CHARACTERIZATION AND MANAGEMENT OF SHALLOW GROUND WATER RESOURCE OF THANDLA AREA, JHABUA DISTRICT, MADHYA PRADESH

Thesis Submitted for the award of degree of

DOCTOR OF PHILOSOPHY IN GEOLOGY

Submitted By

Mr. ANIL KATARA
M.Sc., M. Phil.

Under the Supervision of

Dr. VINITA KULSHRESHTHA
Associate Professor & Head
Department of Geology,
Rajiv Gandhi P.G. College,
Mandsaur, M.P.

Dr. PRAMENDRA DEV
Professor & Head (Ex)
S. S. in Earth Science,
Vikram University,
Ujjain, M.P.

SCHOOL OF STUDIES IN EARTH SCIENCE, VIKRAM UNIVERSITY, UJJAIN - 456010, MADHYA PRADESH

2018

DEDICATED TO

SHREE

MAHAKALESHWAR

AND

MY FAMILY

Dr. VINITA KULSHRESHTHA
(Associate Professor and Head)
Member, Academic Council
Member, Executive Council

Department of Geology,
Govt. Rajiv Gandhi P.G. Collage,
Mandsaur, M. P.- 458001
Tel: 07422- 256291,
Mo: 09425107904
Fax:07422-256291
E- mail: vinitasingh.2005@yahoo.com

Certificate of the Supervisor (Para 26 c) of Ordinance No. 90 for Ph.D. Degree

CERTIFICATE

This is to certify that the work entitled " **Characterization and Management of Shallow Ground Water Resource of Thandla Area, Jhabua District, Madhya Pradesh"** is a piece of research work done by **Mr. Anil Katara** under my guidance and supervisor for the degree of Doctor of Philosophy of Vikram University, Ujjain (M.P.), India, that the candidate has put in an attendance of more than 200 days with me.

To the best of my knowledge and belief the thesis:

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Date:

Place: Ujjain

Dr. Vinita Kulshreshtha
(Research Supervisor)

Forwarded for Evaluation

(Dr. K. N. Singh)

Dr. PRAMENDRA DEV
Rector (Ex)
Professor and Head (Ex)
Dean, Faculty of Science (Ex)
Member, Academic Council (Ex)
Member, Executive Council (Ex)
Chairman, M.P. Central B.O.S. Geology (Ex)
President, VUTA, Ujjain

09 Adrash Vikram Nagar,
Near Mayuri Beauty Parlour
Ujjain, M. P. - 456010
Tel: 0734-2511404,
Mo: 09407131514
E-mail: drpdev@yahoo.com

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Date:

Place: Ujjain

Dr. Pramendra Dev
(Research Co-Supervisor)

Forwarded for Evaluation

(Dr. K. N. Singh)

DECLARATION

Declaration by the candidate under (Para 26 b) of Ordinance for Ph.D. Degree of Vikram University of Ujjain, M. P.

I declare that the thesis entitled **" Characterization and Management of Shallow Ground Water Resource of Thandla Area, Jhabua District, Madhya Pradesh"** is my own work conducted under the supervision of **Dr. Vinita Kulshreshtha and Dr. Pramendra Dev,** approved by the research degree committee. I have put in more than 200 days of attendance with the supervisor at the centre.

I further declare that to the best of my knowlege the thesis does not contain any part of any work, which has been submitted for the award of any degree either in this University or in any other University / Deemed University without proper citation.

Dr. Vinita Kulshreshtha — **Mr. Anil Katara**

(Research Supervisor) — (Research Scholar)

Dr. Pramendra Dev

(Research Co-Supervisor)

Forwarded

(Dr. K. N. Singh)

PREFACE

Hydrogeology is a science, which deals with the occurrence, distribution and movement of ground water, which is a dynamic, renewable, religious, natural, and key earth resource that acts as a replacement of surface water supply. Several states in India, are facing the problem of sustained water supply, particularly in most of the regions of Madhya Pradesh. In recent years, the prevailing trend of rapid population growth, urbanization, industrialization, agriculture, energy and sports sector is resulting into enormous pressure on exploitation of ground water resource. In present scenario, it is visualized that it is need of the day to implement a plan for development and management of ground water resource of Thandla area, Jhabua district, Madhya Pradesh, in order to provide remedial measures to the inhabitants facing crisis of regular water supply.

The present study has been carried out both in field and laboratories. The entire spectrum of research investigation has been presented in the design of thesis containing 8 chapters. Chapter 1 has included objective of research work, location of area, fauna, flora, and soil, previous investigations and scope of future work. Chapter 2 has described a brief account of characteristic features pertaining to regional and geological framework of study area, dominated by quartzite, phyllite, Deccan lava flows and soils. Chapter 3 has been devoted to qualitative and quantitative geomorphology of drainage basin. Morphometric parameters have helped in demarcation of ground water potential zones. Chapter 4 has presented results of rainfall data analyses, forecasting of expected rainfall for 25 years. Environmental role of rainfall on recharge of ground water system has been discussed.

Chapter 5 has described procedure of systematic hydrogeological analysis. Based on ground water levels different seasonal ground water level contour maps, and fluctuation map have been constructed and described. In general, ground water moves towards Padmavati River. Chapter 6 has been designed to quality assessment of ground water on the basis of chemical parameters. The analyzed parameters have indicated that the ground water is suitable for domestic, drinking, and irrigation applications. Chapter 7 has

included a strategy for development and management of ground water. Artificial recharge structures such as pit, trenches, check dams, ponds, percolation tanks, sub-surface dykes, injection wells, and rainwater harvesting structures have been recommended. Chapter 8 has included an account of summary and conclusions of the present research.

Appreciation is recorded to Professor Dr. K. N. Singh, Professor and Head, School of Studies in Earth Science, Vikram University, Ujjain, for extending necessary facilities and encouragement. The sincere obligations are expressed to Associate Professor Dr. Vinita Kulshreshtha, and Professor Dr. Pramendra Dev, Professor and Head (Ex), for guidance inspiration and encouragement during the tenure of research work.

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Place : Ujjain **(Anil Katara)**

Date: **Research Scholar**

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CHAPTER - 1
INTRODUCTION

1.1 GENERAL STATEMENT

The water is one of vital natural resources, which is an essential requirement for the existence of life. It is well-known universal fact that two-third of the globe is occupied by water. However, several parts of world are facing scarcity of potable water in a large quantity for varied applications.

Ground water is a solitary substitute of surface water supply. Water is useful for varied applications such as domestic, drinking, agriculture, irrigation, industry, energy and sports sector. The present trend of population, industrialization, urbanization and energy sector is causing pressure on ground water resource, and resulting in depletion of ground water resource, and even causing drought conditions.

In Madhya Pradesh, there is problem of sustained water availability hence, it is essential to resolve the water supply to the inhabitants of Jhabua district. Thandla is one of the areas, which are facing the problem of regular water supply through the year. Hence, Thandla area has been selected for the present study.

1.2 MAIN OBJECTIVES OF STUDY

The main objectives of present study include the following -

1. Collection and generation of hydrogeological and related data of Thandla sector.
2. Geomorphological and rainfall data analysis for ground water exploration.
3. Estimation of ground water potential.
4. Chemical quality determination for different applications.
5. Integration of analyzed data interpretation for preparation of development and management of ground water resource.

1.3 LOCATION AND PHYSIOGRAPHY OF THE STUDY AREA

1.3.1 LOCATION OF THE STUDY AREA

Present study area is located within latitude $23^{0}0'$ to $23^{0}10'$ N and longitude $74^{0}30'$ to $74^{0}40'$ E, Survey of India Toposheet No.46 I/12, (Figure 1.1) in Thandla of, Jhabua district. It is located at a distance of 5 km. South of the Thandla Road railway station. A panoramic view of Padmavati River in Thandla study area, Jhabua district, Madhya Pradesh has been illustrated (Figure 1.2).

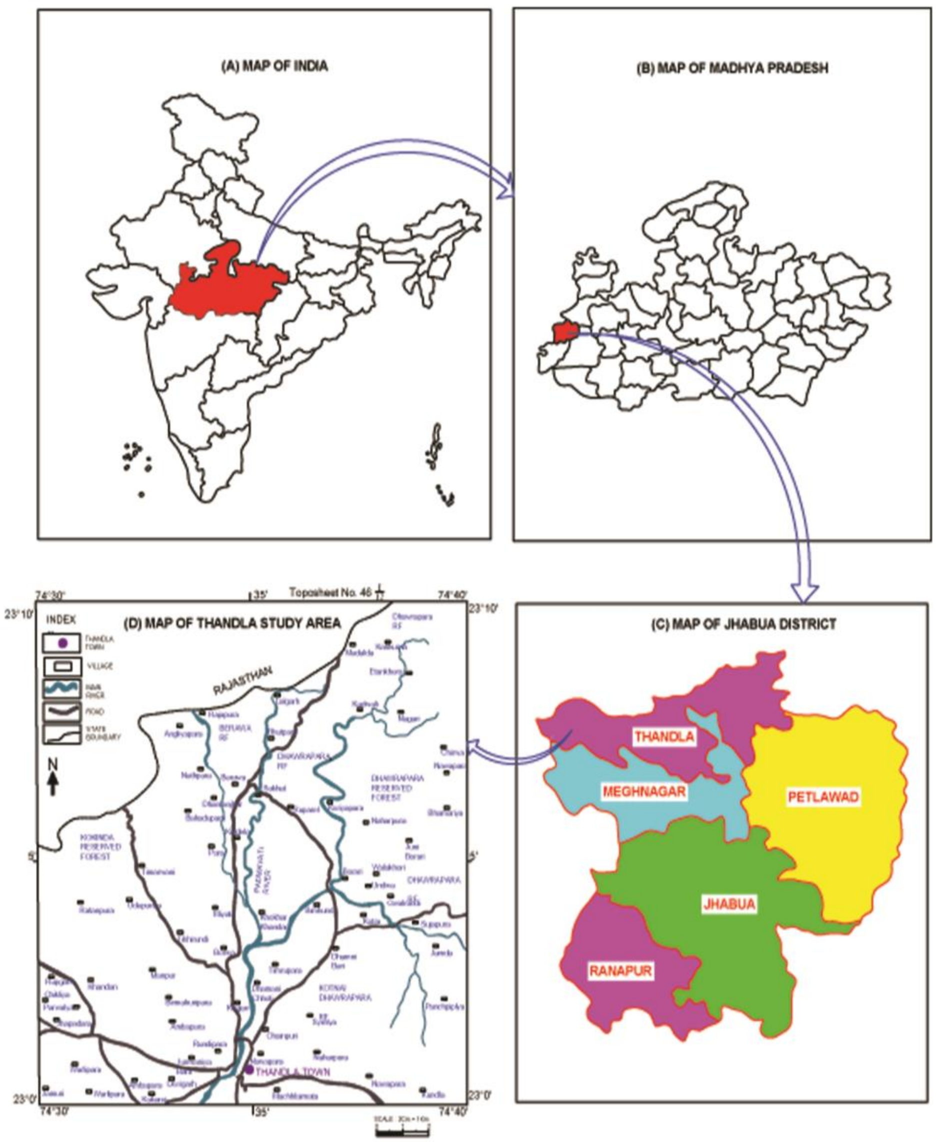


Figure 1.1 Location map of Thandla study area, Jhabua district, Madhya Pradesh, India (www.Google.com).

Figure 1.2 A panoramic view of Padmavati River in Thandla study area, Jhabua district, Madhya Pradesh.

1.3.2 PHYSIOGRAPHY OF THANDLA AREA

Physiography is characteristic of an area developed due to the denudation brought by water and wind as main agents. Three physiographic units- Hilly terrain, Undulating country, and Plain country have been observed in Thandla study area.

1. Hilly terrain

The hill is a higher elevated part of terrain. The middle and northern part of study area exhibit a hilly terrain. A big hill located in the western part of Thandla study area. There mainly quartz and basalt are observed (Figure 1.3).

Figure 1.3 A view of Deccan hill exposed near Chirwa village, Thandla study area.

2. Undulating country

The terrain, covering the North-Western part of the study area is characterized by the presence of the metamorphic rocks, which are found as bolder and boarded by quartzite and quartz grains. The undulating topography exhibits ups and down which look beautiful landscape (Figure 1.4).

Figure 1.4 A view of undulating country exposed near Nagari village, in study area.

3. Plain country

Plains country is characterized by the occurrence of almost flat terrain having the ridges and isolated hillocks cover remaining part of the area, resulted due to differential weathering of different rock types belonging to Precambrian formation. The plains are well developed dominant the isolated hill or ridges (Figure 1.5).

Figure 1.5 A view of Plain country exposed near Nawapara village, in Thandla study area, Jhabua district.

- ## CLIMATE

The climate of study area is mostly tropical. Climate condition of the area is mostly controlled the natural processes, development of land form, soil, water resource. Growth of vegetation mainly depends on climate condition. Climate of Thandla area is considered as tropical monsoon type.

There are different winter seasons (October to February) the summer season (March to June) and the rainy season (July to September). Climate conditions of winter being pleasant are favourable for field studies. The climate during summer day is hot while it is cool during night.

- **TEMPERATURE**

Temperature ranges from 6^0 C to 46^0 C. The average monthly maximum temperature during May for the above period is 40.07^0 C and the maximum temperature is recorded as 46^0 C during May 2013. (Pandey, 2013-2014).

- **HUMIDITY**

Normally, Thandla area is comparatively dry. Relative humidity is about 34.4 to 50%. Humid months of Thandla area are July, August and September maximum evaporation - transpiration loss takes place in the month of March, April, May and June. During the rainy month there is not much difference between day and night relative humidity.

- **RAINFALL**

The rainfall varies from 423.0 to 2086.2 mm, with an average of 964.324 mm. The highest rainfall is noted during the period from June to September.

- **WINDS**

Winds are strong during summer and in monsoon period. Winds move in S-W and N-W directions. During post- monsoon and winter months, Thandla area enjoys as pleasant morning blaze with an easterly direction and dust storms are reported occasionally during summer period.

- **DRAINAGE**

Padmavati River and its tributaries are major river system in Thandla region. Padmavati River is not perennial, occasionally the entire valley gets dried up. The direction of flow is towards North- South.

- **SOIL**

It is essentially a geologic unit formed by the various natural processes. Soil of Thandla area is black and red in colour. The soil is mixture of mineral and organic matter. Mineral matter with water and air occupying the inter spaces. Mineral matter being predominant soil is considered as a geologic formation of Recent age. In general usage soil refers to loose surface of the earth as distinguished from the solid rock.

1.4 FAUNA AND FLORA

- **FAUNA**

Fauna comprises mainly of domestic such as horses, cows, sheep's, cats, dogs, hens, goats, snakes and different types of birds such as sparrow, pigeons and dukes wild life is rather meager. Common wild animals include monkeys, rabbits, wolf, foxes and different types of birds such as owls, cuckoo, raven, bats, nightingales, peacock and others. The other animals are reptiles, warms and insects, turtle, crab, body-licer, ant, beetle, lizard, leech, fire **-** fly, white ant, butterfly, scorpion, fish and drone and others.

- **FLORA**

Flora of Thandla area is rather scanty even having favourable status of environmental scenario. At some locations, study area is covered by thick vegetation. The plants recorded in the area are - amarbel, anar, aawla, banana, banyan tree, babool, carrot, ginger root, jamun, khajur, mahuva, mango, mudar, neem, palas, papita, potato, and sandal wood. The common crops include: groundnut, maize, and wheat.

1.5 RESEARCH METHODOLOGY

The common methods of hydrogeological study have been followed by using conventional methods of investigation both in field and laboratory. The outlines of the work carried out have been given below **-**

1. The collection of data from different organizations has been made. On the basis of survey of India Toposheet No. 46 I/12 on 1:50,000 scale base maps have been prepared.
2. Morphometric analysis of drainage basin of the area has been conducted by using methods of morphometric parameters.
3. The mathematical and statistical analyses of rainfall data determine variation trend and future rainfall trend.

4. Generation of hydrogeological data by well inventory to determine characteristics of the ground water resource of the area.
5. Collection of ground water samples for determination of quality for drinking, domestic and irrigation uses.
6. Analyzed hydrogeological data and prepared the maps.
7. Computation of ground water potential of the study area.
8. Chemical analysis of ground water to determine the quality suitability for domestic, drinking and irrigation application.
9. Interpretation of analyzed data.
10. Classification of watershed into-micro watershed.
11. Integration and preparation of illustrations.
12. Prepared ground water management plan.
13. Prepared thesis.

1.6 REVIEW OF PREVIOUS WORK

Survey of literature reveals that a fairly good number of workers namely, Bose (1884), Fermor (1909), Heron (1936, 1953), Gupta and Mukherjee (1938), Roy Choudhary (1955), Das Gupta (1959), Nayak (1966, 1969), Lahiri (1971), Munshi, Khan and Ghosh (1974), Narayana (1974), Radhakrishnan (1974), Basu (1976), Banerjee and Basu (1979), Kandpal and Sengupta (1988), Sartana (1988), Tiwari *et. al.,* (2003), Khan *et. al.*, (2005), Damor (2008), Chouhan (2008), Bhuriya (2009), Bhuriya (2010), Katara (2012), Bhuriya (2014), Ateria, *et. al.* (2015), Katara and Dev (2016 a), Katara and Dev (2016 b), Katara (2016), Katara and Dev (2017) and Others have conducted geological investigations in the vicinity of Jhabua district.

Katara (2012) for the first time has undertaken a hydrogeological investigation in Thandla area of Jhabua district, Madhya Pradesh. Investigated area is confined between the Latitude 23^0 0' to 23^0 5' N; Longitude 74^0 30' to 74^0 40' E (Survey of India Toposheet in No. 46 I/12).The author has designed first chapter dealing with general information about the location of the study area, objectives, physiographic environment and scope of research work. Second chapter include a concise description of regional geological setup of the Deccan traps (Upper Cretaceous to Eocene age). The geological setting of study area around Thandla block of Jhabua district, indicates the major part of the Archaean rocks- granites, gneisses; phyllites, quartzites, constitute the litho units. Bagh beds (Nimar sandstone, Nodular limestone, Deola Chirakhan Marl and Coralline) observed at a few places. The landforms such as plateau, lava hills and black cotton soil have been described. The morphometric analysis of Thandla block has been conducted. Drainage basin has been sub divided into seven sub basin. The geomorphological parameters have been determined, analyzed and interpreted. The drainage pattern is dendritic and suitable for ground water exploration.

Rainfall data for a period of 25 years (1987 to 2011) of Thandla area, Jhabua district have been subjected to mathematical and statistical analysis. Annual average of rainfall has been calculated as 905.16 mm. Departure from the average annual value of yearly rainfall and cumulative departure have been computed. Based on statistical analysis of rainfall data (mean , median, mode, standard deviation, co-efficient of variation, co-efficient of skewness). Expected future rainfall trends have been predicted. Hydrogeological survey of study area has been conducted in Thandla area, 35 open dug wells have been analyzed for determination seasonal variations of ground water levels and trend of ground water movement in the study area. The chemical analysis of 5 ground water samples indicates that ground water is suitable for drinking and irrigation applications.

Ateria, et. al. (2015) conducted research study on fluoride status in drinking water in the district of Jhabua in Madhya Pradesh and interaction with other ions present in drinking water to assess water safe for human consumption. The authors (Ateria, *et. al.,* 2015) have analyzed 37 water samples from Thandla block and determined the following parameters- pH (7.20), EC, dsm-1 (1.11), Fluoride conc.mg/L (2.188), Nitrate conc. mg/L (1.375) and discussed the significance of fluoride concentration in Thandla area.

Katara and Dev (2016 a) have analyzed rainfall data of Thandla area 25 years (1987 to 2011) by using mathematical and statistical techniques. Rainfall data indicate a variation range from 423.0 to 1655.6 mm., and the computed annual mathematical average rainfall as 905.116 mm. Departure of rainfall from annual average, the cumulative departure have been determined. Rainfall during 1996, 1997, 1998, 2003, 2004, 2006, 2007, and 2011 have been more than the average rainfall and indicate favourable condition for the ground water recharge, while the period of 1987 to 2011, 1988, 1989, 1991, 1992, 1995, 1999, 2000, 2001, 2002, 2005, 2008, 2009, and 2010 exhibit rainfall values less than the average rainfall pointing out rather less contribution of rainwater to the ground water reservoir. Cumulative departure trend reveals a negative condition of ground water system. Statistical analysis of rainfall data of Thandla area indicate mean (904 mm.), median (1425 mm.), mode (1900 mm.), standard deviation (334.66 mm.), co-efficient of variation (37.01mm.), co-efficient of skewness (-2.976).Determined statistical values of parameters reveal a negative trend of rainfall. Environmental impacts of rainfall trend in ground water recharge have been discussed.

Katara and Dev (2016 b) published an account of hydrogeological analysis of Thandla area of Jhabua district, which is occupied by geological formation of Aravalli super group, Lameta beds, Bagh beds, Deccan traps and Alluvium. Thandla area is mainly covered by quartzite, phyllites, granite-gneiss, of Aravalli Super group. At places, Thandla area is covered by the limestone, sandstone of Lametas and Bagh beds overlain by the flows of Deccan traps. The Alluvium is well exposed along Padmavati River. Hydrogeological analysis of 35 open dug wells reveals that the diameters range from 3.65 - 7.95 m., static water levels range from 1.10 - 9.60 m.b.g.l. and depth of wells range from 6.50 - 12.25 m.b.g.l. Seasonal monitoring of water levels indicate a fluctuation range of 2.15 - 6.38 m.b.g.l. Ground water level maps of post and pre-monsoon periods indicate that in general, ground water movement is towards Padmavati River. Potential locations for ground water development have been suggested in the villages of Bhimkund, Dhamni, Junwaniya, Khokhar Khandan, Miyati, Timarwani, and Udepuriya,

Katara (2016) described results of ground water chemical analysis of Thandla study area. Physical analysis indicates that all samples are colourless, odourless, and tasteless. The pH values range from 8.6 to 9.0 and electrical conductivity ranges from 628 to 638 μs /cm. Chemical analysis indicates presence of ionic values (measured in ppm) such as Ca (151 to 159), Mg (65 to 68), Na (100 to 125), Cl (645 to 650), So_4 (370 to 388), No_3 (35 to 39), and $CaCo_3$ (830 to 850). The plots of ionic values on Trilinear Piper's diagram, Wilcox diagram and U. S. Salinity hazards diagrams indicate that the ground water of study area is favourable for drinking and agricultural/irrigation purposes.

Katara and Dev (2017) published a paper on the application of quantitative analysis in the exploration strategy of ground water resource in Thandla area based on Survey of India Toposheet no. 46 I/12, on a 2 cm = 1 km scale. Drainage basin has been divided into seven sub-basins A, B, C, D, E, F and G. Linear, areal and relief parameters have been computed . Determinations of morphometric variables include the number and order of streams, length, width and area of basin. Estimation of important parameters such as bifurcation ratio (1 to 7), drainage density (1.33 to 2.28 1/km), length of overland flow (0.219 to 0.375 km), stream frequency (1.716 to 3.302 1/km2), form factor (0.430 to 0.916), circularity ratio (0.974 to1.35), elongation ratio (10.68 to 19.18 km), lemniscates (0.272 to 0.580), basin relief (5 to 25 m), relief ratio (0.588 to 3.809 m) and ruggedness number (9.7 to 45.6) in respect of seven sub-basins of the study drainage basin have been worked out. Applications of morphometric parameters have been discussed. Morphometric data enables to locate favourable ground water potential zones in Thandla area. Analyzed data provide valuable help in delineation of ground water potential sites.

1.7 SCOPE OF PRESENT WORK

The present study has been conducted on hydrogeological regime of Thandla study area on the basis of data generation in respect of geology, geomorphology, hydrometeorology, hydrogeology and hydrogeochemistry. The study has provided valuable data for preparation of a development and management plan of the ground water resource.

It is suggested that in future, investigation of the geophysical exploration and remote sensing techniques in respect of Thandla area, would also help in demarcation of ground water potential sites in the study area, particularly where is no water supply. The results would resolve the problem of sustained water supply in the Thandla area of Jhabua district, Madhya Pradesh.

CHAPTER - 2

REGIONAL GEOLOGY AND STRATIGRAPHIC SETTING OF STUDY AREA

2.1 REGIONAL GEOLOGY

The present investigation is confined to tribal district of Jhabua in western part of Madhya Pradesh, It is bounded by districts of Ratlam, Dhar, Alirajpur (Madhya Pradesh), Panchmahal, Baroda (Gujarat), and Banswara (Rajasthan) (Figure 2.1).

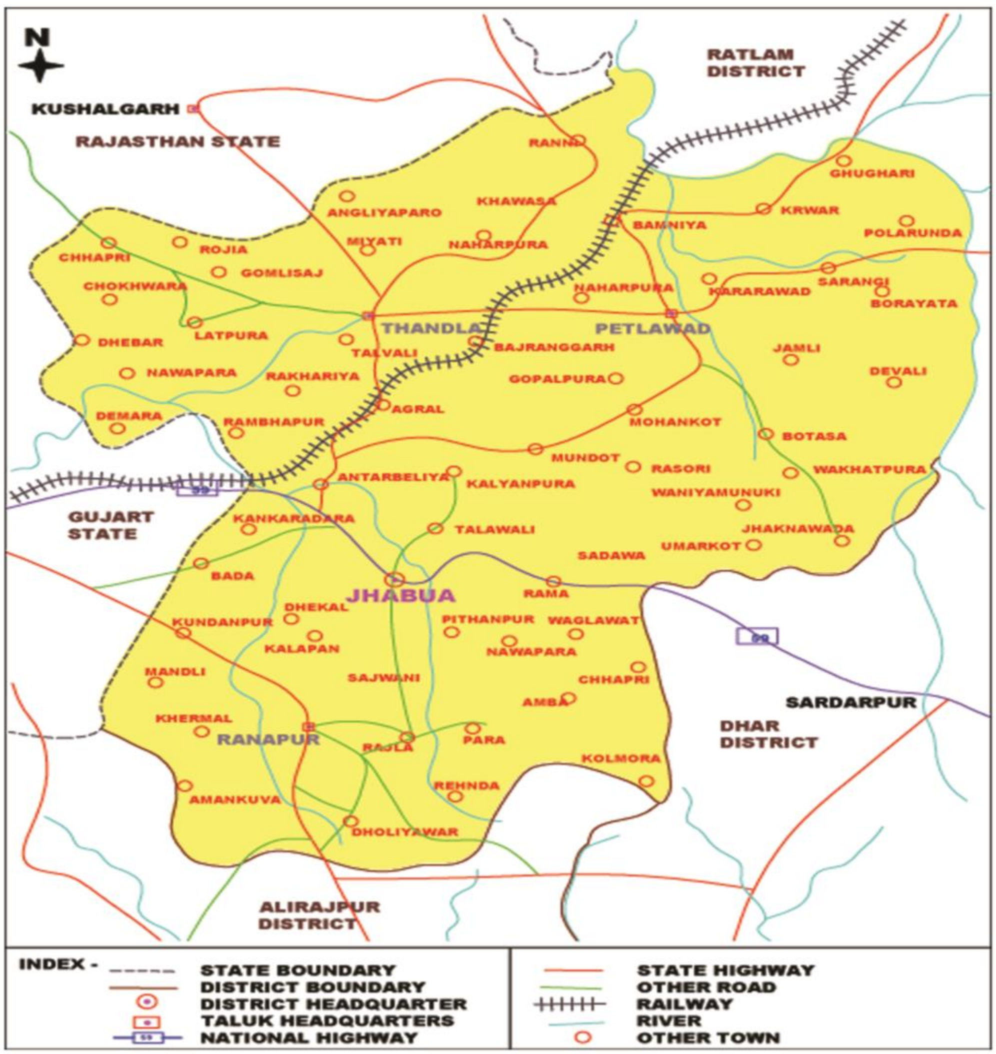


Figure 2.1 Outline Map of Jhabua district and its surrounding (Modified After, Central Ground Water Board, 2013).

The Jhabua region is characterized by the geological formations ranging from Archaean to Recent periods. Geological succession of Jhabua region has been classified by several workers including Geological Survey of India, Central Ground Water Board (C.G.W.B., 2013), Pandey (2013-14). In the Jhabua district the prominent rock types include Quartzite, Granite, Sandstone, Shale; Clay, Coal seams, Boulder beds, Sand, Silt, Clay, Dolomitic Marble, Schist, Phyllites, Granites, shale, Limestone, Basalts with inter trappean clays, Laterite and Alluvium.

The following Geological sequences of Thandla study area in Jhabua district have been elaborated (Table 2.1, 2.2).

Table 2.1 Geological Succession of the Jhabua district, Madhya Pradesh, India (Central Ground Water Board, 2013).

AGE	STRATIGRAPHIC UNIT	LITHOLOGY
Quaternary to Recent	Recent Alluvium	Alluvium and Laterite
....Unconformity...		
Upper Cretaceous to Lower Eocene	Deccan Trap	Basalts with inter trappean clays
Upper Cretaceous	Lameta and Bagh Beds	Limestone and shale
Archaean	Aravalli super Group	Granites, Phyllites, Schist, and Dolomitic Marble

Table 2.2 Geological Succession of the Jhabua district, Madhya Pradesh (Pandey, 2013-14).

GEOLOGICAL AGE	GROUP	ROCK FORMATIOMN
Pleistocene to Recent	Alluvium Plain Older and Newer Alluvium	Unconsolidated sand silt and clay
Cretaceous to Eocene	Deccan Trap	Basalt
Paleozoic to Cretaceous	Gondwana super group	Boulder beds, Sandstone, Shale, Clay and Coal Seams
Pre-Cambrian (Proterozoic)	Vindhyan Super group	Shale, Sandstone
Archaeans	Older Metamarphic Bundelkhand Granite	

- **ARAVALLI SUPER GROUP**

The Aravalli Super group is essentially comprised of the Dolomitic Marble, Schist, Phyllites and granite. These rock exposures have given rise to the undulating topography due to the contrasting variation in their hardness. The main characters of rock types are described in the following text:

Dolomitic Marble/Limestone

Dolomatic Marble is a oldest rock unit of the Aravalli super group exposed in Jhabua district. Above hillock at the N-W portion of the mine, Dolomitic Marble is found. Marble is fined grained and dolomitic. It is an impure variety with siliceous bands and ferruginous veins. They are mostly light brownish in colour at the surface. The granitic types of rocks occur on western side of Anass River. They have given rise to injection Gneisses, Quartzo-feldspathic Gneiss and Pegmatite. The typical weathering and development of solution cavities at depth is beneficial for the ground water occurrence and movement.

Quartzite

Quartzite is mostly exposed at hilly outcrops. These are found associated with Phyllites. There is variation in colour from white, grey and pink to red colour, which is recognized to the varying contents of iron oxides. They are highly jointed and fractured with irregular joints. Due to impervious nature of quartzite, the ground water percolation is along joints.

Phyllite

Phyllites are in abundance in Jhabua region. It is hard and associated with Quartzite. Phyllites are characterized by variable hardness and widely distributed. The contact between the Phyllites and Granite is difficult to be traced out. Phyllites are greenish grey in colour and has poorly development of schistosity, and acquired characters of Slates.

Granite

The main types of Granites are as follows - (a) Grey Granite, (b) Pink Granite, (c) Granitic Gneiss, (d) Quartzo-Feldsathic Gneiss.

Lithological characters of Granite very over a wide range but for the grey and pink types which have much similarity. The grey Granites are developed in single and extensive out-crop N-W of Jhabua district. In general, rocks are gneissic in appearance with alternate bands of feldspar and quartz. Since feldspar are usually pink in colour the rocks acquire pinkish tone. Term granitic is used to cover the group of rocks showing diverse petrographic characters, such as variation in colour, structure, texture and mineral assemblage, but the overall composition of the rock is essentially quartz and feldspar with sub ordinate quantity of other minerals. The classification/ terminology is desirable as the rocks of this group have been recognized throughout the globe. Nomenclature adopted by a number of investigators is not firmly followed.

The lithological characters of the four types of granites reveal a variation range. The grey and pink granites exhibit intimate relationship. Petrographic examination have indicated the uniformity in mineral assemblage of the pink and grey granites. The injection gneisses and quartzo-feldspathic gneisses are much varied in their structural features and mineral constitution, show gradation not only amidst themselves but also with the me but also with the metamorphic on one side and the typical granite on the other. They are foliated in different degrees, fissile, and compact at places and at others. These are developed in the plains and low-lying areas. In contrast to pink and grey granites, which are generally occurs at hillocks or mounds.

- **LAMETA AND BAGH BEDS**

Marine Cretaceous formations are originated in shape of isolate exposures overlain by the Deccan Traps group. The junction of two rock formations (Lameta and Bagh beds) at a few places exhibit prolific development of quartz and calcite vein. The rock types of these formations are shown in (Table 2.3). In the Thandla area, Bagh beds are well developed.

