | Com.14 | 1 | 1 | 1.5 | 0.65 | 4.5 | N |
| 15 | 2 | 1.5 | 1 | 2 | 1 | 3.5 | Co.14 | - | 3.4 | 7.5 | NW |
| 16 | 3 | 3 | 2 | 3.5 | - | - | Co.14 | - | 4.47 | 8 | NE |
| 17 | - | - | - | - | - | - | - | - | 2.27 | 4 | E |
| 18 | - | - | - | - | - | - | - | - | 1.45 | 5 | E |
| 19 | 3 | 2.5 | 2 | 4 | 1 | 2 | - | - | 7.75 | 8 | NE |
| 20 | 15 | 11 | 2 | 6 | 1 | 5 | - | - | 12.37 | 16 | NE |
| 21 | 2 | 1 | 1 | 3 | - | - | - | - | 2.45 | 7.5 | SE |
| 22 | - | - | - | - | - | - | Co.19 | 4 | 4.25 | 10 | SE |
| 23 | 6 | 4 | 2 | 1.5 | 1 | 2 | Co.17 | 1 | 5.02 | 14 | SE |
| 24 | 5 | 2 | 2 | 0.5 | 1 | 1.5 | - | - | 0.95 | 5.5 | NE |
| 25 | 5 | 5 | 2 | 2 | - | - | - | - | 4 | 5.5 | NE |
| 26 | 3 | 3 | 1 | 0.5 | - | - | - | - | 2.67 | - | - |
| 27 | - | - | - | - | - | - | Co.4 | 2 | 1.35 | 5.5 | NE |
| 28 | 10 | 8 | 2 | 3 | 1 | 5 | - | - | 8.05 | 18 | NE |
| 29 | 3 | 4 | 1 | 4.5 | - | - | - | - | 5.8 | 13 | NE |
| 30 | 2 | 2 | - | - | Co.28 | 3 | - | - | 3.85 | 8.5 | N |
| 31 | 1 | 1.5 | - | - | - | - | - | - | 1.05 | 5.5 | N |
| 32 | - | - | - | - | - | - | Co.19 | 5 | 1.7 | 13.5 | NE |
| TOTAL | 83 | 76.5 | 25 | 49.0 | 9 | 40.5 | 1 | 32.0 | 127.14 | 319.5 | |

Co = continuous stream

**Table 15:** Geomorphic Analysis of Large Macro Watershed No. 7

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/$kms^2$ | Frequ-ency/$kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 8.05 | 1 | 6.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.74 | 0.12 | 0.125 | 0.149 | 0.225 | 8.0 |
| 2 | 3.0 | 1 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 1.0 | 4.5 | 2.5 | 2.3 | 0.33 | 0.411 | 0.417 | 0.408 | 2.7 |
| 3 | 11.25 | 4 | 12.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.6 | 0.0 | 0.0 | 0.6 | 1.06 | 0.35 | 0.192 | 0.353 | 0.279 | 7.6 |
| 4 | 9.08 | 1 | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.32 | 0.11 | 0.161 | 0.258 | 0.255 | 7.5 |
| 5 | 1.1 | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.064 | 0.153 | 0.161 | 4.1 |
| 6 | 1.65 | 1 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.33 | 0.60 | 0.161 | 1.023 | 0.255 | 3.2 |
| 7 | 3.55 | 2 | 4.0 | 1.0 | 0.0 | 0.0 | 1.0 | 3.0 | 0.0 | 0.0 | 3.0 | 1.12 | 0.36 | 0.486 | 0.445 | 0.444 | 2.7 |
| 8 | 0.5 | - | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.125 | 0.207 | 0.225 | 2.0 |
| 9 | 4.6 | 6 | 8.5 | 5.0 | 0.0 | 0.0 | 5.0 | 0.7 | 0.0 | 0.0 | 0.7 | 2.06 | 1.30 | 0.248 | 0.524 | 0.317 | 4.3 |
| 10 | 1.46 | 1 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.36 | 0.68 | 0.331 | 0.606 | 0.366 | 2.1 |
| 11 | 1.75 | - | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.074 | 0.244 | 0.173 | 4.8 |
| 12 | 2.4 | 4 | 10.0 | 3.0 | 3.0 | 0.0 | 3.0 | 0.5 | 0.0 | 0.0 | 0.5 | 4.16 | 1.66 | 0.453 | 0.098 | 0.429 | 2.3 |
| 13 | 5.25 | 12 | 11 | 2.6 | 0.0 | 0.0 | 2.6 | 0.7 | 0.7 | 0.0 | 0.7 | 0.0 | 0.0 | 0.383 | 0.598 | 0.394 | 3.7 |
| 14 | 0.65 | 1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 9.0 | 0.0 | 1.5 | 1.5 | 3.84 | 1.53 | 0.253 | 0.403 | 0.320 | 1.6 |
| 15 | 3.4 | 4 | 7 | 2.0 | 0.0 | 0.0 | 2.0 | 1.3 | 1.7 | 0.0 | 1.5 | 0.0 | 0.0 | 0.941 | 0.759 | 0.618 | 1.9 |
| 16 | 4.47 | 5 | 6.5 | 1.5 | 0.0 | 0.0 | 1.5 | 1.1 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 1.01 | 0.877 | 0.541 | 2.1 |
| 17 | 2.27 | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.363 | 1.78 | 0.383 | 2.5 |
| 18 | 1.45 | - | - | 0.0 | 2.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.401 | 0.728 | 0.403 | 1.9 |
| 19 | 7.75 | 6 | 8.5 | 1.5 | 2.0 | 0.0 | 1.7 | 1.6 | 0.5 | 0.0 | 1.0 | 0.0 | 0.0 | 0.921 | 1.52 | 0.611 | 2.9 |
| 20 | 12.3 | 18 | 22 | 7.5 | 0.0 | 0.0 | 7.5 | 0.5 | 0.8 | 0.0 | 0.6 | 0.0 | 0.0 | 0.718 | 0.606 | 0.539 | 4.1 |
| 21 | 2.45 | 3 | 4.0 | 2.0 | 2.0 | 0.0 | 2.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.612 | 0.547 | 0.249 | 4.0 |
| 22 | 4.25 | - | 4.0 | 3.0 | 2.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.265 | 0.533 | 0.328 | 4.0 |
| 23 | 5.02 | 9 | 8.5 | 2.5 | 0.0 | 0.0 | 2.5 | 0.3 | 1.3 | 0.5 | 0.7 | 0.0 | 0.0 | 0.347 | 0.321 | 0.375 | 3.8 |
| 24 | 0.95 | 8 | 4 | 2.5 | 0.0 | 0.0 | 2.5 | 0.2 | 3.0 | 0.0 | 1.6 | 0.0 | 0.0 | 0.237 | 0.394 | 0.310 | 2.0 |
| 25 | 4.0 | 7 | 7.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.4 | 0.0 | 0.0 | 0.4 | 1.75 | 1.75 | 0.367 | 1.66 | 0.386 | 3.3 |
| 26 | 2.67 | 4 | 3.5 | 0.0 | 2.0 | 0.0 | 2.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 |
| 27 | 1.35 | - | 2.0 | 5.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.07 | 2.96 | 0.048 | 0.560 | 0.140 | 5.2 |
| 28 | 8.05 | 13 | 16.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.3 | 1.6 | 0.0 | 1.9 | 1.98 | 1.61 | 0.223 | 0.312 | 0.301 | 6.0 |
| 29 | 5.8 | 4 | 8.5 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 1.1 | 1.46 | 0.68 | 0.232 | 0.431 | 0.306 | 5.0 |
| 30 | 3.85 | 2 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.29 | 0.51 | 0.273 | 0.669 | 0.333 | 3.7 |
| 31 | 1.05 | 1 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.42 | 0.95 | 0.182 | 0.433 | 0.271 | 2.4 |
| 32 | 1.7 | - | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.94 | 0.0 | 0.051 | 0.117 | 0.144 | 5.7 |

## 3.8 Macro Watershed No. 8

This watershed having an area of 14.02 sq kms comprises 3 micro watersheds with an average area of 5.52 sq kms. There are 3 first order streams with a total length of 6.0 kms respectively. The drainage density is 0.13 with stream frequency of 0.18. The total length of watershed is 24.0 kms, while the periphery is 7.5 kms. The average slope is 0.66 m/kms. The elongation ratio is 0.52, while the form factor is 0.64 and circulatory ratio is 0.28. Considering average catchment, the total catchment yield of surface water is 1.34 mcm; while the harvesting potential is 1.00 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 16 and 17 and Figure 13.

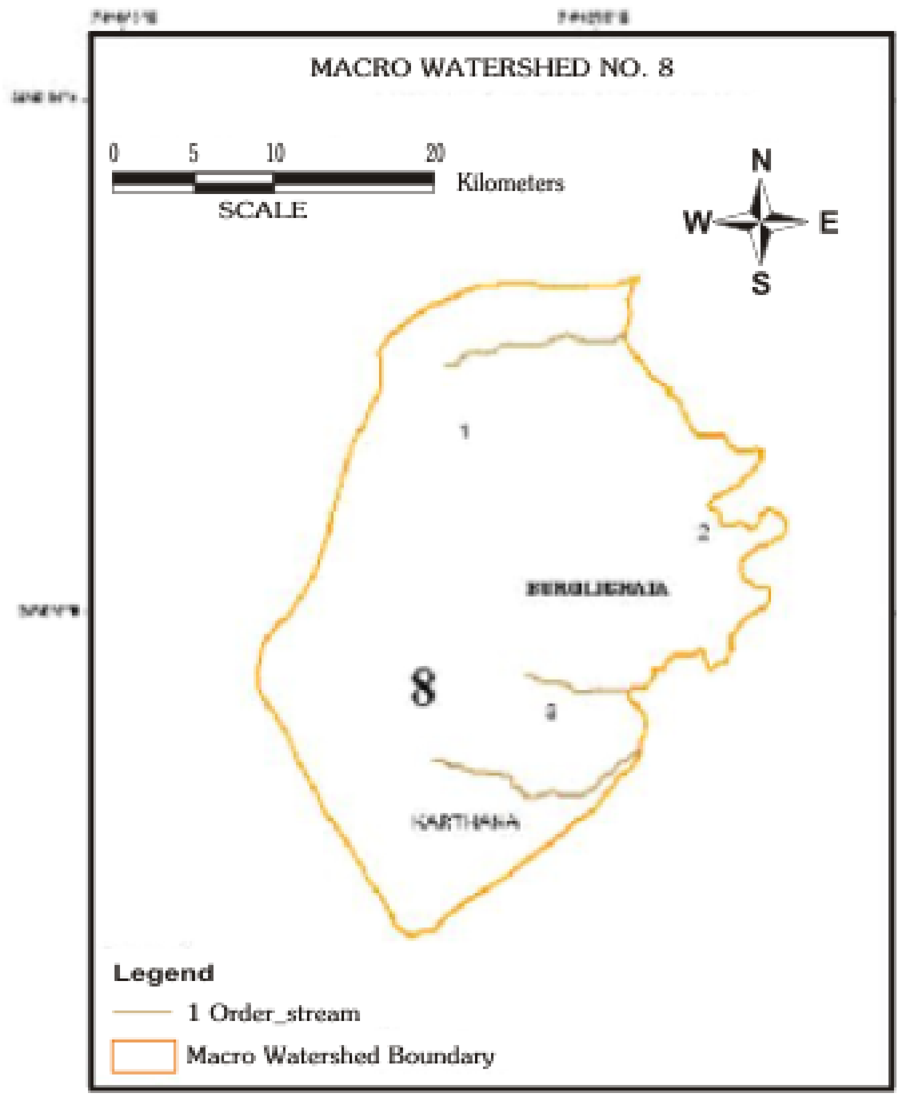



**Figure 13:** Drainage Classification of Macro Watershed No. 8

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 8

Size [area] – 14.02 sq kms

Geology – Suket shale and Nimbahera limestone

Runoff – 1.34 mcm

Vegetation – high

Land use – very low

Shape – polygon shape

**Table 16:** Morphometric Analysis of Macro Watersheds No. 8

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms² | Perimeter in kms | Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 1 | 2.5 | - | - | - | - | - | - | 6.25 | 9.5 | E |
| 2 | - | - | - | - | - | - | - | - | 2.4 | - | - |
| 3 | 2 | 3.5 | - | - | - | - | - | - | 5.37 | - | E |
| TOTAL | 3 | 6 | | | | | | | 14.02 | 9.5 | |

Co = continuous stream

**Table 17:** Geomorphic Analysis of Macro Watershed No. 8

| Micro water-shed No. | Area (kms²) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/kms² | Frequ-ency/kms² | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 6.25 | 1 | 2.5 | - | - | - | - | - | - | - | - | 0.4 | 4.0 | 1.92 | 0.86 | 1.56 | 1.8 |
| 2 | 2.40 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1.75 |
| 3 | 5.37 | 2 | 3.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | 3.3 |
| TOTAL | 14.02 | 3 | 6.0 | | | | | | | | | 0.4 | 4.0 | 1.92 | 0.86 | 1.56 | 6.85 |

## 3.9 Macro Watershed No. 9

This watershed having an area of 79.2 sq kms comprises 18 micro watersheds with an average area of 4.73 sq kms. There are 57 first order streams, 13 second order streams and 3 third order streams with a total length of 66.5, 29.5 and 22.5 kms respectively. The average bifurcation ratio of stream order is 1.03. The drainage density is 1.67 with stream frequency of 0.56. The total length of watershed is 18.0 kms, while the periphery is 44.5 kms. The average slope is 2.50 m/kms. The elongation ratio is 0.32, while the form factor is 0.26 and circulatory ratio is 0.54. Considering average catchment, the total catchment yield of surface water is 8.18 mcm; while the harvesting potential is 6.13 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 18 and 19 and Figure 14.

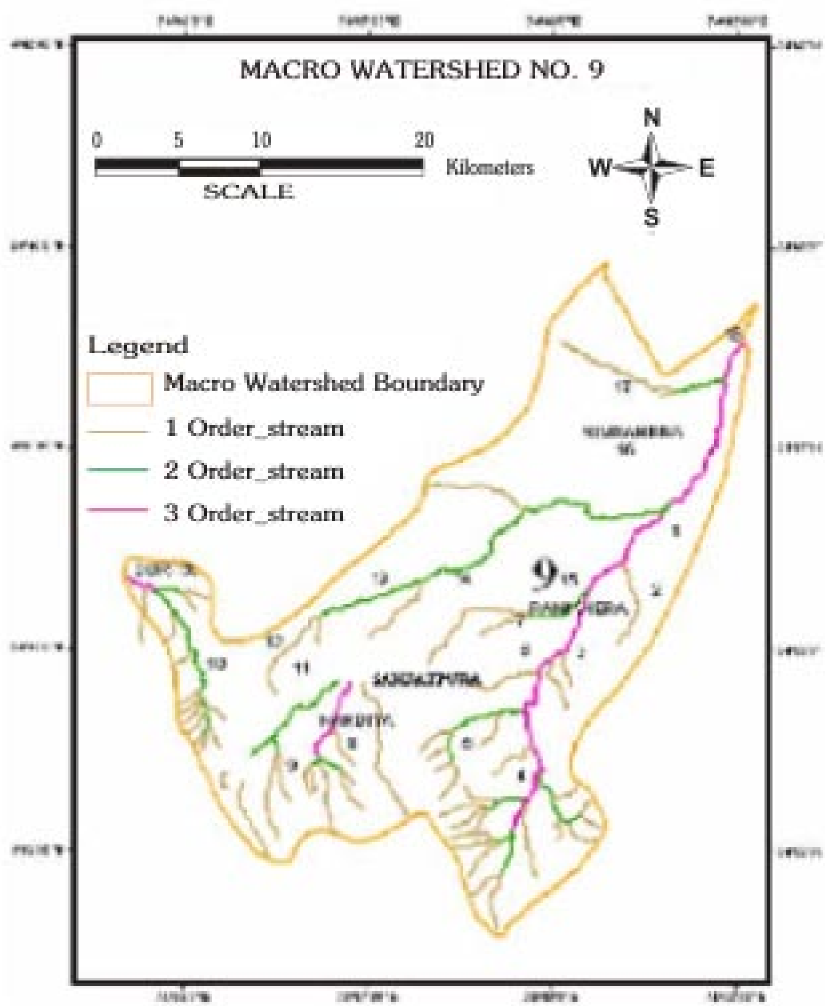



**Figure 14:** Drainage Classification of Macro Watershed No. 9

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 9

Size [area] -- 79.2 sq kms

Geology -- Quartzite, Khardeola sandstone, Bhagwanpura limestone, Sava sandstone, Parli sandstone, Kalmia sandstone, Binota shale, Jircon and Bari (Nimbahera) shale.

Runoff – 8.18 mcm

Vegetation – high

Land use – very high

Shape – polygon shape

**Table 18:** Morphometric Analysis of Macro Watersheds No.9

| Micro Watershed No. | 1st order stream | | $2^{nd}$ order stream | | $3^{rd}$ order stream | | $4^{th}$ order stream | | Area in $kms^2$ | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | - | - | - | - | Co. 4 | 4.5 | - | - | 2.37 | 13 | NW |
| 2 | 1 | 2.5 | - | - | - | - | - | - | 3.57 | 6 | NW |
| 3 | 2 | 3 | - | - | - | - | - | - | 3.12 | 10 | N |
| 4 | 16 | 17.5 | 4 | 5 | 1 | 3 | - | - | 11.3 | 15.5 | N |
| 5 | 5 | 4 | - | 2.5 | Co. 4 | 1 | - | - | 3.47 | 10 | NE |
| 6 | 1 | 2 | - | - | Co. 4 | 2.5 | - | - | 2.95 | 10 | NE |
| 7 | 3 | 5.5 | 1 | 1.5 | - | - | - | - | 5 | 18.5 | NE |
| 8 | 6 | 7.5 | 2 | 1 | 1 | 2.5 | - | - | 3.02 | 10 | N |
| 9 | 4 | 6 | 2 | 3.5 | - | - | - | - | 7.95 | 14.5 | N |
| 10 | 13 | 7.5 | 2 | 4.5 | 1 | 1 | - | - | 7.82 | 13 | N |
| 11 | 1 | 0.5 | - | - | - | - | - | - | 1.52 | 6 | N |
| 12 | 1 | 2.5 | - | - | - | - | - | - | 4.17 | 11.5 | NE |
| 13 | 1 | 2.5 | 1 | 0.5 | - | - | - | - | 7.1 | 21 | NE |
| 14 | 1 | 2 | Co.13 | 9.5 | - | - | - | - | 4.45 | 17.5 | NE |
| 15 | - | - | - | - | Co. 4 | 2.5 | - | - | 1.82 | 9 | NE |
| 16 | - | - | - | - | Co. 4 | 3 | - | - | 7.05 | 13.5 | NE |
| 17 | 2 | 3.5 | 1 | 1.5 | Co. 4 | 0.5 | - | - | 7.62 | 14.6 | NE |
| 18 | - | - | - | - | Co. 4 | 2 | - | - | 0.9 | 5 | NE |
| TOTAL | 57 | 66.5 | 13 | 29.5 | 3 | 22.5 | | | 79.2 | 218.5 | |

Co = continuous stream

**Table 19:** Geomorphic Analysis of Macro Watershed No.9

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/ $kms^2$ | Frequ-ency/ $kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 2.37 | - | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.89 | 0.00 | 0.73 | 0.17 | 0.54 | 1.8 |
| 2 | 3.57 | 1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.70 | 0.28 | 0.29 | 1.24 | 0.34 | 3.5 |
| 3 | 3.12 | 2 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.96 | 0.64 | 0.19 | 0.39 | 0.28 | 4.0 |
| 4 | 11.3 | 21 | 25.5 | 4.0 | 4.0 | 0.0 | 4.0 | 0.2 | 0.6 | 0.0 | 0.4 | 2.25 | 1.85 | 0.31 | 0.59 | 0.35 | 6.0 |
| 5 | 3.47 | 5 | 7.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.2 | 2.30 | 1.72 | 0.19 | 0.43 | 0.27 | 4.2 |
| 6 | 2.95 | 1 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.52 | 0.33 | 0.13 | 0.37 | 0.23 | 4.7 |
| 7 | 5.0 | 4 | 7.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.2 | 0.0 | 0.0 | 0.2 | 1.40 | 0.80 | 0.12 | 0.18 | | |
| 8 | 3.02 | 9 | 11.0 | 3.0 | 2.0 | 0.0 | 2.5 | 0.1 | 2.5 | 0.0 | 1.3 | 3.64 | 2.98 | 0.28 | 0.37 | 0.22 | 6.2 |
| 9 | 7.95 | 6 | 9.5 | 2.0 | 0.0 | 0.0 | 2.0 | 0.5 | 0.0 | 0.0 | 0.5 | 0.88 | 0.37 | 0.31 | 0.47 | 0.34 | 3.2 |
| 10 | 7.82 | 16 | 13.0 | 6.5 | 2.0 | 0.0 | 4.2 | 0.06 | 0.2 | 0.0 | 0.1 | 1.66 | 2.04 | 0.25 | 0.58 | 0.35 | 5.0 |
| 11 | 1.52 | 1 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.32 | 0.65 | 0.26 | 0.53 | 0.32 | 5.5 |
| 12 | 4.17 | 1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.59 | 0.23 | 0.26 | 0.39 | 0.32 | 2.4 |
| 13 | 7.1 | 2 | 3.0 | 1.0 | 0.0 | 0.0 | 1.0 | 0.2 | 0.0 | 0.0 | 0.2 | 0.42 | 0.28 | 0.12 | 0.20 | 0.32 | 4.0 |
| 14 | 4.45 | 1 | 11.5 | 0.0 | 0.0 | 0.0 | 0.0 | 4.7 | 0.0 | 0.0 | 4.7 | 2.58 | 0.22 | 0.06 | 0.18 | 0.22 | 7.5 |
| 15 | 1.82 | - | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.37 | 0.00 | 0.11 | 0.28 | 0.15 | 8.5 |
| 16 | 7.05 | - | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.42 | 0.00 | 0.31 | 0.48 | 0.21 | 4.0 |
| 17 | 7.62 | 3 | 5.5 | 2.0 | 0.0 | 0.0 | 2.0 | 4.2 | 0.3 | 0.0 | 2.3 | 0.92 | 0.39 | 0.47 | 0.45 | 0.35 | 4.7 |
| 18 | 0.9 | - | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.22 | 0.00 | 0.31 | 0.45 | 0.43 | 4.0 |
| | | | | | | | | | | | | | | | | 0.35 | 1.7 |
| TOTAL | 99.2 | 73 | 118.5 | | | | 18.7 | | | | 9.9 | 26.04 | 12.78 | 4.7 | 7.75 | 5.59 | 80.9 |

## 3.10 Macro Watershed No. 10

This watershed having an area of 25.62 sq kms. comprises 7 micro watersheds with an average area of 3.93 sq kms. There are 23 first order streams, 10 second order streams, 1 third order and one fourth order stream with a total length of 22, 13, 7 and 1 kms respectively. The average bifurcation ratio of stream order is 2.43. The drainage density is 1.07 with stream frequency of 1.56. The total length of watershed is 10.0 kms, while the periphery is 27.5 kms. The average slope is 2.85 m/kms. The elongation ratio is 0.51, while the form factor is 0.76 and circulatory ratio is 0.46. Considering average catchment, the total catchment yield of surface water is 2.46 mcm; while the harvesting potential is 1.84 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 20 and 21 and Figure 15.

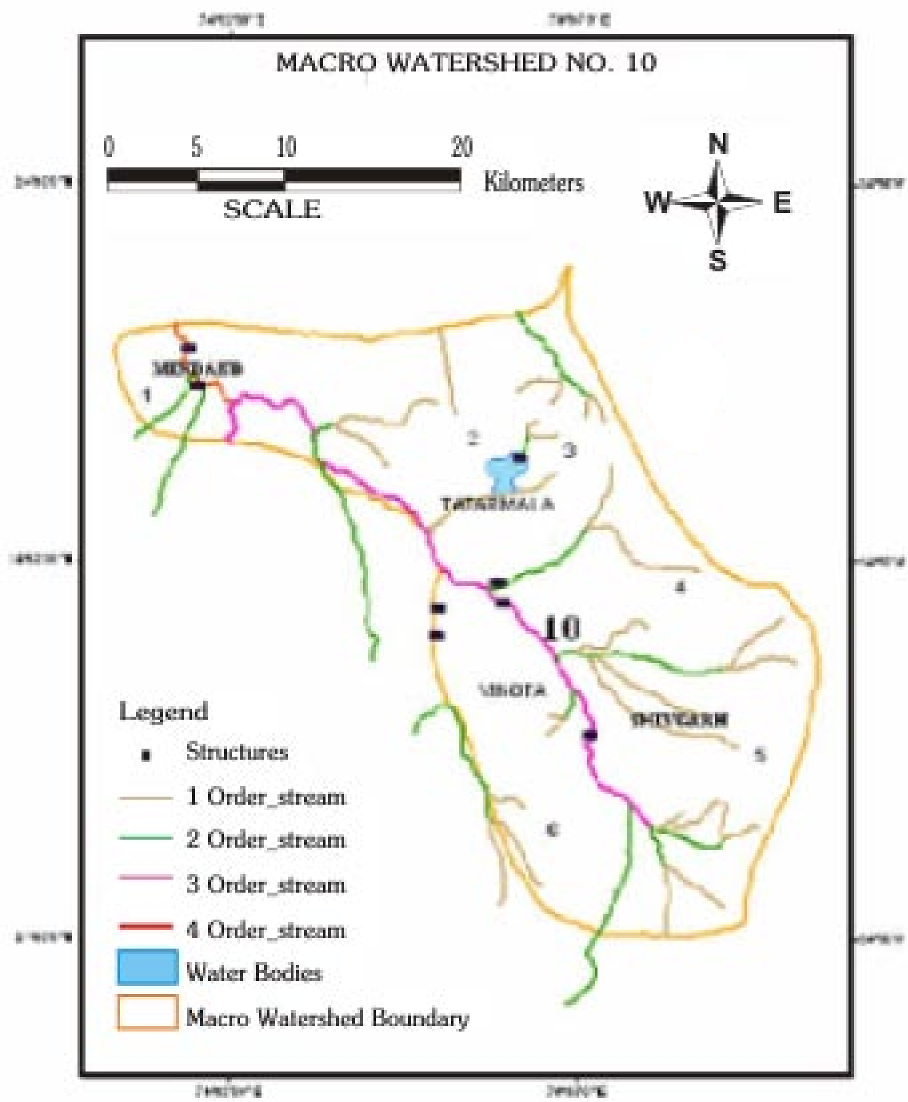



**Figure 15:** Drainage Classification of Macro Watershed No. 10

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 10

Size [area] – 25.62 sq kms

Geology – Binota shale, Bari (Nimbahera) shale, Bhagwanpura limestone and Khardeola sandstone.