Table 2.3 Bagh beds succession on the Jhabua district, Madhya Pradesh (After Krishnan, 1968).

<table>
<tr><td colspan="3" align="center">Deccan Traps</td></tr>
<tr><td rowspan="2" align="center">Bagh beds</td><td align="center">Upper</td><td>Coralline Limestone
Deola Chirakhan Marls
Nodular Limestone</td></tr>
<tr><td align="center">Lower</td><td>Nimar Sandstone</td></tr>
<tr><td colspan="3" align="center">Metamorphics</td></tr>
</table>

Bagh beds in Thandla area are represented by Nimar Sandstone, Nodular Limestone, Deola Chirakhan Marls and Coralline Limestone. The topographical forms represented by the Bagh beds vary from undulating plains to irregular slops and tops. The following the rocks type are met with in the present study area - (a) Nimar Sandstone, (b) Nodular Limestone, (c) Deola Chirakhan Marls, and (d) Coralline Limestone.

(a) Nimar Sandstone

Nimar sandstone exposed in Bagh area in the Jhabua and Dhar district boundaries. It is covered by Nodular limestone and mainly horizontal. Upper part of Nimar Sandstone brown and white.

(b) Nodular Limestone

Nodular limestone is horizontal, fine grained, different colours, with lower part dark gray coloured. This beds is exposed in and around Bagh town, Dhar district.

(c) Deola Chirakhan Marls

The Deola Chirakhan Marls unit is only 3 m in thickness and richly fossiliferous.

(d) Coralline Limestone

Coralline limestone is red to yellow and yield abundant fossil fragments of Bryozoa. Thickness of this bed 0.5 m. and contains high silica percentage.

Shale

Shale is formed by consolidation and in duration of clay sediments. Water is found in porous layer, fractures, bedding planes and weathered zone. Clay does not have yield of water, but on the basis of data available, shale, when fractured, provides small quantities of water to dug and bore wells. when shale is calcareous, fractures may be enlarged by solution of the calcareous matrix.

Limestone

Limestone is oldest rock belonging to the Aravalli group exposed in Jhabua region. They are grey to pinkish, mostly dolomitic, and have veins of silica and ferruginous bands. The exposures near Devjhiri temple display typical weathering of elephant like skin on the surface.

- **DACCAN TRAPS**

Lava flows belonging to Deccan traps igneous activity cover an area of about 800 sq.km. of this district and have wide coverage. Topographic features of the rest of lava plains and lava plateaus are typical of Malwa region. Lavas were erupted in succession as evidenced from the step like appearance. Deccan traps comprised of basalts with little variation at places.

Hathipava hill situated near Jhabua, has maximum elevation, exhibits sequence of basaltic lava flows along road cuttings. Examination has indicated that basaltic lava flows are not so uniform as they are apparent and reveal variation in lithology, hard, compact and massive to highly vesicular, in texture from fine grained or nearly glassy. (Krishnan, 1968,1982)

- **RECENT ALLUVIUM**

Alluvium

Alluvium consists of shale, sand or clay materials, generally along the course of rivers. The alluvial soil is help in the cultivation of crops, vegetables and other uses.

Laterite

Laterite is a weathered material of basaltic lava flow. It is mostly comprised of iron minerals of red colour. It constitute soil material in several areas.

2.2 GEOLOGY OF STUDY AREA

The study area is mainly dominated by the presence of Deccan traps, black cotton soil, lateritic soil and alluvium.

The present study carried out in Thandla area belongs to Jhabua district of Madhya Pradesh. the following general sequence of the geological formations in Thandla area has been observed (Table 2.4).

Table 2.4 Geological succession of Thandla area, Jhabua district, Madhya Pradesh (Modified after Pandey, 2013-14).

AGE	FORMATION	LITHOLOGY
Cretaceous to Eocene	Deccan Traps	Basalts flows
....Unconformity..		
Upper Cretaceous	Lameta and Bagh beds	Sandstone, Limestone
Archaean	Aravalli Super group	Quartz vein, Granite-gneiss, Phyllites, Quartzite**.**
.... Unconformity...		
Basement unknown		

- **ARAVALLI SUPER GROUP**

Quartzite

Quartzites are present in southern part of Thandla near Devigarh village in along the Padmavati River. Quartzite band extend over 2 to 7 km. The quartzite are fine grained containing predominantly quartz. Quartzite exhibits variation in colour from white, pink to almost red and highly jointed and fractured (Figure 2.2).

Figure 2.2 Photograph showing of Quartzite near Devigarh village, study area.

Phyllite

Major portions of western part of Thandla study area, are covered by the phyllite showing considerable difference in their characters. Phyllite are associated with quartzite, their resistance to weathering gives strength for remaining in elevated areas. Phyllites are at some places, grayish grey in colour and have poorly development of schistosity, they have developed characters of slates, which display of foliation planes. Megascopically, this rock contains mainly sericite with less percentage of chlorite this gives silky appearance (Figure 2.3).

Figure 2.3 A view of Phyllite near Jamuri village, study area, Jhabua district.

Quartz vein

Quartz veins are observed in basalts in the study area as a peculiar character. The veins are of different intensity of colours such as white, pink and red (Figure 2.4).

Figure 2.4 Photograph showing a view of basalt with existence of Quartz vein near Warlipara village in Thandla study area, Jhabua district.

- **LAMETA AND BAGH BEDS**

Lameta and Bagh beds are described in study area by a few workers. The importance features of the Bagh beds are described herein. It is remarkable to point out that the Deola marls, which is found in the type area at Bagh, is missing in the study area. In the area cover by survey in the Thandla area, the other has not observed the exposure of Bagh and Lameta beds have not been observed during the survey of study area. The distinctive features are described.

Sandstone

Sandstone is the most productive among the semi consolidated sedimentary rocks. In an incipient stage of cementation, sandstone is incoherent, and almost all the interstitial porosity is preserved to resemble that of sands. The porosity decrease with depth due to compaction, while precipitating conditions of percolating water may also reduce the porosity of near surface layers by deposition. In general, older sandstone are less porous than younger ones.

Limestone

In Bagh beds limestone occurs in two units as Nodular limestone and Coralline Limestone, which contains fossils of invertebrates in majority. Nodular limestone is characterized by hard and compact limestone of reddish colour. Coralline limestone is red to yellow and yield abundant fossil fragments of Bryozoa.

- **DECCAN TRAPS**

Basaltic lava flows of Thandla study area

The study area around Thandla region is covered by basaltic lava flows of Deccan Traps. This volcanic eruption took place during Upper Cretaceous to Eocene period. Basaltic lava flows are almost horizontally disposed, grey to black in colour with prominent vesicles and rounded boulders. Three major types of basaltic flows have been recognized and their salient features are described herein (Figure 2.5).

Third flow: Third flow occupies most of the study area in all direction of the surveyed area. The exposures of this flow have been observed at places such as Ratanpura, Angliyapara, Rajapura, Chirwa, Panchpiplya and others places. Hard and weathered at top of the hill. The flow is reddish brown and with black soil a top of flow. Top of the flow is weathered and vesicular at few places. The vesicular cavities are partly filled with zeolites. The thickness of weathered, vesicular and geologic zone ranges from 2 to 16 m. (Figure 2.6).

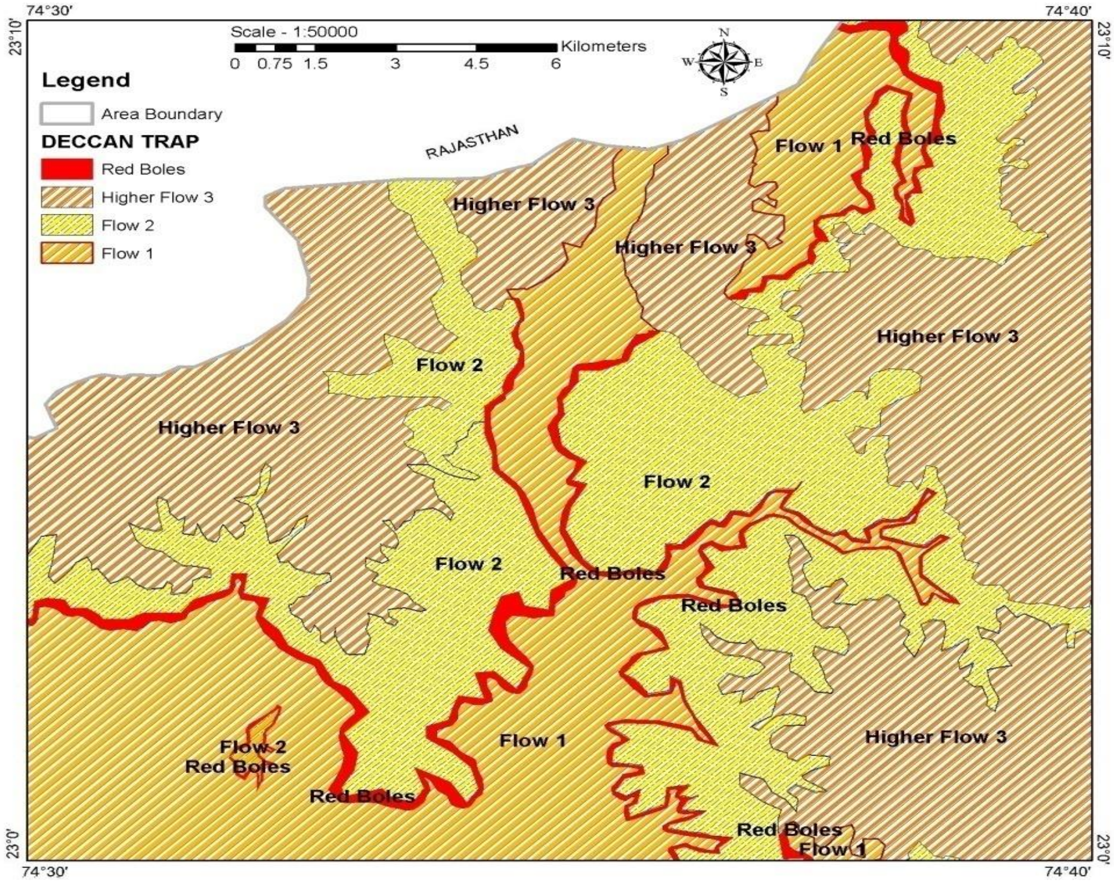


Figure 2.5 Geological Map of Thandla area, Jhabua district, Madhya Pradesh.

Figure 2.6 A view of lava flow third exposed that near Ratanpura village, Jhabua.

At few places, the lava flow is characterized by the evidence of well developed feature of Spheroidal weathering (Figure 2.7).

Figure 2.7 Photograph displaying a view of Spheroidal weathering in lava flow exposed near Junwaniya Bara village in Thandla area.

Figure 2.8 A view of lava flows with red bole exposed near Jamda village, Thandla.

Second flow: Second flow is exposed almost in all direction of study area. The exposures of this flow have been observed at places such as Para, Koriyapara, Etankhera, Nawapara and other villages. Flow is gray and black to brown in colour. Top of flow is weathered and vesicular at few places. Vesicular cavities are partly filled with zeolites.

The thickness of weathered, vesicular and geologic zone ranges from 6 to 13 m. Its massive and jointed portion is extensively quarried for dimension stones (Figure 2.8).

Red bole: It is clearly brick red, fine grained and clay like appearance. It is observed in a exposure just below the bottom of the upper flow and it exhibits maximum thickness up to 1 m. (Figure 2.8).

First flow: North-Western part of the study area reveals the presence of first lava flow. This flow has been observed at villages of Ratanpura, Udepuriya, Manpur, Khandan, Sukhat, Mandalda and others village. It is generally fine grained, black in colour and with few joints. Thickness of the weathered and vesicular zone in this flow ranges from 1 to 2 m. (Figure 2.8)

Black cotton soil

Black cotton soil is argillaceous and contains 40 - 60 % of the clay. It shows fine texture and has a degree of plasticity becoming sticky. When wet and develops cracks when dried up. The soil occurring in the valleys contain gravels of varying size. Black cotton soil has been derived from present basaltic rocks under semiarid conditions. Mixture of red and yellow soil occurs on slops and uplands. There soils are of sandy loam type, showing colour variation from reddish yellow, yellowish brown and light grey (Figure 2.9).

Figure 2.9 A photograph exhibiting nature of black cotton soil observed near Nagari village of Thandla area.

2.3 FEATURES OF JOINTS

- **Joint Structures**

The columnar joints are very common in the study area. At few places joints are vertical and inclined. The columnar joints generally show four, five or six phases. The well development columnar joints are present in basalt. The columnar joints are characterized by the development of four, five or six sided prisms, which may intersected by cross joints. The columns develop perpendicular to the cooling surface so that in a sill or lava flow stand vertically in a dyke. They are more or less horizontal. The columnar joints are well developed near villages of Chirwa, Naharpur Chhota, Koriyapara, Juni Borari, Bhamariya, Bhimkund, Dhamni Chhoti and Rajapura villages (Figure 2.10, 2.11, 2.12).

Figure 2.10 Photograph showing pattern of columnar joints in basaltic rock near Koriyapara village in Thandla study area, Jhabua district, Madhya Pradesh.

Figure 2.11 A Photograph exhibiting vertical joints in basaltic lava flow exposed near village of Bhamariya, in Thandla study area.

Figure 2.12 A view of basaltic lava flow weathered and jointed exposure near village of Koriyapara village in Thandla study area.

CHAPTER - 3

GEOMORPHOLOGICAL ANALYSIS

3.1 CONCEPT OF GEOMORPHOLOGY

Study of Geomorphology deals with origin and evolution of topographic features by physical and chemical processes operating at or near earth's surface. The term originates from Greek words *geo* = earth, *morph* = form, and *logos* = discourse, i.e. the study of earth forms. Geomorphology is based on the principle that all landforms are related to a meticulous geologic process, or set of processes, and landforms thus developed may evolve with time through a sequence of forms dependent in part on the relative time and particular process has been operating (Mackin, 1969).

3.2 GEOMORPHOLOGICAL ANALYSIS

Geomorphological analysis involves the measurements and mathematical analysis of landforms of earth surface. Computation of hydrologic parameters of drainage basin provide valuable evidence for determination of trends runoff and ground water condition of the basin. Geomorphological parameters are measured by using conventional methods followed by Horton (1932, 1945); Strahler (1957, 1964); Marisawa (1959); Leopold and Miller (1956); Krishnamurthy *et.al.* (1996); and others. Geomorphological analysis has been classified into two parts: (A) Qualitative, and (B) Quantitative Analysis.

3.2.1 QUALITATIVE ANALYSIS

The qualitative analysis deals with understanding of phenomena, that is based on numerical data. The emphasis is placed on an idea or concept. Qualitative analysis involves relationship between cause and effect and relied on mathematical and experimental data - Hills, River Valley, Plain, plateau, and Soil.

- **Hills**

Hill is a noteworthy feature of landform. Hills are characterized by height and slope. Leopold *et. al.* (1964) described that slopes are part of landscape between the crest of hills and their drainage lines. Slopes are interdependent with stream channels and the geometry of drainage basins (Figure 3.1, 3.5).

Figure 3.1 A view of Hill developed near Khokhar Khandan village of Thandla area, Jhabua district, Madhya Pradesh.

- **River Valley**

River forms a terrain, which is known as a valley. The linear erosion can be observed in gorges. The young valley has a V shape, the mature valley is broader, has a valley bottom, and the valley sides are smoother. In downstream parts, the river flows in a broad, flat valley, as a old valley. The rock can influence cross section of the valley. The valley sides are steep in a permeable hard rock terrain. The river pattern is affected by the material and geological structure (3.2).

Figure 3.2 A view of Padmavati River valley in vicinity of Rundipara village, Thandla study area, Jhabua distruct.

- ## Plain

Plain is formed by action of mechanisms (Figure 3.3, 3.5). As the floors of adjoining cockpits interconnect at their extremities, the level areas join and gradually form a surface (Ahnert, 1998).

Figure 3.3 A view of plain observed at Thandla town, Jhabua district, M. P.

- **Plateau**

Plateau, is generally recognized as tableland which is also called as high plain. Tableland, is an area of highland generally comprised of relatively flat terrain. A high eroded plateau is called as a dissected plateau. A plateau is a structure which is produced by volcanic activity and it is known as flat-topped mountains. They are found on continents around the world almost in most of the countries. In the study area, the plateau is well developed near Madalda village (Figure 3.4, 3.5)**.**

Figure 3.4 A view of Plateau observed near Madalda village, study area, Jhabua .

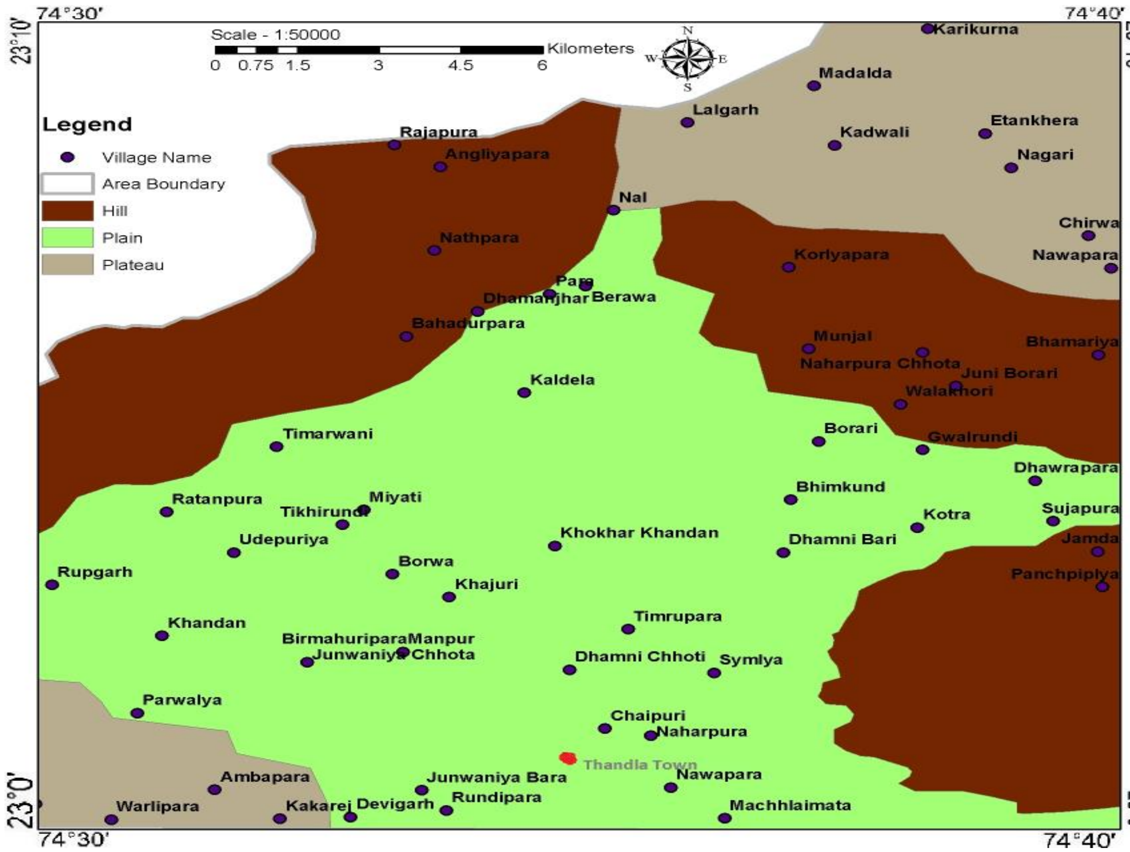


Figure 3.5 A Map showing the configuration of Hill, Plain, and Plateau in Thandla study area, Jhabua district.

• Soil

Soil is a weathered product of rock materials. There is difference of opinion regarding the definition of soil amongst pedologists and geologists. Geomorphologists are concerned with the entire weathered zone-from surface down to unweathered bedrock (Leopold *et. al.*, 1964). Soil is considered as a geological formation of Recent age. The types of soils have been observed in the Thandla study area are- (1) Black cotton soil, (2) Lateritic soil, (3) Red loam and, (4) Alluvial soil.

(1) Black cotton soil

The black cotton soil exhibits black colour and contains clay content, low permeability, high plasticity, moisture and water retaining capacity. This is argillaceous and contains 40 to 60% of clay. It has fine texture and a degree of plasticity becoming sticky. Black cotton soil has been derived from basaltic rocks in the semiarid conditions (Figure 3.6, 3.10).

Figure 3.6 A view of Black cotton soil developed near Khajuri village of Thandla.

(2) Lateritic soil

Lateritic soil covers small area about 14,000 hectors forming about 5 % of the total soil of the area. This type of soil occurs as a thin cop of almost uniform thickness covers the hills formed mainly of quartzites and gneissic ridges (Figure 3.7, 3.10).

Figure3.7 A view of Lateritic soil developed near Ratanpura village in Thandla area.

(3) Red soil

The red soil is also known as red loam. This is characterized by the coarse texture and is poorly sorted. The clay content is reported to be less than 30 %. The soils are found around Thandla occupying the valleys underlain by the gneiss, quartzites and phyllites. This soil is observed at several places in the study area (Figure 3.8, 3.10).

Figure 3.8 A view of Red soil developed near Bhamariya village in Thandla area.

(4) Alluvial soil

Alluvial soil is seen along the banks of rivers and their tributaries. It is mostly pale yellow to grey in colour (Figure 3.9, 3.10).

Figure 3.9 A view of Alluvial soil developed near Khajuri village in Thandla area.

Alluvial soil is a key group of soils and includes such soils, which have been spread out by streams along banks in catchment area. These are made of fine material and stratified. Due to their heterogeneous composition, fine size and negligible leaching, these soils are very fertile (Singh, 2008).

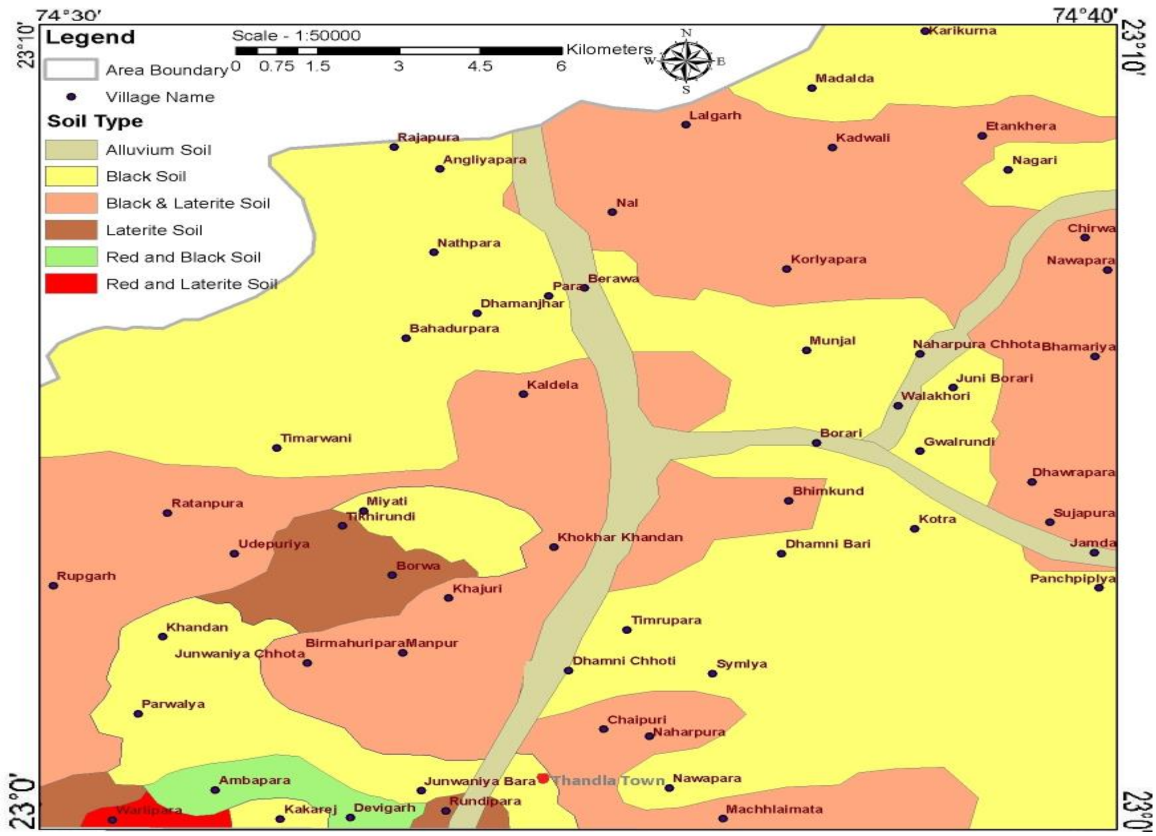


Figure 3.10 A Photograph exhibiting relationship of different types of soils in Thandla study area, Jhabua district.

3.2.2 QUANTITATIVE ANALYSIS

Methodology of quantitative morphometric analysis of a drainage basin has been proposed by Horton (1945), Strahler (1952) and others. Quantitative analysis of a drainage basin deals with the measurements of linear, areal and relief features. Determination of morphometric parameters is conducted to delineate shape extent and channel network of the basin. The term morphometric is derived from the word "Morph"= form and "Metric" = number system.

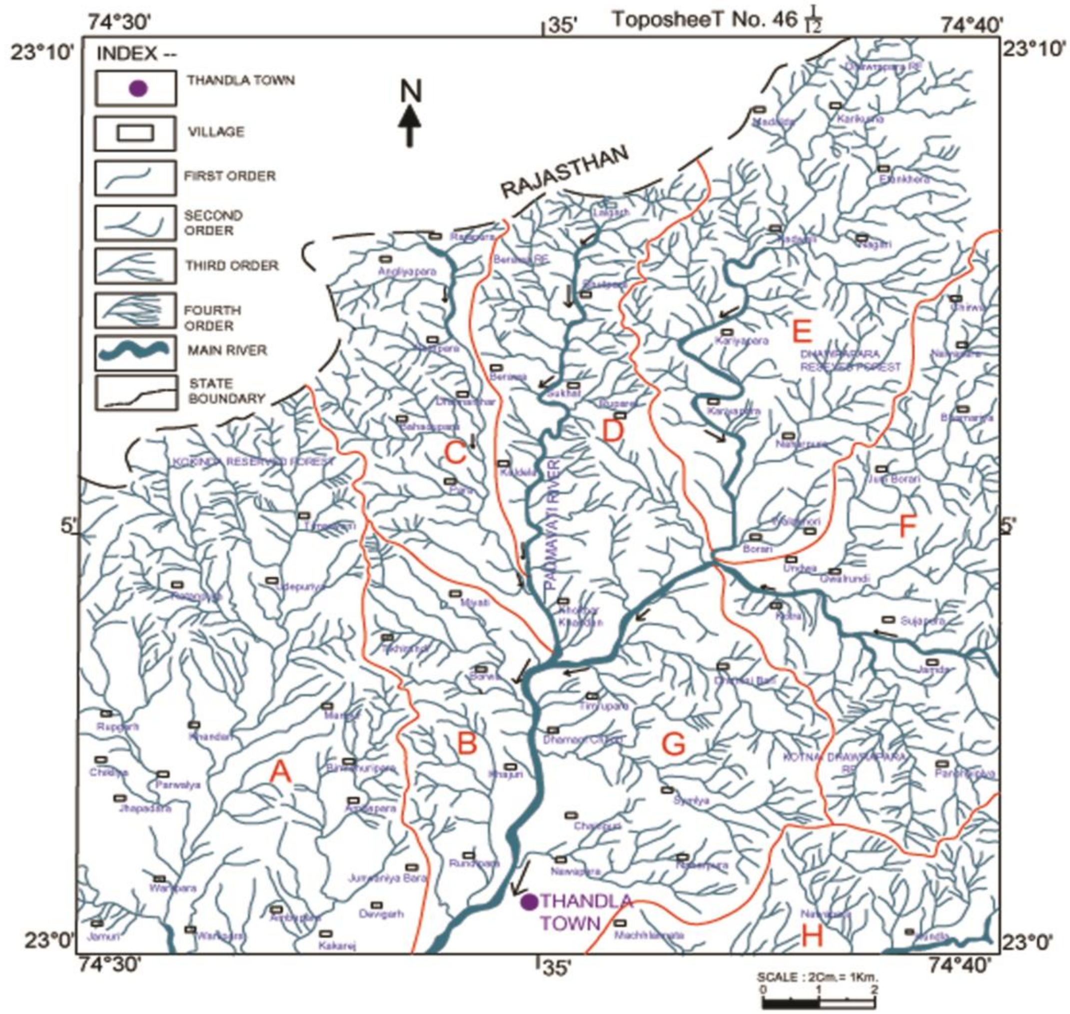


Figure 3.11 Drainage pattern of Thandla study area, Jhabua district, M. P.

Morphometric analysis, is carried out on a drainage map counting of the order of streams, measurement of the catchments area, length and perimeter of the channels, bifurcation ratio, circulatory ratio, drainage density, drainage texture, drainage pattern, basin shape, sub-soil material, infiltration and relief characteristics of drainage basin. Morphometric analysis of the study area has been conducted by preparing a drainage map of the area on a scale of 1: 50,000. Morphometric parameters (order and number of different streams, the length, width and area of the basin) have been measured and displayed in Table 3.1 to depict the nature of study drainage basin. The study drainage basin extents over an area of 366.58 sq. km. The river basin has been classified into 8 sub-basins designated as sub-basin A, B, C, D, E, F, G and H (Figure 3.11) on the basis of trend of streams.

Table 3.1 Morphometric parameters of the drainage sub- basins in Thandla area, Jhabua district, Madhya Pradesh.

Morphometric parameters	Drainage sub-basins of Thandla study area, Jhabua district, M. P.							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Number of 1st order streams	238	63	98	162	223	197	118	68
Number of 2nd order streams	55	10	18	41	57	48	30	17
Number of 3rd order streams	14	4	7	10	12	11	9	5
Number of 4th order streams	3	1	2	1	4	3	3	1
Number of 5th order streams	1	0	1	0	1	1	0	0
Total number of streams	**311**	**78**	**126**	**214**	**297**	**260**	**160**	**91**
Length of 1st order streams (km.)	201	51	70	107	169	136	92	54
Length of 2nd order streams (km.)	77	23	25	41	60	47	36	18
Length of 3rd order streams (km.)	38	10	18	19	31	24	16	8
Length of 4th order streams (km.)	15	5	10	1	14	10	14	3
Length of 5th order streams (km.)	14	0	6	0	1	10	0	0
Total length of streams (km.)	**345**	**89**	**129**	**168**	**275**	**227**	**158**	**83**
Length of the sub-basin (km.)	11.35	7.9	9.25	9.5	11.7	5.25	6.35	2.65
With of the sub- basin (km.)	6.25	2.75	3.3	3.6	5.6	12.7	9	7.5
Area of the sub-basin (sq.km.)	**70.93**	**21.72**	**30.52**	**34.2**	**65.52**	**66.67**	**57.15**	**19.87**
Perimeter of the sub-basin (km.)	66	41	46	51	58	60	50	39
Highest elevation within the sub-basin (m.)	400	340	400	365	416	406	332	346
Lowest elevation within the sub-basin (m.)	280	300	330	334	335	322	300	344
Area of circle with the same perimeter as of basin (sq. km.)	66	41	46	51	58	60	50	39

(A) LINEAR ASPECTS OF THE BASIN

Linear aspects of the basin namely (a) Stream order /number, (c) Stream length, and (d) Bifurcation ratio have been described.

(a) Stream order / Stream number

The first order streams are those which have no tributaries, when two first order streams meet they form the second order and similarly the third order stream is formed by joining of two second order streams. The streams of area under investigation have been numbered in a similar manner (Table 3.1). The study area is characterized by streams ranging from first to fifth order.

(b) Stream length

Stream length has been measured with the help of Rotometer. All identified streams are categorized to their respective orders and all the segments of orders are connected to yield number of the stream of each order in the basin. Length of the stream is indicative of the contributing area of the basin of that order (Table 3.1).

(d) Bifurcation ratio (Rb)

The bifurcation ratio is related to the branching pattern of the drainage network, and has been defined as "a ratio of the number of streams of a given order (Nu) to the number of streams of the next higher order (Nu+1)". It is expressed by the following equation:

Rb = Nu / Nu+1, where, Rb = Bifurcation ratio, Nu = Number of streams of a given order, and Nu+1= Number of streams of the next higher order.

Table 3.2 Bifurcation ratio of sub-basin of study area, Jhabua district, M.P.

Sub-basin	Stream Order	Stream Number	Bifurcation Ratio
A	1	238/55	4.32
	2	55/14	3.92
	3	14/3	4.66
	4	3/1	3
	5	1/0	1
B	1	63/10	6.3
	2	10/4	2.5
	3	4/1	4
	4	1/0	1
C	1	98/18	5.44
	2	18/7	2.57
	3	7/2	3.5
	4	2/1	2
	5	1/0	1
D	1	162/41	3.95
	2	41/10	4.1
	3	10/1	10
	4	1/0	1
E	1	223/57	3.91
	2	57/12	4.75
	3	12/4	3
	4	4/1	4
	5	1/0	1
F	1	197/48	4.10
	2	48/11	4.36
	3	11/3	3.66
	4	3/1	3
	5	1/0	1
G	1	118/30	3.93
	2	30/9	3.33
	3	9/3	3
	4	3/0	3
H	1	68/17	4
	2	17/5	3.4
	3	5/1	5
	4	1/0	1

Bifurcation ratio of drainage basin range from 1 (sub-basins A to F,   H) the sub-basin G indicates bifurcation ratio 10. The bifurcation ratio a large number of studies suggest that trends to be constant for a particular basin and for drainage basins having a uniform climate, lithology, and stages of development. The impacts of geological structures are rather insignificant (Table 3.2).

(B) AREAL ASPECTS OF THE BASIN

Areal aspects of Thandla drainage basin, such as: (a) Drainage density (Dd), (b) Stream frequency (Fs), (c) Form factor (Ff), (d) Circularity ratio (Cr), (e) Elongation ratio (Re), (f) Lemniscates ratio (K), and (g) Length of overland flow (Lg) have been described in the text herein.

(a) Drainage density (Dd)

Drainage density has been defined by Horton (1945) as "the ratio of total length of all stream segments in a given drainage basin to the total area". It is expressed by the formula: **Dd = L / A,** where, Dd = Drainage density, L = Total length of all stream segments of a basin, A = Total area of the basin.

Table 3.3 Drainage density of Thandla study area, Jhabua district, M.P.

Sub-basin	Area of basin (sq.km)	Total length of stream (km.)	Drainage density (1/km.)
A	70.93	345	4.86
B	21.72	89	4.09
C	30.52	129	4.22
D	34.2	168	4.91
E	65.52	275	4.19
F	66.67	227	3.40
G	57.15	158	2.76
H	19.87	83	4.17
			Average = 4.075

The drainage density ranges from 2.76 (sub-basin G) to 4.91(sub-basin D) 1/km with an average of 4.075 1/km. The low value of drainage density is indicative of occurrence of hard resistant rock formation (Table 3.3).

(b) Stream frequency (Fs)

Horton (1932) used the terms stream frequency as "the ratio of the total number of stream segments of all orders per unit area". It is represented is expressed by the formula:

Fs = Nu / A, where, Fs = Stream frequency, Nu = Total number of streams, A = Area of sub-basin in sq.km.

Table 3.4 Stream frequency of sub-basin of Thandla area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km)	Number of stream	Stream frequency ($1/km^2$)
A	70.93	310	4.370
B	21.72	78	3.591
C	30.52	126	4.128
D	34.2	214	6.257
E	65.52	297	4.532
F	66.67	260	3.899
G	57.15	160	2.799
H	19.87	91	4.579
			Average = 4.269

The stream frequency of the study area various from 2.799 (sub-basin G) to 6.257 (sub-basin D) $1/km^2$ indicating a moderate development of streams. The average stream frequency is 4.269 $1/km^2$ (Table 3.4).

(c) Form factor (Ff)

Horton (1932) proposed the form factor as "the ratio between the basin area and square of the basin length". The form factor is determined by the formula:

$Ff = A / L^2$, where, Ff = Form factor, A = Basin area, L = Basin length.

Table 3.5 Form factor of sub-basins study area, Jhabua district, M.P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Form factor
A	70.93	11.35	0.550
B	21.72	7.9	0.348
C	30.52	9.25	0.356
D	34.2	9.5	0.378
E	65.52	11.7	0.478
F	66.67	5.25	2.418
G	57.15	6.35	1.417
H	19.87	2.65	2.829
			Average = 1.096

The form factor of the study area various from 0.348 (sub-basin B) to 2.829 (sub-basin H) with an average value of 1.096. The low average value indicates that the drainage basin is circular in shape (Table 3.5).

(d) Circularity ratio (Cr)

Circularity ratio has been defined by Miller (1953) as "the circularity ratio of basin area with area of the circle with same perimeter as the basin." It is denoted by the formula:

Cr = Ab / Ac, where, Cr = Circularity ratio, Ab = Area of the basin, Ac = Area of the circle with same perimeter as the basin.

Table 3.6 Circularity ratio of sub-basins study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Perimeter of basin (km.^{2})	Area of circle with same perimeter (km.^{2})	Circularity ratio
A	70.93	66	66	1.074
B	21.72	41	41	0.529
C	30.52	46	46	0.663
D	34.2	51	51	0.670
E	65.52	58	58	1.129
F	66.67	60	60	1.111
G	57.15	50	50	1.143
H	19.87	39	39	0.509
				Average = 0.853

The circularity ratio for the present drainage basin under investigation has been calculated to be ranging in between 0.509 (sub-basin H) to 1.143 (sub-basin G) with an average value of 0.853 indicating that the study area is comprised of a homogenous group of rocks with moderate slope (Table 3.6).

(e) Elongation ratio (Re)

Schumm (1956) proposed the term elongation ratio as "the ratio of diameter of a circle of the same area as the basin to the maximum basin length." It can be represented by the expression: **Re =**$\sqrt{4A/\pi}$**) L^2,** where, Re = Elongation ratio, A = Area of sub-basin in sq. km, L = Length of basin in km.

Table 3.7 Elongation ratio of drainage basins study area, Jhabua district, M.P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Elongation ratio
A	70.93	11.35	107.808
B	21.72	7.9	41.554
C	30.52	9.25	57.675
D	34.2	9.5	62.704
E	65.52	11.7	106.889
F	66.67	5.25	48.381
G	57.15	6.35	54.140
H	19.87	2.65	13.331
			Average = 61.324

The elongation ratio of the study drainage basin ranges from 13.331 (sub-basin H) to 107.808 (sub-basin A) with an average value of 61.324 indicates that the drainage basin in nearly circular in shape (Table 3.7).

(f) Lemniscates ratio (K)

Chorley (1957) suggested the term lemniscates ratio, which is based upon comparison of basin with lemniscates curves. It is expressed by the following expression: $\mathbf{K = L^2 / 4A}$**,** where, K = Lemniscates ratio, L = Length of basin in km, A = Area of the sub-basin in sq. km.

Table 3.8 Lemniscates values of sub-basins of study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Lemniscates
A	70.93	11.35	0.454
B	21.72	7.9	0.718
C	30.52	9.25	0.700
D	34.2	9.5	0.659
E	65.52	11.7	0.522
F	66.67	5.25	0.103
G	57.15	6.35	0.176
H	19.87	2.65	0.069
			Average = 0.425

The lemniscates ratio of the study area various from 0.069 (sub-basin H) to 0.718 (sub-basin B) with an average value of 0.425. The determined values of lemniscates ratio points out that the travel distance of water to ground water system is less (Table 3.8).

(g) Length of overland flow (Lg)

Length of overland flow has been defined by Horton (1945) as "it is approximately equal to the half of the drainage density". It can be expressed as: **Lg = 1 /2 Dd,** where, Lg = Length of overland flow, Dd = Drainage density.

Table 3.9 Length of overland flow of study area, Jhabua district, M.P.

Sub-basin	Drainage density (1/km.)	Length of overland flow (km.)
A	4.86	0.102
B	4.09	0.122
C	4.22	0.118

D	4.91	0.101
E	4.19	0.119
F	3.40	0.147
G	2.76	0.181
H	4.17	0.119
		Average = 0.126

In the study area, the length of overland flow ranges from 0.101 (sub-basin D) to 0.181(sub-basin G) km with an average value of 0.126 suggesting that the water covers rather a small distance before entering in to the drainage pattern (Table 3.9).

(C) RELIEF ASPECTS OF THE BASIN

The evaluation of following parameters of Thandla drainage basin have been conducted: (a) Basin relief (Br), (b) Relief ratio (RH), (c) Ruggedness number (Rn), and (d) Ground surface slope (Gs).

(a) Basin relief (Br)

The Strahler (1952) defined basin relief as a difference between highest and lowest point in a basin. It is expressed by formula: **Br = H1 - H2,** where, Br = Basin relief,

H1 = Highest elevation, H2 = Lowest elevation.

Table 3.10 Basin relief of sub-basins Thandla study area, Jhabua district, M.P.

Sub-basin	Highest elevation (m.)	Lowest elevation (m.)	Basin relief (m.)
A	400	280	120
B	340	300	40
C	400	330	70
D	365	334	31
E	416	335	81

F	406	322	84
G	332	300	32
H	346	344	2
			Average = 57.5

Basin relief of the study drainage basin varies from 2 (sub-basin H) to 120 (sub-basin A) m with an average value of 57.5 m indicating the presence of the flat to higher elevated terrain topography (Table 3.10).

(b) Relief ratio (RH)

Relief ratio has been proposed by Schumm (1956) as ratio between the horizontal distance along longest dimension of a basin, dendritic to the principal drainage line and maximum basin relief. It is represented by expression: **RH = H / L,** where, RH = Relief ratio, H = Maximum basin relief, L = Horizontal distance along longest dimension of basin.

Table 3.11 Relief ratio of sub-basin of Thandla study area, Jhabua district, M.P.

Sub-basin	Basin relief (m.)	Horizontal distance (m.)	Relief ratio
A	120	11.35	10.572
B	40	7.9	5.063
C	70	9.25	7.567
D	31	9.5	3.263
E	81	11.7	6.923
F	84	5.25	16
G	32	6.35	5.039
H	2	2.65	0.754
			Average = 6.897

Relief ratio for different sub-basin of study area have been calculated as ranging from 0.754 (sub-basin H) to 16 (sub-basin F) with an average value of 6.897 which is suggestive of the low slope. Hence, it can be visualized that the rate of rather eroded and low relief ratio is indicative of plain area of the drainage basin (Table 3.11).

(c) Ruggedness number (Rn)

Ruggedness number has been defined by Strahler (1964) as product of basin relief and drainage density. It is expressed by the formula: **Rn = Br** × **Dd,** where, Rn = Ruggedness number, Br = Basin relief, Dd = Drainage density.

Table 3.12 Ruggedness number of sub-basins of study area, Jhabua district, M.P.

Sub-basin	Basin relief		Drainage density (1/km.)	Ruggedness number
	(m.)	km.		
A	120	0.12	4.86	0.583
B	40	0.04	4.09	0.163
C	70	0.07	4.22	0.295
D	31	0.031	4.91	0.152
E	81	0.081	4.19	0.339
F	84	0.084	3.40	0.285
G	32	0.032	2.76	0.088
H	2	0.002	4.17	0.008
				Average = 0.239

The ruggedness numbers of different sub-basin range from 0.008 (sub-basin H) to 0.583 (sub-basin A) with an average value of 0.239 it indicates that the basin has the flat topography where as other basins demonstrate uneven topography (Table 3.12).

(d) Ground surface slope (Gs)

Horton (1945) proposed the term ground surface slope, which is represented by "H" and "Dd" by the following equation: **Gs = H** × **2 Dd,** where, Gs = Slope of ground surface, H = Basin relief, Dd = Drainage density.

Table 3.13 Ground surface slope of drainage basin of the study area, Jhabua.

Sub-basin	Basin relief		Drainage density (1/km)	Slope of ground surface
	(m.)	km.		
A	120	0.12	4.86	1.166
B	40	0.04	4.09	0.327
C	70	0.07	4.22	0.590
D	31	0.031	4.91	0.304
E	81	0.081	4.19	0.678
F	84	0.084	3.40	0.571
G	32	0.032	2.76	0.176
H	2	0.002	4.17	0.016
				Average = 0.478

In study area, the values of ground surface slope indicate a range from 0.016 (sub-basin H) to 1.166 (sub-basin A) with an average of 0.478 indicating that the slope of ground surface is maximum in sub-basin "A" (Table 3.13).

3.3 RELATIONSHIP OF MORPHOMETRIC PARAMETERS

The relationship between different morphometric parameters determined in respect of Thandla drainage basin. The relationship between morphometric parameters such as stream number and stream order exhibits that with the increase of order. The number of stream decreases and shown with other parameters have been determined and described here in the following text:

(1) Relationship between total number of streams and total length of streams

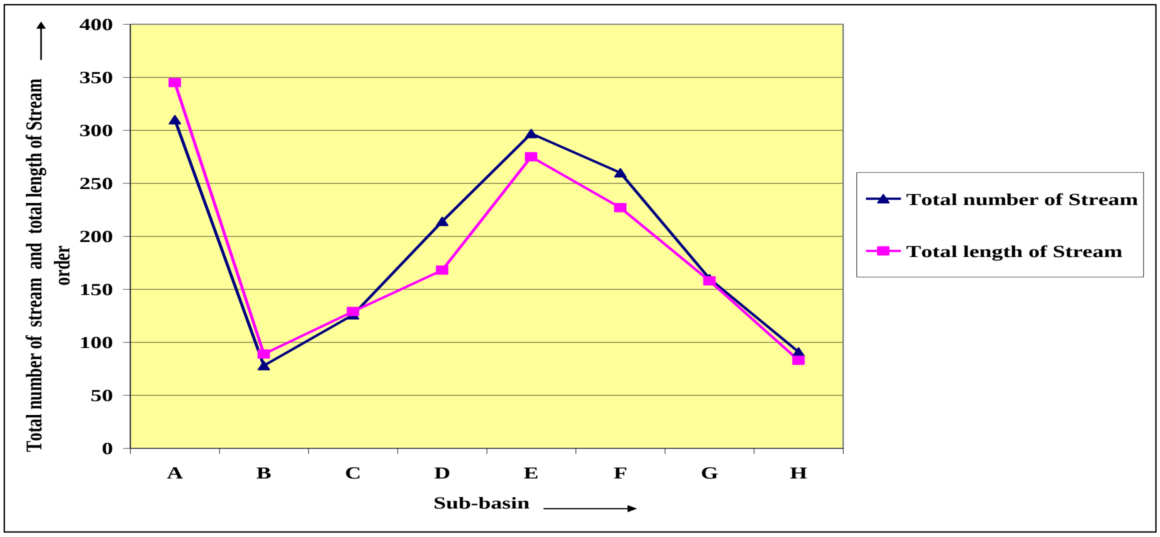


Figure 3.12 Relationship between total number of streams and total length of streams in study area, Jhabua district, M.P.

The relationship points out that with the increase of total number of streams also the total length of streams increases (Figure 3.12).

(2) Relationship between total length of streams and area of the sub-basins

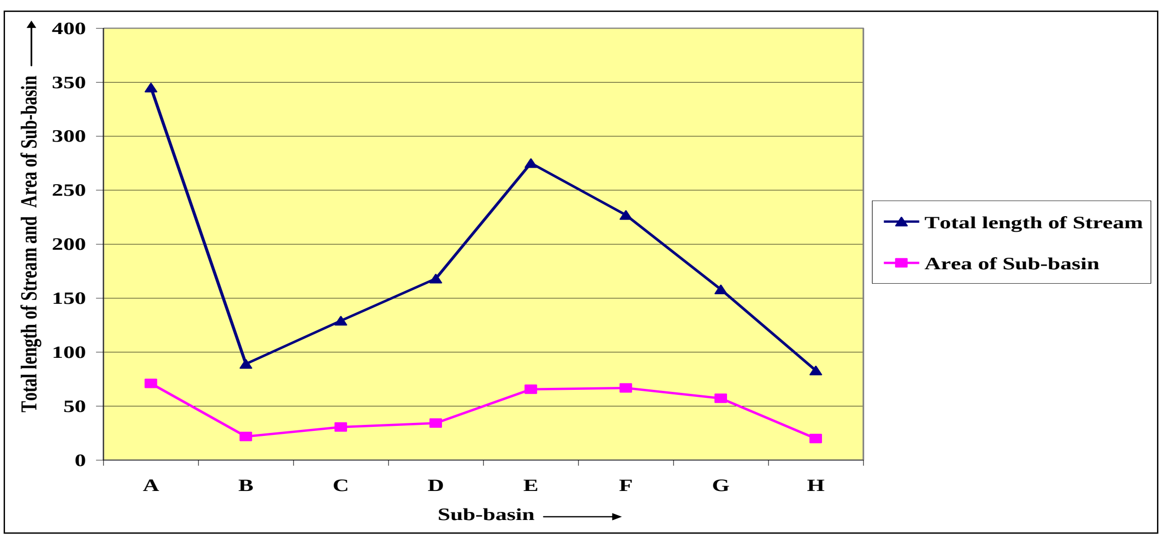


Figure 3.13 Relationship between total length of streams and area of the sub-basins in study area, Jhabua district, M.P.

The relationship reflects that with the increase of total length of streams, area of the sub-basins increases (Figure 3.13).

(3) Relationship between drainage density and stream frequency

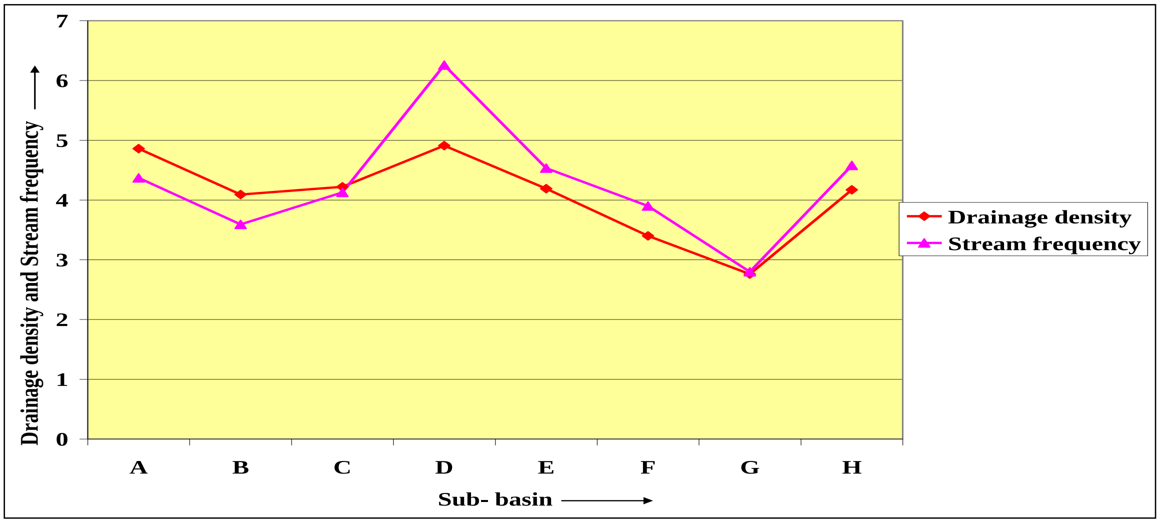


Figure 3.14 Relationship between drainage density and stream frequency in study area, Jhabua district, M.P.

The relationship exhibits that with the increase of drainage density, stream frequency also increases (Figure 3.14).

(4) Relationship between form factor and circularity ratio

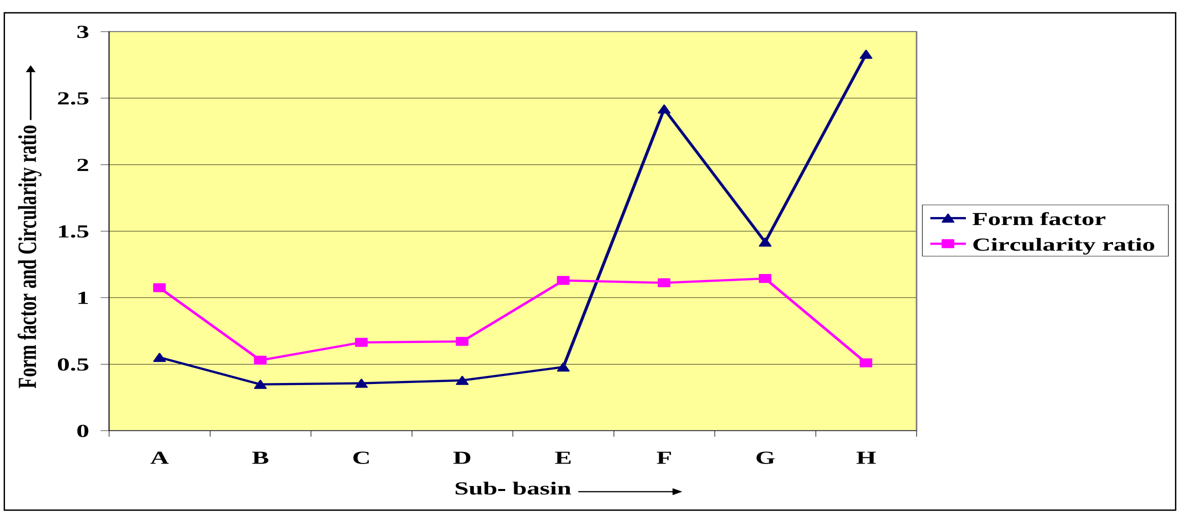


Figure 3.15 Relationship between form factor and circularity ratio in study area.

The relationship reflects the with the increase of form factor in majority of sub-basins the circularity ratio also increases (Figure 3.15).

(5) Relationship between ruggedness number and ground surface slope

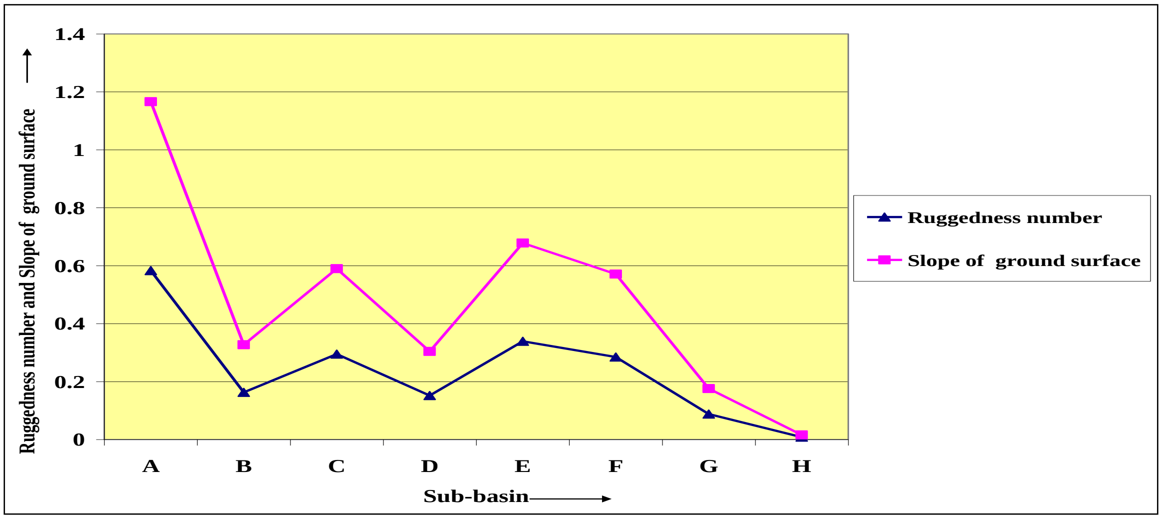


Figure 3.16 Relationship between ruggedness number and ground surface slope in study area, Jhabua district, M.P.

The relationship indicates that with increases of ruggedness number, ground surface slope also increases (Figure 3.16).

(6) Relationship between form factor and lemniscates ratio

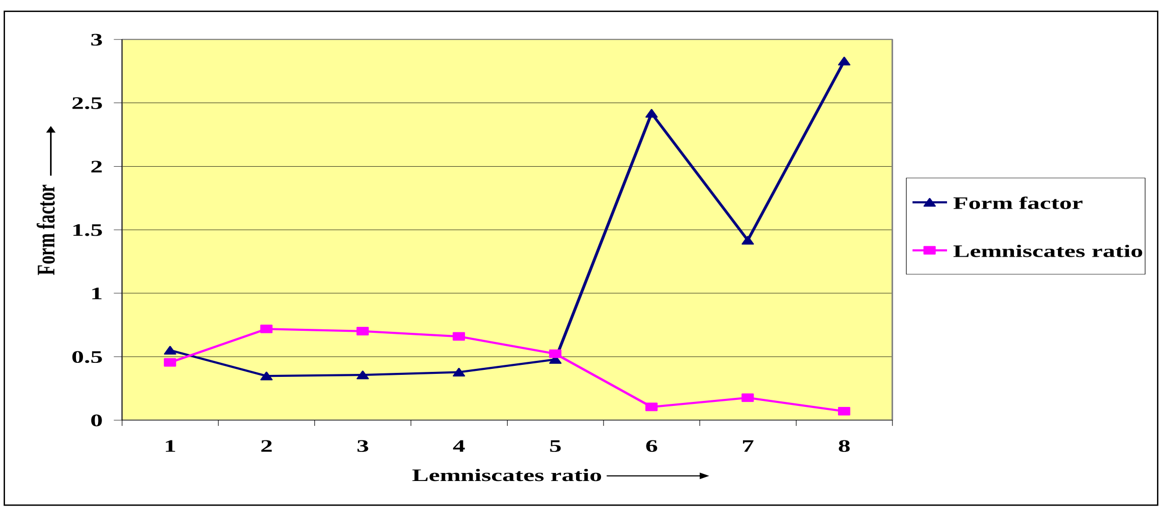


Figure 3.17 Relationship between form factor and lemniscates ratio in study area.

Within the sub-basins A to E, with the lemniscates ratio increase of the form factor decreases. Whereas from sub-basin E to H, increase of form factor the lemniscates ratio decreases (Figure 3.17).

3.4 HYPSOMETRIC ANALYSIS

Hypsometric analysis of Thandla study area has been prepared by adopting procedure given by Strahler (1957, 1964). Hypsometric analysis has been elaborated as the relation of horizontal cross sectional area of drainage basin to its elevation. Following the drainage basin to be bounded by vertical sides and horizontal base plane passing through mouth, the relative height "Y" is ratio of height of a given contour "h" to total basin height "H". Ralative area "X" is the ratio of horizontal cross-sectional area "a" to the entire basin area, "A" (Table 3.14).

Table 3.14 Computed parameters of drainage basin, study area, Jhabua district.

S. No.	Sub-Basin	Lowest Elevation (h) (m.)	Highest Elevation (H) (m.)	Y = h/H (Relative Height)	Basin Area (a) (sq. km.)	X = a/A (Relative Area)
1	**A**	280	400	0.7	70.93	0.19
2	**B**	300	340	0.88	21.72	0.05
3	**C**	330	400	0.82	30.52	0.08
4	**D**	334	365	0.91	34.2	0.09
5	**E**	335	416	0.80	65.52	0.17
6	**F**	322	406	0.79	66.67	0.18
7	**G**	300	332	0.90	57.15	0.15
8	**H**	344	346	0.99	19.87	0.05
				A = Total Area = 366.58 sq. km.		

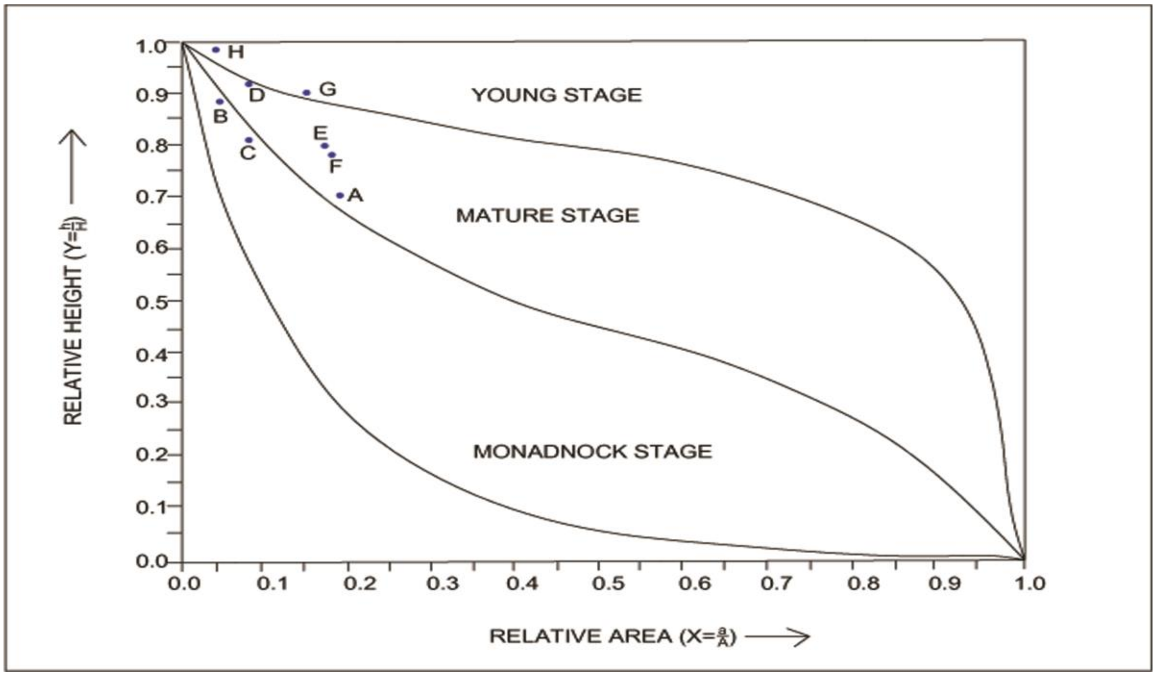


Figure 3.18 Hypsometric curve Padmavati River basin of study area, Jhabua.

Hypsometric curve of the drainage basin study area reveals that the sub-basin A, B, C, D, E, F, G, and H (Figure 3.18). Plots of Sub-basins G and H indicates their locations in the Young stage, A, D, E and F belong to the Mature stage, and plots of B and C refer to the Monadnock stage. The hypsometric analysis exhibits that the major part of the Padmavati River drainage basin in Thandla area of Jhabua district, Madhya Pradesh is representing young stage of development approaching towards maturity.

CHAPTER – 4

RAINFALL DATA ANALYSIS

4.1 CONCEPT OF RAINFALL

Rainfall is a normally recognized term for the precipitation that is one of the noteworthy hdrometeorological parameter, which plays a significant role in the recharge of ground water system. Usually liquid form of precipitation is generally identified as rainwater or rainfall, which acts as a key source for the recharge of ground water system of a particular basin or an area. According to Wiesner (1970), rainfall is a term used for precipitation for depositing of water from the atmosphere on to surface. The deposit may be either liquid or solid to provide the different forms of precipitation. In India, rainfall mostly occurs during the monsoon period. Generally, rainfall amount is measured by using rain gauge. The recorded values of rainfall are expressed in inch, mm or cm. The rainfall records indicate a wide range of variation in the amounts and frequencies from place to place. The duration and frequency of rainfall help in determination of surface runoff for ground water recharge. Measured rainfall data also helps in the estimation of water balance of a basin.

4.2 ANALYSIS OF RAINFALL DATA

Thandla rainfall records of 25 years (1992 to 2016) have been collected from the Jhabua District Office. Rainfall data have been treated to both mathematical and statistical techniques. Environmental impacts of rainfall factor on the recharge of ground water system have been visualized and discussed herein the text.

4.2.1 MATHEMATICAL ANALYSIS

Mathematical analysis is in general, employed for the rainfall data analysis. The procedure involves computation of annual rainfall data for determining the average for period of specific month or years as arithmetic mean. Determined values are expressed in incs, mm or cm (Table 4.1, 4.2). The variation in rainfall is indicated by a stable mean. Calculations of arithmetic mean, monthly average, annual rainfall, monthly cumulative average, departure from average rainfall, and cumulative departure from average rainfall of study area have been computed and illustrated (Figure 4.1 to 4.5).

Rainfall data of Thandla area exhibit a variation range from 423.0 mm to 2086.2 mm. Minimum rainfalls of 423.0 mm has been recorded during year 2000, and maximum rainfall of 2086.2 mm has been observed during year 1997. The mathematical analysis indicates annual average rainfall value of 964.324 mm.