Runoff – 2.46 mcm

Vegetation – low

Land use – low to medium

Shape – polygon shape

**Table 20:** Morphometric Analysis of Macro Watersheds No. 10

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms² | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 2 | 2 | 4 | 4 | 1 | 1.5 | 1 | 1 | 1.3 | 12 | - |
| 2 | 2 | 3 | - | - | - | 2.5 | - | - | 1.85 | 9 | N |
| 3 | 4 | 2 | 1 | 1 | - | - | - | - | 2.45 | 9.5 | N |
| 4 | 2 | 2.5 | 1 | 2.5 | - | - | - | - | 2.95 | 10 | W |
| 5 | 5 | 7 | 1 | 2.5 | Co. 1 | - | - | - | 10.57 | 10.5 | W |
| 6 | 8 | 5.5 | 3 | 3 | 1 | 3 | - | - | 6.5 | 12.5 | N |
| TOTAL | 23 | 22 | 10 | 13 | 1 | 7 | 1 | 1 | 25.62 | 63.5 | |

Co = continuous stream

**Table 21:** Geomorphic Analysis of Macro Watershed No. 10

| Micro water-shed No. | Area (kms²) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/kms² | Frequ-ency/kms² | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 1.3 | 8 | 8.5 | 0.5 | 4.0 | 1.0 | 1.0 | 2.0 | 0.3 | 0.6 | 1.0 | 27.3 | 26.93 | 0.058 | 0.113 | 0.154 | 4.7 |
| 2 | 1.85 | 2 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.97 | 1.08 | 1.85 | 0.286 | 0.866 | 1.0 |
| 3 | 2.45 | 5 | 3.0 | 4.0 | 0.0 | 0.0 | 4.0 | 0.5 | 0.0 | 0.0 | 0.5 | 1.224 | 2.04 | 1.088 | 0.340 | 0.664 | 1.5 |
| 4 | 2.95 | 23 | 5.0 | 2.0 | 0.0 | 0.0 | 2.0 | 1.0 | 0.6 | 0.0 | 1.0 | 1.694 | 1.016 | 0.472 | 0.370 | 0.537 | 2.5 |
| 5 | 10.57 | 6 | 9.5 | 5.0 | 0.0 | 0.0 | 5.0 | 0.3 | 0.0 | 0.0 | 0.3 | 0.898 | 0.567 | 0.772 | 1.204 | 0.559 | 3.7 |
| 6 | 6.5 | 11 | 11.5 | 2.6 | 0.0 | 0.0 | 2.6 | 0.5 | 1.0 | 0.0 | 0.7 | 2.230 | 2.15 | 0.359 | 0.522 | 0.382 | 4.25 |
| TOTAL | 25.62 | 35 | 43.0 | | | | 14.6 | | | | 3.5 | 11.73 | 9.53 | 4.599 | 2.835 | 3.062 | 17.65 |

## 3.11 Macro Watershed No 11

This watershed having an area of 14.27 sq kms. comprises 5 micro-watersheds with an average area of 2.28 sq kms. There are 17 first order streams, 5 second order streams and 2 third order streams with a total length of 11.5, 8.5 and 4.0 kms respectively. The average bifurcation ratio of stream order is 0.19. The drainage density is 1.30 with stream frequency of 1.40. The total length of watershed is 8.0 kms, while the periphery is 19.0 kms. The average slope is 3.75 m/kms. The elongation ratio is 0.34, while the form factor is 0.34 and circulatory ratio is 4.22. Considering average catchment, the total catchment yield of surface water is 16.13 mcm; while the harvesting potential is 12.10 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 22 and 23 and Figure 16.

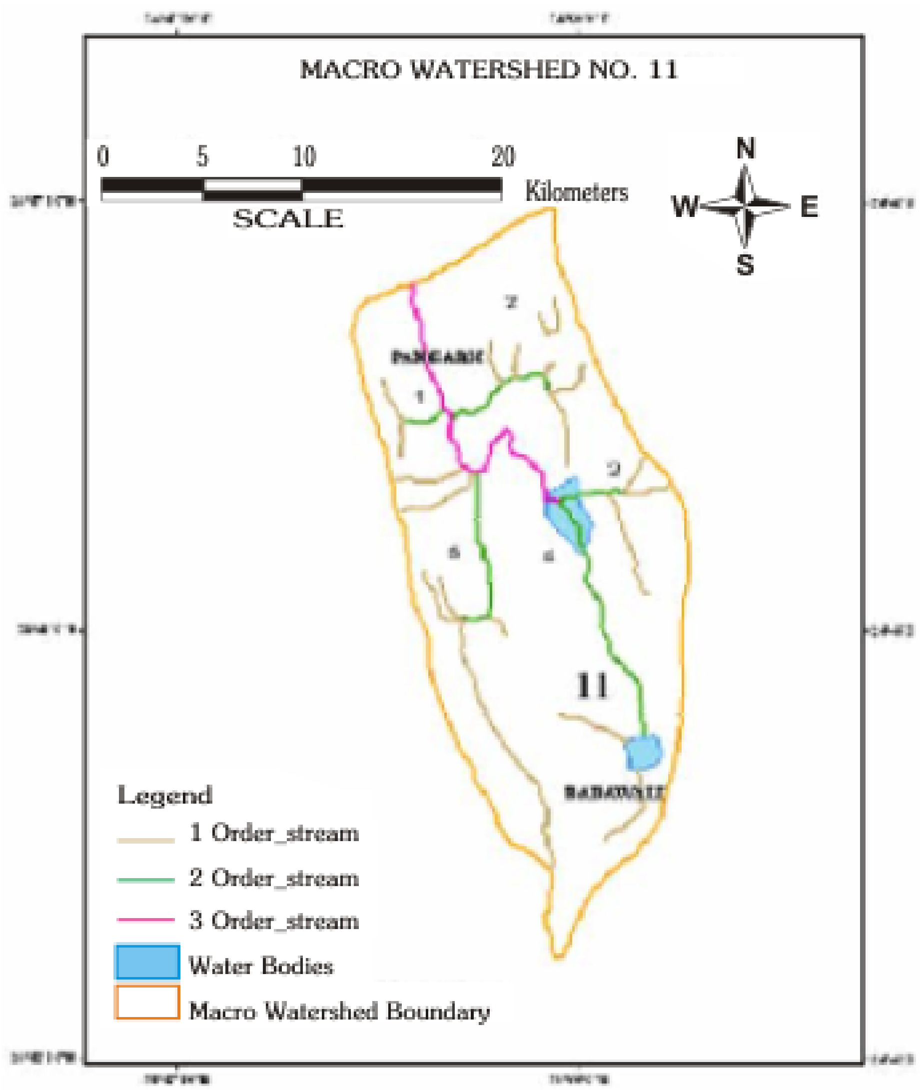



**Figure 16:** Drainage Classification of Macro Watershed No.11

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 11

Size [area] – 14.27 sq kms

Geology – Kamur sandstone, Suket shale and Jircon sandstone

Runoff -- 16.13 mcm

Vegetation -- low

Land use -- high

Shape -- fern leaf-shape

**Table 22:** Morphometric Analysis Macro Watersheds No. 11

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in kms² | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 2 | 1 | 1 | 0.5 | 1 | 2 | - | - | 1.6 | 3 | N |
| 2 | 5 | 2 | 1 | 2 | - | - | - | - | 3.1 | 7.5 | W |
| 3 | 3 | 2 | 1 | 0.5 | - | - | - | - | 1.2 | 6 | W |
| 4 | 2 | 2 | 1 | 3 | 1 | 1 | - | - | 5.47 | 15 | N |
| 5 | 5 | 4.5 | 1 | 2.5 | - | 1 | - | - | 2.9 | - | N |
| TOTAL | 17 | 11.5 | 5 | 8.5 | 2 | 4 | | | 14.27 | 31.5 | |

Co = continuous stream

**Table 23:** Geomorphic Analysis of Macro Watershed No. 11

| Micro water-shed No. | Area (kms²) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/ kms² | Frequ-ency/ kms² | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 1.60 | 4 | 3.5 | 2.0 | 1.0 | - | 1.0 | 0.5 | 4.0 | - | 1.5 | 02.18 | 0.187 | 0.31 | 6.69 | 6.69 | 2.25 |
| 2 | 3.10 | 6 | 4.0 | 5.0 | - | - | 1.6 | 1.0 | - | - | 0.3 | 01.29 | 0.193 | 0.61 | 5.19 | 5.19 | 2.25 |
| 3 | 1.20 | 4 | 2.5 | 3.0 | - | - | 1.0 | 0.25 | - | - | 0.08 | 02.08 | 0.33 | 0.15 | 2.51 | 2.51 | 2.75 |
| 4 | 3.47 | 3 | 5.0 | 2.0 | 1.0 | - | 1.0 | 1.5 | 0.33 | - | 0.61 | 01.09 | 0.073 | 0.21 | 4.58 | 4.58 | 5.0 |
| 5 | 2.90 | 6 | 7.0 | 5.0 | - | - | - | 0.55 | 0.4 | - | 0.31 | 02.75 | 0.206 | 0.42 | 2.14 | 2.14 | 2.6 |
| TOTAL | 14.27 | 23 | 22 | | | | 4.6 | | | | 2.8 | 9.39 | 0.986 | 1.7 | 21.11 | 21.11 | 14.85 |

## 3.12 Macro Watershed No 12

This watershed having an area of 11.44 sq kms. comprises 4 micro watersheds with an average area of 8.50 sq kms. There are 21 first order streams, 2 second order streams and 2 third order streams with a total length of 16.0, 3 and 4.5 kms respectively. The average bifurcation ratio of stream order is 2.25. The drainage density is 0.88 with a stream frequency of 0.81. The total length of watershed is 7.0 kms, while the periphery is 17.5 kms. The average slope is 1.43 m/kms. The elongation ratio is 1.08, while the form factor is 0.96 and circulatory ratio is 3.08. Considering average catchment, the total catchment yield of surface water is 3.85 mcm; while the harvesting potential is 2.86 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 24 and 25 and Figure 17.

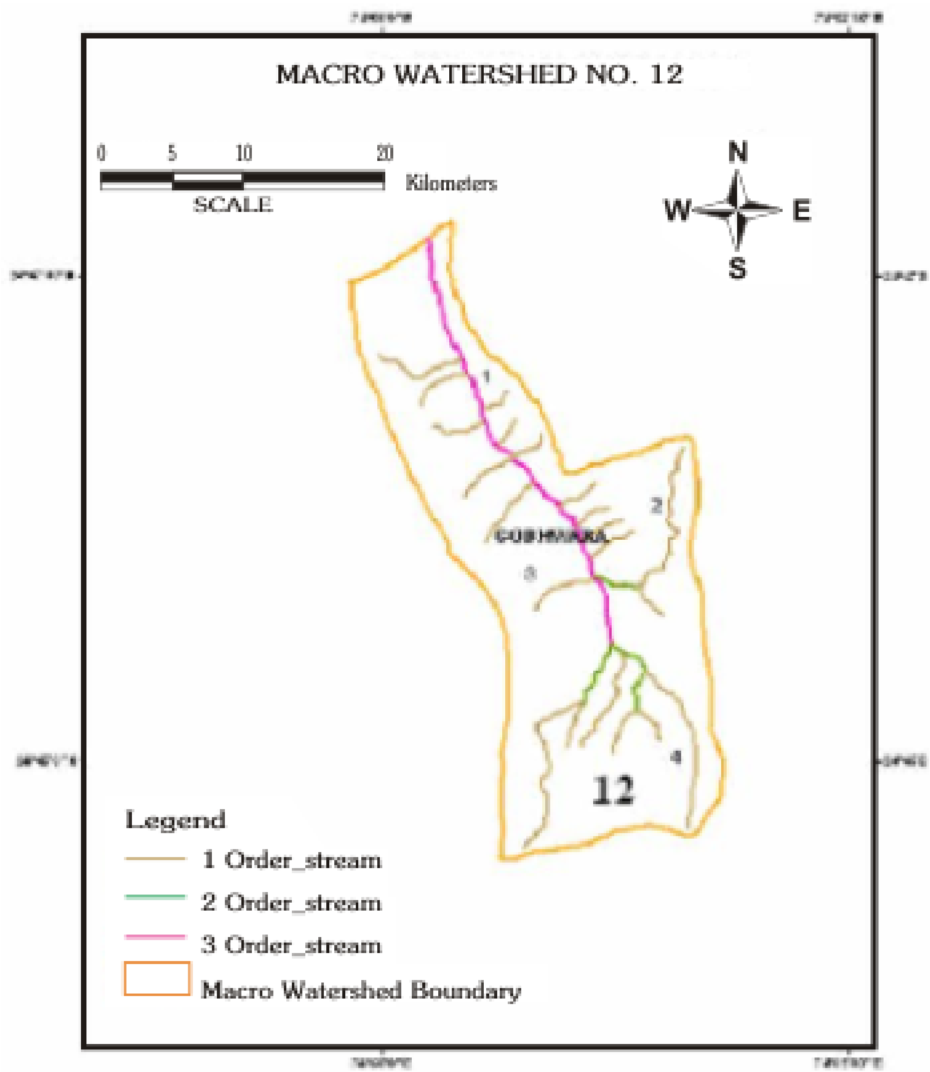



**Figure 17:** Drainage Classification of Macro Watershed No. 12

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 12

Size [area] – 11.44 sq kms

Geology – Kamur sandstone and Panna shale with limestone

Runoff – 3.85 mcm

Vegetation – very low

Land use – very low

Shape – rectangular shape

**Table 24:** Morphometric Analysis Macro Watersheds No.12

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in $kms^2$ | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 9 | 5 | - | - | 1 | 3 | - | - | 1.1 | 8.5 | N |
| 2 | 5 | 4.5 | 1 | 0.5 | 1 | 1.5 | - | - | 1.42 | 5 | W |
| 3 | 1 | 1 | - | - | - | - | - | - | 4.7 | 5 | E |
| 4 | 6 | 5.5 | 1 | 2.5 | - | - | - | - | 4.22 | 7.5 | N |
| TOTAL | 21 | 16 | 2 | 3 | 2 | 4.5 | | | 11.44 | 26 | |

Co = continuous stream



**Table 25:** Geomorphic Analysis of Macro Watershed No.12

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/ $kms^2$ | Frequ-ency/ $kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 1.10 | 10 | 8.0 | - | - | - | - | - | - | - | - | 0.727 | 0.90 | 0.89 | 1.91 | 1.06 | 3.5 |
| 2 | 1.42 | 6 | 6.5 | 5.0 | 1.0 | - | 3.0 | 0.1 | 3.0 | - | 1.5 | 0.457 | 0.49 | 1.34 | 7.13 | 1.30 | 3.2 |
| 3 | 4.70 | 1 | 1.0 | - | - | - | - | 1 | - | - | - | 0.214 | 0.21 | 1.16 | 2.34 | 1.21 | 2.0 |
| 4 | 4.22 | 7 | 8.0 | 6.0 | - | - | 6.0 | - | - | - | - | 1.89 | 1.65 | 0.46 | 0.94 | 0.77 | 3.0 |
| | | | | | | | | 0.4 | | | | | | | | | |
| | | | | | | | | 5 | | | | | | | | | |
| TOTAL | 11.44 | 24 | 23.5 | | | | 9.0 | | | | 1.5 | 3.288 | 3.25 | 3.85 | 12.32 | 4.34 | 11.7 |

## 3.13 Macro Watershed No 13

This watershed having an area of 7.82 sq km comprises 4 micro-watersheds with an average area of 1.95 sq km. There are 22 first order streams, 5 second order streams and one third order stream with a total length of 14, 5.5 and 4.5 km respectively. The average bifurcation ratio of stream order is 4.42. The drainage density is 3.54 with stream frequency of 3.45. The total length of watershed is 5.5 km, while the periphery is 12.5 km. The average slope is 1.45 m/km. The elongation ratio is 0.41, while the form factor is 1.0 and the circulatory ratio is 0.61. Considering average catchment, the total catchment yield of surface water is 0.88 mcm; while the harvesting potential is 0.66 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 26 and 27 and Figure 18.

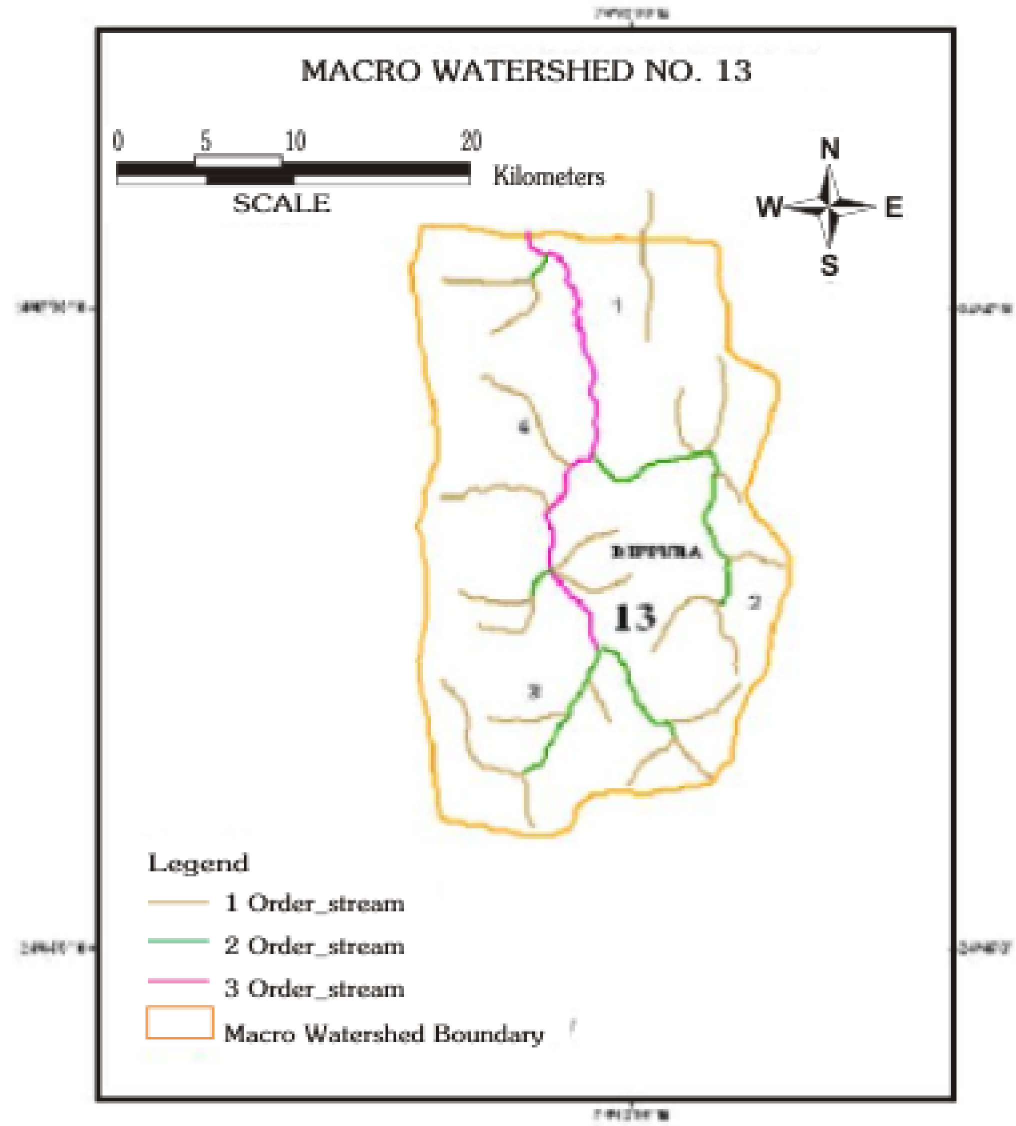



**Figure 18:** Drainage Classification of Macro Watershed No.13

### Classification Based on Shape :-

Morphological Characteristics of Watershed-13

Size [area] – 7.82 sq kms

Geology – Kamur sandstone, Panna shale with lime-stone and Jircon sandstone

Runoff – 0.88 mcm

Vegetation – low

Land use – very low

Shape – rectangular shape

**Table 26:** Morphometric Analysis of Macro Watershed No. 13

| Micro Watershed No. | 1st order stream | | $2^{nd}$ order stream | | $3^{rd}$ order stream | | $4^{th}$ order stream | | Area in $kms^2$ | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 3 | 2.5 | 1 | 0.5 | Co.3 | 2 | - | - | 1.05 | 5 | N |
| 2 | 6 | 2.5 | 1 | 2.5 | - | - | - | - | 1.65 | 6 | NW |
| 3 | 7 | 4 | 2 | 2 | 1 | 0.5 | - | - | 3.45 | 7.5 | N |
| 4 | 6 | 5 | 1 | 0.5 | - | 2 | - | - | 1.67 | 6 | N |
| TOTAL | 22 | 14 | 5 | 5.5 | 1 | 4.5 | | | 7.82 | 24.5 | |

Co = continuous stream



**Table 27:** Geomorphic Analysis of Macro Watershed No.13

| Micro water-shed No. | Area ($kms^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/ $kms^2$ | Frequ-ency/ $kms^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/ N2 | N2/ N3 | N3/ N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 1.05 | 4 | 5.0 | 3.0 | 0.0 | 0.0 | 3.0 | 0.2 | 4.0 | 0.0 | 2.1 | 4.76 | 3.80 | 0.38 | 0.52 | 0.241 | 2.7 |
| 2 | 1.65 | 7 | 5.0 | 6.0 | 0.0 | 0.0 | 6.0 | 1.0 | 0.0 | 0.0 | 1.0 | 3.03 | 4.24 | 0.66 | 0.57 | 0.327 | 2.5 |
| 3 | 3.45 | 10 | 6.5 | 3.5 | 2.0 | 0.0 | 2.7 | 0.5 | 0.2 | 0.0 | 0.3 | 1.88 | 2.89 | 2.3 | 0.77 | 0.788 | 1.5 |
| 4 | 1.67 | 7 | 7.5 | 6.0 | 0.0 | 0.0 | 6.0 | 0.1 | 4.0 | 0.0 | 2.0 | 4.49 | 4.19 | 0.66 | 0.58 | 0.329 | 2.5 |
| TOTAL | 7.82 | 28 | 24 | | | | 17.7 | | | | 5.4 | 14.16 | 15.12 | 4.0 | 2.44 | 1.66 | 9.2 |

## 3.14 Macro Watershed No 14

This watershed having an area of 33.48 sq kms comprises 9 micro-watersheds with an average area of 3.72 sq kms. There are 42 first order streams, 10 second order streams and 5 third order stream with 1 fourth order stream and a total length of 27.5, 10.5 and 7.7 kms and 2.0 respectively. The average bifurcation ratio of stream order is 2.8. The drainage density is 2.53 with stream frequency of 2.55. The total length of watershed is 13.0 kms, while the periphery is 27.5 kms. The average slope is 1.45 m/kms. The elongation ratio is 0.47 while the form factor is 0.96 and circulatory ratio is 0.39. Considering average catchment, the total catchment yield of surface water is 3.78 mcm; while the harvesting potential is 2.83 mcm (75 per cent of total yield). Details of micro watersheds, feasible harvesting structures with their capacities and other parameters are given in Tables 28 and 29 and Figure 19.

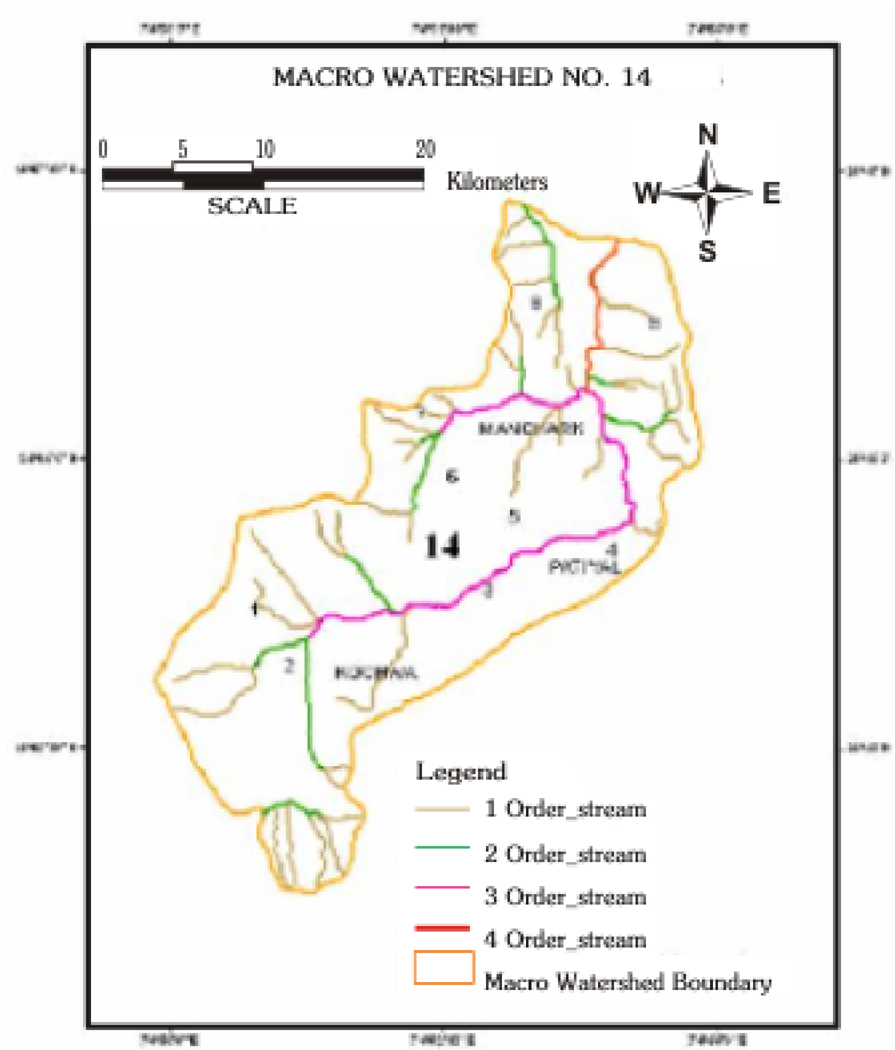



**Figure 19:** Drainage Classification of Macro Watershed No.14

### Classification Based on Shape :-

Morphological Characteristics of Watershed - 14

Size [area] – 33.48 sq kms

Geology – Kamur sandstone, Panna shale with lime-stone and Jircon sandstone

Runoff – 3.78 mcm

Vegetation – medium

Land use – low

Shape – oval shape

**Table 28:** Morphometric Analysis of Macro Watersheds No. 14

| Micro Watershed No. | 1st order stream | | $2^{nd}$ order stream | | $3^{rd}$ order stream | | $4^{th}$ order stream | | Area in $kms^2$ | Perimeter in kms | Slope/ /Flow direction |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | No. of streams | Length in kms | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 1 | 6 | 6 | 2 | 2 | 1 | 2 | - | - | 2.5 | 11 | E |
| 2 | 7 | 4 | 2 | 2.5 | - | - | - | - | 1.67 | 11.5 | E |
| 3 | 1 | 1.5 | - | - | Co.1 | 3.2 | - | - | 6 | 10 | E |
| 4 | - | - | - | - | - | - | - | - | 10.6 | 5 | E |
| 5 | 8 | 5.5 | 2 | 2 | 2 | 1 | - | - | 4.82 | 15 | E |
| 6 | 2 | 1 | 1 | 1.5 | 1 | 0.5 | - | - | 1.05 | 6.5 | NE |
| 7 | 7 | 3.5 | 1 | 0.5 | 1 | 1 | - | - | 4.57 | 8.5 | NE |
| 8 | 5 | 2.5 | 1 | 1.5 | - | - | - | - | 1.27 | 5 | N |
| 9 | 6 | 3.5 | 1 | 0.5 | - | - | 1 | 2 | 1 | 10 | N |
| TOTAL | 42 | 27.5 | 10 | 10.5 | 5 | 7.7 | 1 | 2 | 33.48 | 82.5 | |

Co = continuous stream

**Table 29:** Geomorphic Analysis of Macro Watershed No. 14

| Micro water-shed No. | Area (kms$^2$) | No. of streams | Length of streams in kms | Bifurcation Ratio | | | | Stream length ratio | | | | Drain-age density in kms/kms$^2$ | Frequ-ency/kms$^2$ | Form factor | Circu-latory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N1/N2 | N2/N3 | N3/N4 | Avg. | 2/1 | 3/2 | 4/3 | Avg | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 1 | 2.5 | 9 | 10.0 | 3.0 | 2.0 | 0.0 | 2.5 | 0.3 | 1.0 | 0.0 | 0.6 | 4 | 3.6 | 0.49 | 0.259 | 0.447 | 2.25 |
| 2 | 1.67 | 9 | 6.5 | 3.5 | 0.0 | 0.0 | 3.5 | 0.6 | 0.0 | 0.0 | 0.6 | 2.84 | 0.59 | 0.104 | 0.158 | 0.205 | 4.0 |
| 3 | 6.0 | 7 | 4.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.79 | 0.16 | 0.198 | 0.753 | 0.283 | 5.5 |
| 4 | 10.6 | - | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | 0 | 2.65 | 5.325 | 1.036 | 2.0 |
| 5 | 4.82 | 12 | 8.5 | 4.0 | 1.0 | 0.0 | 2.5 | 0.3 | 0.5 | 0.0 | 0.4 | 1.76 | 2.07 | 0.301 | 0.269 | 0.349 | 4.0 |
| 6 | 1.05 | 4 | 3.0 | 2.0 | 0.0 | 0.0 | 2.0 | 1.5 | 0.3 | 0.0 | 0.9 | 5.23 | 2.85 | 0.099 | 0.312 | 0.200 | 3.25 |
| 7 | 4.57 | 7 | 5.0 | 7.0 | 1.0 | 0.0 | 4.0 | 0.1 | 2.0 | 0.0 | 1.0 | 1.09 | 1.96 | 4.57 | 0.794 | 1.361 | 1.0 |
| 8 | 1.27 | 6 | 3.0 | 5.0 | 0.0 | 0.0 | 5.0 | 0.6 | 0.0 | 0.0 | 0.6 | 3.14 | 4.72 | 0.141 | 0.538 | 0.239 | 3.0 |
| 9 | 1.0 | 7 | 4.0 | 6.0 | 0.0 | 0.0 | 6.0 | 0.1 | 0.0 | 0.0 | 0.1 | 4 | 7 | 0.111 | 0.125 | 0.212 | 3.0 |
| TOTAL | 33.48 | 61 | 44.7 | | | | 25.5 | | | | 4.2 | 22.85 | 22.95 | 8.64 | 3.58 | 4.29 | 28.0 |

CHAPTER

4

# Conclusion

The geomorphic analysis of a given watershed is of great significance in calculating the utilizable runoff potential, number of conservation structures along different streams and optimization of recharge/conservation structures. In the Nimbahera watershed, there are 14 macro watersheds and 125 micro watersheds. The 14 macro watersheds have an area of 565.38 sq kms, total perimeter is 1296.3 sq kms. There are 445 first order stream, 131 second order streams, 38 third order streams and 9 fourth order streams with a total length of 434.5, 194.0, 121.85 and 70.0 kms respectively. Based on the geomorphic analysis, utilizable run-off potential and unit recharge per conservation structure, a total number of 28 sub-surface barriers, 141 percolation tanks, 469 check dams and 281 point recharge structures are feasible in the 14 micro watersheds. The various characteristics of geomorphic analysis for the 14 macro watersheds in Nimbahera watershed is given in Tables 30 and 31. The number, type of conservation structures for individual micro watersheds with utilizing the available runoff are given in Table 33.