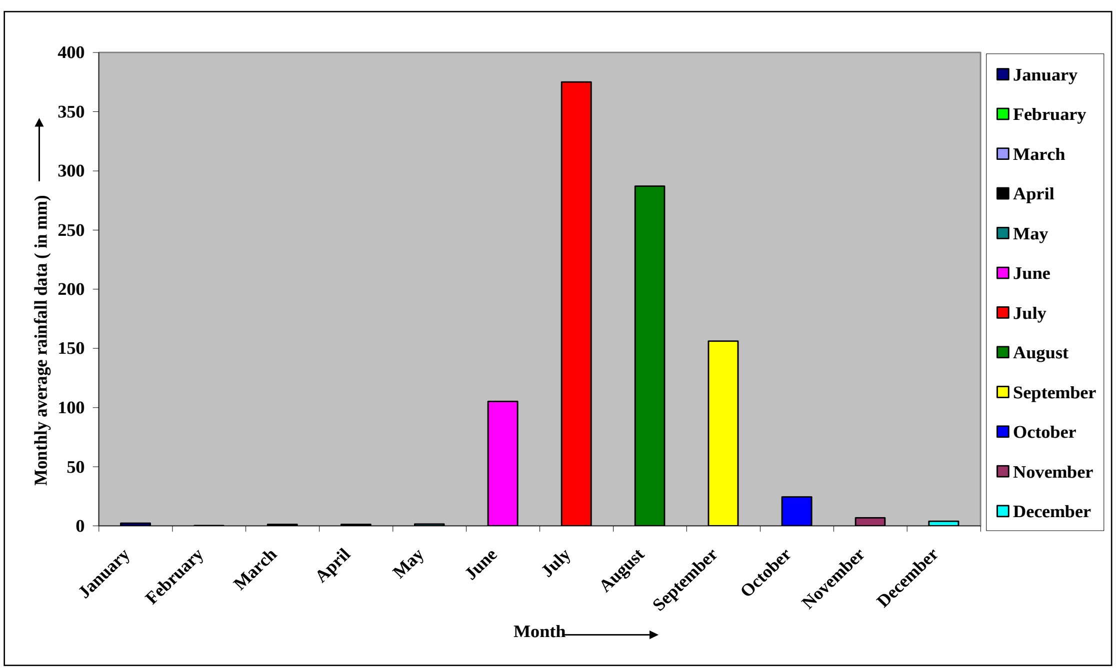


Figure 4.1 Monthly average rainfall data of Thandla area, Jhabua district, M.P.

Table 4.1 Rainfall data for a period of 1992-2016 in respect of Thandla area, Jhabua district, Madhya Pradesh.

S. No.	Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Octo.	Nov.	Dec.	Annual Total
1.	1992	-	-	-	-	11.0	40.7	83.3	279.6	149.0	82.6	28.4	-	674.6
2.	1993	-	-	8.0	-	26.2	48.2	731.6	232.6	95.4	15.0	-	-	1157.0
3.	1994	18.4	-	-	9.4	-	314.8	483.0	500.8	357.0	-	23.0	-	1706.4
4.	1995	36.6	-	2.8	-	-	30.0	377.8	152.8	96.6	12.4	-	-	709.0
5.	1996	-	-	-	-	-	47.2	503.4	441.2	244.6	49.4	-	-	1285.8
6.	1997	-	-	-	-	-	94.8	1456.0	306.4	116.8	22.0	-	90.2	2086.2
7.	1998	-	-	-	-	-	132.6	288.6	144.6	304.4	109.8	4.8	-	984.8
8.	1999	-	5.0	-	-	-	82.0	129.8	23.8	122.8	82.3	-	-	445.7
9.	2000	-	-	-	-	-	110.0	141.0	166.0	6.0	-	-	-	423.0
10.	2001	-	-	-	-	-	193.6	191.4	201.0	-	55.2	-	-	641.2
11.	2002	-	-	-	-	-	206.0	69.0	155.5	156.4	-	-	-	586.9
12.	2003	-	-	-	-	-	214.0	447.0	247.7	185.3	-	-	-	1094.0
13.	2004	-	-	-	-	-	163.0	247.0	540.8	94.0	25.0	-	-	1069.8
14.	2005	-	-	-	-	-	59.0	422.0	64.0	217.0	-	-	-	762.0
15.	2006	-	-	-	-	-	192.0	374.0	710.2	269.8	-	-	-	1546.0
16.	2007	-	-	-	-	-	76.6	552.4	508.2	163.8	-	-	-	1301.0

17.	2008	-	-	-	-	-	65.0	93.0	199.4	104.4	4.0	-	4.6	470.4
18.	2009	-	-	-	-	-	30.2	359.3	102.8	-	32.8	6.0	-	531.1
19.	2010	-	-	-	-	-	77.2	183.4	278.8	116.8	5.2	107.2	-	768.6
20.	2011	-	-	-	-	-	29.8	410.1	452.1	247.6	-	-	-	1139.6
21.	2012	-	-	-	-	-	3.0	320.9	401.8	388.0	-	-	-	1113.7
22.	2013	-	-	-	-	-	208.2	532.2	284.4	146.2	8.0	-	-	1179.0
23.	2014	-	-	20.0	19.1	-	-	314.0	218.2	142.0	22.4	-	-	735.7
24.	2015	-	-	-	-	-	167.1	452.5	49.0	20.4	18.4	-	-	707.4
25.	2016	-	-	-	-	-	41.3	213.8	512.2	157.7	64.2	-	-	989.2
Monthly Total		**55.0**	**5.0**	**30.8**	**28.5**	**37.2**	**2626.3**	**9376.5**	**7173.9**	**3902.0**	**608.7**	**169.4**	**94.8**	**24108.1**
Monthly Average		**2.2**	**0.2**	**1.232**	**1.14**	**1.488**	**105.052**	**375.06**	**286.956**	**156.08**	**24.348**	**6.776**	**3.792**	**964.324**
Cumulative Average		**2.2**	**2.4**	**3.632**	**4.772**	**6.26**	**111.312**	**486.372**	**773.328**	**929.408**	**953.756**	**960.532**	**964.324**	**-**
Average Rainfall = 964.324 mm.														

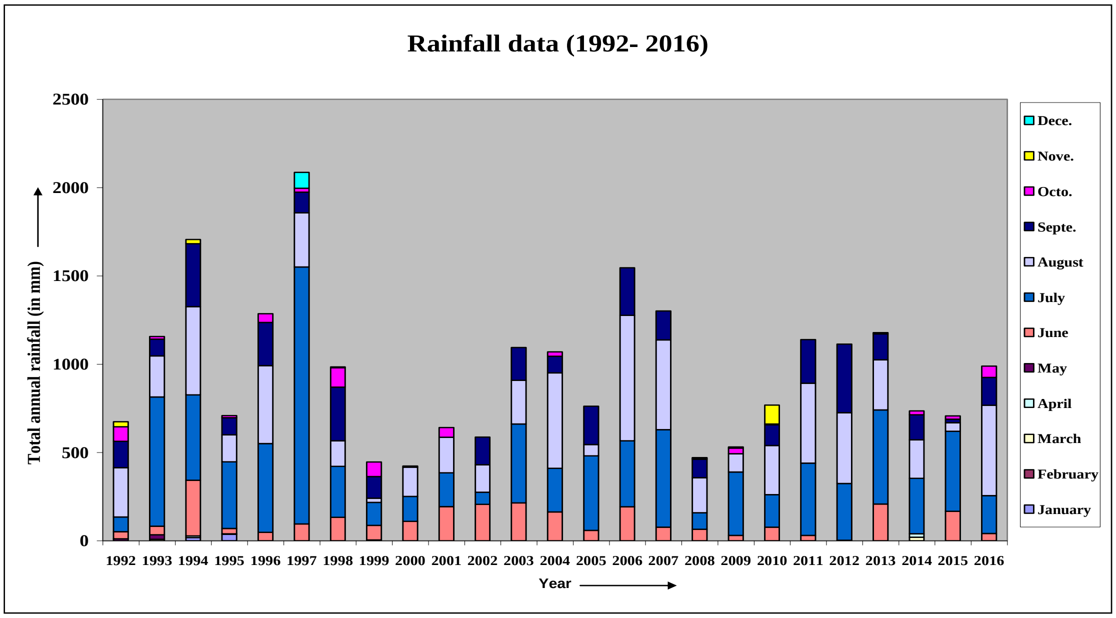


Figure 4.2 Total annual rainfall data (1992-2016) of study area, Jhabua district.

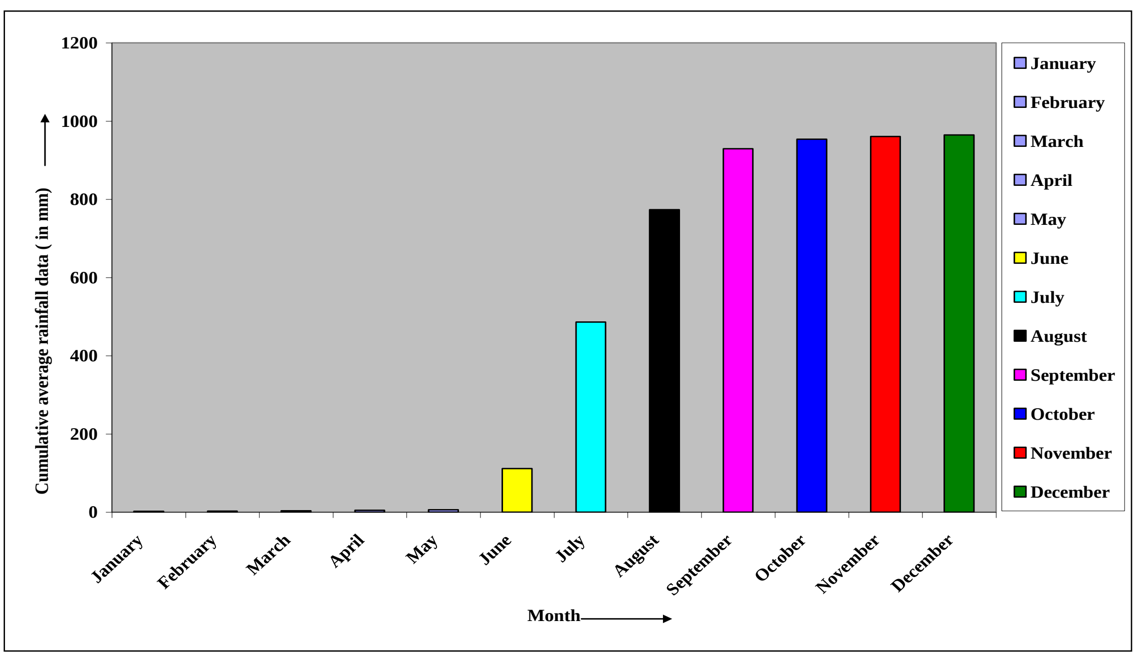


Figure 4.3 Cumulative average rainfall data of Thandla area, Jhabua district, M.P.

Table 4.2 Departure and Cumulative departure from average rainfall in Thandla area, Jhabua district, Madhya Pradesh.

S. No.	Year	Total Annual Rainfall (mm.)	Departure from Average Rainfall (mm.)	Cumulative Departure from Average Rainfall (mm.)
1.	1992	674.6	- 289.724	- 289.724
2.	1993	1157.0	192.676	- 97.048
3.	1994	1706.4	742.076	645.028
4.	1995	709.0	- 255.324	389.704
5.	1996	1285.8	321.476	711.18
6.	1997	2086.2	1121.876	1833.056
7.	1998	984.8	20.476	1853.532
8.	1999	445.7	- 518.624	1334.908
9.	2000	423.0	- 541.324	793.584
10.	2001	641.2	- 323.124	470.46
11.	2002	586.9	- 377.424	93.036
12.	2003	1094.0	129.676	222.712
13.	2004	1069.8	105.476	328.188
14.	2005	762.0	- 202.324	125.864
15.	2006	1546.0	581.676	707.54
16.	2007	1301.0	336.676	1044.216
17.	2008	470.4	- 493.924	550.292
18.	2009	531.1	- 433.224	117.068
19.	2010	768.6	- 195.724	- 78.656
20.	2011	1139.6	175.276	96.62
21.	2012	1113.7	149.376	245.996
22.	2013	1179.0	214.676	460.672
23.	2014	735.7	- 228.624	232.048
24.	2015	707.4	- 256.924	- 24.876
25.	2016	989.2	24.876	0

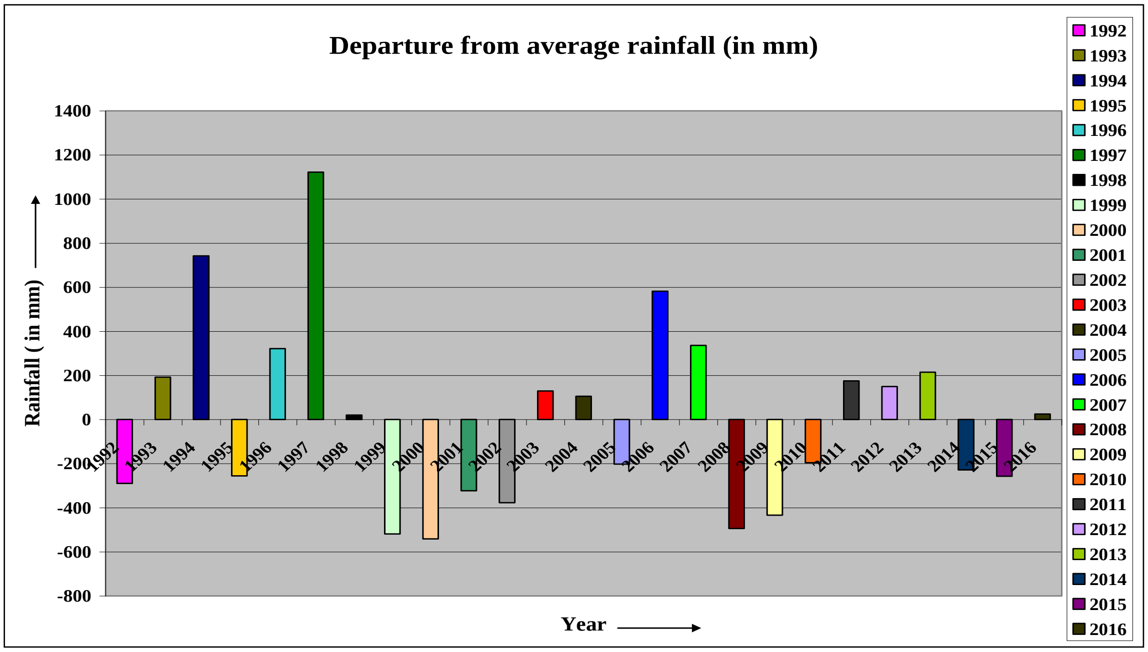


Figure 4.4 Departure from average annual rainfall in Thandla area, Jhabua district.

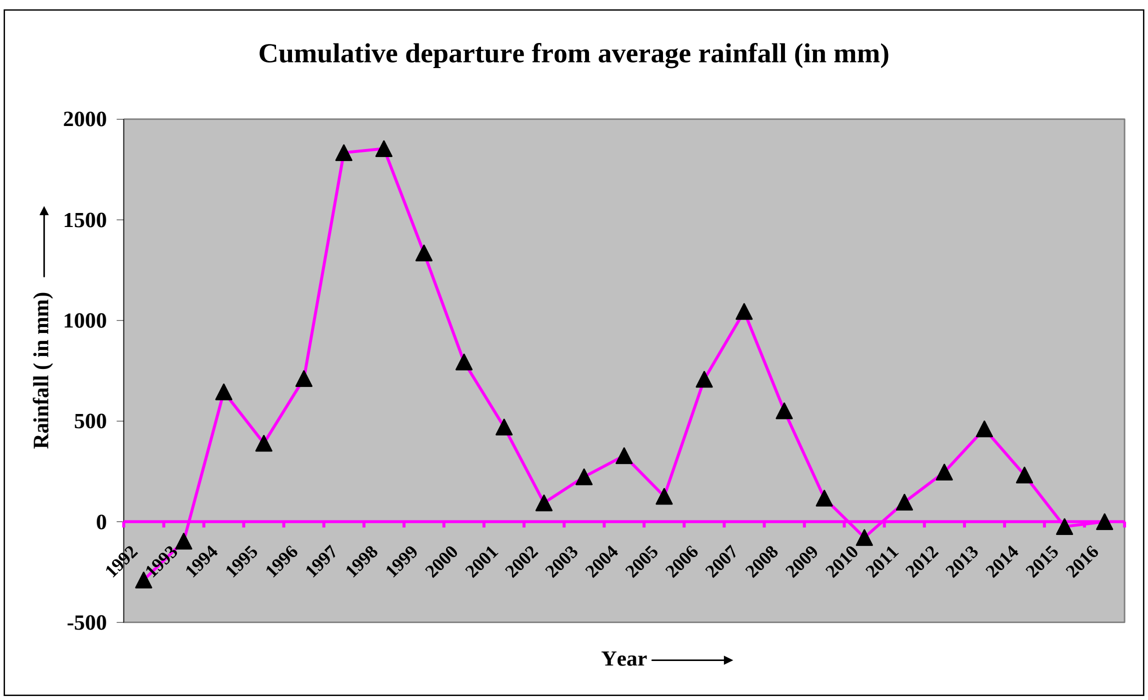


Figure 4.5 Cumulative departure from average annual rainfall in Thandla study area, Jhabua district, M.P.

The departure from the annual average value and cumulative departure have been displayed (Table 4.2, Figure 4.4, 4.5). The rainfall during the years of 1993, 1994, 1996, 1997, 1998, 2003, 2004, 2006, 2007, 2011, 2012, 2013, 2016 have been more than the average rainfall and indicate favourable conditions for the ground water recharge, while the years of 1992, 1995, 1999, 2000, 2001, 2002, 2005, 2008, 2009, 2010, 2014, and 2015 point out the rainfall values below the average rainfall indicating rather less contribution of rainwater to the ground water reservoir.

4.2.2 STATISTICAL ANALYSIS

Thandla rainfall data have been subjected to the statistical analysis, which deals with the computation of different parameters, such as mean, median, mode, standard deviation, co-efficient of dispersion, co-efficient of variation and co-efficient of skewness (Table 4.3). The forecast of rainfall has been estimated by using the method given by Croxton *et. al.* (1988), Davis (1975, 1986, 2002); Gupta and Kapoor (2003); Sahai, *et. al.*(2003); Goswami *et. al.* (2006); and Falahah *et. al.* (2010). The procedure of determination of statistical parameters of rainfall data are described in the following text.

1. Mean

Mean for a set of observation, it is their sum divided by the number of observation. It is computed by the equation: Mean $(\overline{X}) = A + \frac{\sum fu}{N} \text{ x } I$

Where, A = Assumed mean = 1200, I = Class interval = 200, $\sum fu$ = - 28, N = Total frequency = 25

$$\overline{X} = 1200 + \frac{(-28)}{25} \text{ x } 200$$

$$\overline{X} = 1200 + \frac{(-5600)}{25}$$

$\overline{X} = 1200 + (-224)$

$\overline{X} = 1200 - 224$

$\overline{X} = 976\,mm$

Mean $(\overline{X}) = 976\ mm$

The mean rainfall of the study area is 976 mm.

2. Median

Median is the variable for a set of observation, which is divided into two equal parts. It is determined by the formula: Median (M) = $L + \frac{½N - F}{f} \text{ x } I$

Where, L = Lower limit of median class = 1100, I = Class interval = 200,

N = Number of total frequency = 25, F = Cumulative frequency of class preceding the median class = 16, f = Frequency of median class = 5

$$M = 1100 + \frac{½\ 25 - 16}{5} \text{ x } 200$$

$$M = 1100 + \frac{12.5 - 16}{5} \text{ x } 200$$

$$M = 1100 + \frac{-3.5}{5} \text{ x } 200$$

$$M = 1100 - 140$$

$$M = 960 \text{ mm}$$

Median (M) = 960 mm

3. Mode

The mode is a value that occurs as frequency in a given set of observation. It is calculated by using the following formula: Mode (M_0) = $l_1 + \frac{f_1 - f_0}{2f_1 - f_0 - f_2}$ x I

Where, l_1 = Lower limit of model class = 1100, f_1 = Frequency of modal class = 5,

f_0 = Frequency of class preceding the modal class = 4, f_2 = Frequency of class succeeding the model class = 1, I = Class interval = 200

$$M_0 = 1100 + \frac{5 - 4}{2 \text{ x } 5 - 4 - 1} \text{ x } 200$$

$$M_0 = 1100 + \frac{1}{10 - 5} \text{ x } 200$$

$$M_0 = 1100 + \frac{1}{5} \text{ x } 200$$

$$M_0 = 1100 + 40$$

$$M_0 = 1140 \text{ mm}$$

Mode (M_0) 1140 mm.

4. Standard Deviation

Standard Deviation is a positive square root of the arithmetic mean of the squares deviation of a given value for their arithmetic mean. Standard deviation (σ) is calculated by the formula: Standard Deviation (σ) = $I\sqrt{\frac{(\sum fu^2)}{\sum f} - \left(\frac{\sum fu}{\sum f}\right)^2}$

Where, σ = Standard Deviation, I = Class interval = 200, $\sum f$ = Number of total frequency = 25, $\sum fu^2$ = 138, $\sum fu$ = -28

$$\sigma = 200\sqrt{\frac{138}{25} - \left(\frac{-28}{25}\right)^2}$$

$$\sigma = 200\sqrt{5.52 - \frac{784}{625}}$$

$$\sigma = 200\sqrt{5.52 - 1.25}$$

$$\sigma = 200\sqrt{4.27}$$

$$\sigma = 200 \text{ x } 2.06$$

$$\sigma = 412$$

Standard Deviation (σ) = 412 mm.

The calculated value of standard deviation (σ) reveals that deviation of rainfall is of 412 mm over a period of 25 years.

5. Co-efficient of Dispersion

The parameter is the measure of scatteredness and is determined by the formula given herein:

Co-efficient of Dispersion (CD) = $\sigma/\overline{X}$

Where, $\sigma =$ Standard Deviation = 412, $\overline{X}$ = Mean = 976

CD = 0.422

Co-efficient of Dispersion (CD) = 0.422

6. Co-efficient of Variation

It is the percentage variation in the mean. Standard deviation being considered as the total variation in the mean. Co-efficient of variation (CV) is calculated by the expression:

Co-efficient of Variation (CV) = $\frac{\sigma}{\overline{X}}$ x 100

Where, σ = Standard deviation = 412, $\overline{X}$ = Mean = 976

$$CV = \frac{412}{976} x100$$

$$CV = \frac{41200}{976}$$

CV = 42.213

Co-efficient of variation (CV) = 42.213

The extent to which the amount in rainfall varies from year to year is given by co-efficient of variation. The calculated value of co-efficient of variability represents that the amount of rainfall varies up to 42.213.

7. Co-efficient of Skewness

It is lack of symmetry in the given distribution. It is denoted by the symbol S_k and computed by using the formula: Co-efficient of Skewness (S_k) = $\frac{\overline{X} - M_0}{\sigma}$

Where, $\overline{X}$ = Mean = 976, M_0 = Mode = 1140, σ = Standard Deviation = 412

$$S_k = \frac{976 - 1140}{412}$$

$$S_k = \frac{-164}{412}$$

$$S_k = -0.398$$

Co-efficient skewness (S_k) = - 0.398

The co-efficient of skewness has been noted as - 0.398 which indicates that there is lack of symmetry in the rainfall amount.

The statistical analysis of Thandla rainfall data indicate value of mean = 976 mm, median = 960 mm, mode = 1140 mm, standard deviation = 412 mm, co-efficient of dispersion = 0.422, co-efficient of variation = 42.213, and co-efficient of skewness = - 0.398 and These computed values of statistical parameters indicate a negative trend of rainfall.

Table 4.3 Computation of statistical parameters of rainfall data of Thandla area, Jhabua district, Madhya Pradesh.

S. No.	Class Interval	Mid Value (x)	Frequency (f)	fx	u = (x-a) / I	fu	u^2	fu^2	C. F. (Cumulative Frequency)
1.	300-500	400	3	1200	-4	-12	16	48	3
2.	500-700	600	4	2400	-3	-12	9	36	7
3.	700-900	800	5	4000	-2	-10	4	20	12
4.	900-1100	1000	4	4000	-1	-4	1	4	16
5.	1100-1300	1200	5	6000	0	0	0	0	21
6.	1300-1500	1400	1	1400	1	1	1	1	22
7.	1500-1700	1600	1	1600	2	2	4	4	23
8.	1700-1900	1800	1	1800	3	3	9	9	24
9.	1900-2100	2000	1	2000	4	4	16	16	25
Total		**10800**	**$\sum f = 25 = N$**	**$\Sigma fx = 24400$**	**$\Sigma u = 0$**	**$\Sigma fu = -28$**	**$\Sigma u^2 = 60$**	**$\sum fu^2 = 138$**	-

4.3 TIME SERIES ANALYSIS

Time series analysis provides valuable information in respect of trend of observations. The analysis helps in forecasting of future trend. The procedures adopted by Croxton *et. al.* (1988), Davis (2002), Gupta and Kapoor (2003) have been used for the analysis of Thandla rainfall data of Jhabua district. Behavior of rainfall trend has been observed on the basis of least square fit of straight line. The values of "a" and "b" can be determined from the observed data. Simultaneously solving the following normal equations-

$$\sum Y = Na + b\sum X \text{..................... (i)}$$

$$\sum XY = a\sum X + b\sum X^2 \text{.............. (ii)}$$

The values of the different elements in the above equation have been determined by considering Y as variable (annual rainfall), N as number of year and X as constant (year).

The determination are made as per the following procedure -

$\sum Y = 24108.1$, $\sum X = 0$, $\sum XY = -11765.4$, $\sum X^2 = 1300$, $N = 25$

Substituting these values in normal equation (i) and (ii), two equations in terms of (iii) and (iv) are developed -

$$24108.1 = (25)\,a + b\,(0) \text{................. (iii)}$$

$$-11765.4 = a\,(0) + b\,(1300) \text{.............. (iv)}$$

Solving equation (iii) and (iv), the value of "a" and "b" are obtained as 964.32 and -9.05 respectively. Trend value is determined by the following equation-

$$Yc = a + b \text{ ....(v)}$$

The approximation of future forecast of rainfall amount for a period of Nine years (2017 - 2025) has been visualized and these values may indicate - 9.05 mm, variation in the expected amount. The computed values of future rainfall pattern are as: 2017 = 846.67 mm, 2018 = 837.62 mm, 2019 = 828.57 mm, 2020 = 819.52 mm, 2021 = 810.47 mm, 2022 = 801.42 mm, 2023 = 792.37 mm, 2024 = 783.32 mm, and 2025 = 774.27 mm (Table 4.4, 4.5 and Figure 4.6).

Table 4.4 Time series analysis of rainfall data of study area, Jhabua district, M. P.

S. No.	Year	X	Y (Rainfall)	X^2	XY	X^3	Trend value Yc
1.	1992	- 12	674.6	144	- 8095.2	- 1728	1072.92
2.	1993	- 11	1157.0	121	- 12727.0	- 1331	1063.87
3.	1994	- 10	1706.4	100	- 17064.0	- 1000	1054.82
4.	1995	- 9	709.0	81	- 6381.0	- 729	1045.77
5.	1996	- 8	1285.8	64	- 10286.4	- 812	1036.72
6.	1997	- 7	2086.2	49	- 14603.4	- 343	1027.67
7.	1998	- 6	984.8	36	- 5908.8	- 216	1018.62
8.	1999	- 5	445.7	25	- 2228.5	- 125	1009.57
9.	2000	- 4	423.0	16	- 1692.0	- 64	1000.52
10.	2001	- 3	641.2	9	- 1923.6	- 27	991.47
11.	2002	- 2	586.9	4	- 1173.8	- 8	982.42
12.	2003	- 1	1094.0	1	-1094.0	- 1	973.37
13.	2004	0	1069.8	0	0	0	964.32
14.	2005	1	762.0	1	762.0	1	955.27
15.	2006	2	1546.0	4	3092.0	8	946.22
16.	2007	3	1301.0	9	3903.0	27	937.17
17.	2008	4	470.4	16	1881.6	64	928.12
18.	2009	5	531.1	25	2655.5	125	919.07
19.	2010	6	768.6	36	4611.6	216	910.02
20.	2011	7	1139.6	49	7977.2	343	900.97
21.	2012	8	1113.7	64	8909.6	812	891.92
22.	2013	9	1179.0	81	10611.0	729	882.87
23.	2014	10	735.7	100	7357.0	1000	873.82
24.	2015	11	707.4	121	7781.4	1331	864.77
25.	2016	12	989.2	144	11870.4	1728	855.72
Total	**N = 25**	**$\sum X = 0$**	**$\sum Y = 24108.1$**	**$\sum X^2 = 1300$**	**$\sum XY = -11765.4$**	**$\sum X^3 = 0$**	-

Table 4.5 Computation of future rainfall trend value of study area, Jhabua district.

S. No.	Year	Expected trend value rainfall (in mm.)
1.	2017	846.67
2.	2018	837.62
3.	2019	828.57
4.	2020	819.52
5.	2021	810.47
6.	2022	801.42
7.	2023	792.37
8.	2024	783.32
9.	2025	774.27

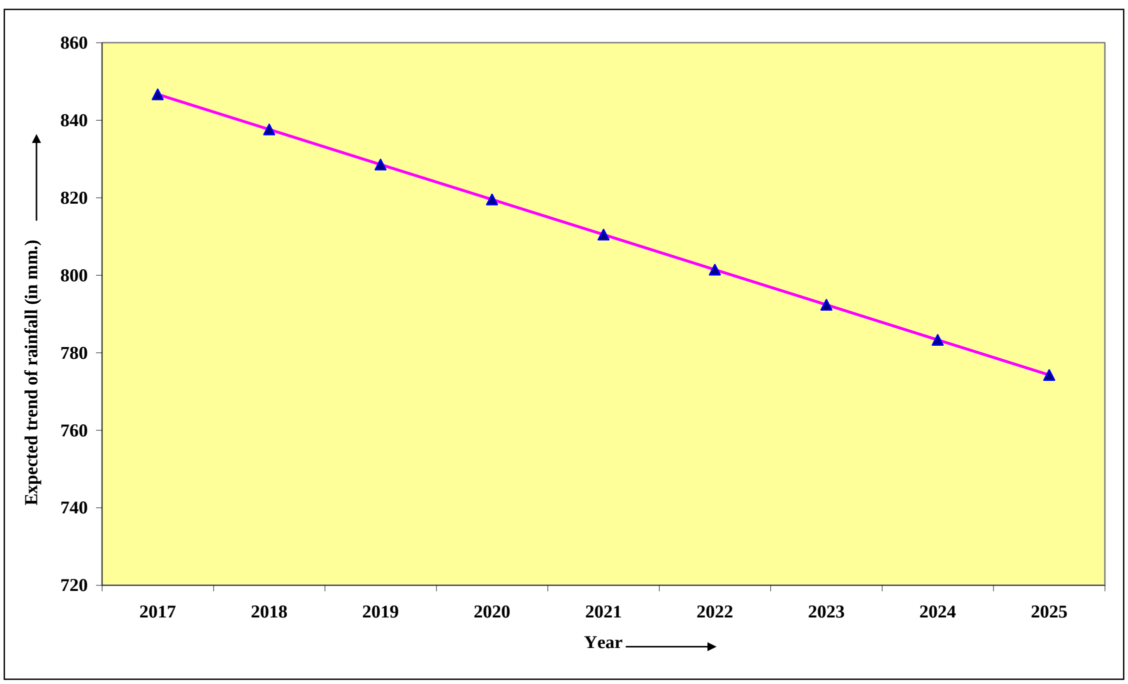


Figure 4.6 Future forecast of expected rainfall in Thandla area, Jhabua district.

4.4 ENVIRONMENTAL IMPLICATIONS

The environmental scenario is immensely affected by the hydrometeorological and meteorological parameters, namely rainfall and temperature respectively. The amount and frequency of rainfall, affects main factors for the ground water recharge. The positive trend of sufficient rainfall indicates good conditions for recharge of ground water system. The excess rainfall creates situation of havoc resulting into river flooding, growth of vegetation, crops, forest, and communication distortion of building structures and others. The negative trend, scarcity and low intensity of rainfall considerably affect the recharge phenomenon generating sustained supply of water for the agriculture development, human and animal kingdoms, even causing drought conditions.

In present study, analyses indicate the occurrence of both positive and negative trends of rainfall factor that point out environmental problems to inhabitants of Thandla area. Present trend of rainfall is indicating negative trend with respect to the annual rainfall values. This is causing conditions of sustained water supply to the inhabitants of the area. It is suggested that implementation of a scheme for development of aforestation, augmentation of ground water recharge, would resolve the present water crisis in the Thandla area.

CHAPTER - 5

HYDROGEOLOGICAL CHARACTERIZATION

5.1 CONCEPT OF HYDROGEOLOGY

Hydrogeology has been considered as a science of the occurrence, distribution and movement of water below surface of earth. It is a general term for water of earth that refers to distribution and movement of ground water in soil and rocks of earth. Meinzer (1923) described Hydrology as a science, which relates to water of earth. Water may be divided into three parts, which occurs in atmosphere, surface of solid part of earth, and below earth's surface. Water below surface can be divided into two parts that occurs in interstices of rocks and other part is supposed to occur in earth's interior, where interstices cannot exist because weight of overlying rocks and water. Tolman (1937) remarked that hydrogeology as all sciences, geology is of greatest importance that deals study of sub-surface water. Hence, Hydrogeology deals with the presence, circulation, and flow of ground water.