**Table 30:** Geomorphic Analysis of Macro Watershed in Nimbahera Watershed, District Chittaurgarh, Rajasthan

| Micro water-shed No. | Length of streams in kms | Bifurcation ratio(Ave) | Stream length ratio (Avg) | Drainage density in kms/ $kms^2$ | Stream Frequency / $kms^2$ | Form factor | Circul-atory ratio | Elong-ation ratio | Basin length in kms |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 166.65 | 0.70 | 0.30 | 1.21 | 0.86 | 0.30 | 0.62 | 0.53 | 119.2 |
| 2 | 27.0 | 2.25 | 0.3 | 0.95 | 0.61 | 0.41 | 0.59 | 0.65 | 14.4 |
| 3 | 42.5 | 3.5 | 1.08 | 0.65 | 1.49 | 0.40 | 0.78 | 0.71 | 12.5 |
| 4 | 59.5 | 3.9 | 0.36 | 0.85 | 1.6 | 0.31 | 0.57 | 0.61 | 17.45 |
| 5 | 36.5 | 1.38 | 0.44 | 2.09 | 1.08 | 1.25 | 0.61 | 1.67 | 9.1 |
| 6 | 35.5 | 1.5 | 0.8 | 1.23 | 0.74 | 0.22 | 0.82 | 0.38 | 24.4 |
| 7 | 146.0 | 3.08 | 0.70 | 1.32 | 0.94 | 0.29 | 0.41 | 0.34 | 119.1 |
| 8 | 6.0 | - | 0 | 0.13 | 0.18 | 0.64 | 0.28 | 0.52 | 6.85 |
| 9 | 118.5 | 1.03 | 0.55 | 1.67 | 0.56 | 0.26 | 0.54 | 0.32 | 80.9 |
| 10 | 43.0 | 2.43 | 0.58 | 1.07 | 1.56 | 0.76 | 0.46 | 0.51 | 17.65 |
| 11 | 24.0 | 0.19 | 0.56 | 1.30 | 1.40 | 0.34 | 0.42 | 0.34 | 14.85 |
| 12 | 23.5 | 2.25 | 0.37 | 0.88 | 0.81 | 0.96 | 0.38 | 1.08 | 11.75 |
| 13 | 24.0 | 4.42 | 1.35 | 3.54 | 3.45 | 1.0 | 0.61 | 0.41 | 9.2 |
| 14 | 47.7 | 2.8 | 0.46 | 2.53 | 2.55 | 0.96 | 0.39 | 0.47 | 28.0 |

**Table 31:** Analysis of Stream Ordering for 14 Macro Watersheds

| Micro Watershed No. | 1st order stream | | 2nd order stream | | 3rd order stream | | 4th order stream | | Area in $kms^2$ | Perimeter in kms |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of streams | Length | No. of streams | Length | No. of streams | Length | No. of streams | Length | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **1** | 68 | 81.5 | 30 | 33.5 | 10 | 34.65 | 2 | 17 | 132.15 | 285.7 |
| **2** | 9 | 21 | 4 | 6 | - | - | - | - | 21.17 | 45 |
| **3** | 28 | 27.5 | 8 | 13 | 1 | 2 | - | - | 22.65 | 33 |
| **4** | 37 | 34.5 | 9 | 11.5 | 3 | 7.5 | 1 | 6 | 24.23 | 47.5 |
| **5** | 20 | 18 | 6 | 6 | 3 | 4.5 | 1 | 8 | 23.99 | 39 |
| **6** | 14 | 18.5 | 4 | 5 | - | 12 | - | - | 31.14 | 57.5 |
| **7** | 83 | 76.5 | 25 | 49.0 | 9 | 40.5 | 1 | 32 | 127.14 | 319.5 |
| **8** | 3 | 6 | - | - | - | - | - | - | 14.02 | 5 |
| **9** | 57 | 66.5 | 13 | 29.5 | 3 | 22.5 | - | - | 79.2 | 218.5 |
| **10** | 23 | 22 | 10 | 13 | 1 | 7 | 1 | 1 | 25.62 | 63 |
| **11** | 17 | 11.5 | 5 | 8.5 | 2 | 4 | - | - | 14.27 | 37.1 |
| **12** | 21 | 16 | 2 | 3 | 2 | 4.5 | - | - | 11.44 | 26 |
| **13** | 22 | 14 | 5 | 5.5 | 1 | 4.5 | - | - | 7.82 | 24.5 |
| **14** | 42 | 27.5 | 10 | 10.5 | 5 | 7.7 | 1 | 2 | 33.48 | 82.5 |

## A brief description of the important parameters of the geomorphic parameters is given below:-

### 4.1 Bifurcation Ratio ($R_b$)

This parameter gives an idea of the shape of the basin and also helps in knowing the runoff behaviour. The bifurcation ratio will not be exactly the same from one order to the next because of the possibility of the change in watershed geometry, but will tend to be a constant throughout the series.

The ratio between the numbers of streams of an order to that of the next highest order is known as a bifurcation ratio. The average value of the Rb for the whole watershed varies from 0.19 to 4.42. The maximum bifurcation ratio value is 4.42 and it comes in 13 micro watersheds. The minimum bifurcation ratio value is 0.19 and it is in 11 micro watersheds. (Table.4) The macro watershed no.1 has the Bifurcation ratio value 0.70.

### 4.2 Drainage Density (Dd)

The drainage system is well developed in the watershed. The main river is Gambhir river (Nimbahera) and Banas river (Rashmi), the drainage density varies from 0.13 to2.53 kms/sq kms. The compute values of Dd for the Nimbahera watershed are presented in Tables. 4, and the macro watershed no.1 has the drainage density value 1.21.

### 4.3 Stream Length Ratio

The stream length ration shows an important relationship with discharge of the surface flow and erosion stage of the basin. The Rl is the ratio of the mean length (Lu) of a stream of any given order (u) to the mean length of a stream of the next lowest order (Lu-1). The stream length ratio varies from 0.0 to 1.35. The compute values of Rl for the Nimbahera watershed basin are presented in Table.4. The maximum stream length ratio value is 1.35 and it comes in 13 micro watersheds. The minimum stream length ration value is 0.0 and it is in 8 micro watersheds.

### 4.4 Circulatory Ratio

The circulatory ratio Rc is a quantitative expression of the shape of basin which is expressed as the ratio of basin area to the area of circle, having the same perimeter as the basin. If the value of Rc is exactly 1.0 the basin is set to be a perfectly circular shape. The value of Rc, ranging from 0.28 (macro watershed no.8) to 0.82 (macro watershed no.6) the average value of Rc compute for all macro watersheds, which is less than 1. This clearly indicates that the watershed is not circular in shape. The circularity ratio average value of all 14 macro watersheds is given in Table 4.

### 4.5 Elongation Ratio

The elongation ratio Re is the ratio between the diameter of the circular of the same area as the basin and the maximum basin length. The compute values of Re vary from 0.32 (macro watershed no. 9) to 1.08 (macro watershed no.12).

Artificial recharge structures are constructed mostly with the objective of augmenting ground water recharge / resources, using the rainfall run-off and Roof Top Rain Water Harvesting.

Central Ground Water Board, an apex organization for the ground water sector for the country has implemented a number of pilot schemes for popularization of cost-effective technologies for artificial recharge to ground water. Various structures like check dams, percolation ponds, recharge shafts and sub-surface dykes in different hydro geological settings. Impact assessment of these schemes has been carried out using direct and indirect methods. Based on the study in and around Rajasthan State, unit recharge / year through various conservation structures were arrived at and are apportioned in the following proportions (Table.32). This will be reviewed and suitably modified when taken up on a micro level basis considering the morphometric of each village

Based on the above, the conservative estimate of recharge to the ground water body through the existing 93 conservation structures in 14 macro watersheds is 16.74 mcm / year, taking into consideration the average recharge of 0.18 mcm per conservation structure.

**Table 32:** Conservation Structure Planning in the Area

| Sl. No. | Conservation Structure | No. of conservation structures (in percentage) | Unit Recharge / structure / annum | Rise in water level (m) /annum expected |
|---|---|---|---|---|
| 1 | Sub-surface Dyke Barriers | 15 | 0.30 mcm | 1.0 -2.0 |
| 2 | Percolation Tank | 50 | 0.20 mcm | 1.5 2.0 |
| 3 | Check Dam | 25 | 0.03 mcm | 0.5 1.0 |
| 4 | Point Recharge Structure | 10 | 0. 02 mcm | 0.5 1.0 |

Surface run-off for the Nimbahera watershed considering 75 per cent of the total runoff available in the catchment as utilizable non-committed run-off, the available water in the watershed is 56.28 mcm. The total utilized run-off water for recharge through the existing 93 structures as 16.74 mcm, leaving behind the non-committed surplus run-off available in the catchment as 39.74 mcm. The proposed 21 recharge structures in the watershed may use 3.78 mcm, thus leaving 35.76 mcm available for future developments in a phased manner. The augmentation of ground water recharge will have an impact on arresting declining in water levels and improving the ground water resources.

The water conservation structures are described below:-

## 4.6 Percolation Tank

These are the most prevalent structures in India as a measure to recharge the ground water reservoir both in alluvial and hard rock formations. Percolation tanks are normally constructed on second to third order streams since the catchment and submergence area would be smaller. The submergence area should be in uncultivable land as far as possible. Percolation tanks should be located on highly fractured and weathered rock for speedy recharge. In case of alluvium, the boundary formations are ideal for locating percolation tanks. The aquifer to be recharged should have a sufficient thickness of permeable vadose zone to accommodate recharge. The benefited area should have a sufficient number of wells and cultivable land to develop the recharge water. The design capacity should not normally be more than 50 per cent of total quantum of rainfall in catchment. Waste weir or spillway should be suitably designed to allow flow of surplus water based on single day maximum seepage losses both below and above the nalabed. To avoid erosion of embankmsent due to ripple action stone pitching should be provided upstream up to HFL. These structures are mostly located in gentle sloping streams having a good storage slope and below the check dams (constructed across the 1st, 2nd and 3rd order streams) and existing defendant tanks. Percolation tanks are constructed in areas where natural depression along with excess surface water was available. As the water generally remains in percolation tanks up to January, the peripheral agricultural land of the submergence area is also being used for taking one crop at least. The cost of the percolation tank will be higher when compared with other conservation structures. The recurring expenditure will be in the de-silting form once two to three years for effective recharge. The silt deposited in the percolation tank will be very rich in bio-mass and should be used in the fields by farmers. The impact assessment reveals that the efficiency of the percolation tank varies from 78 to 91 per cent, the seepage losses range from nil to 9 per cent. The maximum efficiency from percolation tanks can be achieved, if water remains in the tank only till January. The total capacity utilization of the percolation tank during a year of good rainfall can be up to 150 per cent due to repetitive fillings. Maximum surface run-off could be conserved in addition to recharge to ground water benefiting a large area. The cost benefit of the percolation tank varies from 1:1.30 to 1:2.00. The rise of water level around the newly constructed percolation tanks will be up to 10 m, while for old existing percolation tanks it is up to 7 m. The wells in the zone of benefit of the percolation tank could sustain long hours of pumping even during the summer months. The additional recharge to ground water through these percolation tanks has created a positive social impact. Dependence on tankers for irrigation and domestic water supply reduced considerably. The structures are located on highly fractured and weathered rock in gentle sloping streams having a good storage slope and below the check dams (constructed across the 1st, 2nd and 3rd order streams)

## 4.7 Check Dams

These are constructed across small nalas which have gentle slopes both in alluvium and hard rock formations.. The site selected should have sufficient thickness of weathered formation which helps in recharging the stored water within a short span of time. A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on previous soil/ rock surface for a longer body.

The total catchment of the nala should normally be between 40 to 100 hectares. The rainfall in the catchment should be less than 1000 mm / annum. The width of the nala should be at least 5 m. and not exceed 15 m. and the bed should not be less than 1m. The soil downstream of the bund should not be prone to water logging and should have pH between 6.5 to 8.0. The land downstream to check dam should have irrigable land under well irrigation. The nala bunds should be preferably located in an area where contour or graded bunding or lands have been carried out. The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water. Nala bund is generally a small earthen dam, with a cut off core wall of brick work, though cement bunds / plugs are now prevalent.

The height of the banks on both sides of the check dam should be between 3 to 4 m. This helps not only in the deciding height of the bund but also will not damage adjoining agricultural lands during heavy rains. While selecting the site, the availability of dug wells on either side of the stream needs to be considered. The wells located around the check dam will have maximum benefit due to repetitive filling of the check dam since there is a possibility of overflow even during moderate rains. The structures are located in the upper catchment with less than 3 per cent slope and mostly restricted to 1st and 2nd order streams. The check dam should have sufficient storage area, in the upstream. It is normally constructed on second to third order streams.

## 4.8 Sub-surface Barriers

These are basically ground water conservation structures and are effective to provide sustainability to ground water structures by arresting sub-surface flow. A groundwater dam is a sub-surface barrier across stream which retards the natural groundwater flow of the system and stores water below ground surface to meet the demands during the period of need. The main purpose of the ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. By doing so the water level in the upstream part of the ground water dam rises sustaining the otherwise dry part of aquifer.

The underground dam has the following advantages: Since the water is stored within the aquifer, submergence of land can be avoided and land above the reservoir can be used even after the construction of the dam. No evaporation loss from the reservoir takes place. No siltation in the reservoir takes place. The potential disaster like the collapse of the dam can be avoided. The aquifer to be replenished is generally one which is already over exploited by tube well pumpage and the declining trend of water levels in the aquifer have set in. On account of the confining layers of the low permeability the aquifer can get natural replenishment from the surface and needs direct injection through recharge wells.

These structures are mostly restricted to bottlenecked valleys having a shallow basement mostly alluvium or unconsolidated material. These structures are also known as underground Bhandara or ground water dams. This sub-surface structure is constructed across streams. Normally a clay dyke is provided to arrest sub-surface flow. However it is observed that owing to water level fluctuation, the clay wall below the ground level develops cracks especially in the zone of water level fluctuation. Due to these cracks, the efficiency of the sub-surface dam decreases considerably. In order to overcome this, an asbestos sheet is provided in the upstream along with the clay core as impermeable membrane to arrest the leakage. The impact of the sub-surface barriers revealed, considerable rise in water levelling the upstream part of the structure and the wells are sustained through long hours of pumping. Restricted to bottlenecked valleys having a shallow basement mostly alluvium or unconsolidated material. This is a sub-surface structure constructed across streams.

## 4.9 Point Recharge Structures

These are located in and around the low yielding bore wells. They are the most efficient and cost effective structures to recharge the aquifer directly. In areas where source water is available either for some time or perennially, for example base flow, springs, etc., the recharge shaft can be constructed following the design guidelines. The strata can be dug manually if it is of a non-caving nature. If the strata is caving, proper permeable lining in the form of open work, boulder lining should be provided. The diameter of the shaft should normally be more than 2 m. to accommodate more water and to avoid eddies in the well. In the areas where source water has silt, the shaft should be filled with boulder, grave and good sand from the bottom to have an inverted filter. The upper most sand has to be removed and cleaned periodically. A filter is provided before the source water enters the shaft. When water is put into the recharge shaft directly through pipes, air bubbles are also sucked into the shaft through the pipe which can choke the aquifer. The injection pipe should therefore be lowered below the water level to avoid this. The main advantages of the technique are as follows:

It does not require acquisition of a large piece of land like percolation tanks. There are practically no losses of water in the form of soil moisture and evaporation, which normally occur when the source water has to traverse the vadose zone. Disused or even operational dug wells can be converted into recharge shafts

Technology and design of the recharge shaft is simple and can be applied even when base flow is available for a limited period. The recharge is fast and immediately delivers the benefit. In highly permeable formation, the recharge shafts are comparable to percolation tanks with no submergence and hence no land compensation to local farmers.

**Table 33:** Number, Type of Conservation Structure Feasible and Total Recharge to Ground Water

| Sl. No. | Micro water-shed | Utiliz-able runoff (mcm) | No. of Conservation Structures / Recharge to Ground Water (MCM) / Annum | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sub-surface barriers | | Percolation tank | | Check dam | | Point recharge structure | |
| | | | No. of struc-tures | Recharge (mcm) | No. of Struct-ures | Recharge (mcm) | No. of Struct-ures | Recharge (mcm) | No. of Struct-ures | Recharge (mcm) |
| 1 | 1 | 10.27 | 5 | 1.5405 | 26 | 5.135 | 86 | 2.5675 | 51 | 1.027 |
| 2 | 2 | 1.65 | 1 | 0.2475 | 4 | 0.825 | 14 | 0.4125 | 8 | 0.165 |
| 3 | 3 | 1.76 | 1 | 0.264 | 4 | 0.88 | 15 | 0.44 | 9 | 0.176 |
| 4 | 4 | 1.89 | 1 | 0.2835 | 5 | 0.945 | 16 | 0.4725 | 9 | 0.189 |
| 5 | 5 | 1.88 | 1 | 0.282 | 5 | 0.94 | 16 | 0.47 | 9 | 0.188 |
| 6 | 6 | 2.44 | 1 | 0.366 | 6 | 1.22 | 20 | 0.61 | 12 | 0.244 |
| 7 | 7 | 8.94 | 4 | 1.341 | 22 | 4.47 | 75 | 2.235 | 45 | 0.894 |
| 8 | 8 | 1 | 1 | 0.15 | 3 | 0.5 | 8 | 0.25 | 5 | 0.1 |
| 9 | 9 | 6.13 | 3 | 0.9195 | 15 | 3.065 | 51 | 1.5325 | 31 | 0.613 |
| 10 | 10 | 1.84 | 1 | 0.276 | 5 | 0.92 | 15 | 0.46 | 9 | 0.184 |
| 11 | 11 | 12.1 | 6 | 1.815 | 30 | 6.05 | 101 | 3.025 | 61 | 1.21 |
| 12 | 12 | 2.89 | 1 | 0.4335 | 7 | 1.445 | 24 | 0.7225 | 14 | 0.289 |
| 13 | 13 | 0.66 | 0 | 0.099 | 2 | 0.33 | 6 | 0.165 | 3 | 0.066 |
| 14 | 14 | 2.83 | 1 | 0.4245 | 7 | 1.415 | 24 | 0.7075 | 14 | 0.283 |
| Total | 14 | 56.28 | 28 | 8.442 | 141 | 28.14 | 469 | 14.07 | 281 | 5.68 |

# CASE STUDIES

## 1. IMPACT OF INTERVENTIONS ON GROUND WATER REGIME IN MALUR WATERSHED, KOLAR DISTRICT, KARNATAKA STATE

Afaque Manzar Dr. K. Md. Najeeb Dr. K.R. Sooryanarayana
Central Ground Water Board, Bangalore

## 2. DELINATION OF POTENTIAL GROUNDWATER ZONES IN MICRO WATERSHEDS A GEOMORPHIC APPROACH

P. Rajendra Prasad1, N.V.B.S.S Prasad1, N.L.K.Reddy1, D.Nooka Raju1, Bhoop Singh2 and D. K. Chadha3

## 3. GEOMORPHOMETRIC ANALYSIS FOR EFFECTIVE WATER RESOURCES MANAGEMENT THROUGH ARTIFICIAL RECHARGE TO GROUND WATER IN OVEREXPLOITED WATERSHEDS

Dr. S. K. Jain, Scientist, 'D', Central Ground Water Board

## 4. SITE SELECTION FOR RAIN WATER HARVESTING AND ARTIFICIAL RECHARGE TO GROUND WATER IN VATRAK SUB-WATERSHED, SABARMATI BASIN, GUJARAT, INDIA

Based on Geo-informatics Multithematic Multi-criteria Evaluation

Dr.R.C.Jain1, A.P.Bhavsar2, B.S. Patel3, Naveenchandra N. Srivastva4
and
Khalid Mahmood4

## 5. GEOMORPHIC ANALYSIS OF WATERSHED FOR PLANNING OF ARTIFICIAL RECHARGE STRUCTURES IN TYPICAL GRANITIC TERRAIN

A Case Study from Andhra Pradesh, India

Rao, P.N., Varadaraj, N.,and Pandith, M.

# Impact of Interventions on Ground Water Regime in Malur Watershed, Kolar District, Karnataka State

**Afaque Manzar Dr. K. Md. Najeeb, Dr. K.R. Sooryanarayana**
**Central Ground Water Board, Bangalore**

## Abstract

Malur is one of the over-exploited taluks of Kolar district in Karnataka State, India, covered by hard rock aquifers comprising granites and gneisses. The economy of the area is primarily dependent on agriculture. The major source for irrigation is ground water. There was a spurt in ground water development through bore wells due to the tendency to grow more and more crops and easy availability of drilling rigs. There has been unmindful pumping of precious ground water resource in the last two decades. The annual ground water draft in the taluk is 11667 ham against the net annual ground water availability of 4913 hectare metres (ham). Hence, there is an annual overdraft of 6750 ham with the stage of ground water development of 237 per cent. This has resulted in lowering of the water level and drying up of phreatic aquifer in the taluk. A declining trend of 0.6 metres per annum is observed in the area. Almost all the irrigation dug wells and about 231 bore wells have dried up in the taluk causing migration of people in search of livelihoods and jobs. There is acute shortage of drinking water especially in villages where the source is ground water.

Water conservation and artificial recharge structures were constructed as an intervention to control the declining water level trend by augmenting ground water recharge through check dams and percolation tanks. The impact of these interventions helped to build up storage in ground water aquifer in terms of productivity of the ground water abstraction structures. The details are discussed in this paper.

**Key Words:** Intervention, Over Exploitation, Artificial Recharge.

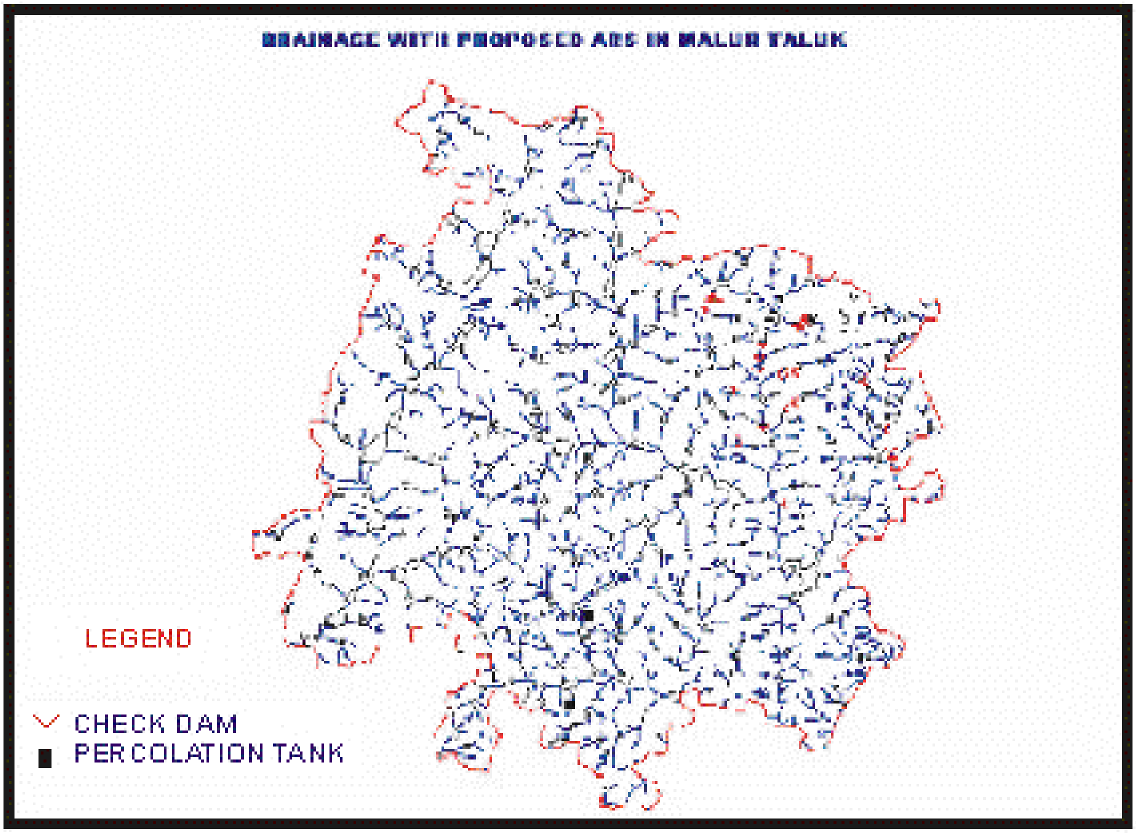



**Figure 1:** Malur Taluk Showing Location of Artificial Recharge

## Introduction

Ground water is the lifeline of the farmers for the domestic and irrigation water requirements in Malur taluk, Kolar district in Karnataka State, India. The demand for water in this ground water dependent area is increasing everyday whereas the yield of wells are decreasing and in some cases the wells are drying up. Hence, an immediate need to manage the water resources in a scientific way by adopting water conservation, efficient use of water in irrigation, crop management, social forestry, etc. has become important for the area with an integrated approach.

The study area broadly covers 16 villages in Malur taluk, Kolar district. The study involves the construction of artificial recharge structures in the ground water stress areas and the impact of these structures on the ground water regime. To achieve this objective, 23 check dams and 2 percolations tanks were constructed in hydro-geologically feasible locations covering 13 villages. (Figure 1).

Agriculture is the main occupation in the area, which provides employment to the rural folk. Their earning is mainly dependent on the agriculture produce, dairy activities and sericulture farming. Apart from agriculture, the brick industry is common in the taluk. About 50per cent of the area comes under dry land cultivation and about 12per cent of the area is covered by irrigation. In the area irrigated, the ground water component received a major share. The dry land cultivation depends mainly on rainfall. The area covered by forests is negligible.

The normal annual rainfall in the area is 624.8 mm (Tekal station) with an average monsoon rainfall of 500.2 mille metres (mm). The rainfall is spread over 30 rainy days. The temperature in the area varies from 20.4 to 29.1 degrees centigrade. The annual potential evapotranspiration (PET) is 1501 mm in the area. The rainfall exceeds PET during August-October. About 40 to 50 percent of the rainfall in the area occurs during September-October.

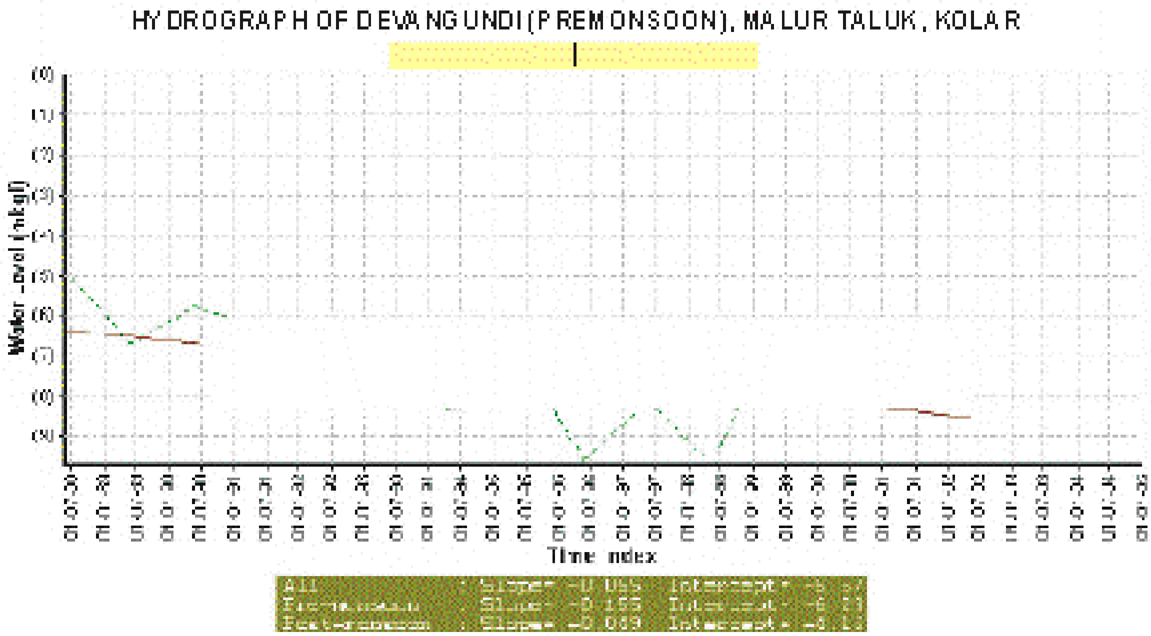



**Figure 2:** Hydrograph of Devanagundi (Pre-Monsoon)

## Ground Water — Scenario and Resources

Malur is one of the over-exploited taluks in the district. The area represents a typical hard rock terrain. Ground water occurs both in phreatic and fractured aquifers in the area. Though the phreatic aquifer is generally dry, ground water pockets exist in places where the basement is shallow. Ground water over-exploitation has taken place in the major part of the study area with isolated patches of shallow water table conditions in the range of 6 to 12 metres below ground level (m bgl) which is mainly confined to topographic depressions and shallow basement areas. The depth to water level in the deeper zone represented by fractured aquifers is in the range of 60 to 160 m bgl. Ground water from the fractured aquifer zone is being pumped through bore wells having a depth up to 350 m bgl. Most of the shallow bore wells and the existing dug wells have dried-up due to lowering of the water table in the area. The bore well yield is in the range of negligible to 7 litres per second (lps).

There is an annual ground water draft of 11667 ham against net annual ground water availability of 4913 ham. Hence, there is an annual overdraft of 6750 ham and the stage of development is 237 %per cent in the watershed. This has resulted in lowering of the water level (Fig 2) and drying up of the phreatic aquifer in the taluk.

About 5677 irrigation wells have dried up in the taluk owing to over exploitation and there is always uncertainty about rainfall and dependency on ground water is increasing. Farmers are losing their livelihood and labourers are losing jobs and many are forced to migrate. There is acute shortage of drinking water due to drying up of water supply and bore wells in many villages. Hence there is need to augment ground water resources by artificial recharge measures so that the declining trend can be arrested/ checked/controlled to help people for domestic/ irrigation needs. This will help in preserving soil moisture, improvement of ecology and development of green grass for cattle grazing.

## Need for Interventions

Water is the lifeline of all activities in the area. The entire watershed depends on rainfall and ground water for domestic, irrigation and industrial activity. The over-exploitation of ground water has taken place due to the prevailing large-scale heterogeneity in aquifer characteristics. Such situations result in steep decline in ground water levels leading to drying up of dug wells and dwindling of yield in bore wells. Owing to political and social considerations, it is difficult to reduce ground water extraction to sustainable levels. In the absence of these management mechanisms, there is a need to adopt other viable options to maintain the sustainability of ground water resources in the area.

## Viable Plan of Action

Optimum utilization of the resources available in any area helps to manage the area from the adverse impacts of over-exploitation, decline in ground water levels and associated problems. If non-committed surface runoff is available in a particular area, this can be utilized for recharging the aquifers through suitable augmentation structures to maintain the sustainability of the aquifer thereby the abstraction structures in the area. In areas receiving moderate rainfall, mostly during the monsoon season and not having inter basin water transfer, the entire efforts of water conservation are required by making use of the insitu precipitation available in the area. Traditional soil and water conservation measures like boulder checks, vegetative checks, gully plugs, check dams and percolation tanks are the ide]al structures which help to recharge the ground water body. The structures are simple and easy to implement using locally available material and man power. The phenomenon becomes incidental in nature and mutually complementary to soil and water conservation.

## Interventions Implemented

To overcome the crisis, the Central Ground Water Board has implemented a scheme of artificial recharge to ground water in parts of Malur taluk. Under the scheme, as mentioned above, 23 check dams and 2 percolation tanks were constructed for recharging ground water with an objective to harvest the non-committed surplus monsoon runoff in the independent catchment area of structures, which worked out as 1.63 million cubic metres (mcm). The storage capacity of all the structures mentioned above put together works out to be 0.126 mcm and the recharge capacity for one filling is 0.0944 mcm. Annual recharge considering four fillings is 0.378 mcm. Thus recharge during 20 years (life of structures) will be 7.556 mcm. The cost of one cubic metre of water harvested is 73 paise taking into consideration of the total cost of the scheme and considering 20 years of life for the structures. Water harvested by structures will create an annual additional irrigation potential of 46 hectares considering 0.82 m average delta value for the area. Catchment area, storage capacity of individual recharge structures and source water availability is given in Table 1.

## Expected Irrigation Potention

## Impact of Interventions

The impact assessment of the studies was carried out in terms of build up in groundwater levels in representative wells, 16 bore wells and 12 dug wells, change in productivity of bore wells and change in cropping pattern in the surrounding areas of artificial recharge structures .

**Change in Water Level:** All the 12 dug wells monitored have shown a rise of water level in the range of 0.53 to more than 4.58 m. Four dug wells, which were dry for many years have got water columns during this post monsoon. The post project ground water level hydrographs of observation wells in the study area are shown in Fig: 3.

Of the total 16 bore wells, 13 have recorded a rise in water level in the range of 0.6 to 21.39 m with an average rise of 5.57 m. Three bore wells have recorded a decline of water level in the range of 0.87 to 6 m, as it may take some more years to have a visible impact of the scheme. Apart from this, 12 bore wells, which were dry in the project area, have started yielding at present.

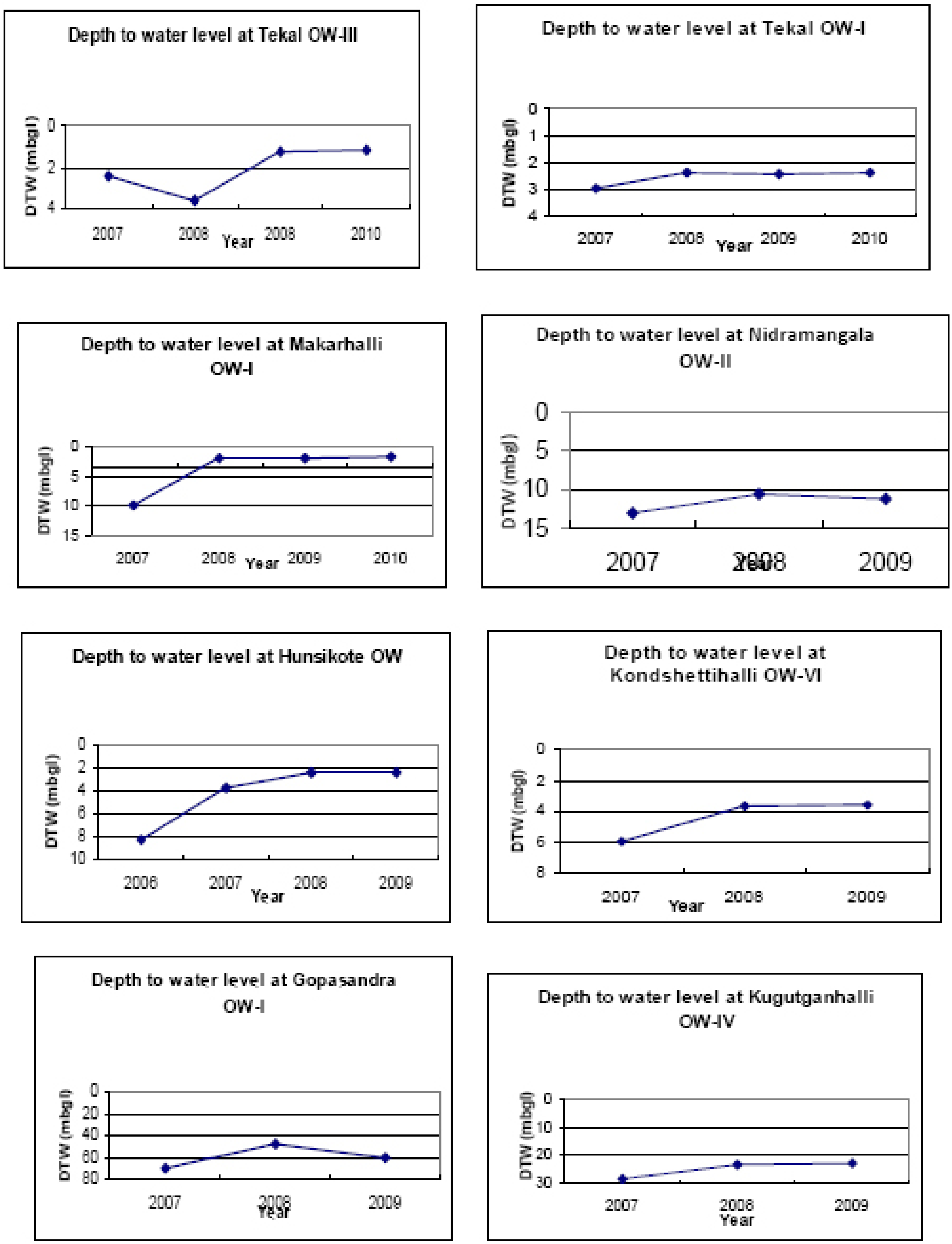
**Change in Productivity of Bore Wells:** There is increase of sustainability of pumping in the range of 50 minutes to one hour. Some wells, which discharged water intermittently, have had a continuous flow during the post-project period. Yield of wells has increased in the range of 0.25 to 6 lps. The data is given in Table 2.

**Change in Cropping Pattern:** The command area of wells in the project area has increased in the range of 0.2 to 2 hectares. A farmer in Hunsikote village has started paddy cultivation during post-project period, which was not so earlier.

**Table 1:** Storage Capacity of Recharge Structures, Source Water Availability, Expected Irrigation Potential

| Location | Structure | Independent catchment area (ha) | Average monsoon rainfall (mm) | Non-committed runoff (mcm) | Storage capacity (mcm) | Annual recharge capacity in 4 fillings (mcm) | Recharge in 20 years life of structures (mcm) | Average crop Water requirement (m) | Irrigation potential to be created (ha) |
|---|---|---|---|---|---|---|---|---|---|
| Halebalahalli CD 1 | Check Dam | 120 | 500.2 | 0.065 | 0.0023 | 0.0070 | 0.14 | 0.82 | 0.85 |
| Makarahalli CD1 | Check Dam | 120 | 500.2 | 0.065 | 0.0022 | 0.0067 | 0.13 | 0.82 | 0.82 |
| Kshetrahalli | Check Dam | 120 | 500.2 | 0.065 | 0.0023 | 0.0070 | 0.14 | 0.82 | 0.85 |
| Mitiganhalli | Check Dam | 110 | 500.2 | 0.059 | 0.0009 | 0.0026 | 0.05 | 0.82 | 0.32 |
| Kondashettihalli CDIII | Check Dam | 110 | 500.2 | 0.059 | 0.0044 | 0.0133 | 0.27 | 0.82 | 1.62 |
| Kondashettihalli CDIV | Check Dam | 120 | 500.2 | 0.065 | 0.0023 | 0.0070 | 0.14 | 0.82 | 0.85 |
| Kondashettihalli CD V | Check Dam | 140 | 500.2 | 0.076 | 0.0014 | 0.0042 | 0.08 | 0.82 | 0.51 |
| Tekal CD II | Check Dam | 110 | 500.2 | 0.059 | 0.0008 | 0.0023 | 0.05 | 0.82 | 0.28 |
| Byratnahalli Pura CD I | Check Dam | 150 | 500.2 | 0.081 | 0.0081 | 0.0243 | 0.49 | 0.82 | 2.96 |
| Gopasandra CD I | Check Dam | 150 | 500.2 | 0.081 | 0.0021 | 0.0064 | 0.13 | 0.82 | 0.78 |
| Nidramangala CD I | Check Dam | 120 | 500.2 | 0.065 | 0.0007 | 0.0022 | 0.04 | 0.82 | 0.27 |
| Tekal CD I | Check Dam | 110 | 500.2 | 0.059 | 0.0008 | 0.0023 | 0.05 | 0.82 | 0.28 |
| Kugutganhalli CD I | Check Dam | 95 | 500.2 | 0.051 | 0.0007 | 0.0021 | 0.04 | 0.82 | 0.25 |
| Puttashettihalli CD I | Check Dam | 90 | 500.2 | 0.049 | 0.0017 | 0.0050 | 0.10 | 0.82 | 0.61 |
| Hunsikote CD I | Check Dam | 95 | 500.2 | 0.051 | 0.0007 | 0.0021 | 0.04 | 0.82 | 0.25 |
| Nidramangala CD III | Check Dam | 110 | 500.2 | 0.059 | 0.0016 | 0.0048 | 0.10 | 0.82 | 0.59 |
| Kugutganhalli CD III | Check Dam | 110 | 500.2 | 0.059 | 0.0008 | 0.0023 | 0.05 | 0.82 | 0.28 |
| Hunsikote CD II | Check Dam | 40 | 500.2 | 0.022 | 0.0007 | 0.0022 | 0.04 | 0.82 | 0.27 |
| Nidramangala CD II | Check Dam | 120 | 500.2 | 0.065 | 0.0022 | 0.0067 | 0.13 | 0.82 | 0.82 |
| Kugutganhalli CD IV | Check Dam | 110 | 500.2 | 0.059 | 0.0008 | 0.0023 | 0.05 | 0.82 | 0.28 |
| Kugutganhalli CD II | Check Dam | 110 | 500.2 | 0.059 | 0.0008 | 0.0023 | 0.05 | 0.82 | 0.28 |
| Komanhalli CD I | Check Dam | 90 | 500.2 | 0.049 | 0.0021 | 0.0063 | 0.13 | 0.82 | 0.77 |
| Nidramangala CD IV | Check Dam | 120 | 500.2 | 0.065 | 0.0023 | 0.0070 | 0.14 | 0.82 | 0.85 |
| Kesargere (Place I) | Percolation Tank | 237.5 | 500.2 | 0.128 | 0.0081 | 0.0243 | 0.49 | 0.82 | 2.96 |
| Hanumanthanagar | Percolation Tank | 225 | 500.2 | 0.121 | 0.0750 | 0.2250 | 4.50 | 0.82 | 27.44 |
| Total | | | | 1.636 | 0.1259 | 0.3778 | 7.56 | 0.82 | 46.07 |

**Figure 3:** Hydrograph of observation wells in the study are Malur taluk



## Summary and Conclusions

Artificial recharge structures, namely check dams and percolation tanks can be taken up on a large scale in the over-exploited areas as a management plan to tackle falling groundwater levels. These structures have proved in building-up groundwater levels and improvement of productivity of groundwater abstraction structures, mainly in bore wells. An increase in the area irrigated by groundwater sources was also observed in the area of influence. Such activities help greatly in providing sustainable drinking water to the rural population.


## Acknowledgements

The authors express their sincere gratitude to Dr.S.C.Dhiman, Chairman, Central Ground Water Board for according permission to present this paper. The authors also express their sincere gratitude to the Members, Central Ground Water Board for their support and encouragement.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# Delination of Potential Groundwater Zones in Micro Watersheds

## A Geomorphic Approach

**P. Rajendra Prasad1, N.V.B.S.S Prasad1, N.L.K.Reddy1, D.Nooka Raju1, Bhoop Singh2 and D.K Chadha3**

## Abstract

The recent spurt in agricultural production, industrial development and urbanization supplemented by uneven distribution of rainfall in time and space, failure of monsoons have created an irrecoverable stress on groundwater resources in hard rock regions. In a bid to comply with the contemporary needs an attempt has been made to select suitable locations for groundwater exploration in Narava basin adopting an integrated study mainly comprising morphometric and hydrogeomorphological surveys. The drainage pattern is dominated by dendetric to sub-dendetric patterns. Various geomorphological units in association with the lineament density were evaluated. Slope is prepared to identify possible groundwater recharge and discharge zones. The area from the hydrogeomorphological perspective can be classified under PPS, PPM, PPG, SH and RH categories.

The groundwater potential of the area is assessed through an integrated analysis of geoelectrical sections, their correlation with lithology and discharges at drilling locations with relevant data on hydrogeomorphology, lineaments, slope, etc. Based on the results of the analyses, groundwater potential in the watershed can be classified into five categories from good to poor. The central part of the basin occupying 20 per cent of the basin area turned out to be a moderate to good potential zone for groundwater exploitation.

Keywords: Narava micro watershed, hydrogeomorphic zones, potential groundwater, pediplain, lineament density.

## Introduction

Groundwater is the primary source of fresh water in the study area. There has been a growing demand for fresh water in domestic, agriculture and industrial sectors. In order to meet the demand, identification and delineation of potential aquifer zones have become essential for which several analogies are in vogue. To assess the groundwater conditions in the area, integrating hydrogeomorphological data with geophysical signatures is evolved to be a simple and rapid approach for demarcation of groundwater potential zones (Nata, T et al., 2010). The study area covered by hard rock formations faces acute water scarcity for irrigation and drinking. For the delineation of the potential groundwater zones in the study area the prevalence of some of the hydrogeological formations play a significant role. It is observed that there is spatial variation both in the occurrence and movement of groundwater.

## LOCATION AND DRAINAGE

Narava micro watershed covers an area of about of 105 sq kms and lies between 17 42'30?–17 47'30? N latitude and 83 04'30?–83 12'30? E longitude and is shown in Fig. 1. The area is covered in Survey of India toposheets 65O/1, O/2 and O/3. The Narava Gedda, an ephemeral river network, drains initially into the SW–NE direction in the upper reaches and later turns to NW–SE direction. The river network eventually merges into the Mehadhrigedda reservoir. This reservoir is one of the important drinking water storage reservoirs catering to the water needs of Visakhapatnam city. The Narava basin has attained semi maturity with a fourth order drainage network dominated by dendritic to sub-dendritic patterns. The drainage patterns of Narava are structurally controlled by lineaments.

## Methodology

In the present study, hydrogeomorphological and lineament maps were prepared by the Institute of Electronic Governance using remote sensing data

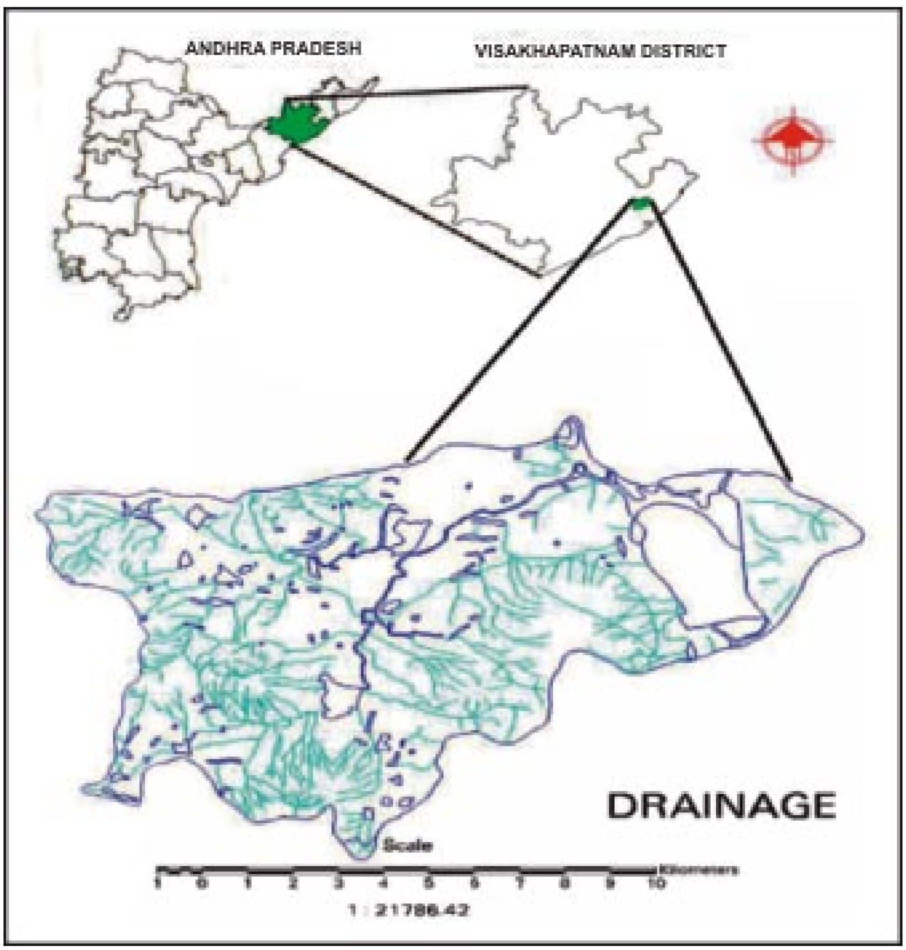


**Figure 1:** Location and Drainage Map of Narava Micro Watershed.

of IRS –LISS -4 of April, 2005 and Cartosat data of November 13, 2005 (Nagarajan, M. and Sujit Singh (2009), Avtar R. et al. (2010), Yassir Arafat, M.N. (2010). Topographic information has been collected from SOI toposheets at 1:25000 scale. Surface drainage map has been prepared from SOI toposheets and satellite image data. Morphometric analysis was carried out on 1:25,000 scale maps. Data on geology, hydrogeology, well inventory complemented by ground truth verification were used to generate the hydro-geomorphological maps.

## Geology

The study area forms a part of the Eastern Ghats tectonic complex which is a major physiographic province and a principal Precambrian metamorphic unit of Peninsular India .The prominent geological formations in the area belong to the Archaean and Quaternary age. The Archaean system includes mainly Khondalite suit of rocks, Granite Gneisses (Leptynites), Charnokite, Granites, Pegmatites and Quartz veins. Mostly the quartz veins occur as intrusive bodies in the Khondalite suite of rocks. The Quarternary system includes Laterites and Surficial deposits .The geological sequence in the area is given below.

The general strike direction of the Khondalitic formation is N 60$^{O}$ E with 40° to 90° dip due south and the strike of the formation varies in the middle of the basin from N 60° E to N 90° E.

| System | Age | Stratigraphic Unit |
|---|---|---|
| Quarternary | Recent | Surficial deposits (Piedmont fans, colluvium red sediments and alluvium) |
| | Sub recent | Laterite /Laterite gravel |
| Archaean | Precambrian | Granites<br>Charnokites<br>Granite Gniesses (Leptynites)<br>Khondalite suite of rock |

## LAND USE/ LAND COVER CLASSIFICATION

The present classification is done with the help of IRS LISS-4 dated April 3, 2005 , Cartosat data dated November 13, 2005, Survey of India toposheets on 1:25,000 scale and ground truth information by visual interpretation techniques. The detailed land use/ land cover statistics of the Narava micro watershed for the year 2005 are given in Table Land use / land cover also influence the percolation of precipitation from the top soil to the sub-surface aquifer zones, forest cover and irrigation. The area under agriculture contributes to higher recharge condition relative to wastelands.

**Table 1:** Land Use Land Cover Classification in Narava Micro Watershed

| Land use/Land Cover Classification | Area in kms$^2$ | Percentage |
|---|---|---|
| Built-up land | 3.9375 | 3.75 |
| Agricultural land | 75.875 | 72.26 |
| Forest degraded/open forest) | 9.375 | 8.92 |
| Waste lands | 8 | 7.61 |
| Mining land | 0.375 | 0.357 |
| Water bodies | 7.437 | 7.08 |

## Drainage Analysis

Evaluation of the characteristics of the drainage network of a basin using quantitative morphometric analysis can give information about the hydrological nature of the rocks exposed within the drainage basin. A drainage map of a basin provides a reliable index of the permeability of the rocks and also gives an indication of the yield of the basin (Wisler and Brater 1959). Aquantitative analysis of the morphometric parameters has been carried out for the Narava micro watershed. The quantitative analyses of the morphometric characteristics of the basin include stream order, stream length, bifurcation ratio, drainage density, drainage frequency, stream frequency, relief ratio, elongation ratio and circularity ratio.