Todd (1959, 1980, 2010) described hydrogeology as a science of occurrence, distribution and movement of water below surface of earth. Davis and Dewiest (1966) remarked that Geohydrology has an identical connotation, and hydrogeology differs only by its greater emphasis on geology. Hydrogeology deals with geological conditions governing occurrence and movement of ground water, which occurs in cavities and spaces in rocks. Todd (1980) affirmed that an increase in the emphasis on hydrology, the subject is coined as "Geohydrology".

Todd and Mays (2005) have considered that Ground water hydrology is a science of occurrence , distribution, and movement of water below surface of earth. Geohydrology has a similar relationship and hydrogeology differs by its important stress on geology.

Consumption of ground water dates from ancient era, while an understanding of the occurrence and movement of ground water as part of hydrologic cycle is recent.

5.2 HYDROGEOLOGICAL SURVEY OF STUDY AREA

Systematic hydro-geological survey is the first step in hydro-geological analysis of basin or an area. Survey is conducted to determine the nature of ground water conditions of present study area. Procedure for systematic hydro-geological survey is first carried out by reconnaissance survey, with the help of Toposheet along with detailed well inventory in respect of existing different wells in area of investigation. Study area covers 366.58 sq. km in vicinity of Thandla town in Jhabua district (Toposheet no. 46 I/12).

Well inventory includes the collection of data such as location (village), name of owner, diameter, total depth of well, static water level, purpose and yield of water in the wells. Data in respects of boreholes are not available to the author and hence, present study is confined to the analysis of dug wells. Locations of examined wells have been displayed (Figure 5.1). The details of examined dug wells existing in study area are recorded (Table 5.1).

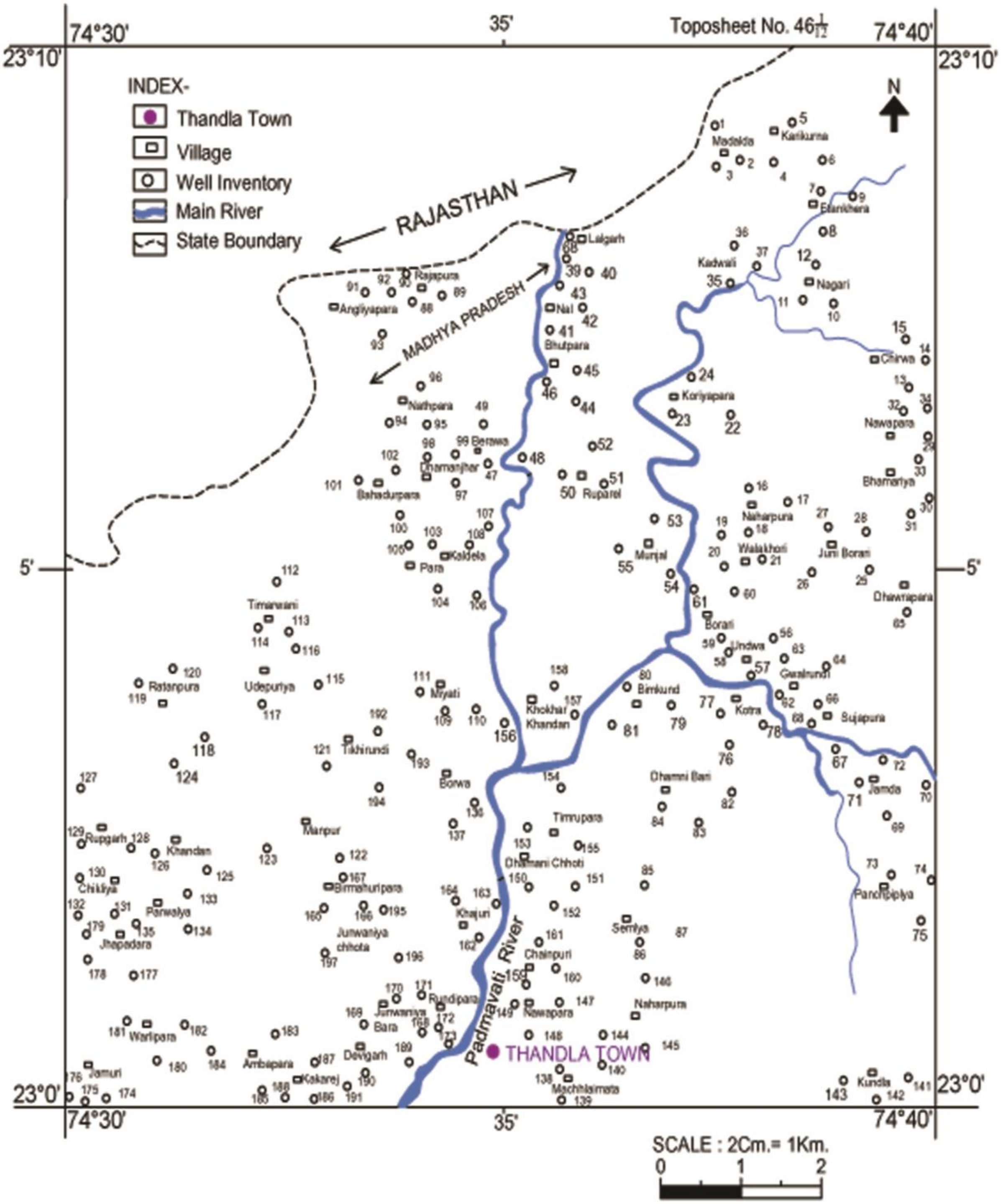


Figure 5.1 Location Map of examined open dug wells in the Thandla study area, Jhabua district, Madhya Pradesh.

5.2.1 WELL DATA EXAMINATION

In the present work, 197 open dug wells have been examined during the period of post-monsoon and pre-monsoon. The examined well data have been displayed (Table 5.1).

Table 5.1 Details of the dug wells existing in Thandla study area, Jhabua district, Madhya Pradesh.

Well No.	Location	Name of Owner	G. L. (m.) A.M. S.L.	Dia. (m)	Total Depth (m.) B.G.L.	Static water level (m)		Reduced water level (m)		Lined /Unlined	Mode of Lifting	Use of Well
						Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon			
1	Madalda	Bhunda Bhuriya	411	9.10	5.50	1.80	4.50	409.2	406.5	Lined Well	Manual, Pump	A + D
2	Madalda	Havala Bhuriya	412	7.50	10.15	1.50	9.45	410.5	402.55	Unlined Well	Manual, Pulley, Pump	A + D
3	Madalda	Mansingh Bhuriya	410	6.12	3.10	1.00	2.47	409.0	407.53	Unlined Well	Manual, Pump	A + D
4	Karikurna	Bharaji Bhuriya	417	7.40	5.00	1.00	4.00	416.0	413.0	Lined Well	Pump	A
5	Karikurna	Nathu Charpota	420	7.45	5.10	1.70	3.05	418.3	416.95	Lined Well	Manual, Pump	A + D

6	Karikurna	Badru Bhuriya	415	8.00	5.20	2.00	3.10	413.0	411.9	Unlined Well	Manual, Pump	A + D
7	Etankhera	Dhulaji singad	404	8.40	5.00	1.80	4.02	402.2	399.98	Unlined Well	Manual, Pump	A + D
8	Etankhera	Badiya Bhuriya	403	9.00	7.10	2.20	5.00	400.8	398.0	Lined Well	Manual, Pulley, Pump	A + D
9	Etankhera	Ramesh Bhuriya	409	7.60	7.20	2.30	5.80	406.7	403.2	Unlined Well	Manual	A
10	Nagari	Nathu Bhabhor	410	8.00	6.10	1.90	4.85	408.1	405.15	Unlined Well	Manual, Pump	A + D
11	Nagari	Haliya Bhabhor	409	8.40	5.00	1.70	4.50	407.3	404.5	Unlined Well	Manual, Pump	A + D
12	Nagari	Viraji Bhabhor	411	8.60	6.00	1.00	4.90	410.0	406.1	Unlined Well	Manual, Pump	A + D
13	Chirwa	Galiya Maida	418	10.40	4.50	2.00	3.45	416.0	414.55	Unlined Well	Manual, Pump	A + D
14	Chirwa	Devchand Katara	420	10.00	5.10	2.30	4.00	417.7	416.0	Unlined Well	Manual, Pump	A
15	Chirwa	Nathu Paragi	417	10.40	4.50	2.10	3.50	414.9	413.5	Unlined Well	Manual	A
16	Naharpura Chhota	Laloo Muniya	367	7.12	4.00	1.70	3.00	365.3	364.0	Lined Well	Manual, Pump	A + D
17	Naharpura Chhota	Galiya Muniya	370	7.50	7.10	1.80	5.07	368.2	364.93	Lined Well	Manual, Pulley, Pump	A + D

18	Naharpura Chhota	Jala Damor	371	7.00	6.50	1.70	5.80	369.3	365.2	Lined Well	Manual, Pump	A + D
19	Walakhori	Amara Amaliyar	362	8.50	10.10	2.00	8.10	360.0	353.9	Lined Well	Manual, Pulley, Pump	A + D
20	Walakhori	Hadiya Maida	364	8.00	10.00	2.10	9.02	361.9	354.9 8	Unlined Well	Manual, Pump	A + D
21	Walakhori	Mansingh Maida	360	8.10	10.20	2.00	9.05	358.0	350.9 5	Lined Well	Manual, Pump	A + D
22	Koriyapara	Havasingh Damor	360	8.00	6.15	1.90	5.00	358.1	355.0	Lined Well	Manual, Pump	A + D
23	Koriyapara	Hursingh Damor	361	12.0 0	8.50	2.20	4.16	358.8	356.8 4	Unlined Well	Manual, Pump	A + D
24	Koriyapara	Hursingh Damor	362	7.00	7.20	2.30	5.82	359.7	356.1 8	Unlined Well	Manual, Pump	A + D
25	Juni Borari	Mohan Bariya	335	7.50	8.00	2.00	6.05	333.0	328.9 5	Unlined Well	Manual, Pump	A
26	Juni Borari	Shantu Damor	333	9.40	9.10	2.10	7.87	330.9	325.1 3	Lined Well	Manual, Pump	A + D
27	Juni Borari	Teru Damor	332	11.0 0	12.20	2.00	9.20	330.0	322.8	Lined Well	Manual, Pulley, Pump	A
28	Juni Borari	Nathiya Damor	334	14.0 0	13.15	2.30	11.03	331.7	322.9 7	Unlined Well	Manual, Pump	A
29	Bhamariya	Kallu Singad	379	9.10	11.00	2.50	7.15	376.5	371.8 5	Unlined Well	Manual, Pump	A + D

30	Bhamariya	Madiya Dabi	378	9.00	9.50	2.70	5.51	375.3	372.49	Lined Well	Manual, Pump	A + D
31	Bhamariya	Karama Singad	380	8.40	8.00	2.70	4.07	377.3	375.93	Unlined Well	Manual, Pump	A + D
32	Nawapara	Homaji Muniya	401	9.00	12.05	2.50	8.52	398.5	392.48	Lined Well	Manual, Pulley, Pump	A + D
33	Nawapara	Madiya Muniya	400	8.00	7.15	2.00	5.06	398.0	394.94	Lined Well	Manual, Pump	A
34	Nawapara	Narsingh Muniya	402	8.45	6.00	2.10	4.90	399.9	397.1	Unlined Well	Manual, Pump	A + D
35	Kadwali	Ramaji Bhuriya	402	7.50	6.07	2.00	4.00	400.0	398.0	Lined Well	Manual, Pump	A + D
36	Kadwali	Titusingh Paragi	404	8.00	5.06	1.90	3.49	402.1	400.51	Lined Well	Manual, Pump	A + D
37	Kadwali	Dhiraji Kamaliya	405	8.45	7.50	1.80	6.91	403.2	398.09	Lined Well	Manual, Pulley, Pump	A + D
38	Lalgarh	Punna Damor	400	10.05	7.09	1.90	5.02	398.1	394.98	Lined Well	Manual, Pulley, Pump	A + D
39	Lalgarh	Warsingh Bhuriya	398	7.50	5.00	1.30	4.00	396.7	394.0	Lined Well	Manual, Pump	A + D
40	Lalgarh	Kanaji Damor	396	6.46	6.05	1.70	4.05	394.3	391.95	Lined Well	Manual, Pump	A + D

41	Nal	Ballu Bhabhor	350	9.48	7.45	2.00	5.10	348.0	344.9	Lined Well	Manual, Pulley, Pump	A + D
42	Nal	Hadiya Kamaliya	352	11.00	8.16	2.20	7.00	349.8	345.0	Unlined Well	Manual	A
43	Nal	Dhulaji Bhuriya	353	7.50	5.00	1.00	4.01	352.0	348.99	Lined Well	Manual, Pump	A
44	Bhutpara	Sardar Add	363	10.09	7.05	1.70	6.00	361.3	357.0	Lined Well	Manual, Pulley, Pump	A + D
45	Bhutpara	Kantu Add	360	8.10	8.00	1.80	7.02	358.2	352.98	Lined Well	Manual, Pulley, Pump	A + D
46	Bhutpara	Huraji Damor	359	8.42	7.03	1.90	4.00	357.1	355.0	Lined Well	Manual, Pulley, Pump	A + D
47	Berawa	Sakara Maida	348	8.02	9.05	2.30	7.02	345.7	340.98	Lined Well	Manual, Pulley, Pump	A + D
48	Berawa	Galiya Maida	350	7.47	10.06	2.70	9.40	347.3	340.6	Lined Well	Manual, Pump	A + D
49	Berawa	Kanaji Maida	351	7.50	13.00	2.90	12.00	348.1	339.0	Lined Well	Manual, Pump	A + D
50	Ruparel	Bhunda Damor	365	11.04	10.08	2.00	8.03	363.0	356.97	Lined Well	Manual, Pulley, Pump	A + D

51	Ruparel	Saliya Singad	362	8.09	9.00	2.10	7.48	359.9	354.52	Unlined Well	Manual, Pump	A + D
52	Ruparel	Balsingh Bhabhor	360	7.35	14.00	2.90	12.80	357.1	347.2	Lined Well	Manual, Pulley, Pump	A + D
53	Munjal	Hakaru Katara	341	11.05	12.09	2.60	11.00	338.4	330.0	Unlined Well	Manual, Pump	A + D
54	Munjal	Dalla Garwal	338	6.47	8.46	2.10	8.01	335.9	329.99	Lined Well	Manual, Pump	A + D
55.	Munjal	Matiyas Damor	340	6.00	10.50	2.00	8.48	338.0	331.52	Lined Well	Manual, Pump	A + D
56	Undwa	Kallu Waniya	322	12.20	10.05	2.00	9.04	320.0	312.96	Unlined Well	Manual, Pump	A
57	Undwa	Mansukh Maida	320	7.05	7.15	2.00	6.00	318.0	314.0	Lined Well	Manual, Pulley, Pump	A
58	Undwa	Havasingh Ninama	319	7.10	10.09	2.30	9.06	316.7	309.94	Lined Well	Manual, Pulley, Pump	A
59	Borari	Karsingh Mavi	335	7.50	10.00	2.30	8.07	332.7	326.93	Lined Well	Manual, Pulley, Pump	A + D
60	Borari	Dhiru Damor	333	7.45	11.60	2.90	8.50	330.1	324.5	Lined Well	Manual, Pulley, Pump	A
61	Borari	Mangilal	331	7.55	8.00	2.70	4.00	328.3	327.0	Lined	Manual,	A

		Damor								Well	Pump	
62	Gwalrundi	Raisingh Bhabhor	326	9.05	7.08	1.80	5.08	324.2	320.92	Lined Well	Pump	A
63	Gwalrundi	Rupsingh Bhabhor	328	9.00	12.00	2.00	10.90	326.0	317.1	Unlined Well	Manual, Pump	A + D
64	Gwalrundi	Mansingh Bhabhor	329	8.06	7.07	2.10	6.00	326.9	323.0	Lined Well	Manual, Pump	A
65	Dhawrapara	Nathu Machhar	358	6.50	8.00	2.10	7.48	355.9	350.52	Lined Well	Manual, Pulley, Pump	A
66	Sujapura	Ramsingh Damor	352	7.02	8.10	1.90	7.45	350.1	344.55	Lined Well	Manual, Pump	A + D
67	Sujapura	Nanaji Ninama	350	8.00	6.00	1.70	5.01	348.3	344.99	Lined Well	Manual, Pump	A
68	Sujapura	Teru Devada	349	6.14	8.00	1.50	5.53	347.5	343.47	Lined Well	Manual, Pulley, Pump	A + D
69	Jamda	Bhanaji Damor	342	8.50	7.00	1.70	6.00	340.3	336.0	Unlined Well	Pump	A
70	Jamda	Kasara Damor	340	8.51	7.62	1.90	3.55	338.1	336.45	Unlined Well	Manual, Pump	A + D
71	Jamda	Khimchand Singad	338	8.00	6.05	1.50	3.04	336.5	334.96	Lined Well	Manual, Pump	A
72	Jamda	Kalsingh Rana	339	10.50	11.00	2.00	7.03	337.0	331.97	Lined Well	Manual, Pulley, Pump	A + D

73	Panchpiplya	Wahadiya Singad	358	8.55	7.10	1.90	6.00	356.1	352.0	Lined Well	Manual, Pulley, Pump	A + D
74	Panchpiplya	Harsan Singad	360	12.00	9.13	2.00	6.02	358.0	353.98	Unlined Well	Manual, Pump	A + D
75	Panchpiplya	Dhanaji Dodiyar	364	6.50	10.00	2.10	8.05	361.9	355.95	Lined Well	Manual, Pulley, Pump	A + D
76	Kotra	Madu Damor	333	8.00	14.06	3.20	13.00	329.8	320.0	Lined Well	Manual, Pulley, Pump	A
77	Kotra	Rumal Damor	335	11.14	13.02	3.40	11.48	331.6	323.52	Unlined Well	Manual, Pump	A
78	Kotra	Bhamar Garwal	336	7.50	8.00	2.90	7.00	333.1	329.0	Lined Well	Manual, Pump	A + D
79	Bhimkund	Manak Katara	329	5.55	14.08	2.50	9.12	326.5	319.88	Lined Well	Manual, Pulley, Pump	A + D
80	Bhimkund	Kaliya Katara	327	8.50	5.00	1.90	6.00	325.1	321.0	Unlined Well	Manual, Pump	A
81	Bhimkund	Ballu Amaliyar	330	7.00	10.05	2.00	6.05	328.0	323.95	Lined Well	Manual, Pump	A + D
82	Dhamni Bari	Andariyas Devada	357	9.02	13.00	2.00	12.02	355.0	344.98	Unlined Well	Manual, Pump	A + D
83	Dhamni Bari	Prakash Katara	360	10.45	9.50	2.10	8.49	357.9	351.51	Unlined Well	Manual, Pump	A + D

84	Dhamni Bari	Rajesh Vasuniya	356	6.51	7.03	2.00	4.00	354.0	352.0	Lined Well	Manual, Pump	A + D
85	Semlya	Ramchand Garwal	332	7.01	4.50	1.00	4.02	331.0	327.98	Unlined Well	Manual, Pump	A + D
86	Semlya	Mohansigh Bariya	335	8.00	6.00	1.90	5.00	333.1	330.0	Lined Well	Manual, Pump	A + D
87	Semlya	Dita Katija	337	8.05	9.02	2.00	6.05	335.0	330.95	Unlined Well	Manual, Pump	A + D
88	Rajapura	Babu Damor	397	9.00	6.10	1.50	4.50	395.5	392.5	Unlined Well	Manual, Pump	A + D
89	Rajapura	Mansingh Damor	398	10.01	8.03	1.90	7.40	396.1	390.6	Unlined Well	Manual, Pump	A + D
90	Rajapura	Mansingh Damor	396	6.00	7.06	2.20	6.48	393.8	389.52	Unlined Well	Manual, Pump	A + D
91	Angliyapara	Mangilal Garwal	400	7.02	8.00	2.10	7.45	397.9	392.55	Unlined Well	Manual, Pump	A + D
92	Angliyapara	Mangu Garwal	401	7.50	8.10	2.90	7.40	398.1	393.6	Lined Well	Manual, Pulley, Pump	A + D
93	Angliyapara	Laxaman Garwal	399	6.56	9.21	2.40	8.00	396.6	391.0	Lined Well	Manual, Pump	A + D
94	Nathpara	Nathu Garwal	394	7.57	10.11	2.50	9.00	391.5	385.0	Lined Well	Manual, Pulley, Pump	A + D
95	Nathpara	Bhagala Garwal	392	6.00	8.00	2.60	7.02	389.4	384.98	Lined Well	Manual, Pulley,	A + D

											Pump	
96	Nathpara	Hurtan Singad	391	9.10	8.02	2.00	7.00	389.0	384.0	Lined Well	Manual, Pulley, Pump	A + D
97	Dhamanjhar	Jyoti Katija	340	8.51	8.57	2.50	6.50	337.5	333.5	Lined Well	Manual, Pulley, Pump	A + D
98	Dhamanjhar	Waru Katija	338	8.00	6.50	1.90	5.00	336.1	333.0	Lined Well	Manual, Pulley, Pump	A + D
99	Dhamanjhar	Jogada Khadiya	337	9.03	6.02	1.50	4.48	335.5	332.52	Unlined Well	Manual, Pump	A
100	Bahadurpara	Jeviyar Bhuriya	402	7.53	5.61	2.00	3.51	400.0	398.49	Unlined Well	Manual, Pump	A + D
101	Bahadurpara	Kalla Bhuriya	400	7.00	8.13	2.50	5.53	397.5	394.47	Lined Well	Pump	A
102	Bahadurpara	Rupa Bhuriya	398	8.97	5.21	1.60	4.00	396.4	394.0	Lined Well	Pulley, Pump	A + D
103	Para	Chhagan Bhabhor	330	8.09	8.50	2.30	7.00	327.7	323.0	Lined Well	Manual, Pulley, Pump	A + D
104	Para	Bhodariya Khadiya	328	8.57	4.49	1.70	3.50	326.3	324.5	Lined Well	Manual, Pump	A
105	Para	Shevala Katara	327	8.14	5.03	1.80	4.00	325.2	323.0	Lined Well	Manual, Pump	A
106	Kaldela	Mangliya	338	8.22	10.04	2.70	9.00	335.3	329.0	Lined	Manual,	A + D

		Kharadi								Well	Pump	
107	Kaldela	Bhodara Dodiyar	340	13.0 1	9.61	2.90	8.20	337.1	331.8	Lined Well	Manual, Pump	A + D
108	Kaldela	Havasingh Damor	337	7.59	9.16	2.80	8.10	334.2	328.9	Lined Well	Manual, Pump	A + D
109	Miyati	Kallu Kamaliya	325	12.0 0	8.22	2.00	6.50	323.0	318.5	Lined Well	Manual, Pulley, Pump	A + D
110	Miyati	Ramchand Bhabhor	327	5.57	6.47	1.90	3.00	325.1	324.0	Lined Well	Pulley, Pump	A + D
111	Miyati	Kusal Khihori	328	7.00	9.27	2.20	8.40	325.8	319.6	Lined Well	Pulley, Pump	A + D
112	Timarwani	Mansingh Amaliyar	360	11.5 4	7.50	1.90	3.50	358.1	356.5	Unlined Well	Manual, Pump	A + D
113	Timarwani	Sinu Rawat	356	9.49	6.52	1.80	4.46	354.2	351.5 4	Lined Well	Manual, Pump	A + D
114	Timarwani	Titiya Bhuriya	358	7.51	5.50	1.50	3.45	356.5	354.5 5	Lined Well	Manual, Pulley, Pump	A + D
115	Udepuriya	Badahing Paragi	340	10.4 6	9.00	2.00	8.50	338.0	331.5	Unlined Well	Manual, Pump	A + D
116	Udepuriya	Sukiya Vasuniya	341	10.0 7	6.80	1.90	4.60	339.1	336.4	Unlined Well	Manual, Pump	A + D
117	Udepuriya	Titiya Vasuniya	343	9.00	15.75	2.20	6.58	340.8	336.4 2	Lined Well	Manual, Pulley, Pump	A + D

118	Ratanpura	Ramchand Kharadi	342	8.35	7.63	1.90	4.50	340.1	337.5	Lined Well	Manual, Pump	A + D
119	Ratanpura	Divan Damor	344	7.81	7.00	1.80	5.00	342.2	339.0	Unlined Well	Manual, Pump	A + D
120	Ratanpura	Rupa Bhuriya	341	8.58	6.00	1.70	5.48	339.3	335.5 2	Unlined Well	Manual, Pump	A + D
121	Manpur	Mangu Khadiya	321	7.53	12.17	2.10	10.00	318.9	311.0	Lined Well	Pump	A + D
122	Manpur	Jogee Damor	322	10.3 6	12.26	2.50	8.50	319.5	313.5	Lined Well	Pump	A
123	Manpur	Mala Garwal	323	11.1 5	16.37	2.90	7.00	320.1	316.0	Unlined Well	Pump	A
124	Khandan	Versingh Muniya	317	10.5 0	16.00	3.00	14.00	314.0	303.0	Lined Well	Manual, Pump	A + D
125	Khandan	Gendal Garwal	312	6.58	14.07	3.20	5.00	308.8	307.0	Unlined Well	Manual, Pump	A + D
126	Khandan	Laxaman Ganawa	313	8.02	19.08	3.40	9.50	309.6	303.5	Lined Well	Manual, Pump	A + D
127	Rupgarh	Fransis Singadiya	315	13.0 3	5.09	1.90	4.50	313.1	310.5	Unlined Well	Manual, Pump	A + D
128	Rupgarh	Sama Dabee	312	8.61	9.00	2.00	5.50	310.0	306.5	Unlined Well	Manual, Pump	A + D
129	Rupgarh	Densingh Bhuriya	311	8.52	9.87	2.10	6.70	308.9	304.3	Unlined Well	Manual, Pump	A + D
130	Chikliya	Villu	309	11.0	12.38	2.20	11.00	306.8	298.0	Unlined	Manual,	A + D

		Khadiya		2						Well	Pump	
131	Chikliya	Gumansin gh Maida	307	10.4 7	12.81	2.50	11.02	304.5	295.9 8	Unlined Well	Manual, Pump	A
132	Chikliya	Gumansin gh Maida	311	9.05	7.50	1.90	3.51	309.1	307.4 9	Lined Well	Pump	A
133	Parwalya	Pissu Muniya	301	8.07	13.34	2.00	9.00	299.0	292.0	Lined Well	Manual, Pulley, Pump	A + D
134	Parwalya	Kanta Muniya	298	7.22	9.27	2.10	7.50	295.9	290.5	Lined Well	Manual, Pump	A + D
135	Parwalya	Govermen t	302	10.3 5	9.52	2.80	4.50	299.2	297.5	Lined Well	Manual, Pump	A + D
136	Borwa	Khumcha nd Damor	325	10.3 8	6.00	1.70	5.00	323.3	320.0	Unlined Well	Manual, Pump	A + D
137	Borwa	Shaitan Bhuriya	320	7.74	7.83	2.00	6.50	318.0	313.5	Lined Well	Manual, Pump	A + D
138	Machhlaima ta	Raisingh Pal	307	11.0 4	6.17	1.90	5.00	305.1	302.0	Lined Well	Manual, Pump	A
139	Machhlaima ta	Kasan Bhabhor	308	9.02	12.06	2.00	9.00	306.0	299.0	Lined Well	Manual, Pump	A
140	Machhlaima ta	Galiya Bhabhor	309	7.18	14.16	2.10	11.80	306.9	297.2	Lined Well	Manual, Pump	A + D
141	Kundla	Joga Khadiya	346	8.02	9.22	2.00	8.04	344.0	337.9 6	Unlined Well	Manual, Pump	A + D
142	Kundla	Ballu Khadiya	342	8.57	8.35	2.50	7.00	339.5	335.0	Lined Well	Manual, Pump	A

143	Kundla	Havasingh Khadiya	341	8.09	5.78	1.90	3.50	339.1	337.5	Unlined Well	Manual, Pump	A
144	Naharpura	Gorsingh Vasuniya	324	15.1 6	10.83	3.00	8.00	321.0	316.0	Unlined Well	Manual, Pump	A + D
145	Naharpura	Kaliya Muniya	322	8.15	10.28	2.90	9.00	319.1	313.0	Lined Well	Manual, Pump	A + D
146	Naharpura	Makan Ganawa	323	9.18	10.30	3.10	8.90	319.9	314.1	Unlined Well	Manual, Pump	A + D
147	Nawapara	Puniya Maida	320	11.2 5	17.16	2.10	8.00	317.9	312.0	Lined Well	Manual, Pump	A + D
148	Nawapara	Kasan Vasuniya	321	8.05	7.92	1.90	6.50	319.1	314.5	Lined Well	Manual, Pump	A + D
149	Nawapara	Rakesh Telee	319	9.00	14.05	2.50	10.00	316.5	309.0	Lined Well	Manual, Pump	A + D
150	Dhamni Chhoti	Joraji Bhabhor	325	7.04	11.00	2.10	9.05	322.9	315.9 5	Lined Well	Manual, Pump	A + D
151	Dhamni Chhoti	Kailash Bariya	322	10.2 5	7.37	2.00	5.00	320.0	317.0	Unlined Well	Manual, Pump	A
152	Dhamni Chhoti	Parsingh Vasuniya	323	9.19	12.02	2.50	7.21	320.5	315.7 9	Lined Well	Manual, Pulley, Pump	A + D
153	Timrupara	Himat Paragee	320	6.70	9.42	2.00	7.55	318.0	312.4 5	Lined Well	Manual, Pump	A
154	Timrupara	Bassu Rana	320	8.03	8.72	2.10	7.00	317.9	313.0	Lined Well	Manual, Pump	A + D
155	Timrupara	Badiya	318	8.32	9.30	1.90	3.20	316.1	314.8	Unlined	Manual,	A + D

		Rana								Well	Pump	
156	Khokhar Khandan	Mannu Khokhar	334	6.70	11.16	2.20	5.10	331.8	328.9	Lined Well	Manual, Pump	A + D
157	Khokhar Khandan	Anton Khokhar	335	6.87	6.80	2.00	4.56	333.0	330.44	Unlined Well	Manual, Pump	A + D
158	Khokhar Khandan	Maku Khokhar	336	8.20	14.32	2.90	9.00	333.1	327.0	Unlined Well	Manual, Pump	A
159	Chainpuri	Govermen t	311	8.90	9.18	2.30	8.07	308.7	302.93	Lined Well	Manual, Pulley, Pump	A
160	Chainpuri	Sukram Ninama	312	8.35	8.77	2.40	4.00	309.6	308.0	Lined Well	Manual, Pulley, Pump	A + D
161	Chainpuri	Mahesh Ninama	314	8.10	6.82	2.00	5.50	312.0	308.5	Unlined Well	Manual, Pump	A + D
162	Khajuri	Monu Damor	302	11.02	6.25	1.60	4.50	300.4	297.5	Lined Well	Manual, Pulley, Pump	A + D
163	Khajuri	Walchand Ninama	300	9.06	9.57	2.40	6.00	297.6	294.0	Lined Well	Manual, Pump	A + D
164	Khajuri	Radiya Patel	300	11.52	12.46	2.50	10.50	297.5	289.5	Unlined Well	Manual, Pump	A + D
165	Birmahuripa ra	Tufan Khadiya	330	7.61	14.04	3.00	12.52	327.0	317.48	Lined Well	Manual, Pump	A
166	Birmahuripa ra	Kasariya Bariya	328	12.06	14.03	3.20	12.00	324.8	316.0	Unlined Well	Manual, Pump	A

167	Birmahuripa ra	Ballu Maida	329	8.51	8.66	3.40	7.50	325.6	321.5	Lined Well	Manual, Pump	A + D
168	Junwaniya Bara	Narsingh Palasiya	304	7.20	9.40	2.00	5.60	302.0	298.4	Lined Well	Manual, Pump	A + D
169	Junwaniya Bara	Surpal Khadiya	302	10.1 5	9.61	2.80	6.48	299.2	295.5 2	Lined Well	Manual, Pulley, Pump	A + D
170	Junwaniya Bara	Raisingh Bhuriya	305	9.57	7.02	1.90	2.50	303.1	302.5	Lined Well	Manual, Pump	A + D
171	Rundipara	Marsal Maida	300	8.16	9.08	2.00	7.00	298.0	293.0	Lined Well	Manual, Pump	A + D
172	Rundipara	Soniya Gavalee	303	9.10	9.19	2.10	5.00	300.9	298.0	Lined Well	Manual, Pulley, Pump	A
173	Rundipara	Suraj Dindor	301	10.0 2	7.65	2.00	6.50	299.0	294.5	Unlined Well	Manual, Pump	A
174	Jamuri	Chhagan Bariya	300	8.10	8.86	2.50	7.50	297.5	292.5	Lined Well	Manual, Pulley, Pump	A + D
175	Jamuri	Jamura Maida	300	8.02	11.34	2.70	4.00	297.3	296.0	Lined Well	Manual, Pulley, Pump	A + D
176	Jamuri	Dalsingh Maida	302	8.55	11.20	3.00	10.46	299.0	291.5 4	Unlined Well	Manual, Pulley, Pump	A
177	Jhapadara	Govermen	303	10.2	7.33	2.10	5.61	300.9	297.3	Lined	Manual,	A + D

		t		0					9	Well	Pump	
178	Jhapadara	Alok Jerom Ming	300	12.02	12.87	2.50	7.00	297.5	293.0	Lined Well	Manual, Pulley, Pump	A + D
179	Jhapadara	Parsingh Damor	301	10.97	11.02	2.30	10.30	298.7	290.7	Unlined Well	Manual, Pump	A
180	Warlipara	Bhurchand Bhuriya	281	7.56	12.01	2.10	10.00	278.9	271.0	Lined Well	Manual, Pulley, Pump	A + D
181	Warlipara	Lalu Bhuriya	285	12.00	12.75	2.70	10.20	282.3	274.8	Unlined Well	Manual, Pump	A
182	Warlipara	Tansingh Bhuriya	287	6.20	8.26	2.60	6.00	284.4	281.0	Unlined Well	Manual, Pump	A
183	Ambapara	Jamusingh Katara	295	11.07	12.28	2.70	10.45	292.3	284.55	Unlined Well	Manual, Pump	A + D
184	Ambapara	Kalaji Charpota	293	11.02	10.43	1.90	9.00	291.1	284.0	Unlined Well	Pump	A
185	Ambapara	Revasingh Damor	293	13.03	11.17	2.00	9.50	291.0	283.5	Unlined Well	Manual, Pump	A + D
186	Kakarej	Khanu Gamod	297	8.06	9.25	2.00	8.06	295.0	288.94	Lined Well	Manual, Pulley, Pump	A + D
187	Kakarej	Harchand Bhuriya	296	10.20	14.15	2.50	3.00	293.5	293.0	Unlined Well	Manual, Pump	A + D
188	Kakarej	Mannu Gamod	296	10.01	10.80	2.60	8.00	293.4	288.0	Unlined Well	Manual, Pump	A + D

189	Devigarh	Mangu Bhuriya	300	8.57	9.30	1.90	7.60	298.1	292.4	Lined Well	Manual, Pump	A
190	Devigarh	Navalsingh Parmar	302	9.15	16.02	2.50	11.00	299.5	291.0	Unlined Well	Manual, Pump	A + D
191	Devigarh	Kevaliya Bamaniya	301	9.00	11.20	3.00	7.00	298.0	294.0	Unlined Well	Manual, Pump	A
192	Tikhirundi	Radhu Bhabhor	340	9.56	12.00	2.00	11.50	338.0	328.5	Lined Well	Manual, Pump	A
193	Tikhirundi	Narsingh Bhabhor	341	9.10	10.50	2.10	6.50	338.9	334.5	Lined Well	Manual, Pulley, Pump	A + D
194	Tikhirundi	Lulla Bhabhor	342	4.51	7.52	2.00	7.00	340.0	335.0	Lined Well	Manual, Pump	A + D
195	Junwaniya Chhota	Kaliya Muniya	318	6.20	7.30	2.00	5.00	316.0	313.0	Lined Well	Manual, Pump	A
196	Junwaniya Chhota	Khusal Muniya	320	8.50	6.59	2.10	4.50	317.9	315.5	Unlined Well	Manual, Pump	A + D
197	Junwaniya Chhota	Punjiya Muniya	321	10.00	7.30	2.00	5.00	319.0	316.0	Unlined Well	Manual, Pump	A

Abbreviations G.L. = Ground Level, A.M.S.L. = Above Mean Sea Level, Dia. **=** Diameter, B. G.L. = Below Ground Level,

A = Agriculture, D = Domestic / Drinking

Out of 197 examined dug wells, a total of 35 dug wells have been selected as observation wells (Figure 5.2, Table 5.2). The monitoring of seasonal ground water levels has been conducted with a view to study the variations in ground water levels during post-monsoon and pre-monsoon periods.