Hydrogeological observations, integrated with drainage analysis, provide useful clues regarding broad relationships among the geological framework of a watershed, surface flow and the recharge. The drainage map of the Narava micro watershed, prepared from the Survey of India topographic sheets numbered 65O/1 and O/2 andO/3. For the analysis of the drainage characteristics and relief, intensive use has been made of Survey of India toposheets on 1:25000 scale. This drainage map was analysed by making two types of measurements, linear scale measurements and dimensionless numbers. The linear-scale measurements are the length of the stream channel of a given order, drainage density and the dimensionless numbers are usually the ratios of these length measures. The Narava micro watershed was analysed for stream-order analysis, bifurcation ratio ($R_b$), length ratio ($R_l$), drainage density ($D_d$) and stream frequency (F).

## Stream Order

The advantage of ordering streams is that the stream order is a dimensionless number. The study area encompasses a fourth order drainage, which drains initially in SW–NE direction and later turns to NW-SE. The Narava micro watershed drainage network was classified as per Strahler (1952). The details of the stream order of the Narava micro watershed are as given in Table 2.

## Bifurcation Ratio ($R_b$)

The Horton's bifurcation ratio ($R_b$) ranges from 4.7 to 9 with mean bifurcation ratio of 6.2 (Table 3). High bifurcation ratio (> 5.00) is noticed between third and fourth order streams indicating structurally controlled development of the drainage network (Strahler 1957).

It can be seen from Table 3 that the bifurcation ratio for the fourth order Narava micro watershed is 6.2, indicating the prevalence of structural control on the development of the drainage pattern.

## Length Ratio ($R_l$)

The length of a stream is a measure of the hydrological characteristics of the underlying rock formations and the degree of drainage. The mean length of a stream of any given order is always greater than the mean length of a stream of the next lower order and, based on this, Horton (1945) proposed the factor length ratio ($R_l$), which is the ratio of the mean length of a stream of any given order to the mean length of a stream of the next lower order. The length ratio gives a general idea about the relative permeability of the rock formations in a basin. More specifically, it indicates whether there is a major change in the hydrological characteristics of the underlying rock formations over areas of consecutive stream orders. The stream length ratio of the Narava watershed ranges from 1.7 to 2.4. The average length ratio for the fourth order Narava micro watershed is 2. However, the length ratio for the fourth order stream within the Narava micro watershed is quite low (1.75). This indicates that the rock formations in the areas drained by the fourth order stream are nearly plain in slope and/or more permeable than the rock surfaces relative to those underlying the lower order streams.

## Drainage Density ($D_d$)

The drainage density is an indicator of the linear scale of landform elements in a stream-eroded topography (Horton 1945). It is the ratio of the total stream length of all orders within a basin to the area of the basin. It is indicative of the closeness of spacing of the streams and also the texture of the drainage basin. Table 3 shows that the fourth order Narava micro watershed has an average drainage density of 1.419 kms/kms$^2$ and is indicative of a medium textured drainage. A medium textured drainage with medium to coarse grained soils indicates the existence of good groundwater resources.

## Stream Frequency (F)

Horton (1932) proposed the stream frequency as the ratio of the total number of streams in a basin to the basin area. The stream frequency for the fourth order Narava micro watershed is 2.6 /sq kms (Table 3), indicating moderate slope with medium permeability complemented by moderate runoff and infiltration rate.

## Ruggedness Number ($N_d$)

The ruggedness number of the Narava micro watershed is 3.5713. Extremely high values of ruggedness number represent a watershed with large surface runoff potential. The relatively low ruggedness number of Narava micro watershed supports moderate infiltration.

**Table 2:** Measured Morphometric Parameters of Narava Micro Watershed

| Basin Parameters: | on 1:25000 |
|---|---|
| Drainage pattern | Dendritic |
| Perimeter | 42.5 km |
| Total channel length | 149 km |
| Basin length | 14.25 km |
| Basin width | 12 km |
| Main channel length | 10.25 km |
| No. of 1st order streams | 217 |
| No. of 2nd order streams | 46 |
| No. of 3rd order streams | 9 |
| Total No. of streams | 273 |
| Relief | 370 m |

**Table 3:** Derived Morphometric Parameters of Narava Micro Watershed

| Derived Parameters | on 1:25000 |
|---|---|
| Drainage density | 1.41904 km/km2 |
| Stream frequency | 2.6 /km2 |
| Bifurcation ratio | 6.2 |
| Infiltration number | 3.6895 |
| Circulatory ratio | 0.7387 |
| Elongation ratio | 0.784 |
| Form factor | 0.48261 |
| Relative relief | 0.875 |

## Hydrogeomorphic Classification

Hydrogeomorphology is the study of geological and hydrological aspects of water bodies and changes to these in response to flow variations. The landforms identified from the satellite imageries are helpful in delineating favourable zones for groundwater prospect (Thornburry, 1969, Bajpayee et al., 2003) such as Pediplain with moderate weathering at shallow depths. Different geomorphic units identified in the area are shown in Fig. 2. The identified hydrogeomorphic units indicated the information on the hydrologic characteristics of geological formation of the study area.

## Pediplain with Moderately Weathered Zone (PPM)

Moderately weathered pediplain are observed to be located in the central, north west and north east parts of the study area. The zone covered with brownish soil exhibits plain surfaces and underlined by more than 30 m weathered rock formation. The weathered and continuity of the fracture system have also been evidence in terms of an increase in discharges. The bore wells drilled in this zone by local farmers indicate the depth varies from 5 m to 50 m with continuous pumping rate of 5000 to 8000 litres per hour. The quality of the groundwater is also suitable for agriculture purpose. The groundwater prospects are moderate to good.

## Pediplain with Shallow Weathered Zone (PPS)

Pediplain associated with shallow weathered zones are observed in northern, central, north west and north east parts of the basin. The zones covered with brownish soil exhibit smooth to irregular surfaces. The thickness of the underlying weathered material varies between 15-20 m. Granite gneisses are prevalent in this zone. The combined thickness of the weathered and fractured zones extends from 5 m to 40 m below the surface. The discharges from bore wells located in the zone vary from 1500 litres per hour to 5,000 litres per hour depends on the thickness of aquifer zone. The groundwater prospects are moderate.

## Pediplain with Gullies (PPG)

The western, south western and eastern regions of the study area are covered by pediplain with gullies. This landform is erosional in character and acts mainly as a runoff zone resulting in poor to moderate groundwater prospects.

## Piedmont Zone (PZ)

The Piedmont zone is located in western, south western and the eastern part of the study area. This zone mainly consists of colluvium and gravel. Khondalite formations occur beneath the colluvial zone. On account of gentle to moderate slope and with low soil cover thickness, the recharge conditions are minimized and contributed to runoff. The groundwater prospects in the zone are poor to moderate which are also supported by the presence of weathered zone in the borehole drilled by the local government.

## Structural hills (SH), Residual hills (RH) and Inselbergs (I)

Structural hills are mostly located in the

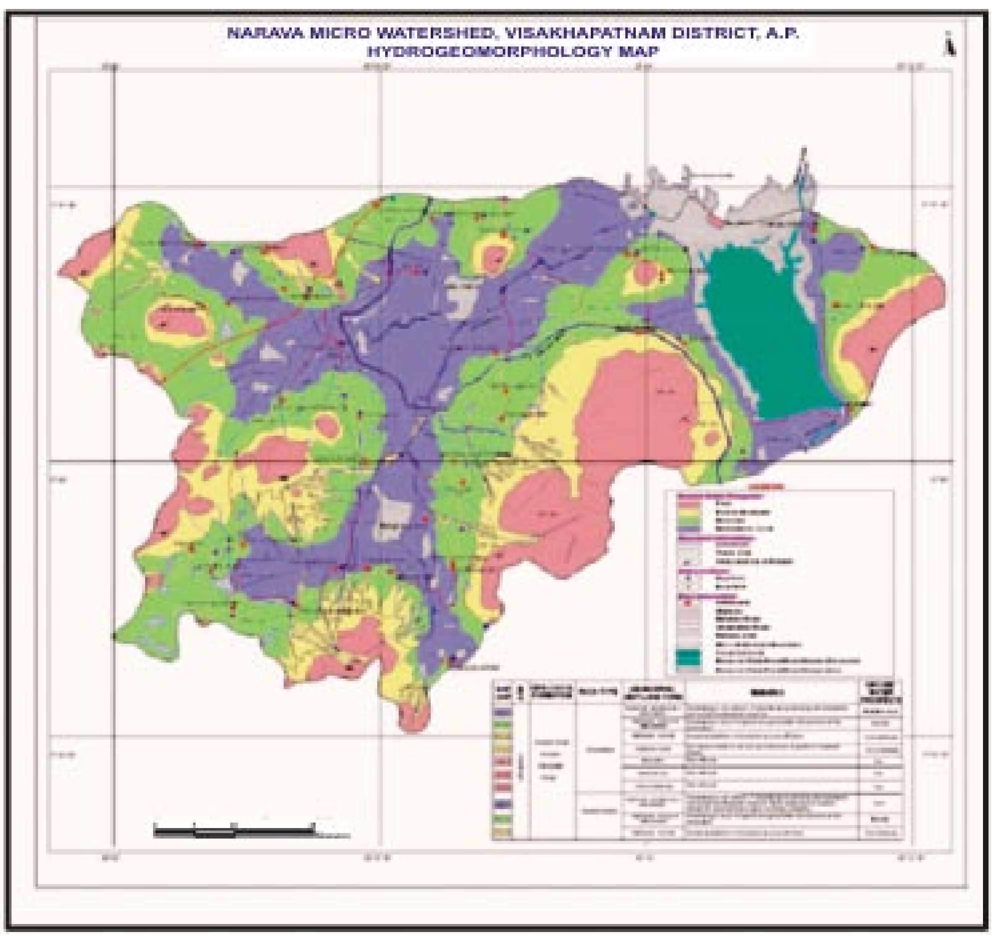


**Figure 2.** Hydrogeomorphology of the Narava Micro Watershed

**Table 4:** Different Hydrogeomorphic Zones and Groundwater Prospects

| Hydrogeomorphic Unit | Area of each unit ($km^2$) | Groundwater prospects | Percent of the unit in the basin | Development feasibility for irrigation purposes |
|---|---|---|---|---|
| Structural Hill(SH) | 51.35 | Poor | 51 | Not suitable for dug well |
| Residual Hill (RH) | 2.2 | | | |
| Piedmont Zone | 11.1 | Poor to Moderate | 12 | Moderately suitable for dug wells and suitable for low yield bore wells (1500 – 2000 litres per hour) |
| Pediplain gully | 1.5 | | | |
| Pediplain shallow | 15.75 | Moderate | 15 | Suitable for dug wells and bore wells |
| Pediplain moderate | 23.1 | Moderate to good | 22 | Dug cum bore well is feasible and also suitable for bore wells |

eastern, western and southern part of the area, whereas residual hills are observed in the northern and central parts of the area. The groundwater prospects are very poor in these zones. Different hydrogeomorphic zones and groundwater prospects are furnished in Table 4.

## Lineament Studies

A lineament is defined as a large scale linear feature of tectonic origin that is long, narrow and a relatively straight alignment visible in satellite imageries as tonal difference compared to other terrain features. The lineaments observed in the study area may be the result of faulting and fracturing. Hence it is inferred that these are zones of increased porosity and permeability within the hard rock. Lineament studies are significant in groundwater prospecting and remote sensing data provide useful information to identify such structural features. The lineaments were identified by visual interpretation of satellite imageries. Similarly, a number of major and minor lineaments are identified from the satellite images as shown in the lineament map of the study area (Fig.3). The lineaments identified are of varying dimensions with different orientations. From geoelectrical surveys it is found that in areas where lineaments are intersecting, the thickness of the weathered zone is high indicating potential areas for occurrence of groundwater.

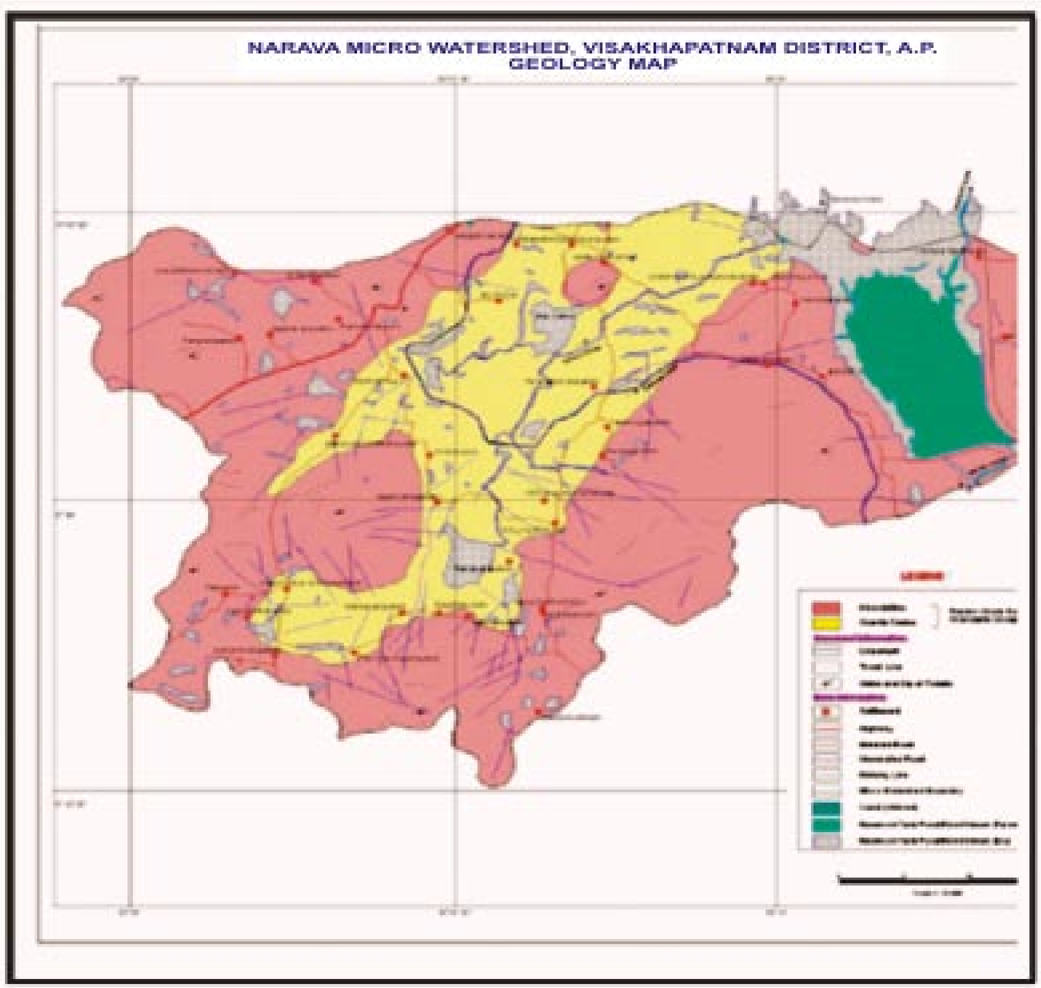


**Figure 3.** Geology and Lineament Map of the Narava Micro Watershed

## Lineament Density Map

The lineaments in the basin vary in dimensions. Based on the distribution and length of lineaments, a lineament density map has been prepared. The lineament map is superimposed on a grid map of 1 cm X 1 cm (0.25 kms X 0.25 kms) and the total length of lineaments passing from each

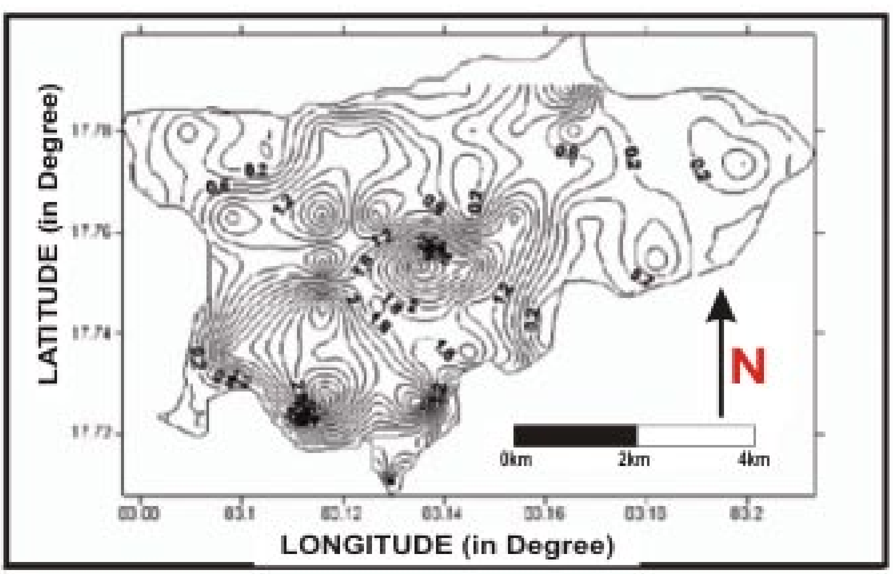


**Figure 4.** Lineament Density Map of Narava Micro Watershed

grid is measured and plotted in the respective grid centres. Contours are drawn for the values obtained from each grid and a lineament density map is prepared as shown in Fig.4.

## Geoelectrical Investigations

The geoelectrical cross-section that encompassed through the different geomorphologic units, namely (a) Pediplain with shallow weathering (PPS), (b) Pediplain with moderate weathering (PPM) and (c) Pediplain gully (PPG) shows the variation in thickness of the weathered zone. Thirty vertical electrical soundings (VES) that were carried out in shallow weathering pediplain (PPS) geomorphologic unit shows the shallow thickness of the weathered zone. Twelve VES conducted in pediplain moderate weathering (PPM) geomorphologic unit show three and four layer cases indicating the presence of relatively thick weathered zone. In the PPM zone, the weathered zone thickness varies from 20-30 m and is classified as good with regard to groundwater prospecting. In the second group, the area covered with weathered zone thickness ranging between 15-20 m is classified as moderate to good. In the third group, the area with weathered zone thickness between 10 and 15 m is classified as moderate. The fourth group, consisting of the area having weathered zone thickness from 0-5 m is classified as moderate to poor. In the fifth group, the area is classified as poor and unsuitable for groundwater prospecting (Dhakate, R. et al., 2008).

## Results and Discussions

By integrating the information on slope, geology, lineament, hydrogeomorphology, lineament density, weathered zone thickness, geoelectrical and hydrogeological cross sections and by overlying these maps, the groundwater potential zones are delineated and classified as good, good to moderate, moderate, moderate to poor and poor (Table 5).

The drainage density of the basin is 1.419 $kms/kms^2$ which indicates the rate of infiltration to be moderate (Karanth 1987). The percentage of slope varies from 0 to more than 10 (Table 5). The slope percentage of the study area serves to build up the hydraulic gradient to favour lower surface runoff and moderate infiltration. This leads to the possibility of groundwater accumulation. The presence of the lineaments in the study area which are the surface manifestations of structurally controlled linear features. The lineament density ranges from 0.5 to more than 2 per sq kms in the basin. The occurrence of weathered and fractured rocks in the watershed provides the necessary permeability and storage space, which act as good potential groundwater zones. Based on these parameters the groundwater potential zones in the study area have been classified.

The geomorphological features such as structural hill and residual hill in the study area with slope percentage exceeding 10 resulted in higher runoff and little or no infiltration. The thickness of the weathered zone is also less than 3 m leading to low groundwater. Hence these areas spread over an area of 53.55 sq kms are classified as poor groundwater zones.

The piedmont zone and pediplain gully with a moderate to steep slope, colluvium and loamy sand soils reduce the surface runoff and are favourable for infiltration. The water table is deep owing to the limited weathered zone. The well yields are also limited to 500 to 800 litres per hour. These zones formed mostly in the north western corner of the study area and limited to 12.6 sq kms area. The groundwater prospects are poor to moderate.

The shallow weathered pediplain comprising an area of 15.5 sq kms has a gentle slope and medium lineament density. The thickness of the weathered zone varies from 20 - 25 m with moderately shallow water table (3 -7 m). The groundwater prospect is moderate with well yields of 1500 to 5000 litres per hour.

The moderately weathered pediplain covering an area of 23.1 sq kms is nearly plain with lineament density (>2) and proximity of surface water bodies. Thickness of weathered zone is more than 30 m with a shallow water table. The groundwater prospects are moderate to good yielding 5000 to 8000 litres per hour.

Good groundwater potential zones cover an area of only 1.373 sq kms as pockets. Occurrence of good groundwater potential zones in the watershed are in plain terrain with high density of lineament (>2) and thickness of weathered and fractured zone (> 30m). Such terrain also has good drainage density and medium to coarse grained soils with high infiltration capacity.

## Groundwater Potential Zones

The groundwater potential maps are prepared using the slope, lineament density and weathered zone thickness (Sree Devi P.D., et al, 2001, Srivastava P.K., and Bhattacharya A.K., 2006, Ballukraya P.N and Kalimuthu. R, 2010).To identify and measure the thickness of the weathered and fractured zones in the study area geoelectrical data has been used. The groundwater potential map of the Narava basin thus prepared is classified into five categories ranging from poor to good i.e., poor, moderate to poor, moderate, moderate to good and good. The poor groundwater potential zones that occur around the basin are characterized by shallow depth to hard rock with less thickness of the saturated zone.

The moderate to poor groundwater potential zone occurs in the northern, central, north western

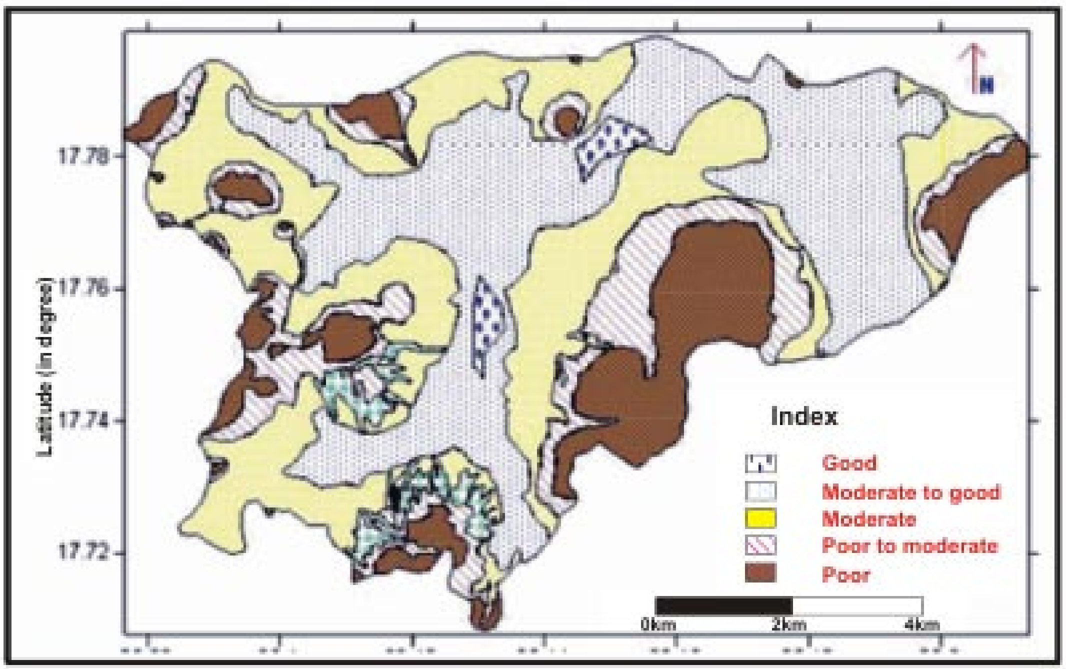


**Figure 5:** Groundwater Potential Demarcation Map.

**Table- 5:** Criteria for Selection of Groundwater Potential Zones Using Multi Parameter Integration

| Sl No. | Slope per cent | Lineament density | Weathering thickness (m) | Groundwater prospects |
|---|---|---|---|---|
| 1 | >10 | <0.5 | <10 | Poor |
| 2 | 5-10 | 0.5 – 1.0 | 10-20 | Poor to moderate |
| 3 | 3-5 | 1.0 – 1.5 | 20-25 | Moderate |
| 4 | 1-3 | 1.5 - 2 | 25 – 30 | Moderate to good |
| 5 | 0 – 1 | >2 | >30 | Good |

and north eastern parts which are occupied by granite gneisses. The productive zone classified as good zone is observed in the central and north central parts of the basin. Table 5 depicts the criteria for selecting groundwater potential zones using slope, lineament density and weather zone thickness. Demarcated groundwater potential zones of Narava basin are depicted in figure 5. The areas characterized by high lineament density with thick weathered zones are delineated as potential zones for exploration of groundwater. The map thus demarcated indicates the areas around Gollalapalem and Amrutapuram villages which are potential groundwater zones.

## Conclusion

A synergic approach integrating results of morphometric analysis, hydrogeological observations, lineaments density, geo-electrical sections, analysis of satellite imageries proved to be an effective approach for the delineation of potential zones for the ground water development. Thick weathered sub-surface zones associated with low slopes and high lineament densities are observed to have good prospects while the areas characterized by thin weathered zones, higher slopes and low lineament densities have poor prospects for groundwater potential. Areas occupied by pediplains with moderate weathering are observed to be better conduits for ground water resources. Similarly, wells located in the lineament junctions, thick weathered and fracture zones and locations close to drainage network are observed to have significantly high yields relative to other regions.


## Acknowledgments

The authors are grateful to the Department of Science and Technology (DST), NRDMS, New Delhi for financial support.

**Table 1:** Morphometric Analysis of Madharam Watershed, Mahabubnagar District, Andhra Pradesh

| *Mini water-shed* | *Area* (Au) *(kms²)* | *Peri-meter* (P) *(kms)* | *Stream Order Number (Nu). and Stream Length (Lu) (in kms)* | | | | | | | | | | | | *Bifurcation Ratio (Rb)* | | | | | *Drain-age Den-sity (Dd)* | Cons-tant *of Chan-*nel *Main-ten-ance (Cm)* | Stream frequ-*ency (Fs)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Nu* | *Lu* | *Nu* | *Lu* | *Nu* | *Lu* | *Nu* | *Lu* | *Nu* | *Lu* | *Nu* | *Lu* | *1\2* | *2\3* | *3\4* | *4\5* | *Aver-age* | | | |
| *A* | 8.76 | 12.2 | 14 | 13.18 | 4 | 3.35 | 1 | 2.79 | | | | | 19 | 19.32 | 3.5 | 4 | | | 3.75 | 2.21 | 0.45 | |
| *B* | 4.75 | 9.68 | 6 | 3.94 | 2 | 3.06 | 1 | 1.07 | | | | | 9 | 8.07 | 3 | 2 | | | 2.5 | 1.70 | 0.59 | 1.89 |
| *C* | 1.91 | 6.01 | 2 | 1.35 | 1 | 1.08 | | | | | | | 3 | 2.44 | 2 | | | | 2 | 1.27 | 0.78 | 1.57 |
| *D* | 1.92 | 6.99 | 2 | 0.88 | 1 | 1.38 | | | | | | | 3 | 2.26 | 2 | | | | 2 | 1.18 | 0.85 | 1.56 |
| *E* | 2.95 | 7.85 | 2 | 1.80 | 1 | 0.87 | | | | | | | 3 | 2.67 | 2 | | | | 2 | 0.90 | 1.11 | 1.02 |
| *F* | 2.65 | 7.28 | 1 | 3.09 | | | | | | | | | 1 | 3.09 | | | | | | 1.16 | 0.86 | 0.38 |
| *G* | 11.38 | 17.61 | 20 | 11.98 | 5 | 7.07 | 1 | 4.18 | | | | | 26 | 23.23 | 4 | 5 | | | 4.5 | 2.04 | 0.49 | 2.28 |
| *H* | 11.8 | 15.92 | 18 | 10.43 | 5 | 7.19 | 1 | 5.32 | | | | | 24 | 22.94 | 3.6 | 5 | | | 4.3 | 1.94 | 0.51 | 2.03 |
| *I* | 3.94 | 8.41 | 7 | 4.103 | 1 | 2.84 | | | | | | | 8 | 6.95 | 7 | | | | 7 | 1.76 | 0.57 | 2.03 |
| *J* | 12.98 | 19.05 | 18 | 13.83 | 5 | 5.70 | 2 | 3.42 | 1 | 2.4 | | | 26 | 22.94 | 3.6 | 2.5 | 2 | | 2.7 | 1.77 | 0.57 | 2.00 |
| *K* | 3.68 | 8.16 | 4 | 4.29 | 1 | 1.62 | | | | | | | 5 | 5.91 | 4 | | | | 4 | 1.61 | 0.62 | 1.36 |
| *L* | 6.45 | 12.18 | 9 | 6.57 | 3 | 2.13 | 1 | 3.88 | | | | | 13 | 12.58 | 3 | 3 | | | 3 | 1.95 | 0.51 | 2.02 |
| *M* | 5.79 | 10.23 | 8 | 6.64 | 2 | 5.50 | 1 | 0.44 | | | | | 11 | 12.58 | 4 | 2 | | | 3 | 2.17 | 0.46 | 1.90 |
| *ISA* | 16.33 | 40.73 | 9 | 9.09 | 1 | 1.36 | | | 1 | 8.8 | 1 | 7.0 | 11 | 10.44 | 9 | | 0 | 1 | 4.5 | 0.64 | 1.56 | 0.67 |
| Total | 95.29 | 182.3 | 120 | 91.16 | 32 | 43.14 | 8 | 21.10 | 2.0 | 11.14 | 1.00 | 6.99 | 162 | 155.39 | 3.75 | 4 | | | 3.88 | 1.63 | 0.61 | 1.70 |

**Table 2:** Proposed Artificial Recharge Structures in Madharam Watershed, Mahabubnagar District, A.P

| Sub Basin | Area | Per cent of Area to Total Basin Area | Total Runoff MCM | Available Run off ( 50per cent of Total Run-off) | No. of Structures feasible Check Dam/ Gabion structures | No. of Structures Feasible Percolation Tank/ Mini Percolation Tanks | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **A** | 8.76 | 9.19 | 0.52 | 0.26 | 5 | - | Tank in down stream |
| **B** | 4.75 | 4.98 | 0.28 | 0.14 | 2 | 1 | |
| **C** | 1.91 | 2.00 | 0.11 | 0.06 | 1 | | |
| **D** | 1.92 | 2.01 | 0.11 | 0.06 | 1 | | |
| **E** | 2.95 | 3.10 | 0.18 | 0.09 | 1 | 1 | |
| **F** | 2.65 | 2.78 | 0.16 | 0.08 | 1 | 1 | |
| **G** | 11.38 | 11.94 | 0.68 | 0.34 | 5 | 1 | |
| **H** | 11.8 | 12.38 | 0.70 | 0.35 | 4 | 1 | |
| I | 3.94 | 4.13 | 0.23 | 0.12 | 1 | | Tanks in down stream |
| **J** | 12.98 | 13.62 | 0.77 | 0.39 | 5 | | 3 Tanks in down stream |
| **K** | 3.68 | 3.86 | 0.22 | 0.11 | 2 | | |
| **L** | 6.45 | 6.77 | 0.38 | 0.19 | 3 | 1 | Tanks in down stream |
| **M** | 5.79 | 6.08 | 0.34 | 0.17 | 2 | | Tanks in down stream |
| **ISA** | 16.33 | 17.14 | 0.97 | 0.48 | | | |
| Total | 95.29 | 100.00 | 5.66 | 2.83 | 32 | 6 | |

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# Geomorphometric Analysis for Effective Water Resources Management through Artificial Recharge to Ground Water in Overexploited Watersheds

**Dr. S. K. Jain, Scientist 'D', Central Ground Water Board**

Physiography and drainage play a pivotal role in formulating a realistic and effective plan for management of water resources in each watershed. The rainfall- runoff needs to be stored according to the physiographic and drainage characteristics in order to maximize the groundwater recharge potential of the study area with due consideration to several other land characteristics and natural features.

A detailed study has been taken up in a part of the Tapi alluvial belt of Jalgaon district, Maharashtra which is a proven overexploited watershed of the state during the period of 1995-2003. The study area is drained by the river Bhaunak, a northern bank tributary of the Tapi river. There are 27 revenue villages in the watershed of the study area. The major part (70 per cent) of the study area is cultivated land. It is followed by the forest land (around 21 per cent) in the elevation range of 300 to 1074 m above mean sea level.

Geomorphometric analysis of the watershed has been carried out for quantitative description of the physiographic, topographic and drainage characteristics. The analysis reflects the practical image of the water courses and scope of water storage potential in terms of number, size and prospective locations, spacing of water conservation, storage and recharges structures primarily feasible in the watershed.

## 1.0 Physiographic Features of the Watershed

The watershed is located on the northern bank of the river Tapi. It is bounded by the Satpuda hill range in the north, while the Tapi river forms the southern boundary. It is a part of the Tapi river basin. The hilly area, which forms about 20 per cent of the total watershed, has steep slopes. The Satpuda hill range runs broadly in east-west direction. The river Tapi flows from east to west. The highest point in the watershed is 1074 metres above mean sea level (m.amsl), while the lowest point has an elevation of 147 m amsl in the southwest in the Tapi riverbed. The watershed is about 25 kms from north to south while the east-west extension is about 15 kms. The watershed has a general slope from north to south, which is around 37 m/kms. In the southern part of the watershed and, along the northern bank of the river Tapi, bad land topography has developed owing to higher clay contents in flood plain deposits. This is around 15 sq kms and is not suitable for cultivation.

## 2.0 Drainage of the Study Area

He drainage pattern of the major river is parallel to sub-parallel. In the hilly areas the major drainage pattern is dendritic. The major streams of the watershed are Bhaunak, Baghzira and Manudevi. The Baghzira and Manudevi join Bhaunak before they meet the Tapi. Most of these streams originate from the Satpuda hill ranges. Figure 1 shows the drainage map of the area, which was used for detailed drainage analysis. The morphometric analysis of drainage was carried out to understand the watershed characteristics which help in categorizing the watershed as youthful, mature, poorly drained or well drained, and so on. This also helps to understand the hydrological parameters, pattern of runoff, sediment load and proper location of water conservation structures.

**Figure**- 1 Drainages of the Study Area

The drainage course of major streams is from north to south. However, in the southern part, the Bhaunak river suddenly takes a westerly turn and flows for a considerable distance parallel to the river Tapi before it joins the Tapi at Siragad and Nhavi.

## 3.0 Morphometric Analysis of the Study Area

Development of drainage is the result of climate, lithology, structure and geomorphic processes. The occurrence of groundwater and groundwater recharge also depends on these factors. Defining the watershed in quantitative terms also helps in understanding their functional relationship with runoff (Morisowa, 1967).

According to Wisler and Brater (1959), a fully analyzed drainage map of an area provides a reliable index for the permeability of the rocks and also gives an indication of yield of the rocks in the area. The control of lithological, structural and tectonic features on drainage network development has been emphasized in many studies (Leopold et al., 1964; Bloom, 1979). Importance of geomorphological studies has also been emphasized by Phillips and Singhal (1991). Morphometric analysis has been therefore, done for the study area using Survey of India toposheets on 1: 50,000 scale and aerial photographs.

### 3.1 Number and Order of Streams

The order of streams has been determined using the methodology given by Horton (1945) and Strahler (1964). There are 624 streams of various orders with a total length of about 516 kms in the watershed. Table 1 gives the details of the order of

**Table 1:** Order of Streams and Their Length in the Study Area

| S. No. | Drainage Order | No. of treams | Total Length of-Streams (km) | Avg. Length (km) | Length Ratio |
|---|---|---|---|---|---|
| 1 | I | 485 | 248.5 | 0.51 | -- |
| 2 | II | 105 | 128.3 | 1.22 | 2.39 |
| 3 | III | 23 | 75.6 | 3.29 | 2.69 |
| 4 | IV | 6 | 35.6 | 5.90 | 1.79 |
| 5 | V | 3 | 22.9 | 7.60 | 1.29 |
| 6 | VI | 1 | 8.0 | 8.80 | 1.05 |
| 7 | VII | 1 | 7.7 | 7.70 | - |
| **Total / Avg.** | **624** | **516.2** | **5.0*** | **1.84*** | |

various streams in the watershed and their length. It also suggests that river Bhaunak, which is the main tributary to the Tapi, is a 6th order stream.

## 3.2 Bifurcation Ratio

It is a relationship between the numbers of streams of o ne order to that of the number of streams of the lower order. Thus, the numbers of streams in each order are counted. The bifurcation ratio is determined and is given in Table 2.

**Table 2:** Bifurcation Ratio of Drainages in the Study Area

| No. | Order of Streams | Bifurcation Ratio |
|---|---|---|
| 1 | V | 1: 3.0 |
| 2 | IV | 1: 2.0 |
| 3 | III | 1: 3.8 |
| 4 | II | 1: 4.5 |
| 5 | I | 1: 4.6 |

A graphical presentation of the relationship between stream order and log of stream number shows a linear relationship (Figure 2). The best fitting regression equation is:

$$\log Y = -0.5329 X + 3.0867$$

Where, Y is the number of streams and X is the order of stream.

The bifurcation ratio of the streams (1st to 5th order) varies between 1:2.0 and 1:4.6. The average bifurcation ratio is 1:3.58 for the watershed indicating that there are about 3.6 times as many numbers of streams of any given order to that of the next higher order.

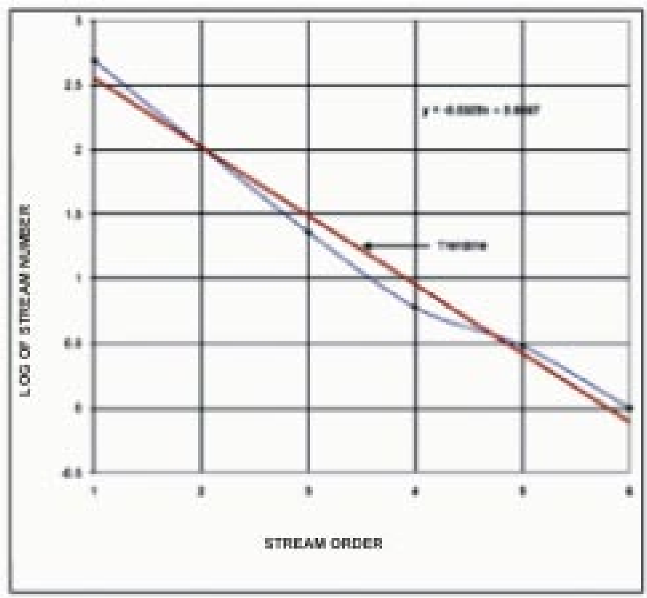


**Figure 2:** Relationship of Stream Numbers and Order

According to Strahler (1952), the value of bifurcation ratios, higher than five, indicates the structural control on the drainage network. In this watershed, the 4th order stream has the least bifurcation ratio of 2.0, therefore indicating no structural control on these streams. The streams of order 1 to 2 have the bifurcation ratio near five (i.e. 4.6) indicating that some portion of drainage is controlled by the structures / fractures.

## 3.3 Length Ratio

The length of stream is a dimensional property, indicating basically, the hydrologic nature of the contributing surface of the drainage network. The length of the stream is an indication of the steepness of the drainage basin and of the degree of drainage. A steep, well-drained basin has numerous streams, which are smaller in length. In general, in more permeable strata, the streams flowing will be small in number and greater in length.

The mean length of a stream of any given order, is greater than the mean stream length of the next lower order, but always less than the next higher order. Based on this fact, Horton (1945) proposed a factor 'Length ratio', which is the ratio of the mean length of the stream of any order to the mean length of the stream of the next lower order.

The variation in the values of the length ratio, for different stream orders within a basin indicates the permeability of the surface contributing to the drainage network of the basin. It is evident from the values for the Bhaunak watershed that the length ratio for the third order stream is higher (2.69) than the length ratios for the streams of the other orders. It is followed by the second order stream (2.39). This indicates the permeable nature of the region through which the third and second order streams flow.

The length of stream for each order was measured using the map measurer. The total length of each order of stream and its mean length were computed. From this mean length, the length ratio for a succeeding order of streams is calculated. A graphical plot of the log of the mean lengths of the stream to the order of streams shows a direct relationship up to the $4^{th}$ order (Figure 3.3) and the equation of the line is:

$$\log Y = 0.206\,X - 0.184$$

Where, Y is the mean length of stream and X is the order of the stream.

## 3.4 Form Factor

Hortan (1932) defined the form factor as the ratio between watershed area to the square of watershed length. The value of the form factor for the Bhaunak watershed is calculated as 0.425.

## 3.5 Shape Factor ( $S_f$ )

The shape factor is defined as the ratio between the squares of basin length to the basin area. The shape parameters can be used to quantify the degree of similarity of drainage basin shapes. A square drainage basin would have a shape factor ( $S_f$ ) = 1, whereas the long narrow drainage basin would have a shape factor ($S_f$ ) > 1. The basin shape may influence the hydrographic shape especially for small basins. For example, if a basin is long and narrow, then it will take a longer time for water to travel from basin extremities to the outlet and the resulting runoff hydrograph will be flatter. Runoff hydrograph is expected to be sharper with a greater peak and shorter duration for a more compact basin. A compact basin is more likely to be covered by the area of maximum rainfall intensity of local streams. The shape factor for the watershed is worked out as 2.35 which indicates that the watershed is elongated and the runoff hydrograph is expected to be flatter in this area.

## 3.6 Circulatory Ratio

Miller (1959) defined the circulatory ratio as the ratio of the watershed area to the area of a circle having the same perimeter as the perimeter of the watershed. The circulatory ratio for the watershed is 0.601.

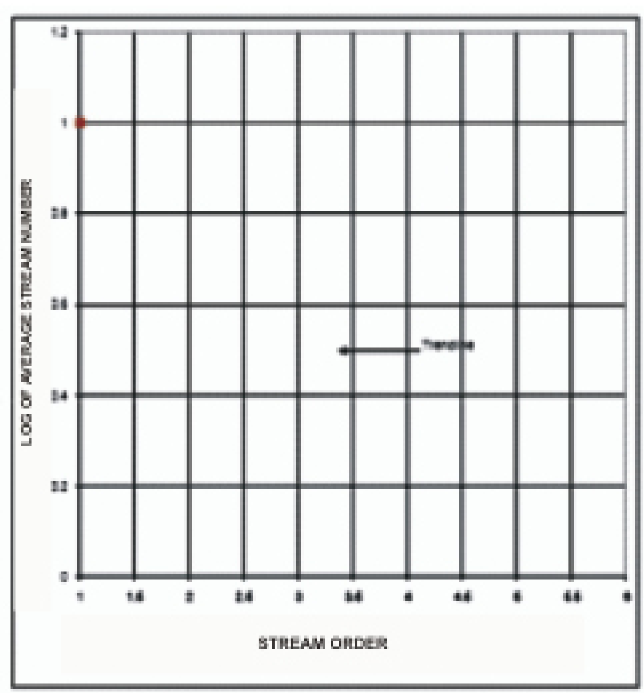


**Figure 3:** Relationship of Stream Length and Order

## 3.7 Elongation Ratio

It is defined as the ratio between the diameter of the circle having the same area as the basin to the maximum length of the basin (Schumm, 1956). The elongation ratio for the watershed is 0.74. It is observed that the value of the elongation ratio is more than the circulatory ratio for the watershed, which indicates that the watershed is elongated.

## 3.8 Drainage Density

It is defined as the average length of the stream per unit area. The drainage density is the measure of the texture of the drainage in that basin and indirectly indicates the area having a higher slope and better permeability. Lithology, infiltration capacity, vegetative cover, climate, runoff, etc are the major controlling factors of drainage density.

The drainage density for the watershed is 2.26 kms per sq kms. The value indicates that the basin is medium textured. The value of drainage density indicates moderate to high permeability and relief in the watershed. Carlson (1963) observed a tendency for groundwater contribution to stream flow to decrease with increasing drainage density.

## 3.9 Relief Ratio

The 'relief ratio' is the controlling factor for surface runoff. The higher the relief ratio, the higher is the surface runoff. The relief ratio is computed by dividing the maximum relief by the length of the watershed. The relief ratio for the watershed is 0.036.

## 3.10 Stream Frequency

`The number of streams per unit area is known as the 'stream frequency', which is controlled by relief, nature of formation, etc. There are 625 streams in the entire area of 235 sq kms. Thus, the stream frequency for the watershed is 2.77 per sq kms suggesting that the watershed is well drained. Sinhagad area in Pune district, having mountainous relief and low permeable strata, indicated the stream frequency of 14.68 per sq kms in a fourth order basin (Lele, 1985).

## 3.11 Length of Overland Flow

The surface water has to flow as a sheet to a certain distance before it reaches to a well-defined stream channel. This distance of travel is termed as 'length of overland flow'. If the formations are permeable and the slope is gentle, the volume of water reaching the channel will be less. Thus, the higher value of overland flow indicates poor permeability of formations. It is taken as half the reciprocal of the drainage density (Horton, 1945).

The length of overland flow for the watershed is 0.22 kms. Very low value of 0.078 was observed in a fourth order basin of the mountainous terrain of Sinhagad area (Lele, 1985). Kulkarni (1987) obtained the values of length of overland flow as 0.122, 0.128 and 0.164 kms for third and fourth order basins in Pabal area of Pune district.

## 3.12 Constant of Channel Maintenance

The constant of channel maintenance (C) is the inverse of drainage density (Schumm, 1956). In general the constant of channel maintenance increases with the size of the basin. The constant of channel maintenance for the watershed is 0.442 sq kms / kms. This value indicates that about 0.442 sq kms of area is required to support one-kilometre length of the stream.

Kulkarni (1987) obtained values of constant of channel maintenance, for three fourth order basins in the Deccan trap of Pabal area as 0.2451, 0.2477 and 0.3289 sq kms/ kms respectively. When compared to this lower value in the Pabal case, the higher values of constant of channel maintenance for the Bhaunak watershed indicate in general, the high permeability of this region.

Mulay (1980) has obtained value of the constant of channel maintenance for the fourth order basin from the Lonavala area of Pune district, as around 0.246 $kms^2$ .This value is also very low compared to the constant of channel maintenance values as obtained for the Pabal case. Lele (1985) has obtained a very low value of the constant of channel maintenance (0.1577 sq kms / kms) for the fourth order basin in the hilly area of Simhagad in Pune district.

## 3.13 Slope of Sreams

The general slope ranges from 5 to 150 m/kms in the watershed. The slope is very steep and generally ranges from 55 to 150 m/kms in the northern hilly area. The slope is moderate and varies from 14 to 17 m/kms in the foothill zone of the watershed (Bazada Zone) having highly permeable strata. The slope is gentle and ranges from 5 to 7 m/kms in the alluvial plain.

This suggests that in the alluvial plain, having a gentle gradient, the infiltration will be higher and the length of overland flow will also be more. Table 3 shows the slope of various streams in different segments. The slope of the Bhaunak River, which is the main tributary of the Tapi river, varies from 150, 17 and 6 m/kms. in hilly, bazada and alluvial areas respectively. Similarly, for Baghzira it is 55, 14 and 5 m/kms and for Manudevi 112, 14 and 7 m/kms.

**Table 3:** Slope of Streams in the Study Area

| S.No | Stream and its Segment | Total Fall (m) | Total Stream Length (km) | Slope ( m/ km ) |
|---|---|---|---|---|
| **1** | BHAUNAK | | | |
| i) | Hilly area | 734 | 4.70 | 150.0 |
| i) | Bazada zone | 90 | 5.08 | 17.0 |
| ii) | Alluvial plain | 103 | 16.76 | 6.1 |
| **2** | BAGHZIRA | | | |
| i) | Hilly area | 620 | 11.10 | 55.0 |
| ii) | Bazada zone | 90 | 6.40 | 14.0 |
| iii) | Alluvial plain | 40 | 7.68 | 5.2 |
| **3** | MANUDEVI | | | |
| i) | Hilly area | 532 | 4.76 | 111.7 |
| ii) | Bazada zone | 90 | 6.40 | 14.0 |
| iii) | Alluvial plain | 83 | 11.52 | 7.2 |

## 3.14 Hypsographic Study

It is a correlation between the altitudes of the watershed with percentage of area falling in different altitude range. It can be seen (Figure 4) that, for the watershed, the median altitude (50 per cent of the basin area) is 250 m above msl. Around 73 per cent of the watershed area falls between 320 and 175 m above msl. The surface recharge structures and water conservation structures will have a better geomorphic setup in areas above 250 m amsl.

## 3.15 Hypsometric Analysis

It relates to the distribution of the horizontal cross section area of the watershed with respect to the elevation (Langbein,1947). The two ratios considered are:

a / A (%) - where 'a' is the area enclosed between a given contour and the basin boundary and 'A' is the total area.

h / H - where 'h' is the height of the contour above base and 'H' is the maximum watershed relief.

The values have been worked out and the graph is prepared (Figure 5) to get a hypsometric curve. The median value is only 0.22 suggesting that the watershed is not mature because of which the streams may change their course.

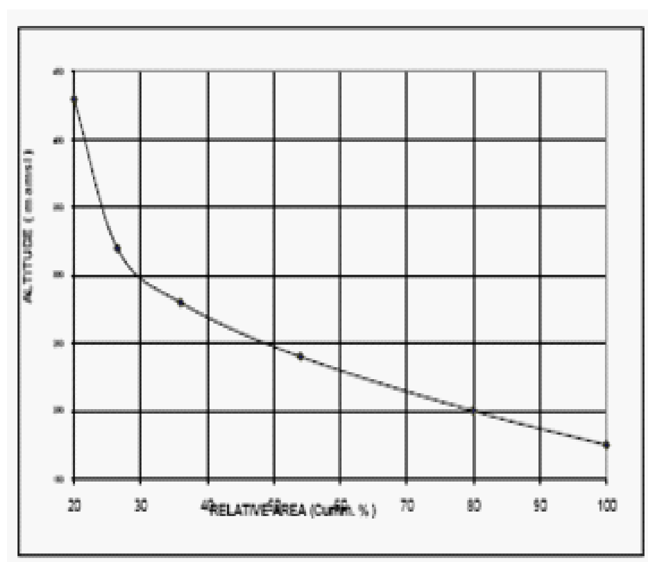


**Figure 4:** Hypsographic Curve of the Study Area

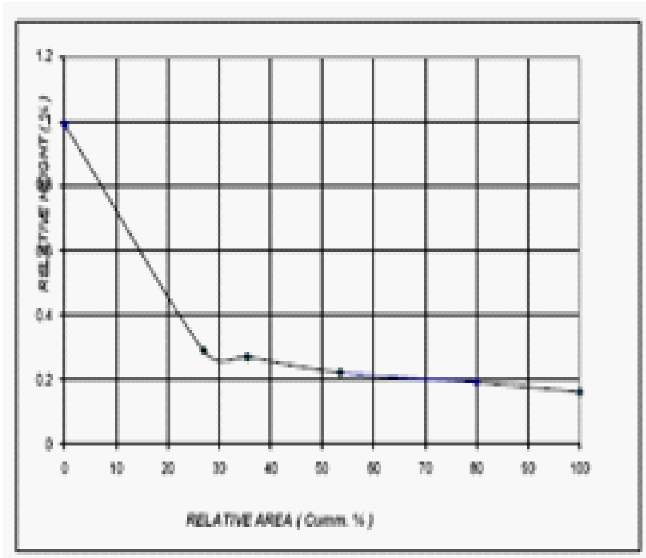


**Figure 5:** Hhypsometric Curve of the Study Area

## 3.16 Summary

A well-analysed drainage basin forms a reliable index for hydrogeological characteristics like permeability (Kulkarni, 1991). The following observations are drawn based on the morphometric study and analysis of the watershed characteristics of the study area.

The major streams of the watershed are parallel to sub-parallel. The watershed is elongated in the north-south direction and runoff hydrograph is expected to be flatter in the area. The watershed is not mature and streams may change their course in the event of heavy rainfall.

Streams of first and second orders have a bifurcation ratio nearer 5 indicating control of fractures / structures on some portion of the watershed. The sudden change in the course of streams suggests that these are controlled by lineaments.

The second and third order stream basins have a higher bifurcation ratio, indicating higher permeability of the soil media in the watershed. The value of drainage density indicates moderate to high permeability and relief in the watershed.

The drainage length and slope of the drainages are essential input to work out the number of water conservation structures required in the mountainous terrain of the study area.

A better geomorphic setup is available for favourable sites to store the surface runoff for augmenting the groundwater resources through artificial recharge, in areas above median elevation, i.e. 250 m above mean sea level (amsl).

The drainage length and slope of the drainages are essential inputs to work out the number of water conservation structures required in the mountainous terrain of the study area. A better geomorphic setup is available for favourable sites to store the surface runoff for augmenting the groundwater resources through artificial recharge, in areas above the median elevation, i.e. 250 m amsl.

# 4.0 Other Characteristics of the Watershed

## 4.1 Rainfall and Climatic Features

The watershed is semi-arid and partly drought prone. The rainfall is moderate and erratic. Rains are mainly received during the monsoon from June to September. Rains occur in 40 to 80 days. However, in reality, effective rainfall beyond 10 mm / day takes place for 15 - 20 days only. Rain spells of more than 20 mm / day occur for around 5 to 10 days in a monsoon year. Rain hours are around 100 hours in the monsoon season in the study area. The daily rainfall analysis and the rainfall intensity analysis indicate that the roof top rainwater harvesting schemes may be designed as per the intensity of 50 mm / hour.

Weather parameters like temperature, wind velocity, relative humidity and sunshine hours support the rising evaporation from February onwards. Therefore, water storage in the open reservoir for artificial recharge to groundwater should be used before March. Surface water once transferred to the aquifer will get rid of the evaporation losses. The analysis suggests that a rainfall of 50 mm per day is appropriate to plan the water conservation in the hilly tract of the study area. The percolation tanks or other water storage / conservation structures can be designed for a rainfall of 698.5 mm arrived at 50 per cent dependability based on 100 years of rainfall analysis.