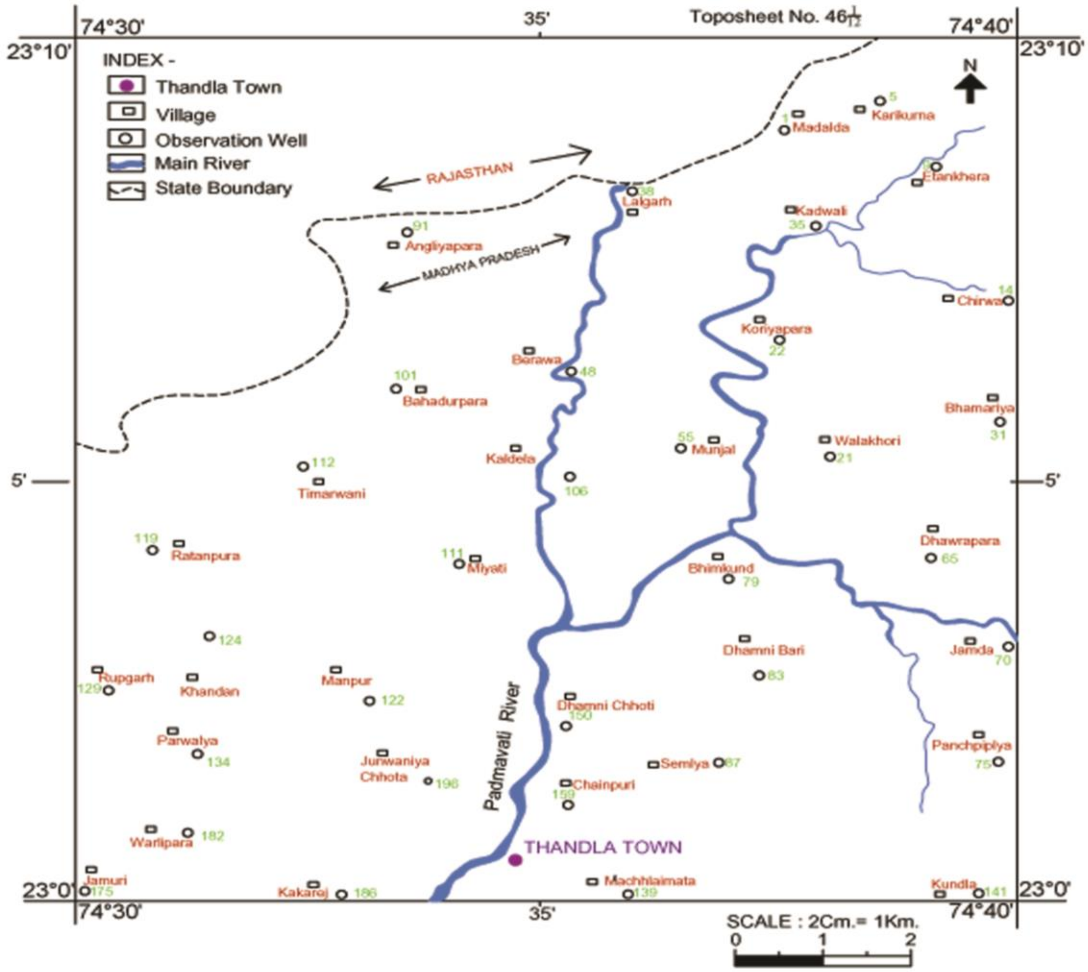


Figure 5.2 Location Map of Observation wells in Thandla area, Jhabua district.

The well inventory data includes, such as well diameter, total depth of well, static water level, location of well, name of owner and purpose are recorded (Table 5.1). The water level measurement in these well, were taken up during post-monsoon and pre-monsoon period to observe the variation in water level and study of movement of ground water by preparing water level contour map of different post-monsoon and pre-monsoon seasons. The present work has been limited to nature of shallow ground water régime, as bore holes data not available for analysis.

Table 5.2 Fluctuation of Ground water Levels in Thandla study area, Jhabua district, Madhya Pradesh.

S. No.	Well No.	Location	Ground level in m. (A.M.S.L.)	Static water level (m.) b.g.l.		Reduced water level (m.)		Fluctuation (m.)
				Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	
1	1	Madalda	411	1.80	4.50	409.2	406.5	2.7
2	5	Karikurna	420	1 .70	3.05	418.3	416.95	1.35
3	9	Etankhera	409	2.30	5.80	406.7	403.2	3.5
4	35	Kadwali	402	2.00	4.00	400.0	398.0	2.0
5	38	Lalgarh	400	1.90	5.02	398.1	394.98	3.12
6	91	Angliyapara	400	2.10	7.45	397.9	392.55	5.35
7	101	Bahadurpara	400	2.50	5.53	397.5	394.47	3.03
8	48	Berawa	350	2.70	9.40	347.3	340.6	6.7
9	22	Koriyapara	360	1.90	5.00	358.1	355.0	3.1
10	14	Chirwa	420	2.30	4.00	417.7	416.0	1.7
11	31	Bhamariya	380	2.70	4.07	377.3	375.93	1.37
12	21	Walakhori	360	2.00	9.05	358.0	350.95	7.05
13	55	Munjal	340	2.00	8.48	338.0	331.52	6.48
14	106	Kaldela	338	2.70	9.00	335.3	329.0	6.3
15	65	Dhawrapara	358	2.10	7.48	355.9	350.52	5.38
16	70	Jamda	340	1.90	3.55	338.1	336.45	1.65

17	75	Panchpiplya	364	2.10	8.05	361.9	355.95	5.95
18	79	Bhimkund	329	2.50	9.12	326.5	319.88	6.62
19	83	Dhamni Bari	360	2.10	8.49	357.9	351.51	6.39
20	150	Dhamni Chhoti	325	2.10	9.05	322.9	315.95	6.95
21	87	Semlya	337	2.00	6.05	335.0	330.95	4.05
22	141	Kundla	346	2.00	8.04	344.0	337.96	6.04
23	139	Machhlaimat a	308	2.00	9.00	306.0	299.0	7.0
24	159	Chainpuri	311	2.30	8.07	308.7	302.93	5.77
25	196	Junwaniya Chhota	320	2.10	4.50	317.9	315.5	2.4
26	186	Kakarej	297	2.00	8.06	295.0	288.94	6.06
27	119	Ratanpura	344	1.80	5.00	342.2	339.0	3.2
28	112	Timarwani	360	1.90	3.50	358.1	356.5	1.6
29	111	Miyati	328	2.20	8.40	325.8	319.6	6.2
30	124	Khandan	317	3.00	14.00	314.0	303.0	11.0
31	122	Manpur	322	2.50	8.50	319.5	313.5	6.0
32	134	Parwalya	298	2.10	7.50	295.9	290.5	5.4
33	182	Warlipara	287	2.60	6.00	284.4	281.0	3.4
34	175	Jamuri	300	2.70	4.00	297.3	296.0	1.3
35	129	Rupgarh	311	2.10	6.70	308.9	304.3	4.6

5.2.2 WELL DATA ANALYSIS

The relevant data collected in respect of 197 open dug wells a during periods of post-monsoon and pre-monsoon have been analyzed. The analysis of well data is recorded (Table 5.3).

(A) DIAMETER OF WELL

The analysis of diameter of well measurements indicate that 197 dug wells have a range from 4-16 m. (Table 5.3, Figure 5.3). Only 1 well is having a smallest diameter range of 4-5 m. at village of Tikhirundi and large diameter range of 15-16 m. is also represented by 1 well only at village of Naharpura. The majority of 60 wells are within the range of 8-9 m. indicating withdrawal of adequate water from the open dug wells existing in the Thandla study area.

Table 5.3 Diameter range of dug wells in Thandla area, Jhabua district, M. P.

S. No.	Range of diameter (m.)	Number of wells	Percentage (%)
1	4-5	1	0.50
2	5-6	2	1.01
3	6-7	17	8.62
4	7-8	41	20.81
5	8-9	60	30.45
6	9-10	27	13.70
7	10-11	23	11.67
8	11-12	14	7.10
9	12-13	7	3.55
10	13-14	3	1.52
11	14-15	1	0.50
12	15-16	1	0.50
	Total	**197**	**99.93%**

A **B**

Figure 5.3 (A) A view of large diameter dug well at Naharpura,Thandla.

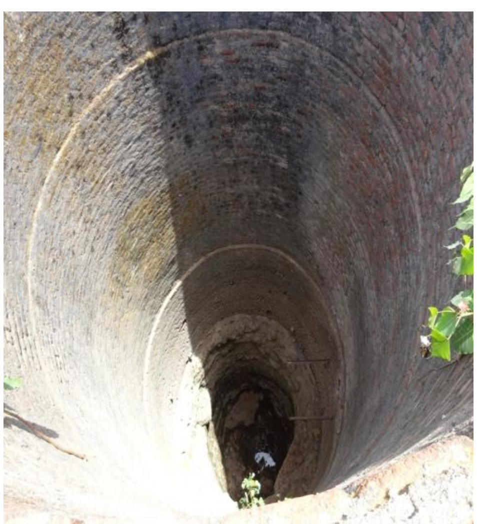
(B) A view of small diameter dug well at Tikhirundi, Thandla.

(B) TOTAL DEPTH OF WELL

The analysis of total depth of well measurements indicate that 197 dug wells have a range from 3-20 m.b.g.l. (Table 5.4, Figure 5.4). Only 1 well is having a smallest total depth of well range of 3-4 m.b.g.l. at village of Miyati and large diameter range of 19-20 m.b.g.l. is also represented by 1 well only at village of Khandan. The majority of 31 wells are within the range of 7-8 m.b.g.l. indicating withdrawal of adequate water from the dug wells in the Thandla study area.

Table 5.4 Total depth range of dug wells in Thandla area, Jhabua district, M. P.

S. No.	Range of total depth (m.) b. g. l.	Number of wells	Percentage (%)
1	3-4	1	0.5
2	4-5	5	2.53
3	5-6	17	8.62
4	6-7	23	11.67
5	7-8	31	15.73
6	8-9	26	13.19
7	9-10	27	13.70
8	10-11	20	10.15
9	11-12	10	5.07
10	12-13	16	8.12
11	13-14	5	2.53
12	14-15	10	5.07
13	15-16	1	0.50
14	16-17	3	1.52
15	17-18	1	0.50
16	18-19	-	-
17	19-20	1	0.50
	Total	**197**	**99.9%**



A

B

Figure 5.4 (A) A view of large depth of well at Khandan, Thandla.

(B) A view of small depth of well at Madalda, Thandla.

(C) STATIC WATER LEVEL

The static water levels have been measured in 197 open dug wells, in the study area during post-monsoon and pre-monsoon (Table 5.5). The static water level during post-monsoon varies from 1-4 m.b.g.l., out of which maximum number of 126 wells are indicating a range of 2-3 m.b.g.l. The maximum depth of static water levels has been observed in 12 wells within 3-4 m.b.g.l. The static water level during pre-monsoon varies from 2-15 m.b.g.l., out of which maximum number of 32 wells are indicating a range of 4-5 m.b.g.l. The maximum depth of static water levels has been observed in 62 wells within 4-6 m.b.g.l.

Table 5.5 Seasonal Static water level in wells of study area, Jhabua district, M. P.

S. No.	Range of static water level (m.) b.g.l.	Post-monsoon		Pre-monsoon	
		Number of wells	Percentage (%)	Number of wells	Percentage (%)
1	1-2	59	29.94	-	-
2	2-3	126	63.95	2	1.01
3	3-4	12	6.09	17	8.62
4	4-5	-	-	32	16.24
5	5-6	-	-	30	15.22
6	6-7	-	-	23	11.67
7	7-8	-	-	29	14.72
8	8-9	-	-	22	11.16
9	9-10	-	-	18	9.13
10	10-11	-	-	9	4.56
11	11-12	-	-	8	4.06
12	12-13	-	-	5	2.53
13	13-14	-	-	1	0.50
14	14-15	-	-	1	0.50
	Total	**197**	**99.98**	**197**	**99.92**

(D) WATER LEVEL FLUCTUATION

The fluctuation of ground water level of the study area calculated on the basis of data collected from the open dug wells during the period of post-monsoon and pre-monsoon. The maximum numbers of 10 wells reveal fluctuation of water level within the range of 6-7 m.b.g.l. The minimum fluctuation has been observed within range of 1-2 m.b.g.l. at villages of Karikurna, Chirwa, Bhamariya, Jamda, Timarwani and Jamuri. The highest fluctuation range of 11-12 m.b.g.l. has been noted in 1 well at Khandan village. The range of variation in ground water level have been recorded (Table 5.6, Figure 5.7).

Table 5.6 Fluctuation range of water level of study area, Jhabua district, M. P.

S. No.	Fluctuation range (m.)	Number of wells	Percentage (%)
1	1-2	6	17.14
2	2-3	3	8.57
3	3-4	6	17.14
4	4-5	2	5.71
5	5-6	5	14.28
6	6-7	10	28.57
7	7-8	2	5.71
8	8-9	-	-
9	9-10	-	-
10	10-11	-	-
11	11-12	1	2.85
	Total	**35**	**99.97%**

5.3 GROUND WATER LEVEL CONTOUR MAPS

The ground water level contour maps of Thandla area during post-monsoon and pre-monsoon periods have been constructed and described in the following text:

5.3.1 POST-MONSOON GROUND WATER LEVEL CONTOUR MAP

Post-monsoon ground water level contour map has been prepared on 2 cm = 1 km scale. The ground water level contour map of the study area has been prepared on the basis of the Reduced water level (Bench mark – Static water level). Ground water level contour map has been prepared by plotting reduced water level contours on the base map of study area. The area is mainly drained by Padmavati River, different direction of water flow is towards Padmavati River. Ground water flow direction has been marked, with the help of a symbol ‘arrow’, on the ground water level contour map (Figure 5.5).

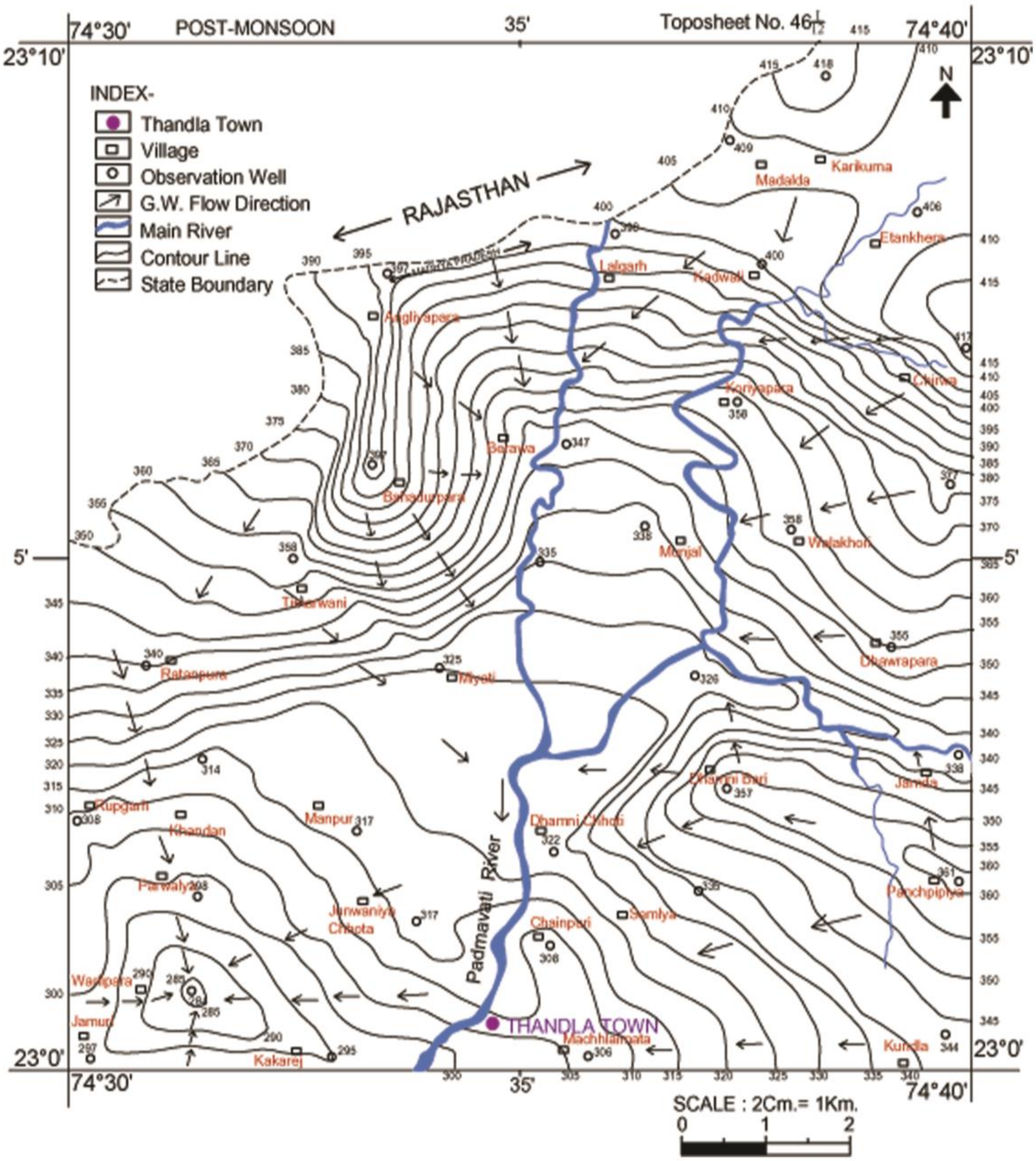


Figure 5.5 Post-monsoon ground water level contour map of Thandla study area.

The villages of Madalda, Karikurna, Etankhera, Munjal, Walakhori, Panchpiplya, Kundla, Dhamni Chhoti, Chainpuri, Semlya, Machhlaimata, Kakarej, Junwaniya Chhota, Warlipara, Parwalya, Khandan, Manpur, Rupgarh, Miyati, Ratanpura and Timarwani indicate widely spaced ground water level contours pointing out the favourable zone of ground water recharge.The water in dug wells yield rather inadequate quantity of water in several wells located at villages of Bahadurpara, Angliyapara, Berawa, Lalgarh, Kadwali, Koriyapara, and Chirwa.

5.3.2 PRE-MONSOON GROUND WATER LEVEL CONTOUR MAP

The Pre-monsoon contour levels are more or less similar to pattern, except at places namely Karikurna, Miyati, Junwaniya Chhota and Panchpiplya. In general, most of the wells indicates lowering of water levels during pre-monsoon period (Figure 5.6) as compared to post-monsoon period (Figure 5.5). The ground water levels in the area reveal fluctuation range from 1.3 (Jamuri) to 11.00 (Khandan) m.b.g.l. In the study area most of the wells located at Manpur, Khandan, Rupgarh, Prwalya, Warlipara, Jamuri, Kakarej, Miyati, Munjal, Panchpiplya, Dhamni Chhoti, Chainpuri, Machhlaimata, Kundla, Madalda, Karikurna, and Etankhera indicate fairly good yield of water in dug wells during even Pre-monsoon period . A few number of wells become dry during Pre-monsoon period at villages of Angliyapara, Bahadurpara, Kaldela, Lalgarh, Berawa, Koriyapara and Dhawrapara.

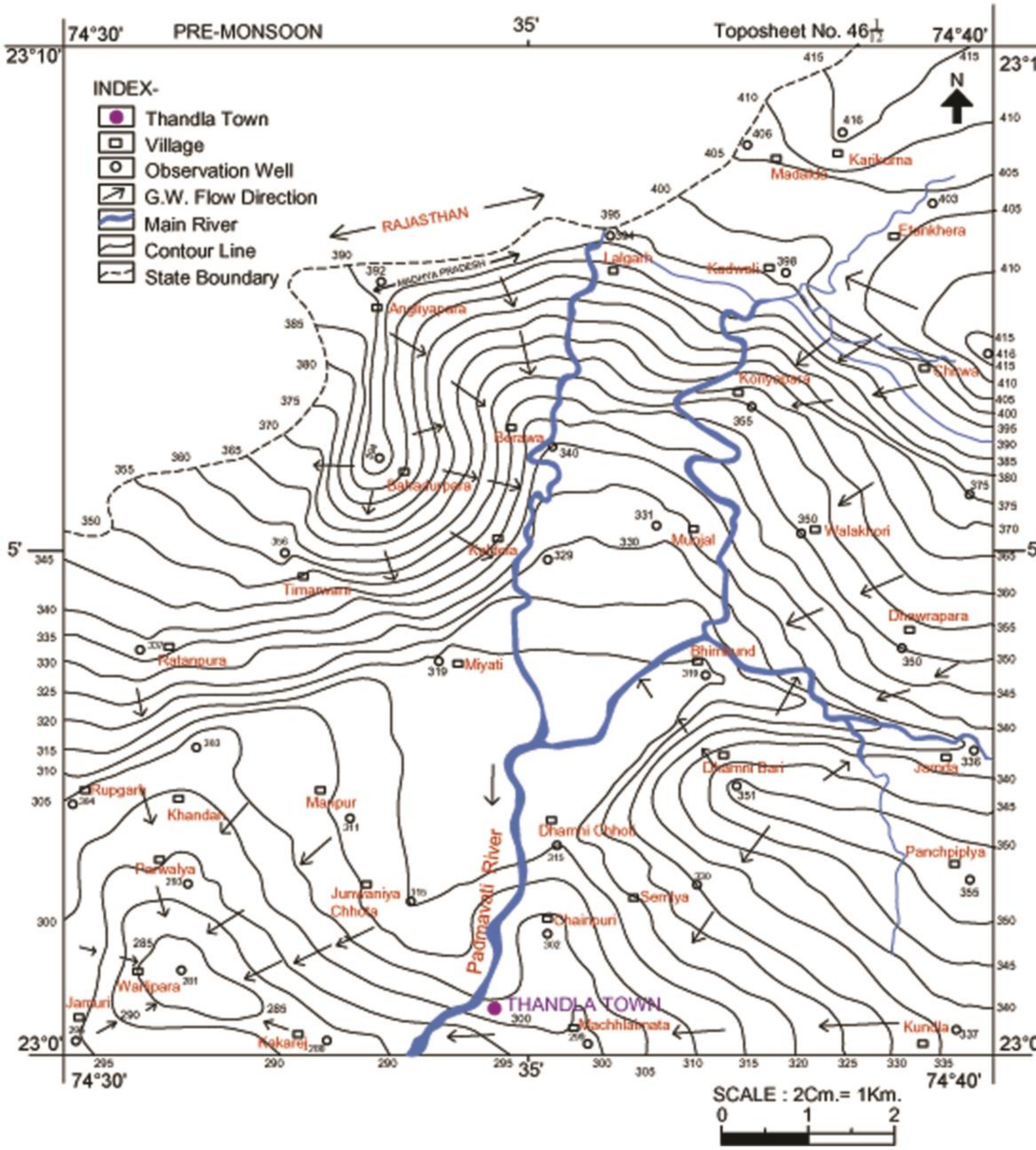


Figure 5.6 Pre-monsoon ground water level contour map of Thandla study area.

5.3.3 MONITORING OF SEASONAL GROUND WATER LEVELS

The monitoring of ground water levels in observation wells have been conducted during Post-monsoon and Pre-monsoon periods in Thandla study area. It has been observed that the water levels indicate a range from 1.3-11 m.b.g.l. during the period from Post-monsoon to Pre-monsoon. The minimum fluctuation range of 1-2 m. is indicating good yield of water in wells in vicinity of Karikurna, Chirwa, Bhamariya, Jamda, Timarwani and Jamuri. The maximum seasonal fluctuation of 11 m.b.g.l. has been recorded at Khandan is indicating the shortage of water supply and exhibits rather unsuitable prospects for construction of new dug wells in the study area. It is recommended that the dug wells in the study area may be further constructed up to a range of 07 m. fluctuation of water in dug wells (Figure 5.7).

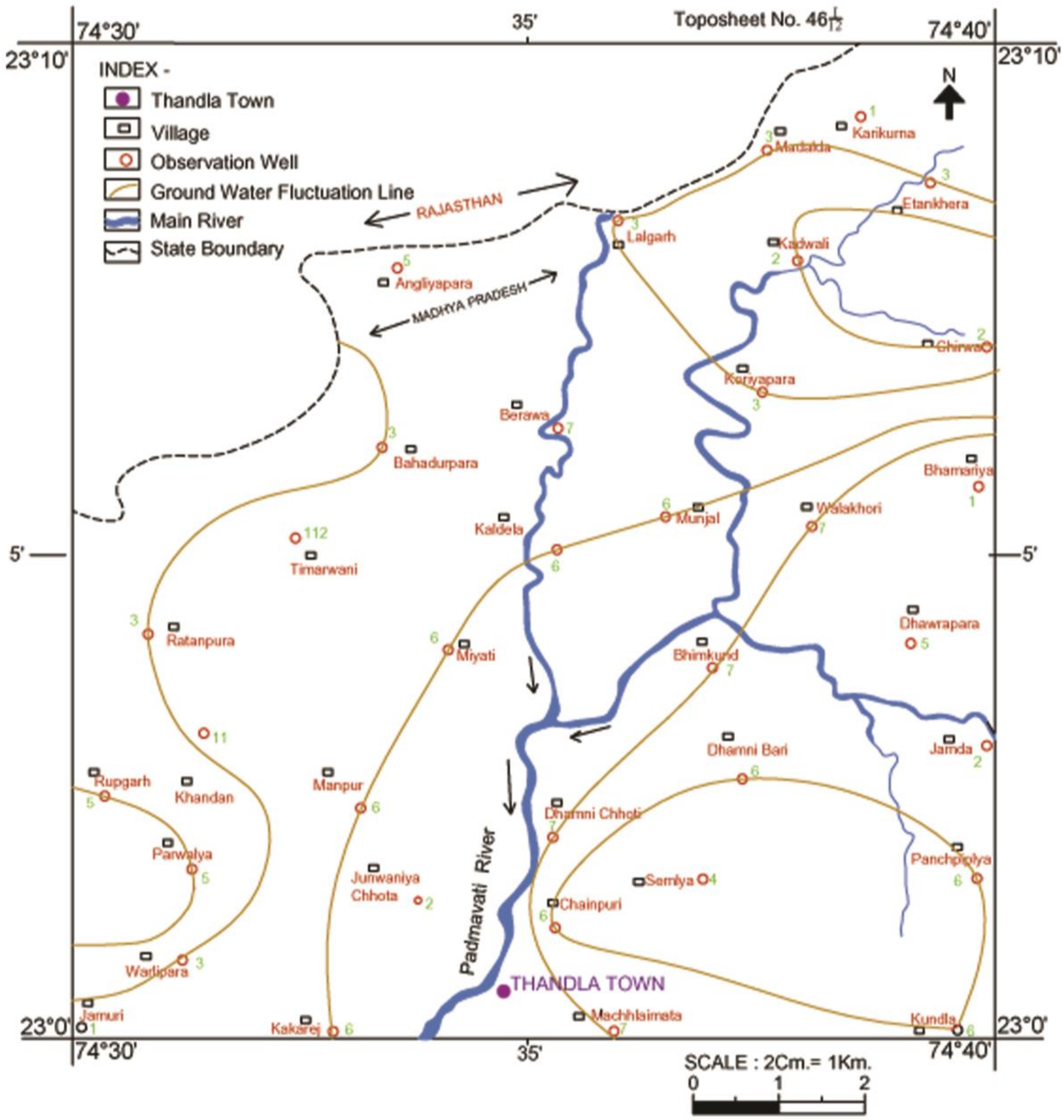


Figure 5.7 Fluctuation Map of Thandla area, Jhabua district, Madhya Pradesh.

5.4 GROUND WATER MOVEMENT

The ground water movement is through pore spaces or interstices of weathered, vesicular zones, fractured and jointed zone of basaltic lava flows mostly as laminar flow. Author has selected 35 open dug wells observed during post-monsoon and pre-monsoon period to observed trend of ground water flow based on the ground water level contour map (Figure 5.5 and Figure 5.6) prepared for monsoon period. Ground water moves from levels of higher energy to levels of lower energy, where by its energy is essentially the result of elevation and pressure. The direction of ground water flow has been exhibited by the symbol "arrow" on the ground water level contour maps. In general, the ground water movement in study area is towards the Padmavati River. The direction of ground water movements are determined by drawing perpendicular lines from higher ground water contour levels to lower ground water contour levels, which point out effluent nature of Padmavati River, i.e. ground water movement is towards the Padmavati River.

CHAPTER – 6

GROUND WATER QUALITY ESTIMATION

6.1 CONCEPT OF CHEMICAL QUALITY

Ground water quality demarcation by chemical analysis constitutes the subject matter of Hydro-geochemistry. Chemical composition of ground water is subjective to soluble product of rock weathering and changes with respect to time space. Concentrations of dissolved elements in water are helpful to estimate suitability of water for diverse applications, such as domestic, drinking, industry, agriculture and irrigation. Chemical analysis is to be carried out with accuracy with a view to find out ground water quality. Todd (1980, 2010) recognized that in order to set up quality criteria, procedures of chemical, physical, biological and radiological constituents should be precise and standard techniques for reporting and comparing the results of water analysis.

Charlu and Dutt (1982) remarked that physical and chemical exchanges of ground water result into solubility of a majority of minerals of parent rock in ground water system. Mineral content increases in ground water as it moves along until a balanced or equilibrium of the dissolved substances is obtained. According to Karanth (2003) ground water usability is determined by its physical, chemical, and bacteriological properties. Ground water quality envisages field observation regarding the source and environment of ground water occurrence, source, pollution and other related aspects are effecting the quality of ground water. Some of the properties such as temperature and p^H have to be recorded in the field.

6.2 GROUND WATER CHEMICAL ANALYSIS

Chemical quality assessment has been established on the basis of selected 30 ground water samples of Thandla study area. Location and number of samples have been marked on plastic bottles used for collecting ground water from existing dug wells in the study area. Ground water samples have been analyzed in laboratory.

Determination of physical analysis involves Colour, Odour, Taste, p^H (Hydrogen ion concentration), Turbidity, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Hardness (TH), and Alkalinity. Chemical analysis determines Cations (Ca, Mg, Na, K) and Anions (Cl^-, SO_4^-, CO_3^-, HCO_3^-, NO_3^-, F^-). The estimations of present Sodium and Sodium Adsorption Ratio (SAR) have been calculated for assessment of suitability of water for agricultural and irrigation applications.

6.2.1 GROUND WATER SAMPLES COLLECTION

Method of ground water samples collection is based on the ground water quality requirements. The general process of water samples collection considered the following: (a) Selection of sampling sit, (b) Frequency sampling, (c) Equipment of sampling, and (d) Instruction for sampling.

The common method of collection of water samples has been followed in the study. The processor of sample collection proposed by Rainwater and Thatcher (1968) has been fevered on the basis of hydrogeological data and delineation of chemical composition of ground water samples.

The collection of water samples has been conducted by selecting sites in the study area. The samples have been taking in plastic bottles of 1 liter capacity. The bottles were rinsed before sampling and tightly sealed after the collection of water. The labels indicating location of sample site, type of well, number of water sample and date of collection have been pasted on the respective bottles. The sampling bottles were placed in a container and transported to the laboratory for chemical analysis. The locations of sampling sites of dug wells have displayed (figure 6.1 and 6.2).

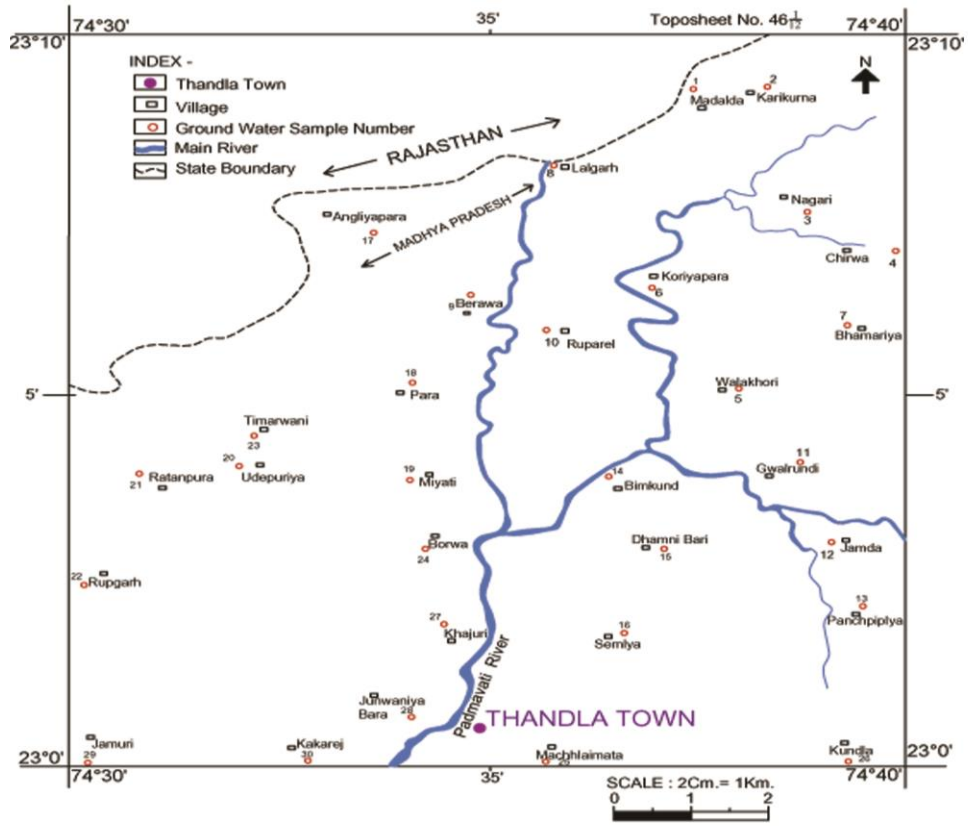


Figure 6.1 Location of ground water samples from Thandla study area, Jhabua.

Figure 6.2 A view of photograph exhibiting collection of water sample from open dug well near Panchpipalya village, Thandla study area, Jhabua district.

6.2.2 METHODS OF CHEMICAL ANALYSIS

The chemical analysis data are represented by tabular and graphic methods of data display. The methods adopted by various workers for chemical treatment of quality evaluation have been employed in the present research study. The methods suggested by Richards (1954), U. S. Salinity Staff (1954), Wilcox (1955), Todd (1959, 1980, 2010), Rainwater and Thatcher (1968), Wellborn and Skinner (1968), Brown *et.al.* (1970), Walton (1970), Montgomery and Hart (1974), I.C.M.R. (1975), Clark *et.al.* (1977), A.P.H.A. (1980, 1998, 2005), Raghunath (1982, 1985), Wilson (1982), B.I.S. (1983, 1991), W.H.O. (1984, 1993, 1994, 2004, 2011, 2012), Fetter (1988, 1990), Singhal and Gupta (1999), Karanth (2003), Gupta (2005) and others.

6.3 PHYSICAL AND CHEMICAL ANALYSIS OF GROUND WATER

The physical and chemical analysis of 30 ground water samples have been conducted in laboratory by adopting standard chemical analysis. The results of analysis are recorded in the following text:

6.3.1 PHYSICAL CHARACTERSTICS OF GROUND WATER

The physical characteristics of ground water samples include detection of Colour, Odour, Taste, Turbidity, Hydrogen ion concentration (p^H), Electrical Conductivity (EC), and Total Dissolved Solids (TDS) have been determined and described (Table 6.1).

- **Colour**

The water is generally colourless. The colour in water may be due to presence of due to inorganic ions and manganese, humus and peat, planktons and industrial wastes. In the present study, all the ground water samples are colourless (Table 6.1).

- **Odour**

It is a typical factor that affect quality suitability of drinking water. A good number of organic and a few inorganic chemicals also affect odour. These chemicals generate from natural, municipal and industrial wastes. All the analyzed ground water samples are odourless (Table 6.1).

- **Taste**

Taste of ground water samples is due to presence of higher concentration of acidic and alkaline salts, organic and toxic materials. All examined samples of ground water are tasteless (Table 6.1).

- **Hydrogen ion concentration**

Hydrogen ion concentration (p^H) has been referred to effective concentration (activity) of hydrogen ions in water. It is expressed as negative logarithm (base 10) of the H^+ activity in mol/l. At a p^H of 7 the H^+ activity is 10^{-7} mol/l. and the solution is considered natural. When the p^H is less than 7, the solution behaves as an acid, particularly below (p^{H4}). Above p^H of 7, the solution reacts like a base. Most of natural waters are within a p^H range from 6 to 8.5 (Hem, 1970, *vide etiam,* Nagabhushaniah, 2001).

In present study area, the p^H value of water samples have been determined. These determined values of p^H record a range of 7.05 (Nagari village) and 8.30 (Dhamni Bari village) and the rest of the water samples p^H are within the permissible range of 6.5 to 9.2 (W.H.O., 1993, 2004, 2011) indicating that water is safe for drinking application (Table 6.1).

- **Turbidity**

Turbidity of ground water, generally expressed in terms of reduced light transmission by the water or as suspended solids contents, is principally caused by clay, silt and other fine materials that enter the well from aquifer (Nagabhushaniah, 2001). Turbidity is measured in laboratory by the Turbidity meter (Garg, 1979).

In Thandla study area, the turbidity values are ranging from 0.89 (Bhimkund village) to 4.91 (Karikurna village) and recorded (Table 6.1).

- **Total Dissolved Solids**

Absorption of total dissolved solids (TDS) in water is expressed by weight of the material on evaporation of water to dryness, which is followed by heating for one hour at 180^0 C.

Desirable limit 500 ppm and permissible limit 1500 ppm of T.D.S. is recommended by World Health Organization (W.H.O.; 1993, 2004, 2011).

Aravindan *et.al.*(2004) remarked that higher content of TDS are attributed to contribution of salts from the thick mantle of soil and weathered media of the rock and there can be some oxidation and reduction processes during winter and summer, thereby also causing enrichment in total dissolved solids. Devis and De Wiest (1966) stated that high TDS value has adverse impact on biomass.

In Thandla study area, determined values of total dissolved solids have being recorded. Total dissolved solids values reveal a minimum of 275 mg/1 (Angliyapara village) and maximum of 481 mg/1 in (Borwa village) rest samples are under permissible limits. All samples are having T.D.S. values below the desirable limit of 500 mg/l (Table 6.1).

- **Electrical Conductivity**

Electrical conductivity (EC) has been described as conductance of a cubic centimeter of water at a standard temperature of $25\ ^0$ C, an increase of 1^0 C increases conductance by about 2 percent (Todd, 1959, 1980, 2010). Electrical conductivity is also known as Specific conductance and measured in µS/cm (microsiemens/cm).

In Thandla study area, determined Electrical conductivity values range from 307 (Berawa village) to 600 (Kakarej village) mohos/cm . World Health Organization (W.H.O.,1993, 2004, 2011) has recommended the desirable limit of E.C. as 1400 µS/cm (microsiemens/cm). In study area the determined values of E.C. are in recommended limits (Table 6.1).

- **Total Hardness**

Total Hardness (TH) results from presence of divalent metallic cations, of which Calcium and Magnesium are most plentiful in ground water. These ions react with soap to form precipitates and with certain anions present in water to form scale. Because of their adverse action with soap, hard water are unsuitable for household cleansing purposes, hence water-softening processes for removal of hardness are required (Todd, 1959, 1980, 2010).

In Thandla study area, the values hardness are determined and described. Its minimum value 230 ppm (Chirwa village) and maximum 340 ppm (Junwaniya Bara village) and rest samples are under the permissible limits (Table 6.1).

- **Alkalinity**

Alkalinity is capacity of water to neutralize acid. It is produced by carbonate and bicarbonate ions expressed as equivalent concentration of $CaCo_3$ mg/1 (Nagabhushaniah, 2001). In Thandla study area ground water samples indicate a range of alkalinity from 132 (Angliyapara village) to 198 (Koriyapara village) (Table 6.1).

Table 6.1 Determination of physical parameters of ground water samples from in study area, Jhabua district, M. P.

Location	Sample No.	Colour	Odour	Taste	pH	Turbidity	T.D.S.	E.C.	T.H.	Alkalinity
Madalda	1	CL	OL	TL	7.31	4.50	468	349	295	180
Karikurna	2	CL	OL	TL	7.85	4.91	310	418	270	190
Nagari	3	CL	OL	TL	7.05	3.10	390	340	251	195
Chirwa	4	CL	OL	TL	7.83	4.20	480	549	230	197
Walakhori	5	CL	OL	TL	7.92	2.05	430	472	286	182
Koriyapara	6	CL	OL	TL	7.51	3.70	395	401	301	198
Bhamariya	7	CL	OL	TL	7.41	1.95	420	429	295	189
Lalgarh	8	CL	OL	TL	8.02	2.80	290	412	275	185
Berawa	9	CL	OL	TL	7.81	3.40	435	307	261	192
Ruparel	10	CL	OL	TL	7.60	0.95	407	449	272	183
Gwalrundi	11	CL	OL	TL	8.03	1.20	370	420	305	162
Jamda	12	CL	OL	TL	7.61	2.86	295	517	256	168
Panchpiplya	13	CL	OL	TL	7.86	3.02	300	430	265	180
Bhimkund	14	CL	OL	TL	7.83	0.89	315	318	285	190
Dhamni Bari	15	CL	OL	TL	8.30	1.85	302	338	279	135
Semlya	16	CL	OL	TL	7.95	3.50	410	362	266	138
Angliyapara	17	CL	OL	TL	7.21	3.30	275	410	286	132

Para	18	CL	OL	TL	7.87	4.25	367	540	310	180
Miyati	19	CL	OL	TL	7.88	2.80	400	590	258	172
Udepuriya	20	CL	OL	TL	7.62	2.40	290	470	320	189
Ratanpura	21	CL	OL	TL	7.30	3.25	325	345	295	132
Rupgarh	22	CL	OL	TL	7.70	3.47	340	420	331	145
Timarwani	23	CL	OL	TL	7.56	2.95	460	330	287	148
Borwa	24	CL	OL	TL	7.36	2.80	481	560	275	190
Machhlaimata	25	CL	OL	TL	8.20	3.75	376	480	240	197
Kundla	26	CL	OL	TL	7.11	4.20	285	481	270	198
Khajuri	27	CL	OL	TL	7.90	0.90	345	455	290	167
Junwaniya Bara	28	CL	OL	TL	8.0	2.78	363	430	340	161
Jamuri	29	CL	OL	TL	7.15	3.05	435	330	295	167
Kakarej	30	CL	OL	TL	7.65	4.32	416	600	280	180

Abbreviations - CL = Colourless, OL = Odourless, TL = Tasteless, T.D.S. = Total Dissolved Solids, E.C. = Electrical Conductivity, T.H. = Total Hardness.

6.3.2 CHEMICAL CHARACTERSTICS OF GROUND WATER

Ionic parameters such as Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl^-), Sulfate (SO_4^-), Carbonate (CO_3^-), Bi-carbonate (HCO_3^-), Nitrate (NO_3^-), Fluoride (F^-) and others, have been determined and the values are recorded (Table 6.2). Values of different element measured in part per million (ppm) have been converted to equivalent per million (epm) and are displayed (Table 6.3).

CHARACTERSTICS OF CHEMICAL PARAMETERS
Calcium (Ca) - Calcium is most common element in ground water generally due to its large abundance and high soluble nature. Its main source is the presence of some members of silicates mineral groups (plagioclase, pyroxene, and amphibole). Silicate minerals are insoluble in water but due to weathering it gets break down the minerals into soluble calcium products and clay minerals. Carbonates and sulphates of calcium, are soluble in nature and rarely chloride. Recommended range is 75 to 200 ppm.
Magnesium (Mg) - In general, ground water contains relatively small amounts of magnesium. In igneous rock, it occurs as dark coloured micas, and amphiboles. In metamorphic and other altered rock it occurs like chlorite, and montmorillonite. It occurs in sedimentary rocks as magnetite. Dolomite contains calcium and magnesium (Nagabhushaniah, 2001). Commonly, less than 50 mg / l, ocean water contains more than 1000 mg / l, and brines contain 57, 000 mg / l (Todd, 1980).
Sodium (Na) - Sodium is derived from igneous rock. Generally, sodium occurs less than 200 mg / l; about 10,000 mg / l in seawater; about 25,000 mg / l in brines.
Potassium (K) - In igneous rocks, potassium is less common than sodium, and more abundant in sedimentary rocks as potassium feldspars. In general, less than 10 mg / l to 100 mg / l in hot springs, and 25,000 mg / l in brines (Nagabhushaniah, 2001; Todd, 1980).
Chloride (Cl^-) - Sources of chloride in ground water are evaporites, salty connate water,

and marine water. Igneous rocks add modest chloride. Ground water containing important amounts of chloride also tend to have high amounts of sodium, indicating prospects of contact with water of marine origin. Generally**,** less than 10 mg/l in humid regions, up to 1000 mg / l in arid regions, about 19,300 mg/l in seawater; and up to 200,000 mg/l in brines
Sulfate (SO_4^-) - Sulfate is formed by oxidation of pyrite and other sulfides widely distributed in igneous and sedimentary rocks. Most important sulfate deposits are observed in evaporite leaching sediments (gypsum, anhydrite, sodium sulfate). Sulfate concentration in drinking water is desirable up to 250 mg / l. Normally less than 300 mg / l sulfate occur in wells influenced by acid mine drainage, and 200,000 mg / l in some brines
Carbonate (CO_3^-) - Carbonate and bi-carbonate sources include Co_2 from atmosphere and soil also contributes to some extent. Sodium carbonate can accumulate as evaporite in closed basins, causing high carbonate levels in ground water. Carbonate concentrations in ground water are usually less than 10 mg / l. Water high in sodium may contain as much as 50 mg / l of carbonate.
Bicarbonate (HCO_3^-) - Bicarbonate concentration of more than 200 mg / l is common in ground water, and higher concentration can occur where Co_2 is produced within the aquifer. Generally HCO_3^- - ranges up to less than 500 mg / l, may exceed 1000 mg / l in water highly charged with carbon dioxide.
Nitrate (NO_3^-) - Nitrogen is a minor constituent of rocks, but is a major constituent of atmosphere. Nitrogen and oxygen of atmosphere are combined by electrical discharge during lightning, and dissolve in rain water. Average nitrate content in rain water is reported as 0.2 ppm (Riffenburg, 1926, *vide etiam*, Karanth, 2003).
Fluoride (F^-) - Sources of fluoride in ground water are minerals like calcium fluoride, apatite, cryolite (in igneous rocks), fluoraspar (in sedimentary rocks) and so on. Ground water with more than 1 mg / l of fluoride are often found. High concentrations tend to be associated with a high p^H. Some fluorine in drinking water is beneficial because it reduces tooth decay. At higher levels, however, mottling of the teeth (fluorous) occurs. Hence, fluorine concentration is recommended for drinking water ranges from 1.4 to 2.4 mg/l depending on how much water is ingested. (Nagabhushaniah, 2001).

Table 6.2 Chemical parameters determined in ground water samples of study area, Jhabua district, M. P. (Values expressed in ppm).

Location	Sample No.	Concentration of Cation				Concentration of Anion					
		Ca	Mg	Na	K	Cl^-	SO_4^-	CO_3^-	HCO_3^-	NO_3^-	F^-
Madalda	1	115	147	28	1.10	110	69	-	122	28	0.70
Karikurna	2	120	130	37	1.70	98	110	-	235	21	0.20
Nagari	3	95	98	30	2.30	170	125	-	146	27	0.80
Chirwa	4	170	76	37	1.80	120	70	-	122	35	0.75
Walakhori	5	195	81	32	3.60	165	78	-	134	40	0.67
Koriyapara	6	185	135	22	3.40	181	180	-	165	45	0.81
Bhamariya	7	137	122	44	1.20	132	178	-	170	50	0.25
Lalgarh	8	200	136	23	0.30	192	195	-	130	41	0.60
Berawa	9	187	120	45	0.70	215	138	-	146	42	0.95
Ruparel	10	125	67	36	1.20	195	169	-	207	40	0.30
Gwalrundi	11	89	78	47	1.35	117	68	-	150	30	0.40
Jamda	12	175	95	38	2.30	138	125	-	208	38	0.50
Panchpiplya	13	181	137	50	1.95	162	126	-	190	35	0.80
Bhimkund	14	198	85	48	1.50	186	175	-	185	27	0.65
Dhamni Bari	15	177	110	35	1.70	230	190	-	178	38	0.20
Semlya	16	185	127	54	1.85	118	150	-	145	41	0.35

Angliyapara	17	155	135	30	1.65	120	76	-	160	36	0.40
Para	18	187	65	29	3.25	181	139	-	155	28	0.36
Miyati	19	190	69	51	2.50	215	128	-	205	31	4.00
Udepuriya	20	170	123	37	1.20	220	121	-	190	29	1.21
Ratanpura	21	178	118	30	1.15	97	148	-	130	26	1.13
Rupgarh	22	186	139	41	1.80	138	136	-	195	32	2.30
Timarwani	23	198	63	35	1.40	157	117	-	210	37	3.70
Borwa	24	115	138	55	2.05	172	98	-	200	40	3.60
Machhlaimata	25	135	140	58	2.10	235	117	-	170	35	0.35
Kundla	26	147	147	25	1.55	156	68	-	120	31	0.71
Khajuri	27	150	95	60	1.40	240	182	-	135	28	0.25
Junwaniya Bara	28	181	91	45	1.85	198	110	-	140	34	0.37
Jamuri	29	195	128	48	1.90	170	87	-	185	30	0.30
Kakarej	30	180	116	40	1.50	150	93	-	180	38	0.28

Abbreviations - Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, Cl^- = Chloride, SO_4^- = Sulfate, CO_3^- = Carbonate, HCO_3^- = Bi-Carbonate, NO_3^- = Nitrate, F^- = Fluoride.

Table 6.3 Determination of chemical parameters in ground water samples of Thandla study area , Jhabua district, Madhya Pradesh (Values expressed in epm).

Location	Sample No.	Concentration of Cation				Total of Cation	Concentration of Anion				Total of Anion
		Ca	Mg	Na	K		Cl^-	SO_4^-	CO_3^-	HCO_3^-	
Madalda	1	5.738	12.092	1.218	0.028	19.076	3.103	1.436	-	1.999	6.538
Karikurna	2	5.988	10.693	1.609	0.043	18.333	2.764	2.290	-	3.851	8.905
Nagari	3	4.740	8.061	1.305	0.058	14.164	4.795	2.602	-	2.392	9.789
Chirwa	4	8.483	6.251	1.609	0.046	16.389	3.385	1.457	-	1.999	6.841
Walakhori	5	9.730	6.663	1.392	0.092	17.877	4.654	1.623	-	2.196	8.473
Koriyapara	6	9.231	11.105	0.957	0.086	21.379	5.106	3.747	-	2.704	11.557
Bhamariya	7	6.836	10.035	1.914	0.030	18.815	3.723	3.705	-	2.786	10.214
Lalgarh	8	9.98	11.187	1.000	0.007	22.174	5.416	4.059	-	2.130	11.605
Berawa	9	9.331	9.871	1.957	0.017	21.176	6.065	2.873	-	2.392	11.33
Ruparel	10	6.237	5.511	1.566	0.030	13.344	5.500	3.518	-	3.392	12.41
Gwalrundi	11	4.441	6.416	2.044	0.034	12.935	3.300	1.415	-	2.458	7.173
Jamda	12	8.732	7.814	1.653	0.058	18.257	3.892	2.602	-	3.409	9.903
Panchpiplya	13	9.031	11.269	2.175	0.049	22.524	4.570	2.623	-	3.114	10.307
Bhimkund	14	9.880	6.992	2.088	0.038	18.998	5.247	3.643	-	3.032	11.922
Dhamni Bari	15	8.832	9.048	1.522	0.043	19.445	6.488	3.955	-	2.917	13.36
Semlya	16	9.231	10.447	2.349	0.047	22.074	3.328	3.123	-	2.376	8.827

Angliyapara	17	7.734	11.105	1.305	0.042	20.186	3.385	1.582	-	2.622	7.589
Para	18	9.331	5.346	1.261	0.083	16.021	5.106	2.893	-	2.540	10.539
Miyati	19	9.481	5.675	2.218	0.063	17.437	6.065	2.664	-	3.359	12.088
Udepuriya	20	8.483	10.117	1.609	0.030	20.239	6.206	2.519	-	3.114	11.839
Ratanpura	21	8.882	9.706	1.305	0.029	19.922	2.736	3.081	-	2.130	7.947
Rupgarh	22	9.281	11.434	1.783	0.046	22.544	3.892	2.831	-	3.196	9.919
Timarwani	23	9.880	5.182	1.522	0.035	16.619	4.428	2.435	-	3.441	10.304
Borwa	24	5.738	11.351	2.392	0.052	19.533	4.852	2.040	-	3.278	10.17
Machhlaimata	25	6.736	11.516	2.523	0.053	20.828	6.629	2.435	-	2.786	11.85
Kundla	26	7.335	12.092	1.087	0.039	20.553	4.400	1.415	-	1.966	7.781
Khajuri	27	7.485	7.814	2.61	0.035	17.944	6.770	3.789	-	2.212	12.771
Junwaniya Bara	28	9.031	7.485	1.957	0.047	18.52	5.585	2.290	-	2.294	10.169
Jamuri	29	9.730	10.529	2.088	0.048	22.395	4.795	1.811	-	3.032	9.638
Kakarej	30	8.982	9.542	1.74	0.038	20.302	4.231	1.936	-	2.950	9.117

Abbreviations - Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, Cl^- = Chloride, SO_4^- = Sulfate, CO_3^- = Carbonate, HCO_3^- = Bi-Carbonate.

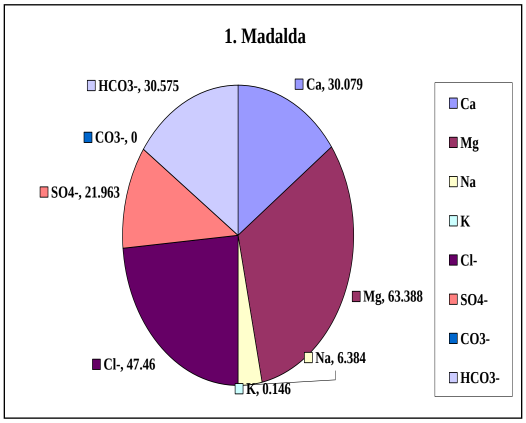
Table 6.4 Determination of chemical parameters of ground water samples of Thandla area, Jhabua district, Madhya Pradesh (Values expressed in percentage (%) epm).

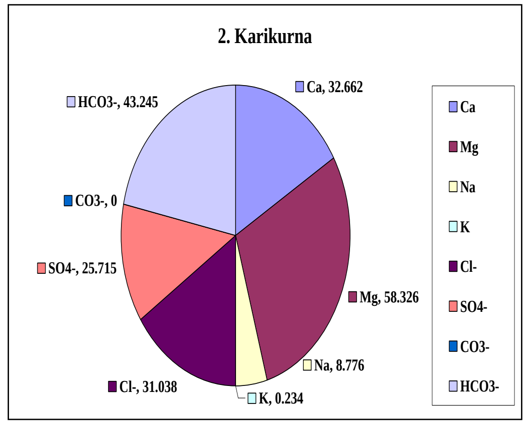
Location	Sample No.	Concentration of Cation				Concentration of Anion			
		Ca	Mg	Na	K	Cl^-	SO_4^-	CO_3^-	HCO_3^-
Madalda	1	30.079	63.388	6.384	0.146	47.460	21.963	-	30.575
Karikurna	2	32.662	58.326	8.776	0.234	31.038	25.715	-	43.245
Nagari	3	33.465	56.911	9.213	0.409	48.983	26.580	-	24.435
Chirwa	4	51.760	38.141	9.817	0.280	49.481	21.298	-	29.220
Walakhori	5	54.427	37.271	7.786	0.514	54.927	19.154	-	25.917
Koriyapara	6	43.177	51.943	4.476	0.402	44.181	32.421	-	23.397
Bhamariya	7	36.332	53.335	10.172	0.159	36.449	36.273	-	27.276
Lalgarh	8	45.007	50.450	4.509	0.031	46.669	34.976	-	18.354
Berawa	9	44.064	46.614	9.241	0.080	53.530	25.357	-	21.112
Ruparel	10	46.740	41.299	11.735	0.224	44.319	28.348	-	27.332
Gwalrundi	11	34.333	49.601	15.802	0.262	46.005	19.726	-	34.267
Jamda	12	47.828	42.800	9.054	0.317	39.301	26.274	-	34.423
Panchpiplya	13	40.095	50.031	9.656	0.217	44.338	25.448	-	30.212
Bhimkund	14	52.005	36.803	10.990	0.200	44.011	30.556	-	25.431
Dhamni Bari	15	45.420	46.531	7.827	0.221	48.562	29.603	-	21.833
Semlya	16	41.818	47.327	10.641	0.212	37.702	35.380	-	26.917
Angliyapara	17	38.313	55.013	6.464	0.208	44.604	20.845	-	34.550

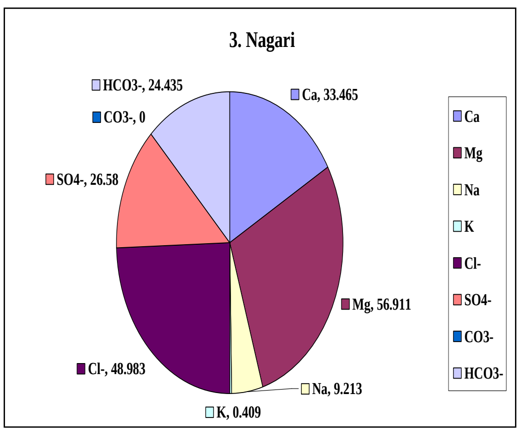
Para	18	58.242	33.368	7.870	0.518	48.448	27.450	-	24.100
Miyati	19	54.372	32.545	12.720	0.361	50.173	22.038	-	27.787
Udepuriya	20	41.914	49.987	7.949	0.148	52.419	21.277	-	26.302
Ratanpura	21	44.583	48.720	6.550	0.145	34.428	38.769	-	26.802
Rupgarh	22	41.168	50.718	7.908	0.204	39.237	28.541	-	32.220
Timarwani	23	59.450	31.181	9.158	0.210	42.973	23.631	-	33.394
Borwa	24	29.375	58.111	12.245	0.266	47.708	20.058	-	32.232
Machhlaimata	25	32.341	55.290	12.113	0.254	55.940	20.548	-	23.510
Kundla	26	35.688	58.833	5.288	0.189	56.548	18.185	-	25.266
Khajuri	27	41.713	43.546	14.545	0.195	53.010	29.668	-	17.320
Junwaniya Bara	28	48.763	40.415	10.566	0.253	54.921	22.519	-	22.558
Jamuri	29	43.447	47.014	9.323	0.214	49.750	18.790	-	31.458
Kakarej	30	44.241	47.000	8.570	0.187	46.407	21.235	-	32.357

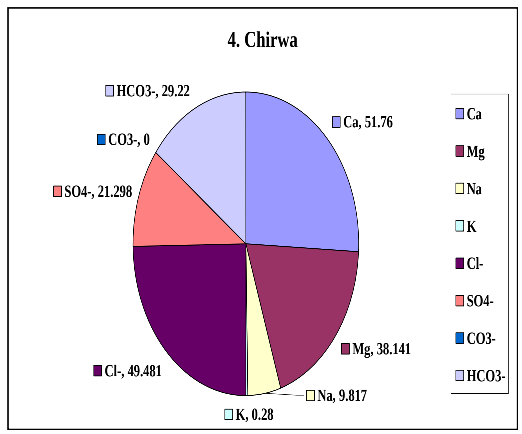
Abbreviations - Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, Cl^- = Chloride, SO_4^- = Sulfate, CO_3^- = Carbonate, HCO_3^- = Bi-Carbonate.