## 4.2 Soil Characterestics

The texture of soils is coarser in the mountain front occupied by bazada formations. The soil moisture is less than five per cent in the upper reaches. Infiltration rate of 20 - 30 cm / hour and more than 30 cm / hours is observed in the upper reaches along the foothills of Satpuda over the bazada formations. This tract is therefore, most suitable for percolation tanks compared to downward locations over alluvium. The soil properties indicate that the impounding of water at the surface would not create any meaningful percolation in the alluvial plains. Artificial recharge to groundwater may not be efficient owing to poor infiltration from water pond in the alluvial areas compared to the foothill areas. Injection technique through wells or shaft would be a better option if soil texture is given due weightage along with aquifer geometry in the alluvial terrain.

## 4.3 Hydrological Characterestics

The detailed hydrological studies carried out in the area have given a realistic estimate of catchment yield in different types of catchments. The catchment yield is the main input to specify the storage capacity of the surface tanks. The study indicated that the prevailing practice of categorizing the whole catchment as 'Good ' using Strange's table to arrive at catchment yield is inappropriate. The storage capacity of percolation tanks proposed henceforth is to be modified accordingly. The runoff estimation for the mountainous terrain is to be done by using the equation $Y = 0.0072\ X^{1.4106}$ and for the alluvial tract by the equation $Y = 0.028\ X^{1.1552}$ derived from the study. This would result in enhancing the capacity utilization and economizing the recharge operations in the study area.

Runoff in the study area is estimated as 8.1 per cent of the dependable rainfall (50 per cent) against the 14.2 per cent estimated by using Strange's table. The status of water conservation is assessed as 4.15 mcm and around 9.187 mcm is let out to the Tapi river unconserved from the study area. The mountainous streams flow for a considerable period consistently with silt free clean water, which can be used as a source for artificial recharge to groundwater by direct injection in the foothills itself. The available source water would result in maximum augmentation of groundwater if utilized at the highest possible part of the Bazada formations at the Satpuda foothills. This process will augment the aquifer water availability. The non-mountainous stream discharge is inconsistent and of relatively less duration though in large quantity. The presence of low to moderate silt load suggests not to use this for direct injection to the aquifer as it will quickly clog the pervious part of the recharge structures.

## 4.4 Geological Features

The area is an alluvial terrain surrounded by the typical hard rock terrain of Deccan Traps. The general geological characteristics of the area are also remarkably different. The geology divides the study area into three prominent categories. The northern most part of the study area is occupied by the basaltic lava flows over around 50 sq kms and is classified as consolidated or the hard rock terrain. Talus and scree sediments commonly known as bazada occur at south of the basaltic lava flows occupying the foothills and are unconsolidated in nature (soft rock). The third category of formation is unconsolidated alluvial sediments deposited as a layered sequence in a faulted basin. These sediments are more than 300 m thick at places like Dongaon and contain many granular horizons separated by the clay beds. Contact of the basaltic flows and bazada is faulted as manifested by the common features of the faulting present in the fault zone. Hydrology and ground water hydraulics is significantly influenced by the fault zone and bazada formations owing to presence of porous strata at the surface and underneath.

## 4.5 Hydrology of the Area

Alluvium occupies around 60 per cent of the area and 12 water bearing zones are encountered in a 300 m deep exploratory tube well drilled by CGWB. Depth to water level predominantly ranged from 30–40 m bgl in the study area according to observations of 2000. The historical data of the water level are gathered from various sources. The record of 1964 is the oldest database followed by the data of 1975. The water table was predominantly in the depth range of 10 – 15 m bgl in 1964 in the alluvial belt.

Comparison and analysis of depth to water level have proved the depletion of groundwater level in the alluvial and bazada formations. There is overall decline of the water table both during pre and post–monsoon seasons and maximum decline of around 1 m per year as calculated for the period of 1990 – 2003. Seasonal fluctuations of water table were in the range of 1– 8 m and water table altitude is between 149 and 320 m amsl in the study area. Yield of dug wells vary between 100 – 200 $M^3$ /day and discharge from tube wells were in the range of 0.5 to 90.2 $M^3$ / hour. A total of 3139 dug wells and 534 irrigation tube wells are the main groundwater abstraction structures in the study area, pumping out the water through 3833 electric pumps.

Aquifer parameters have been defined for shallow and deeper aquifer systems. The specific yield of the granular zones has been assessed as 15 per cent for the sand / gravel / boulder horizons and their admixture excluding the clay strata. Specific yield of the bazada formations is assessed as 10 per cent. Thickness of granular zones has been calculated based on the intensive analysis of litho logs and prevailing depth to water level in the study area. The average thickness of granular zones is 4.45 m to 18.85 m in the alluvium and 17.45 m in the bazada formations. There is a potential to store around 397.945 mcm of water in the unsaturated strata of the alluvial and bazada formations in the study area.

Hydro geological framework and aquifer geometry decides the type of recharge structures and to identify the location of sites. For this purpose detailed investigations and study of litho logs and well sections have been carried out. The surface spreading technique, e.g. percolation tanks, cement plugs, basin spreading, etc., is not feasible in the alluvial tract owing to unfavourable disposition of granular horizons and clay layers in the study area. Techniques like injection well and recharge shaft would be most feasible and appropriate based on hydro geological setup. The hydro geological framework of talus and scree deposits occurring at the foothill of Satpuda provides a favourable setup for artificial recharge through surface spreading and direct recharge techniques. Therefore construction of percolation tanks, recharge shafts and recharge pits is suggested in the bazada zone.

## 5.0 Findings and Conclusions

Water conservation measures are planned for the hilly area which consist of 1545 nala bunds of average 1 m height and 6622 kms long continuous contour trenches (CCT) of 0.60 x 0.30 m cross section. It would indirectly increase the groundwater recharge in the bazada and alluvial aquifers. In the foothills, 2 percolation tanks and 12 recharge shafts are proposed for the artificial recharge to groundwater. Further, gently sloping bazada tract, require 3500 recharge pits of 7m x 7m x 3m dimensions to recharge the groundwater by using the rainwater. The alluvial tract is the most overexploited part of the study area and it is not possible to restore the groundwater storage within 15 years even after conserving the last drop of river runoff. Therefore, artificial recharge is proposed by utilizing the external water resources. A major source water of 23.04 mcm from the existing Hatnur canal may provide groundwater recharge to the tune of 20.69 mcm through 216 injection wells and 215 recharge shafts on an annual basis.

Rooftop rainwater harvesting has been identified as an important scheme of artificial recharge to augment the groundwater resources around the villages of the study area so as to make the drinking water supply more sustainable and dependable in the summer season also. The rise in the water table could be 0.5 to 1.0 m in and around the village area.

The area has a net annual rainfall recharge of 20.2 mcm against the total annual draft of 26.2 mcm, with an annual overdraft of about 6.0 mcm of ground water. The total potential of artificial recharge to groundwater is estimated to be around 23.24 mcm as per the plan emerged from the study. Over drafting of 6.04 mcm would be taken care of and an additional groundwater pool of 17.20 mcm would be available to meet the rising demand of coming years. The declining trend of groundwater level would therefore be reversed and the rise in the water level may take place @ 0.49 to 1.65 m per year in the granular zones.

The input from the drainage and morphometric analysis in conjunction with other features of the watershed has given a thorough knowledge of the watershed and all the inputs have been converged to formulate a water management plan. A similar approach may be very useful to manage the depleted groundwater resources of the overexploited and critical areas.

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# Site Selection for Rain Water Harvesting and Artificial Recharge to Ground Water in Vatrak Sub-Watershed, Sabarmati Basin, Gujarat India

## Based on Geo-informatics Multithematic Multi-criteria Evaluation

**Dr.R.C.Jain[1], A.P.Bhavsar[2], B.S. Patel[3], Naveenchandra N. Srivastva[4] and Khalid Mahmood[4]**


## Abstract

Rain water harvesting and artificial recharge to groundwater has gained momentum in recent years for providing sustainability to water-stressed aquifers as natural replenishment of ground water reservoir is a slow process and is often unable to keep pace with the excessive and continued exploitation of groundwater resources. A case study of Vatrak sub-watershed, Sabarmati basin, has been carried out to identify suitable sites for rain water harvesting structures. The various geo-informatics based thematic maps such as land use map, geomorphology map, slope map, drainage map, Digital Elevation Model, etc. were prepared in order to evaluate the sub-watershed. With the help of geo-visualization of water resources and other relevant natural resource data pertaining to Vatrak sub-watershed, issues of knowledge sharing and information communication can be effectively addressed. Based on multi-thematic multi-criteria evaluation, different types of structures suited for rain water harvesting and artificial recharge to groundwater have been suggested for providing sustainability to the water-stressed aquifers in the sub-watershed.


## 1. Background

The Vatrak River originates in Durgapur district of Rajasthan. The total area of Vatrak sub watershed is 598.4 sq kms. The study area falls in Sabarkantha district (Gujarat). Vatrak is a rain fed river and principal tributary to Sabarmati river. Owing to fairly low rainfall, the Sabarmati river basin has one of the lowest water wealth potentials in India. The basin is highly exploited in its water resources front. The study area falls in the hot and semi-arid region of northern Gujarat. Topographically, the area of Sabarkantha district is undulating.

Geologically, the area comprises various types of igneous, sedimentary and metamorphic formations, such as basalt, alluvium, quartzite, etc. The rainfall pattern is uneven and erratic in the study area. As climatic conditions are unfavourable for creating surface storage, water harvesting structures have to be adopted for diverting most of the surface storage to the groundwater reservoirs within the shortest possible time. The present study aims to identify suitable locations to get maximum benefits from recharge structures.

## 2. Objectives

The study has the following major objectives:

1. To generate thematic maps of various natural resources.

2. To integrate the thematic maps through the GIS environment

3. To identify suitable sites for water harvesting structures

4. Geo-visualization of data in GIS environment

2.1. Problems intended to be addressed by this study

a) Rain water harvesting

b) Optimize recharge to groundwater for water-stressed aquifers in the study area

## 3 Pre-study status

Some check dams have been constructed in Sabarkantha district to raise the groundwater level in the vicinity. During the rainy season in 2007, a flood alert was sounded in villages on the banks of the Vatrak River. (http://timesofindia.indiatimes.com /India/Gujarat on_flood_alert_20_dead_in_MP_/articleshow/2189767.cms). Groundwater is available from the weathered zone, cracks, fractures and joint planes in limited quantity through wells, hand pumps and bore wells. Owing to some recharge structures constructed in Sabarkantha district water level has risen up to 24 m (http://www.gwssb.org/impact/sabarkantha.pdf).

### 3.1. Geology

Geologically the area comprises various types of igneous, sedimentary and metamorphic formations, such as basalt, quartzite, schist, alluvium, carbonate rock (Lower Proterozoic), etc. (Fig. 1). Metamorphic rocks cover the northern part of the study area. The central and southern parts are occupied by alluvium, channel fill deposits, volcanic rocks (Porphyritic and amygdular basalt of Cretaceous to Eocene age), etc. Physiographically, the study area can be divided into two zones, viz. the hilly regions and the plains. Hills cover the northern parts, whereas the plains are confined towards the south.

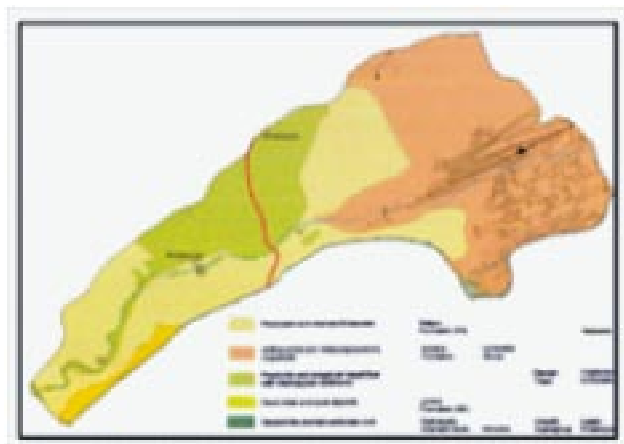

**Figure 1.** Geological Map of Study Area

### 3.2. Drainage

The area is drained by the southwesterly flowing river Vatrak and its tributaries. The stream flow in these regions is mostly restricted to the rainy season. The surface drainage is located above the water table. The drainage pattern is dendritic.

### 3.3. Rain Water Harvesting and Artificial Recharge to Groundwater

Water harvesting is a method of water collection applied in arid and semi-arid regions, where rainfall is either not sufficient to sustain a good crop and pasture growth or where, due to the erratic nature of precipitation, the risk of crop failure is very high (www.geotunis.org/2009/file/ppt/Dr Mutawakil Obeidat. ppt). Water harvesting can be accomplished through in situ harvesting, soil conservation methods, and increasing infiltration for recharge of groundwater. Water harvesting structures are extremely important to conserve precious natural resources like soil and water, which is depleting every day at an alarming rate. In the study area, precipitation is variable over time and space due to the monsoon climate and land-hill topography. Several water harvesting structures have been constructed at appropriate sites that check floods and provide irrigation to downstream. There are always strong links between soil conservation and water conservation measures.

Water harvesting structures store rainwater to be used for irrigation and increase groundwater recharge (https://engineering.purdue.edu/~abe527/Projects_2006 /Macaluso Trepanier.pdf). The problem of water shortage in arid and semi-arid regions is one of low rainfall and uneven distribution throughout the season, which makes rainfed agriculture a risky enterprise (http://oldwww.wii.gov.in/eianew/eia/dams and development / kbase/ contrib/opt158.pdf).

Khan 1992; Karla 2005, made significant studies in the construction of check dams and percolation ponds.

Water harvesting has the potential to increase the productivity of arable and grazing land by increasing the yields and by reducing the risk of crop failure. They also facilitate re- or afforestation or agroforestry (http://oldwww.wii.gov.in/eianew/eia/dams and development/kbase/contrib/opt158.pdf). Locations of existing water harvesting structures on various streams of study area are shown in Fig.2.

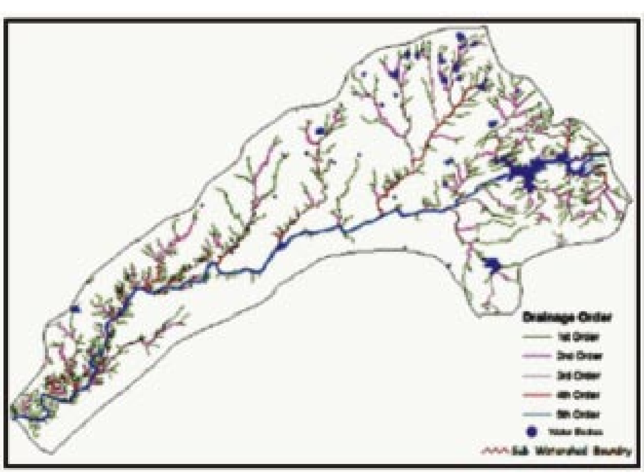


**Figure 2.** Location of Existing Water Harvesting Structures in Study Area

The present study envisages the identification of potential suitable sites for rain water harvesting and artificial recharge to groundwater in the watershed with the help of geo-informatics.

### 3.4 Source Water

Availability of source water is one of the basic prerequisites for taking up any water harvesting structure study. The source water available in the Vatrak sub-watershed is ***in situ*** precipitation. The availability of water varies considerably from place to place.

## 4. Application of Geo-informatics

Thematic maps are derived from remote sensing data and integrated in GIS to evaluate suitable sites for water harvesting. Remote sensing is of immense use for natural resources mapping and generating necessary spatial database required as an input for GIS analysis. GIS is a tool for collecting, storing and analysing spatial and non-spatial data. It can be used to evaluate appropriate natural resource development and management action plans. Both these techniques can complement each other to be used as an effective tool for selecting suitable sites for water harvesting structure (ICRAF, 2005). The application of GIS as an integrating tool to store, analyse and manage spatial information to facilitate decision-making by providing identification of harvesting sites has been applied by de Winnaar et al., (2007).

## 5. Database Components for Present Work

Objectives of the study can be met by obtaining the following water resource data and other natural resource data.

Water resource data consists of

Rainfall data (Data source: Gujarat Water Resource Development Corp., Gandhinagar)

Drainage Map - {Data source: satellite imagery LISS III (IRS1C data product, spatial resolution 23.5

m) and LISS IV (IRS-P6 data product, spatial resolution 5.8 m)}

Water bodies – {Data source: satellite imagery LISS III (IRS1C data product, spatial resolution 23.5 m) and LISS IV (IRS-P6 data product, spatial resolution 5.8 m)}

Other natural resource data consists of

- Geology (District Resource Map, Sabarkantha District, Gujarat – Publisher Geological Survey of India, 2002).

- Geomorphology [satellite imagery {LISS III, (IRS1C data product, spatial resolution 23.5 m),and LISS IV (IRS-P6 data product, spatial resolution 5.8 m) }].

- Landuse [satellite imagery {LISS III (IRS1C data product, spatial resolution 23.5 m) and LISS IV (IRS-P6 data product, spatial resolution 5.8 m) }].

- Soil [National Bureau of Soil Sciences and Landuse Planning, Nagpur and LISS III (IRS1C data product, spatial resolution 23.5 m) satellite imagery].

- NDVI : Normalized Difference Vegetative Index (Downloaded from http://dsc.nrsc.gov.in:14000/DSC/Drought/NDVIimage GalleryStateTable.jsp)

## 5.1. Aster DEM (Digital Elevation Model)

Aster Dem with 30m resolution tile number ASTGTM_N23E073 was downloaded (http://www.gdem.aster.ersdac.or.jp/) and was used for this study. The DEM was further analysed to remove pits (sinks). Digital Elevation Model (DEM) shows that area of study consists of several gentle slopes in the southern part and relatively steep slope in the northern part (Fig. 3).

A digital elevation model (DEM) is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. A DEM in grid format stores elevations in a regular array, very much like a raster image comprised of pixels. DEM is used in the generation of three-dimensional graphics displaying terrain slope, aspect (direction of slope), and terrain profiles between selected points (http://rockyweb.cr.usgs.gov/elevation/dpi_dem.html). The fact that locations are arranged regularly permits the raster GIS to infer many interesting associations among locations.

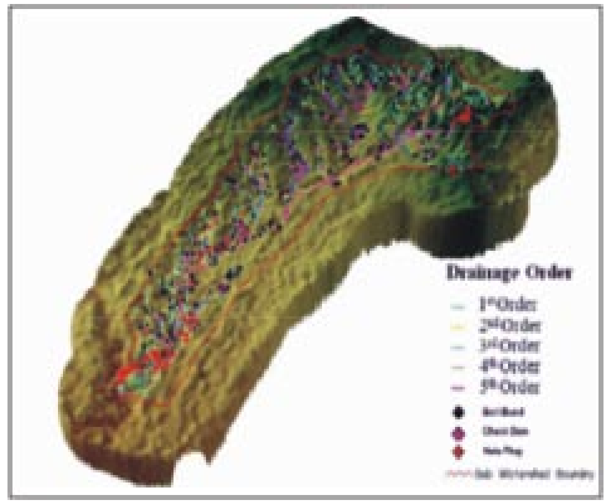


**Figure 3.** Aster Digital Elevation Model of Study Area

## 6.. Methodology

Various thematic maps were prepared through visual interpretation of satellite data, showing land use map, geomorphology map, soil map, drainage map, water bodies map, etc. The digital analysis was carried out using GIS software. Geo-informatics based multi-criteria evaluation (MCE) was adopted for this study. MCE combines the information from several criteria. The stepwise details of methodology adopted for evaluation of the Vatrak sub-watershed is presented through flowchart (Fig. 4). The following are evaluations of various types of information:

## 6.1. Rainfall

The knowledge of rainfall characteristics for a given area is one of the prerequisites for designing a water harvesting system. In the study area, rainfall is typically monsoonal in nature. Plot of rainfall data versus months of the year 2009 are shown in Fig. 5 In resource evaluation of a sub-watershed, the average depth of rainfall of a number of rain gauges is required. The average was obtained by the Theissen polygon method. Weighted average using Theissen Polygon method is shown in Table 1.

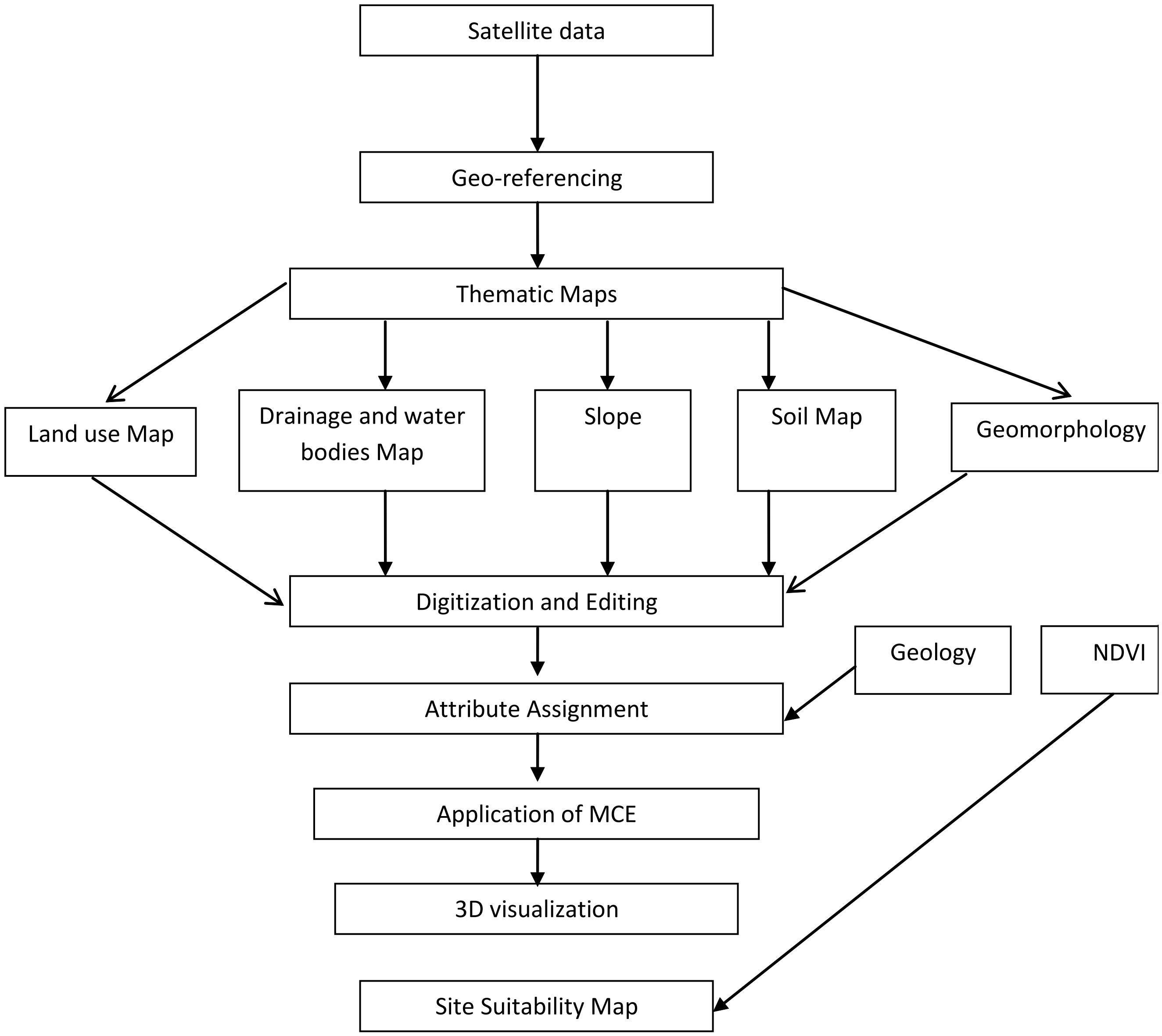


**Figure 4.** Methodology for Evaluation of Sub-watershed to Identify Locations of Suitable Rain water Harvesting Structures

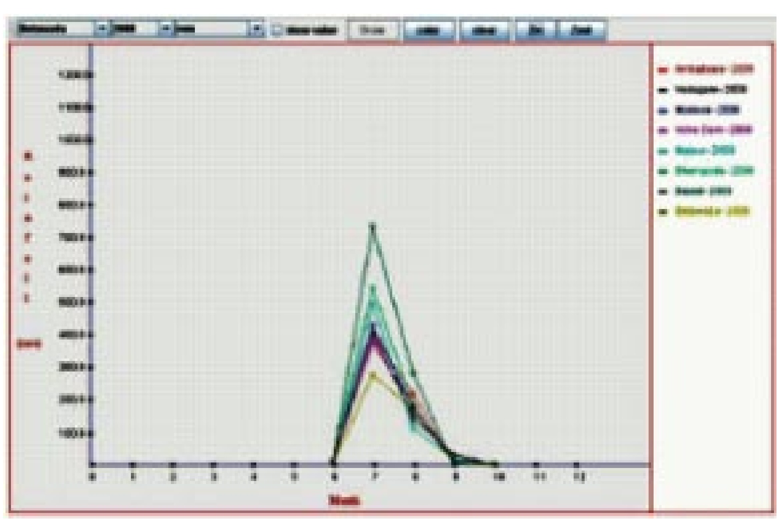

**Figure 5.** Plot of Rainfall Data Versus Months (for the year 2009)

| Sr. No. | Station Name | Year | Effective Area (km2) | Rain fall<br>2009 | Weight | Weighted Average Rainfall (mm) |
|---|---|---|---|---|---|---|
| 1 | Ambliyara | 2009 | 88.75 | 619.5 | 14.83 | 91.88 |
| 2 | Betawada | 2009 | 11.62 | 448.2 | 1.94 | 8.70 |
| 3 | Modasa | 2009 | 37.60 | 615 | 6.28 | 38.64 |
| 4 | Bayad | 2009 | 127.96 | 1003 | 21.38 | 214.46 |
| 5 | Vadgam | 2009 | 87.63 | 572 | 14.64 | 83.76 |
| 6 | Bhempoda | 2009 | 237.31 | 735 | 39.66 | 291.47 |
| 7 | Malpur | 2009 | 0.01 | 633 | 0.002 | 0.01 |
| 8 | Volva | 2009 | 7.54 | 578.3 | 1.26 | 7.29 |
| | **Total** | **598.43** | | | | **736.2187** |

**Table 1.** Weighted Average Rainfall Using Theissen Polygon Method

## 6.2. Land Use or Vegetation Cover

Vegetation Is another important parameter that affects the surface runoff. From the studies in West Africa (Tauer and Humborg 1992) and Syria (Prinz et al., 1999) proved that an increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff. In the study area, a total of 6 land use classes were identified, viz. agriculture, wasteland, built up, etc (Fig. 6).

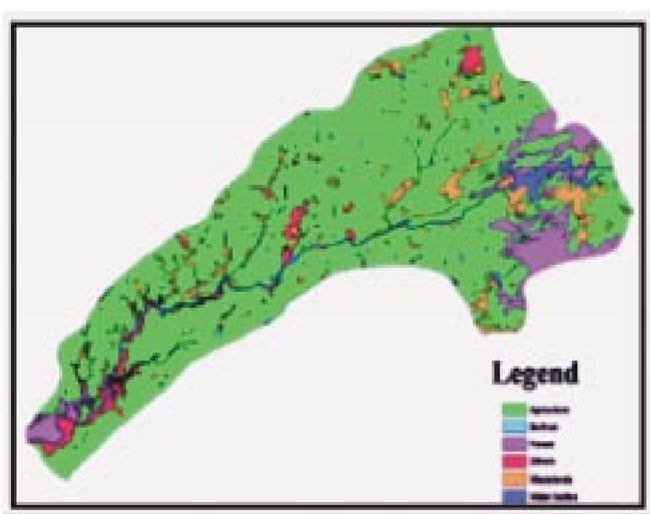


**Figure 6.** Land Use Map of Study Area.

## 6.3. Geomorphology

Different geomorphic units have different groundwater prospects. Alluvial plains and flood plains have got good groundwater prospects, while hills consisting of barren rocks have got poor groundwater prospects. A total of five geomorphic units were identified in the study area (Fig. 7).

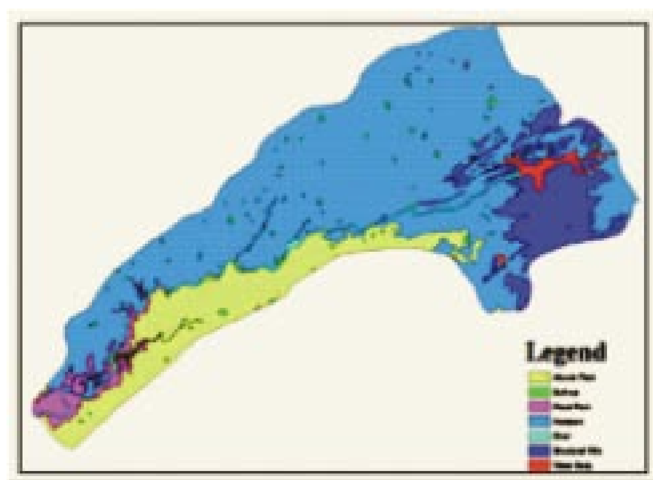


**Figure 7.** Geomorphological Map of Study Area.

## 6.4. Topography

The area of study is characterized by wide river valleys and structural hills reaching a maximum of about 199 m in the northern part. Topography controls the extent of runoff and retention.

## 6.5. Soil Type

The suitability of a certain area either as catchment or as cropping area in water harvesting depends strongly on its soils characteristics. Four different classes of soil were mapped in the study area.

## 6.6. Stream Orders

All stream segments were assigned orders (Fig. 8). The number of segments of each order was then counted to yield the figures in Table 2.

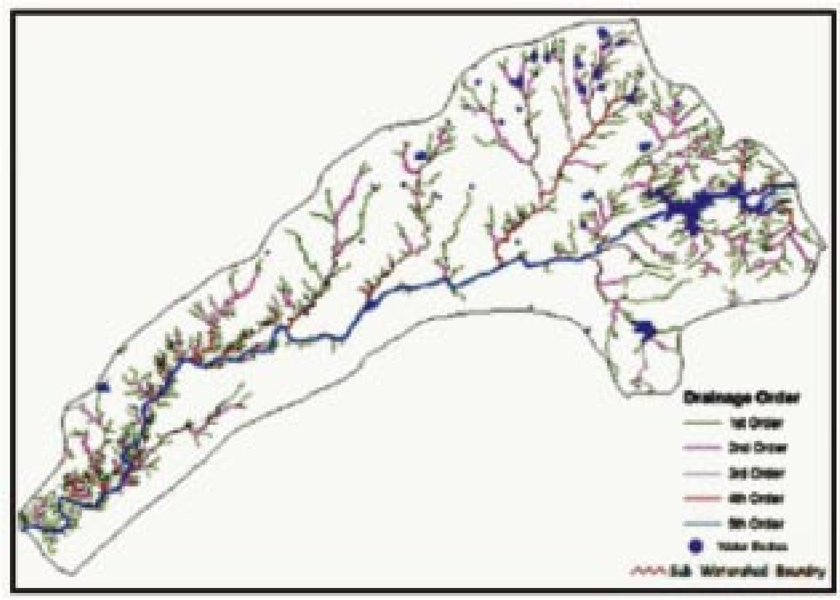

**Figure 8.** Stream Orders and Water Bodies.

| Sr. No. | Stream Order | Number of Sgments | Length of Segments (Metre) |
|---|---|---|---|
| 1 | 1 | 959 | 471162.96 |
| 2 | 2 | 270 | 163853.79 |
| 3 | 3 | 71 | 126778.85 |
| 4 | 4 | 35 | 38546.53 |
| 5 | 5 | 17 | 61604.99 |
| | **TOTAL** | **1352** | **861947.13** |

**Table 2.** Details of Stream Orders

## 6.7. Slope

There were a total of six categories of slope pertaining to the study area These categories were used to explore potential suitable sites for several water harvesting structures. 0 – 1 per cent slope category is the most prevalent one in the study area.

## 7. Multi criteria evaluation of the Vatrak sub-watershed for identification of potential sites for water harvesting structures

The following criteria were used for making decisions on selecting potential suitable sites for various water harvesting structures:

The rainfall in the sub-watershed should be preferably less than 1000 mm / annum (http://cgwb.gov.in/documents/Manualon Artificial Recharge of Ground Water. pdf).

The stream bed should be 5 to 15 m wide.

- The area downstream of the water harvesting structure should have irrigable land under well irrigation.
- The rock/soil exposed in the ponded area should be adequately permeable to cause groundwater recharge.
- The land use may be near agricultural land.
- The slope should be less than 15 per cent.
- The depth to water level in the area should remain more than 3 m below ground level during the post-monsoon period.
- Soft rocks are preferred for water harvesting structures.
- Hard rocks with lineaments are preferred for water harvesting structures.
- The type of soil should be coarse loam.
- Second and third order streams are preferred for construction of check dams.
- First and Second order streams are preferred for construction of boribund and nala-plug.

Based on geo-informatics based multi-criteria evaluation different potential suitable sites for various water harvesting structures, viz. check dams, nala plugs, bori bund, etc. were identified (Fig. 9).

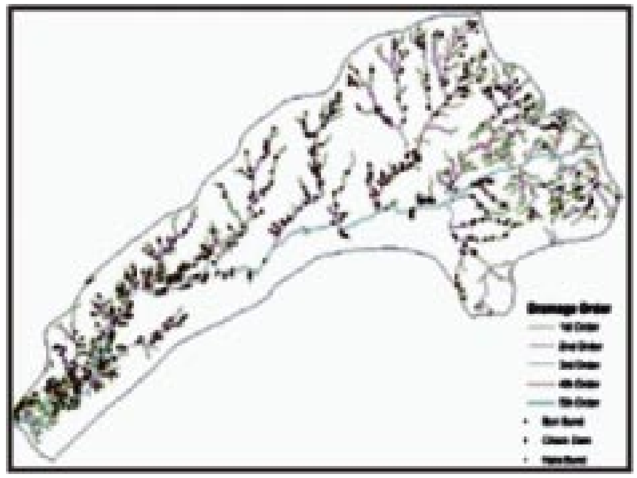

**Figure 9.** Location of Potential Suitable Sites for Water Harvesting Structures on Drainages

## 8. 3-D Visualization

Geo-visualization provides easy and efficient accessing, analysing, and viewing of water resource data. In the present work, GIS software is used for 3-D visualization. Details of geo-visualization of water resources and other natural resource data are as follows:

Overlay of land use information on ASTER DEM

Overlay of geomorphological information on ASTER DEM

Overlay of geological information on ASTER DEM

Overlay of slope information on ASTER DEM

Overlay of soil information on ASTER DEM

Overlay of drainage and water bodies information on ASTER DEM

Overlay of pre-monsoon NDVI image (Year 2009) on ASTER DEM

Overlay of post-monsoon NDVI image (Year 2009) on ASTER DEM

Overlay of drainage and potential sites for water harvesting structures on ASTER DEM (Fig.10)

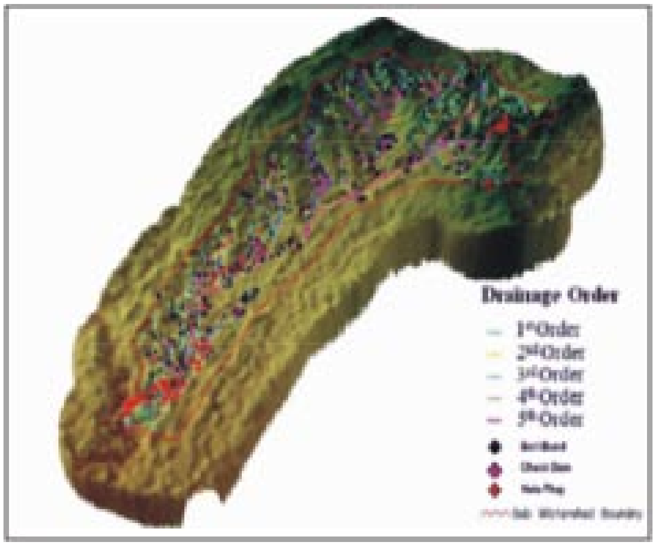


**Figure 10.** Overlay of Drainage and Potential Sites for Water Harvesting Structures on Aster DEM

## 9. Results and Discussion

Geo-visualization of spatial, aspatial and multilayered water resource information can be an effective tool for multi-purpose applications. Land use map of the study area consists of 6 classes. Geo-morphology maps of the study area consists of 5 classes. The geological map shows 5 classes. The suitability of water harvesting structures can be confirmed as the structure is proposed on appropriate drainage order and satisfies the conditions of land use, soil, geomorphology, slope, etc.

A total of 128 potential sites of check dam, 149 potential sites of nala plug and 393 sites of bori bund were identified based on multi-criteria analysis. According to MCE, potential sites are located on low order stream. Sites have distribution throughout the sub-watershed.

## 10. Summary and Conclusions

The Vatrak sub-watershed faces a water scarcity problem. Keeping this in view, an attempt has been made to evaluate the sub-watershed for site suitability of water harvesting structures. Geo-visualization of water resource data pertaining to the Vatrak sub-watershed was carried out using geo-informatics. In the present study, overlay of water resources and other natural resource data was done on ASTER DEM. At present, there are a total of 159 existing water harvesting structures. Using geo-informatics based technologies, 670 potential appropriate sites were identified for various water harvesting structures.

## Disclaimer

Maps presented in this paper are indicative only. Maps are not to scale.

## Acknowledgements

The authors express gratitude to Mr. T. P. Singh, Director, BISAG, Gandhinagar for providing necessary support and permission to publish this work. The authors are thankful to Dr. V. K. Agarwal, Distinguished Professor (Bhaskaracharya Institute for Space Applications and Geo-informatics, Gandhinagar) for providing necessary guidance. The project funding by NRDMS Division, Department of Science and Technology, Government of India is gratefully acknowledged for part of the study. The authors also acknowledge Narmada, Water Resources, Water Supply and Kalpsar Department, Gandhinagar, Gujarat for providing the relevant information regarding existing water harvesting structures.

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# Geomorphic Analysis of Waershed for Planning of Artificial Recharge Structures in Typical Granitic Terrain

A Case Study from Andhra Pradesh, India

**Rao, P.N., Varadaraj, N., and Pandith, M.**

## Abstract

Geomorphic analysis has been made for Madharam watershed falling in typical granitic terrain and perennially drought-prone Mahabubnagar district of Andhra Pradesh for planning of artificial recharge structures. A comparative high number of first order streams (120 no) out of a total of 162 indicates that the area is still under active process of erosion. The medium drainage density (1.63 kms/sq kms), low stream frequency (1.70) suggest medium runoff, gentle slope and medium-good infiltration characteristics. The overall bifurcation ratio (3.88) indicates geomorphic control on the development of drainage pattern. Variations in computed morphometric parameters are observed in different mini watersheds. Main landforms observed include denudational hill, moderate weathered pediment, shallow weathered pediplain, valley fill and pediment inselberg complex. Potential surface runoff is estimated at 5.66 mcm, of which 0.90 mcm only is considered for augmentation, leaving 2 mcm for existing tanks and 50 per cent of surface runoff to downstream for maintaining ecological balance. Considering morphometric analysis, landform, land use pattern and hydrological information, 38 artificial recharge structures have been proposed in the watershed to augment the recharge to groundwater system from the available surplus run off.

Keywords: Watershed, Granitic terrain, Geomorphic analysis, Hydrogeological conditions, Artificial recharge.

## Introduction

Rapid industrialization and the need for food security of the ever-increasing population have led to increased demand for water in the country. Hence development of groundwater received a thrust to meet the water demands of the intensified agricultural activities and industrial requirements. With the unplanned groundwater development, problems of declining water levels and depleting groundwater resources have cropped up. This problem is so prominent in Andhra Pradesh State, where nearly 83 per cent of the State is underlain by hard rocks and rainfall is low as well as erratic. The State frequently faces drought situations and is categorized as water scarce (Andhra Pradesh Water Vision-2020 document) and this called for urgent steps for urgent augmentation of ground resources through artificial recharge. Considering this, artificial recharge to groundwater was taken up in a massive way and a huge investment was made by constructing lakhs of structures in the State. However, these structures were constructed without due consideration of available runoff, geomorphic and hydrogeological criteria. In the random selection of sites and in appropriate design of structures, the desired results are not likely to be achieved.

Topographical, geomorphological, hydrological, and hydrogeological conditions play a significant role in planning and execution of artificial recharge in watershed development programmes. The interrelationship between rock type, structure and drainage network in different parts of India have been studied earlier by several workers. (Vaidyanathan, 1962, 1964., Sankara Pitchaiah and Rao, 1985., Nag and Chakraborthy, 2003., John Devdas et al., 2006., Manu and Anirudhan, 2008). The analysis of morphometric data, which is a reflection of the structural fabric and the type of underlying hard rocks, can provide useful information on the relative variation in permeability of the rocks exposed in any area (Subba Rao 2009). Hydrogeological conditions of the area are among important factors in planning artificial recharge structures (CGWB, 2007). Thus evaluation of drainage characteristics of a basin, using morphometric analysis in relation to landforms in conjunction with hydrogeological, hydrological and land use analysis help in scientific planning of artificial recharge structures which can bring in best results for augmentation of groundwater resources. Considering this, an attempt is made to apply geomorphic analysis of watershed in planning of artificial recharge in typical granitic terrain in Andhra Pradesh.

## Study Area

The Madharam, an elongated watershed (named after Madharam village), lies between north latitude 16 37’ 46” to 16 47’ 41” and east longitude 78 21’ 16” to 78 26’ 02” having an area of 95.30 $kms^2$ consisting of 9 villages (fig.1). Most of the area falls in Midjil mandal and a small part in Kalvakurthy Mandal of Mahabubnagar district. It is situated at about 100 kms from Hyderabad, the state capital in the southeast direction. The study area falls in Dindi river sub-basin of Krishna river basin. The main stream through which all discharge of water passes is of the fifth order. The drainage pattern in general is dendritic to sub-dendritic, typical of granitic terrain. Though a trellis pattern is also observed in two to three tributary streams indicating the structural control over the drainage and streams are ephemeral in nature. About 15 minor and 2 medium tanks (surface water bodies) are located in the area. The watershed receives a normal annual rainfall of 618 mm and the area declared as chronically drought-prone and is characterized by scarce vegetation, erratic rainfall and lack of adequate soil moisture for most part of the year. There is no assured surface water irrigation (except the above tanks) and the entire drinking and irrigation water requirements are met through groundwater only.

## Hydrological Setup

The area is mainly underlain by pink and grey granites of Archaean age. A Dolerite dyke/ intrusion, lying in NNW-SSE direction is observed in the eastern part of the study area. Three sets of lineaments trending NNE-SSW, NNW-SSE and NE-SW are observed. Groundwater occurs under unconfined (20 metre depth), semi-confined to confined conditions (20-100 metre depth). Owing to the desatuartion of the phreatic zone, most of the shallow dug wells of 20 m depth have gone dry or under seasonal presence of groundwater. The depth of weathering varies from 6 to 22 metres below ground level (m bgl). Groundwater extraction is mainly by bore wells of 60 to 100 m depth. The yield of these bore wells varies from 0.14 to 5 lps. The depth to water level generally varies from 8-30 m during the pre-monsoon season and 6-24 m during the post-monsoon season. Average density of irrigation wells is 17 wells/kms$^2$ and the watershed is a part of overexploited basin (APSGWD and CGWB (2005).

## Geomorphological Features

**Lineaments:** The area is criss-crossed with several lineaments. Prominent directions are NNE-SSW, NNW-SSE, NE-SW and E-W (fig.2). It can be seen that the main stream is structurally controlled as evident from near N-S lineaments from N-S of the watershed. Those lineaments emanating from runoff/fringe and divide areas lie in NW-SE and NE-SE directions.

**Landforms:** Landforms observed in the study area are denudational hill (DH) and residual hill (RH), pediment (PD), moderate weathered pediment (PPM), shallow weathered pediplain (PPS), valley fill (VF), pediment inselberg complex (PIC), inselberg (I) (fig. 2). The denudational hills occur as isolated zones in the north-eastern and mid-eastern parts, with a high relief of 672 m above mean sea level (amsl) with steep slopes. The pediment zone occurs in small area in the foot-hill zone of the hill, and is developed by a combination of erosion and sheet wash with gentle to moderate slopes. Pediplain comprising moderately weathered pediplain (PPM) and shallow weathered pediplain occupy the major part. Of these PPM occurs in mid-eastern and south-eastern parts, while PPS occurs as isolated patches all over the watershed particularly in fringe areas of the watershed. Valley fills occupy a narrow stretch bordering major stream from north to south direction. The area occupied by the valley fills shows a gentle slope.

## Morphometry

The morphometric analysis of the drainage basin covers linear (stream order, stream number (Nu), stream length (Lu), bifurcation ratio (Rb) etc.,), areal aspects like drainage density (Dd), constant of channel maintenance (Cm), stream frequency (Fs), etc. and relief aspects like elongation ratio (Re), form factor (Rf) and circulatory ratio (Rc). In the present study, some of the above important parameters are studied using Survey of India Toposheet maps 65 L/5 and L/6 on a scale of 1: 50,000. Map Info (6.5 version), a GIS software, is used for digitization, computation and output generation of the data. The watershed having an area (Au) of 95.3 sq kms with a perimeter of 45.81 kms is divided into 13 mini watersheds (A to M) for comparative evaluation of subunits in relation to hydrogeological conditions (fig.3). The minute basin, an area covering the first order stream and other areas at the mouth of the watershed is classified as inter-stream and other minor stream area (14$^{th}$ mini watershed).

The concept of stream ordering of drainage basin is based on the numerological analysis (Horton, 1945) and methodology proposed by Strahler (1952) is followed in the present study. The total number of streams in various 13 mini watersheds varies from 3 to 26 (total 162) with an average of 12 streams in each unit (Table 1). In the sub-units, the number of first order streams varies from 1 to 20 (total 120) with an average of 9.23, the second order streams 1 to 5 (total 32, average 2.46), the third order streams 1 to 2 (total 8, average 0.62) and fourth order streams, a total of 2 streams. The total stream length is 155.39 kms in the entire watershed, being minimum (2.26 kms) in D mini watershed and maximum (23.23 kms) in the G mini watershed. It is also observed that the total stream length is a maximum in the case of first order streams in all the mini watersheds of the watershed. The computed average value of the bifurcation ratio (Rb) (Schumm, 1956) for the whole watershed varies from 2 to 4.5 with an average of 3.88. The average values for second order, and third order streams of the watershed are 3.75 and 4 respectively. The maximum basin length of basin is 18.83 kms. The computed values of elongation ratio (Re), form factor (Rf) and circulatory ratio (Rc) are 0.58, 0.27 and 0.57 respectively. The drainage density (Dd) for the entire watershed ranges from 0.90-2.21 with an average of 1.63/kms/ sq kms indicating coarse nature (Smith, 1950). The stream frequency (Fs) ranges from 0.38-2.17 with an average of 1.70/kms$^2$ indicating lithological controls over the stream network (Horton, 1932). The constant of channel maintenance (Cm) varies from 0.45 -1.11 with average value of 0.61 kms/sq kms.

## Planning of Artificial Recharge

The climate, topography, soil, land use, and hydrogeological conditions are important factors controlling the suitability of an area for artificial recharge. The climatic conditions broadly determine the spatial and temporal availability of water for recharge, whereas topography controls the extent of runoff and retention. The prevalent soil and land use conditions determine the extent of infiltration, whereas the hydrogeological conditions govern the occurrence of potential aquifer systems and their suitability for artificial recharge (CGWB, 2007). Of these, climate (rainfall) does not vary much, since the area is small. The soil type is mainly loamy (sandy loam, silty loam) in nature. The area is mainly agrarian and dependent on agriculture (khariff and rabi) (Fig.4). Therefore, there is a need to adopt artificial recharge for sustainable management of groundwater resources considering that the watershed falls in an overexploited basin. In the current study it is endeavoured to focus on the importance of geomorphic analysis which includes drainage and landform analysis in conjunction with hydrogeological and hydrological information of the watershed in planning of artificial recharge.

An attempt is made to estimate the available surface runoff using Strange's table (CGWB, 2007). It is estimated that potential surface runoff of 5.66 mcm for a normal annual rainfall of 620 mm can be generated, of which 2.83 mcm is considered for augmentation, leaving 50 per cent (2.83 mcm) to downstream, for maintaining the ecological and environmental balance. There are about 15 tanks including two medium irrigation tanks for which 2 mcm (out of 2.83 mcm) is considered. Thus the balance surplus runoff of about 0.83 mcm can be used for augmenting ground water recharge through construction of additional structures based on geomorphic, hydrogeological and irrigated areas.

## Integrated Approach for Selection of Sites for Construction of Structures

**Morphometric and Landform Analysis:** A comparative high number of first order streams (120 out of 162) indicates that the topography is still under evolution/erosion It can be seen that in certain mini watersheds like A, presence of more short streams suggests that this is recharge zone and infiltration is likely to be less. Hence this unit is considered for construction of suitable recharge structures like check dams. On the other hand the presence of long streams with fewer number of streams in certain mini watersheds (G, J and H) reveals that these are structurally controlled and infiltration is likely to be more. Further that the presence of a long length of third and fourth order streams than the lower order streams demonstrate that the rock formations in these formations are more permeable with high infiltration. Thus natural recharge is likely to be more and interventions through construction of artificial recharge structures can be minimal in these units. The bifurcation ratio greater than > 5 indicates structurally controlled development of drainage network (Strahler, 1957). It can also be seen from the table that in G and H, the bifurcation ratio is close to 5 indicating structural control of streams in these units particularly in downstream areas. It is also observed that most of the sub-units have drainage density of 1.5 to 2.5 indicating medium runoff and infiltration. Low values of stream frequency in several sub-units indicate gentle slopes and infiltration. Based on the synthesis and analysis of several computed morphometric parameters in various sub-units, it can be summarized that mini watersheds A, B, have high runoff, low infiltration, and mini watersheds G,H,I,J have low runoff, high infiltration, while others have medium runoff and infiltration characteristics. The infiltration studies in the watershed reveal that the rates vary from 2 to 20 per cent.

It can also be seen that in the runoff zones, shallow weathered pediment and pediment inselberg complex are main landforms, where weathering thickness is less. In these areas, percolation tanks are not suitable and gully plugs/check dams/gabion structures are suitable. A considerable part of the watershed is occupied by PPM, where weathering thickness is greater and the slope is also less. These areas are suitable for percolation tanks. However, the number of tanks that exist in these areas can receive surplus runoff. Thus there is no need no construct additional percolation tanks except in places where there are no tanks.

**Hydrogeologic and Land Use Factors:** Hydrogeological conditions of the area are among important factors in planning artificial recharge of any area. Sufficient thickness of weathered material and ability to take recharged water are prerequisites to facilitate recharge of stored water. The watershed has sufficient thickness of weathered material in most parts of the area (Fig.2). However, it is necessary that the structures be constructed considering local slope and land use pattern. Therefore apart from technical feasibility, it is also to be ensured that the structures are constructed where there is groundwater development in the form of irrigated areas. Considering this, irrigated areas have been delineated from satellite image LISS-IV (Fig.4).

**Structures Proposed:** Considering geomorphic analysis, hydrogeological criteria and land use pattern, artificial recharge structures have been proposed (Table 2). In mini watersheds/areas where runoff and slope are more, check dams have been proposed. In all 32 check dams (Cds)/gabion structures and 6 mini percolation tanks (MPT) are proposed in the entire watershed with favourable locations (Fig.3). The length of CD could be the order of 10-15 m length. Similarly, in middle reaches and high infiltration/ low runoff zones, construction of MPT of about 50 m length (6 nos) are proposed. The total estimated storage capacity of proposed check dams is 0.64 mcm for 1.5 to 2 fillings (@ 0.02 mcm/annum per unit), while the estimated capacity of MPT is 0.27 mcm (@ 0.045 mcm/annum per unit) for 6 structures totalling 0.91 mcm/annum. Care has been taken to ensure the filling up of existing tanks, by leaving about 70 per cent of available estimated runoff to the tune of 1.92 mcm.

It is suggested that the site selected for check dam should have sufficient thickness of weathered material to facilitate recharge of stored water. The stream bed should be 5 to 15 m wide and at least, 1 m deep. The area downstream of the structure should have irrigable land under irrigation and should be preferably located in areas where contour or graded bunding of lands have been carried out. The check dams can be 10 - 15 m long, 1- 3 m wide and 2 -3 m in height. A trench of about 0.6 m wide in hard rocks and 1.2 m wide in soft impervious rock is dug for construction of core wall (CGWB, 2007).

Similarly percolation tanks should be located downstream of runoff zone with land slope of 3-5 per cent with good permeable aquifers. The size of the structure should be guided by the percolation capacity of the rock strata rather than the yield of the catchment and it should not retain water beyond February (CGWB, 2007).

## Conclusion

Geomorphic analysis of watershed in conjunction with hydrogeological and hydrological data help in evaluation of surface runoff/ infiltration characteristics in various mini watersheds/sub-basins in the watershed which help in planning of artificial recharge structures on a scientific basis. This is only an indicative study and the approach needs to be adopted in all areas with suitable modifications for scientific planning of rain water harvesting and achieving better results.

## Acknowledgements

The authors thank B.M. Jha, Chairman, CGWB, Dr S.C.Dhiman, Member, CGWB and.S.Kunar, Member , CGWB for their motivation for preparation of this paper and also guidance, valuable suggestions and meticulous scrutiny of this paper. The authors also thank K.Seshadri, Scientist, National Remote Sensing Centre, Government of India for providing landform and irrigated area maps. Thanks are also due to A.D.Rao and G.Sudarshan, CGWB, SR for their useful suggestions. The assistance received from Praveen Kumar, B.Sarat, CGWB, SR in digitization work is duly acknowledged.

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## About the Book

Topographical, geomorphological, hydrgeological, geological, hydrological conditions play an important role in the planning and implementation in watershed development programme for water conservation and recharge. In order to combine the utilization of total runoff potential, location and construction of different type of water conservation recharge structures, the geomorphic analysis becomes imperative. The demand of water resources is continuously increasing to maintain the food security to meet the demand of the population domestic and industrial requirement .The existing water resources are not adequate to meet the demand but there is surplus monsoon runoff which can be harnessed for creating surface and sub surface storages by constructing different structures along the different drainage lines. It thus becomes essential to study the regional characteristics of a watershed to calculate the potential runoff and further ascertain the availability of non- committed runoff in the macro/micro watersheds and designing the conservation/ recharge structures as per the order of drainage system (streams). The construction of structures as per stream ordering and drainage area helps in optimum utilization of the available runoff at different locations within the watershed.

This publication was prepared within the framework of the Global Water and Development Information for Arid and Semi-Arid Areas (GWADI) project under the International Hydrological Programme of UNESCO and has explored the applications of geomorphic analysis as a basis to optimize aquifer recharge.

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