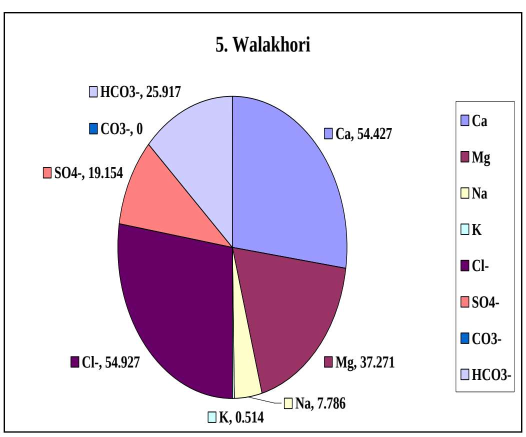
6.3.3 GRAPHIC REPRESENTATION OF IONIC CONCENTRATION OF GROUND WATER SAMPLES

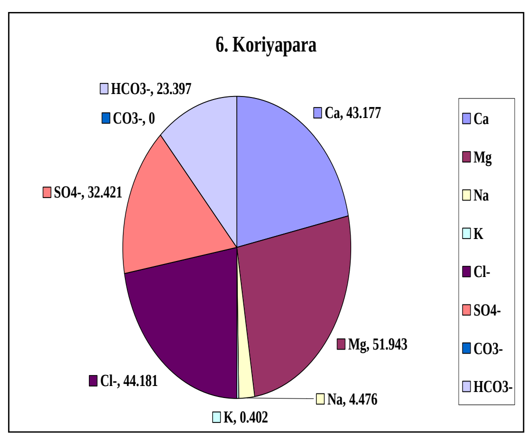


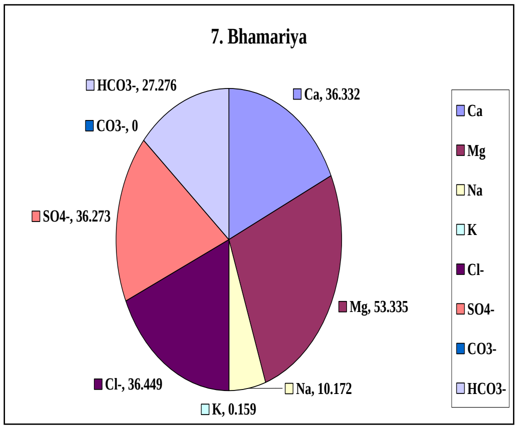











7. Bhamariya
HCO3-, 27.276
CO3-, 0
SO4-, 36.273
Cl-, 36.449
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Mg, 53.335
Ca, 36.332
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K
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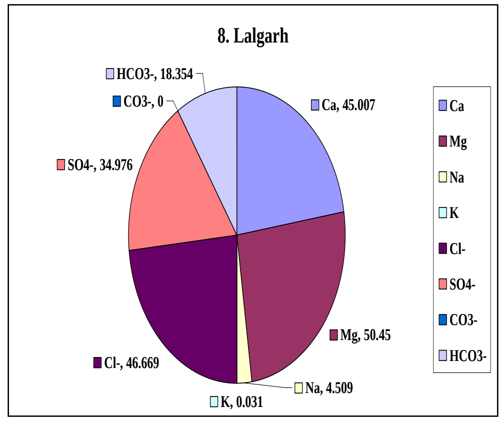
CO3-
HCO3-


8. Lalgarh
HCO3-, 18.354
CO3-, 0
SO4-, 34.976
Cl-, 46.669
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Ca, 45.007
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Mg
Na
K
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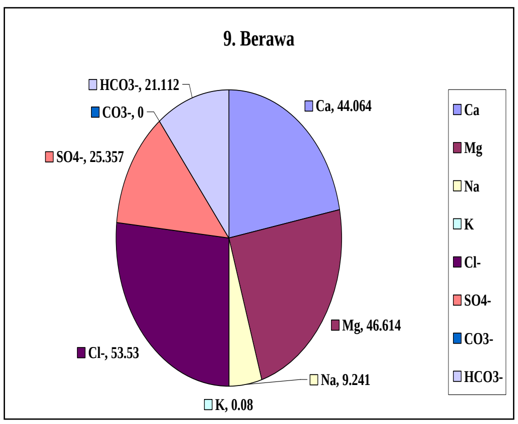
CO3-
HCO3-


9. Berawa
HCO3-, 21.112
CO3-, 0
SO4-, 25.357
Cl-, 53.53
K, 0.08
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Ca, 44.064
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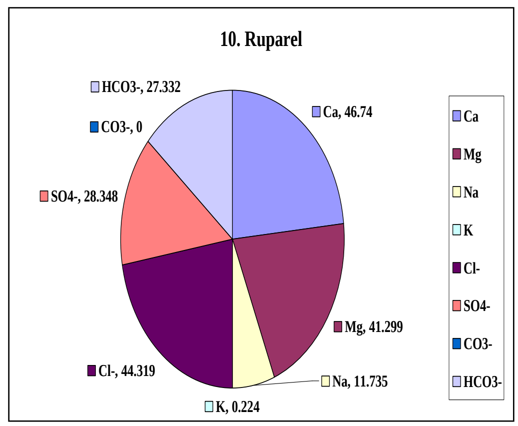
K
Cl-
SO4-
CO3-
HCO3-


10. Ruparel
HCO3-, 27.332
CO3-, 0
SO4-, 28.348
Cl-, 44.319
K, 0.224
Na, 11.735
Mg, 41.299
Ca, 46.74
Ca
Mg
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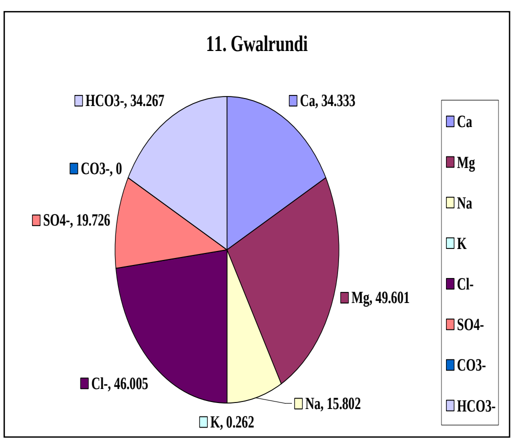
SO4-
CO3-
HCO3-


11. Gwalrundi
HCO3-, 34.267
CO3-, 0
SO4-, 19.726
Cl-, 46.005
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Mg, 49.601
Ca, 34.333
Ca
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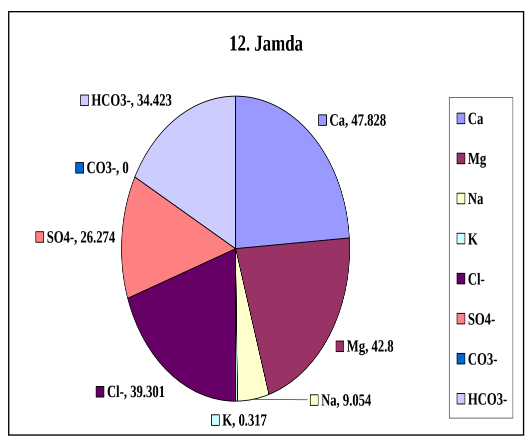
SO4-
CO3-
HCO3-


12. Jamda
HCO3-, 34.423
CO3-, 0
SO4-, 26.274
Cl-, 39.301
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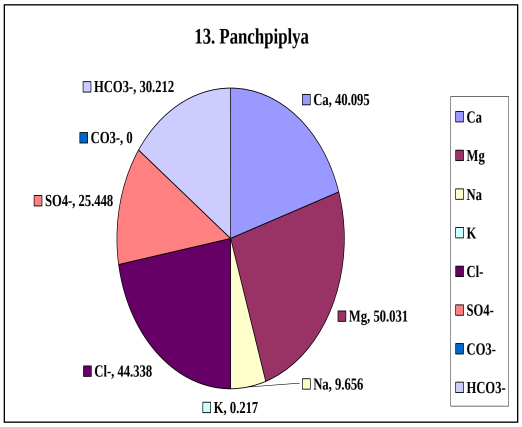
SO4-
CO3-
HCO3-


13. Panchpiplya
HCO3-, 30.212
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SO4-, 25.448
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K
Cl-
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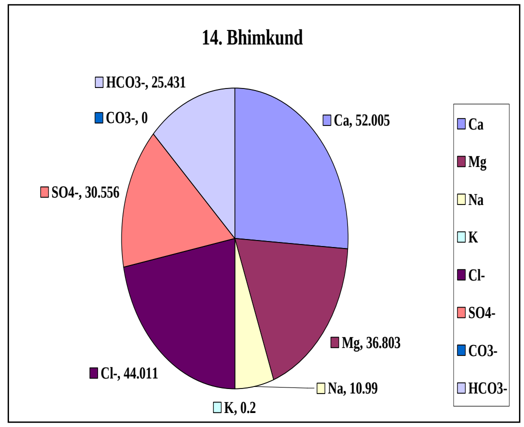
CO3-
HCO3-


14. Bhimkund
HCO3-, 25.431
CO3-, 0
Ca, 52.005
SO4-, 30.556
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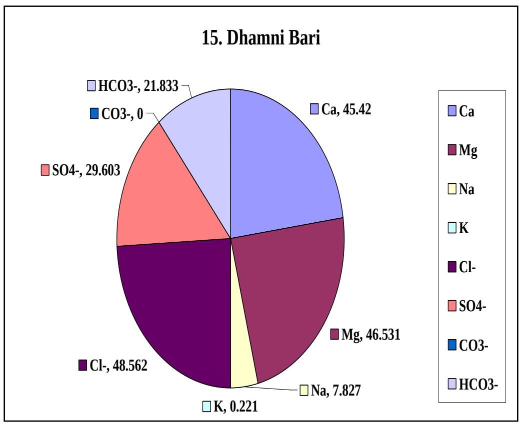
15. Dhamni Bari
HCO3-, 21.833
CO3-, 0
Ca, 45.42
SO4-, 29.603
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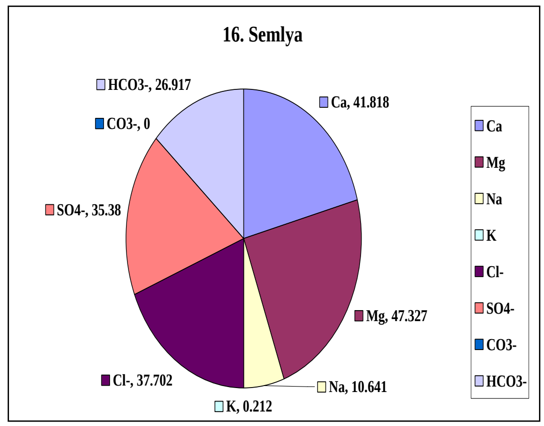
Cl-
SO4-
CO3-
HCO3-


16. Semlya
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Ca, 41.818
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SO4-, 35.38
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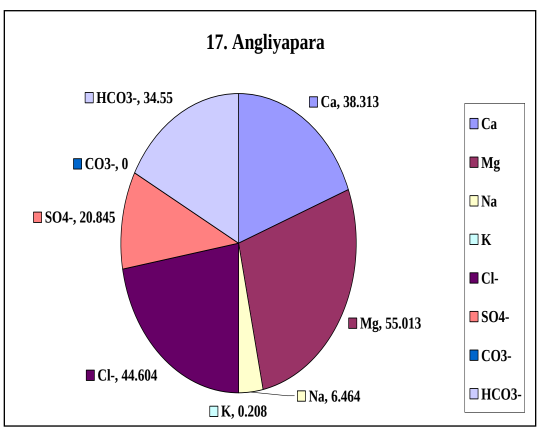
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


17. Angliyapara
HCO3-, 34.55
Ca, 38.313
CO3-, 0
SO4-, 20.845
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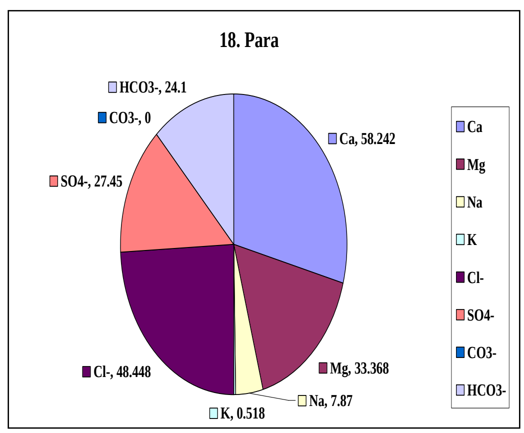
18. Para
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CO3-, 0
Ca, 58.242
SO4-, 27.45
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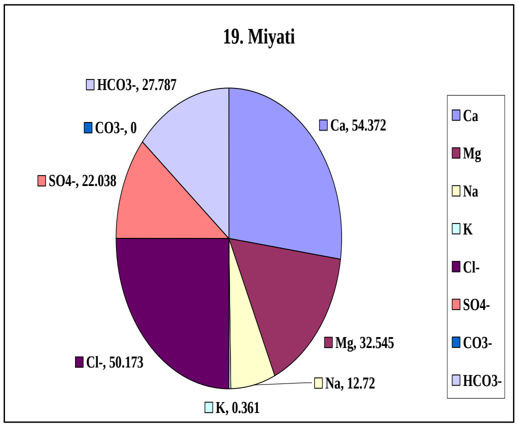
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


19. Miyati
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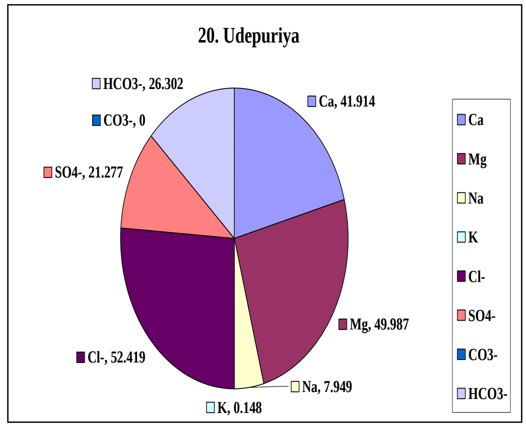
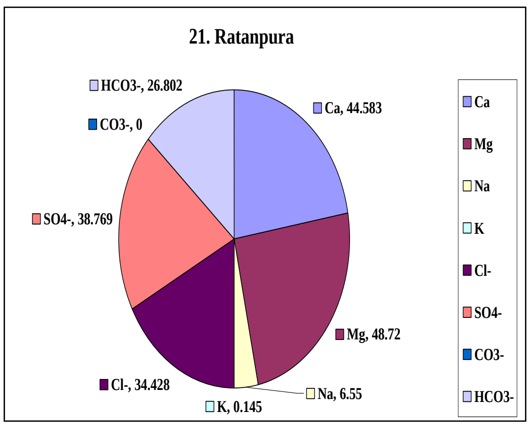
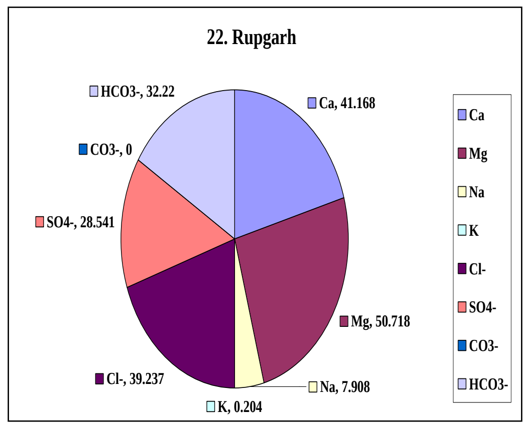
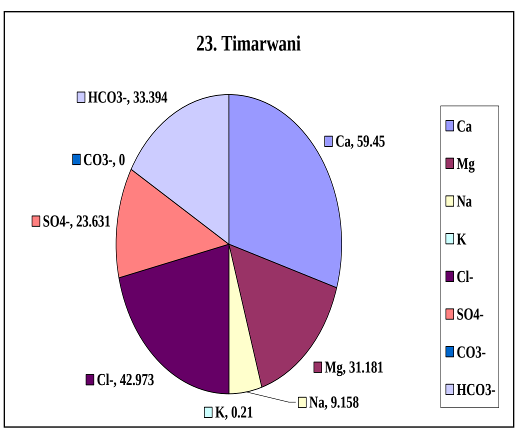
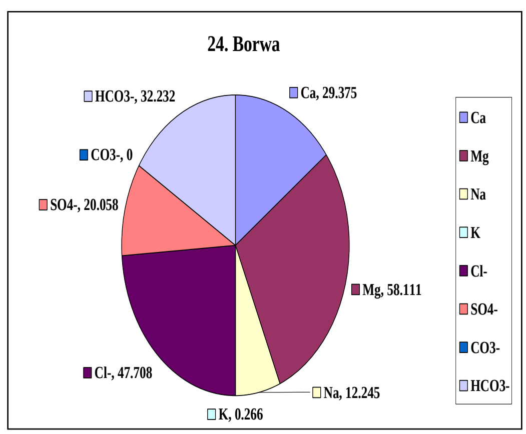
CO3-, 0
SO4-, 22.038
Ca, 54.372
Mg, 32.545
Cl-, 50.173
Na, 12.72
K, 0.361
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


20. Udepuriya
HCO3-, 26.302
CO3-, 0
SO4-, 21.277
Ca, 41.914
Mg, 49.987
Cl-, 52.419
Na, 7.949
K, 0.148
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


21. Ratanpura
HCO3-, 26.802
CO3-, 0
SO4-, 38.769
Ca, 44.583
Mg, 48.72
Cl-, 34.428
Na, 6.55
K, 0.145
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


22. Rupgarh
HCO3-, 32.22
CO3-, 0
SO4-, 28.541
Ca, 41.168
Mg, 50.718
Cl-, 39.237
Na, 7.908
K, 0.204
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


23. Timarwani
HCO3-, 33.394
CO3-, 0
SO4-, 23.631
Ca, 59.45
Mg, 31.181
Cl-, 42.973
Na, 9.158
K, 0.21
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-


24. Borwa
HCO3-, 32.232
CO3-, 0
SO4-, 20.058
Ca, 29.375
Mg, 58.111
Cl-, 47.708
Na, 12.245
K, 0.266
Ca
Mg
Na
K
Cl-
SO4-
CO3-
HCO3-

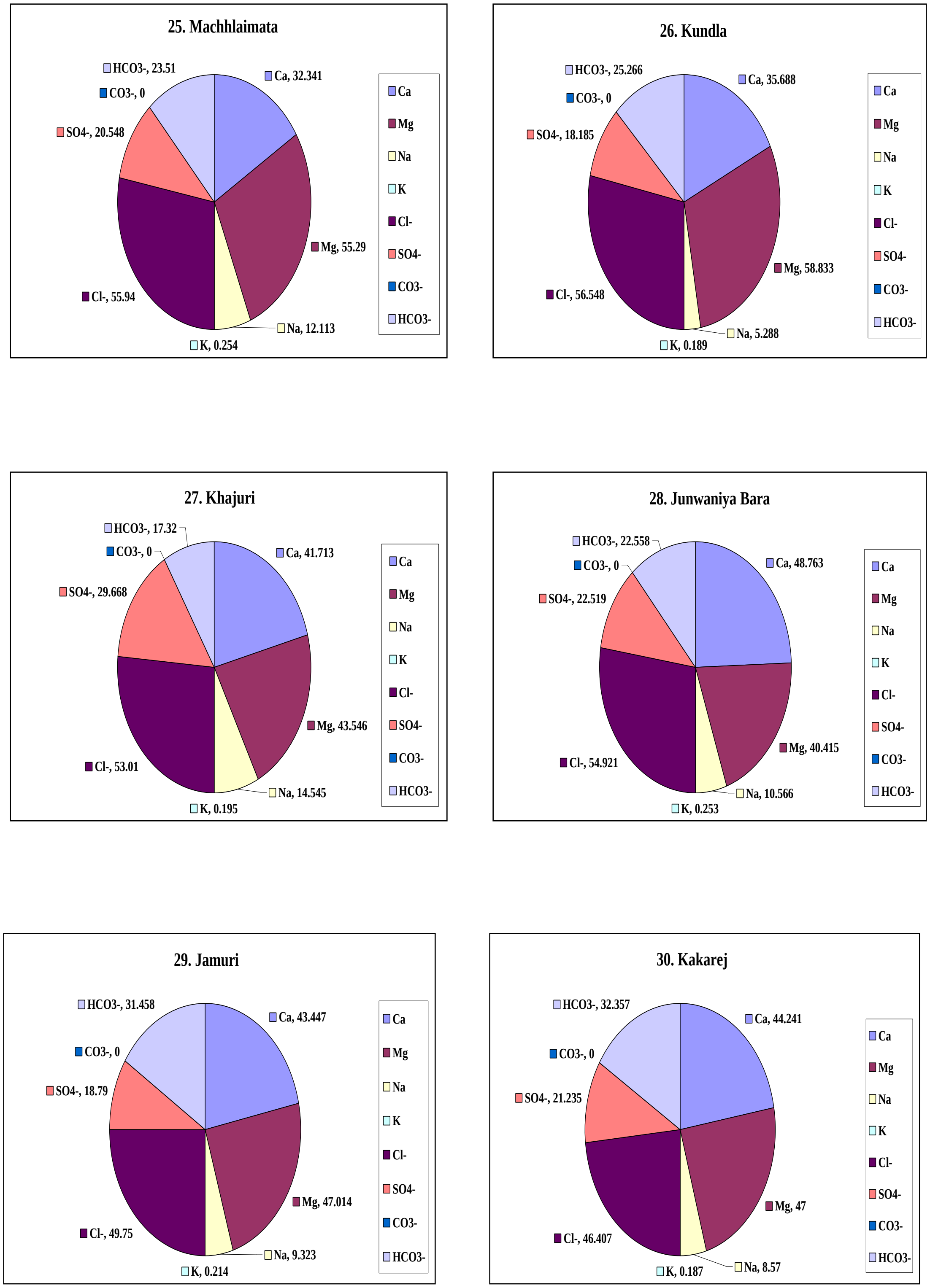


Figure 6.3 Graphic representation of ionic concentration of ground water samples of Thandla study area, Jhabua district, Madhya Pradesh.

6.4 EVALUATION OF CHEMICAL QUALITY APPLICATIONS

The chemical quality Assessment for the domestic and drinking use are described in the text herein.

6.4.1 GROUND WATER QUALITY SUITABILITY FOR DOMESTIC AND DRINKING USE

Ground water in general, is free from suspended impurities and pollution. It is having constant temperature that makes ground water as superior in comparison of surface water. Chemical quality of ground water remains nearly constant, except water supply points are located close up to saline zones. The permissible and maximum desirable limits of different ions and physical parameters of water recommended by Piper (1944), BIS (1983), WHO (1993) have been followed. Comparative examination of chemical quality standards with determined values of ground water of present study area have been carried out for evaluation of suitability of ground water for drinking and domestic.

Most useful graphic representation for comparing water quality analysis is the Trillinear diagram proposed by Piper (1944). Expressed as percentage of total cations in milli equivalents per liter, plot as a single point on the left triangle, and anions, similarly expressed as percentage of total anions, plotted as a point in the right triangle. These two points are then projected into the central diamond -shaped figure parallel to the upper edges of the central area. This single point is thus distinctively related to the total ionic distribution (Todd, 1959).

- **PLOTS OF ANALYZED DATA ON TRILINEAR DIAGRAME (PIPER'S DIAGRAM)**

The Trilinear diagram was first used by Hill (1940) for graphic representation of chemical analysis of water samples. This method has been modified by Piper (1944,1953) and modified diagram is most commonly being used for classifying the natural water (Figure 6.4).

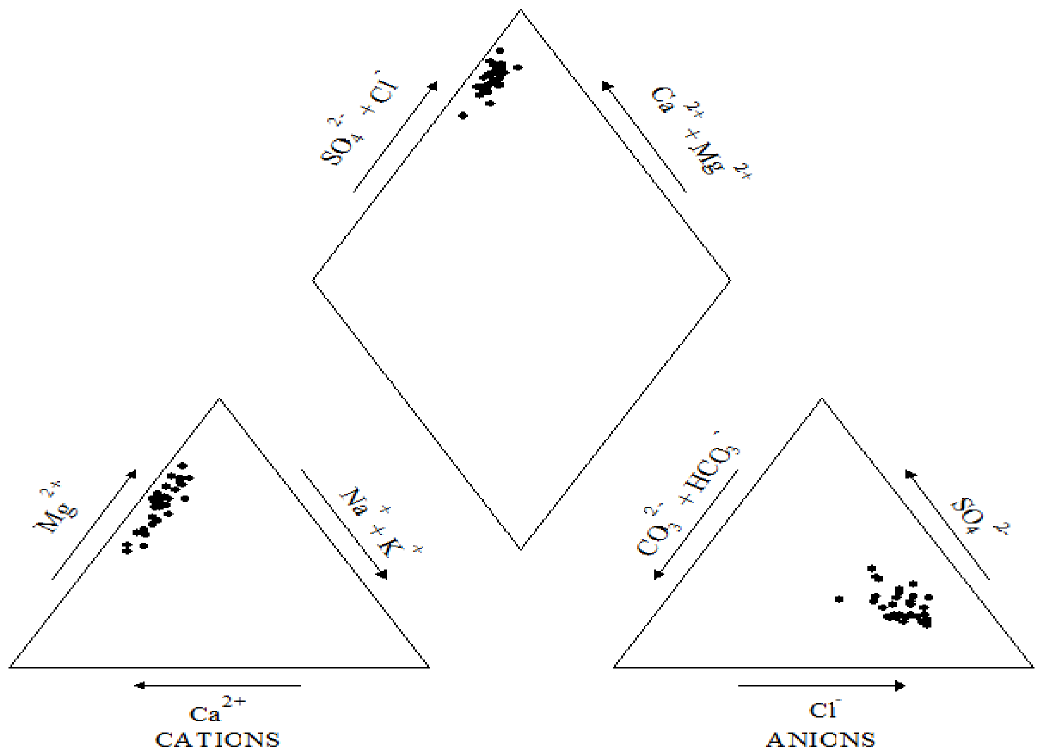


Figure 6.4 Trilinear diagram (Piper's diagram) for water analysis of study area.

Karanth (2003) described Trillinear methods of plotting Piper's diagram has been extensively used. to understand problems concerning with the geochemical evolution of ground water. The diamond shaped field has been subdivided into nine areas. The plot on diamond shaped field represents the type of water.

(1) Alkaline earth (Ca + Mg) exceed alkalies (Na + K), (2) Alkalies exceeds alkaline earth, (3) Week acids (CO_3 + HCO_3) exceed Strong acids (SO_4 + Cl), (4) Strong acids exceeds weak acids, (5) Magnesium bicarbonate type, (6) Calcium-Chloride type, (7) Sodium-chloride type, (8) Sodium-Bicarbonate type, and (9) Mixed type (No cation-anion exceed 50%).

The chemical analysis of Thandla ground water samples indicate that reveals that all the plots of ground water samples represents category 6 (Calcium-chloride type) classification suggested by Karanth (2003).

6.4.2 COMPARISON OF GROUND WATER FOR DOMESTIC AND DRINKING PURPOSES

Table 6.5 Comparison of physical and chemical parameters of ground water samples in Thandla study area with BIS (1983, 1991), and WHO (1983, 1984, 2004) for drinking use.

S. No.	Water Quality Constituents	Bureau of Indian Standards (BIS, 1983, 1991)		World Health Organization (WHO, 1983, 1984, 2004)		Ground water samples in study area, Jhabua district	
	Physical and Chemical Parameters	Highest Desirable	Maximum Permissible	Highest Desirable	Maximum Permissible	Concentration Range in study area (mg/l)	Remark
1	Colour	-	-	-	-	Colourless	-
2	Taste	-	-	-	-	Tasteless	-
3	Odour	-	-	-	-	Odourless	-
4	TDS	500	1000	500	1500	275 - 481	Samples indicate low value
5	p^H	6.5 - 8.5	6.5 - 9.2	7.0 - 8.5	6.5-9.2	7.05 - 8.30	-
6	TH (mg/lit)	300	600	100	500	230 - 340	Low value
7	Ca (mg/lit)	75	200	75	200	89 - 200	-
8	Mg (mg/lit)	30	100	30	150	63 - 147	-
9	Na^- (mg/lit)	-	200	-	200	22 - 60	Low minimum value
10	SO_4^- (mg/lit)	150	1000	200	400	68 - 195	Low minimum value
11	Cl^- (mg/lit)	250	1000	45	600	97 - 240	-
12	NO_3^- (mg/lit)	45	45	-	-	21 - 50	Low minimum value
13	HCO_3^- (mg/lit)	-	-	-	-	120 - 235	-
14	F^- (mg/lit)	0.5	1.5	1	1.5	0.20 - 4.00	Higher than maximum value

The comparative analysis of analyzed values of ground water samples with Bureau of Indian Standards (BIS) and World Health Organization (WHO) recommended values indicate that the ground water of the present study area is in general, suitable for domestic and drinking applications. However, a few ionic concentrations such as TDS, TH, Na, SO_4^-, NO_3^- and F^- are revealing less values than the minimum prescribed standards. It indicates that these values are to be increased in water before supply. In the study area, 4 samples of ground water exhibits higher values of fluoride than the prescribed value of fluoride. The people of the area suffering health problems due to excess concentration of fluoride content. The ground water of Miyati, Timarwani, Borwa and Rupgarh villages revealing higher fluoride content needs to be treated for permissible limit of fluoride before supply.

6.4.3 IRRIGATION QUALITY APPRAISAL OF GROUND WATER

The ground water quality suitability for irrigation use has been determined on the basis of chemical parameters determination as described in the following text:

Table 6.6 Computation of parameters derived for ground water quality for irrigation purposes of Thandla area, Jhabua district, Madhya Pradesh.

Location	Sample No.	Na %	Kelley's Ratio	S.A.R.	R.S.C.	Mg- Hazard
Madalda	1	6.531	0.068	0.408	-15.831	67.818
Karikurna	2	9.011	0.096	0.557	-12.83	64.102
Nagari	3	9.622	0.101	0.516	-10.409	62.971
Chirwa	4	10.098	0.109	0.592	-12.735	42.425
Walakhori	5	8.301	0.084	0.486	-14.197	40.645
Koriyapara	6	4.878	0.047	0.300	-17.632	54.607
Bhamariya	7	10.332	0.113	0.659	-14.085	59.480
Lalgarh	8	4.541	0.047	0.307	-19.037	52.851
Berawa	9	9.321	0.101	0.631	-16.81	51.406

Ruparel	10	11.960	0.133	0.646	-8.356	46.910
Gwalrundi	11	16.064	0.188	0.877	-8.399	59.095
Jamda	12	9.371	0.099	0.574	-13.137	47.225
Panchpiplya	13	9.873	0.107	0.682	-17.186	55.512
Bhimkund	14	11.190	0.123	0.719	-13.84	41.441
Dhamni Bari	15	8.048	0.085	0.509	-14.963	50.604
Semlya	16	10.854	0.119	0.749	-17.302	53.089
Angliyapara	17	6.672	0.069	0.425	-16.217	58.946
Para	18	8.388	0.091	0.465	-12.137	36.424
Miyati	19	13.081	0.146	0.805	-11.797	37.443
Udepuriya	20	8.098	0.086	0.527	-15.486	54.392
Ratanpura	21	6.696	0.070	0.428	-16.458	52.216
Rupgarh	22	8.113	0.086	0.554	-17.519	55.196
Timarwani	23	9.368	0.101	0.554	-11.621	34.404
Borwa	24	12.512	0.139	0.818	-13.811	66.422
Machhlaimata	25	12.367	0.138	0.835	-15.466	63.094
Kundla	26	5.478	0.055	0.348	-17.461	62.243
Khajuri	27	14.740	0.170	0.943	-13.087	51.075
Junwaniya Bara	28	10.820	0.118	0.681	-14.222	45.319
Jamuri	29	9.537	0.103	0.656	-17.227	51.971
Kakarej	30	8.757	0.093	0.571	-15.574	51.511
Range	**1-30**	**4.541 - 16.064**	**0.047-0.188**	**0.300 - 0.943**	**-19.037-8.356**	**34.404 - 67.818**

Abbreviations - Na = Sodium Percentage, S.A.R. = Sodium Absorption Ratio, R.S.C. = Residual Sodium Carbonate, Mg-Hazards = Magnesium Hazards.

(a) Sodium Percent

Sodium concentration has an important role in classification of water for the assessment to delineate suitability for irrigation use. The sodium content is generally represented as sodium percent (Na %) and is determined by the following formula as:

$$\textbf{Sodium Percent (Na \%)} = \frac{(\mathbf{Na+K}) \times \mathbf{100}}{\mathbf{Ca+Mg+Na+K}}$$

Where, the ionic concentrations are expressed in epm (equivalent per million).

Fetter (1988), considered that extreme sodium percentage in irrigation water will reduce the base exchange reaction with soil, where by Calcium and Magnesium in soil are replaced by sodium. Approximate prediction of this exchange reaction is possible and the effect does not become significant until the sodium percent is greater than 50%. The sodium percent in the water sample of study area has been calculated range of sodium percent 4.541 (Lalgarh village) to 16.064 (Gwalrundi village, Table 6.6).

(b) Kelley's Ratio

This ratio is proposed by (Kelley, 1940) and is computed by the formula as:

$$\textbf{Kelley's Ratio} = \frac{\mathbf{Na}}{\mathbf{Ca + Mg}}$$

Kelley's ratio calculated for ground water samples of Thandla study area varies from 0.047 (Koriyapara and Lalgrah village) to 0.188 (Gwalrundi village, Table 6.6).

(c) Sodium Adsorption Ratio

Sodium Absorption Ratio (SAR) is calculated based on the basis of ionic concentration of Sodium, Calcium and Magnesium as per following expression:

$$\textbf{Sodium Adsorption Ratio (SAR)} = \frac{\mathbf{Na}}{\frac{\sqrt{Ca + \mathbf{Mg}}}{\mathbf{2}}}$$

Where, the ion concentrations are expressed as epm (equivalent per million). The values of Sodium Adsorption Ratio (SAR) of water samples of Thandla study area, have been calculated within range of 0.300 (Koriyapara village) to 0.943 (Khajuri village, Table 6.6).

(d) Residual Sodium Carbonate

Residual Sodium Carbonate (RSC) is estimated for assessment of ground water suitability for irrigation purpose by using the following formula:

$$\textbf{Residual Sodium Carbonate (RSC)} = (HCO_3^- + CO_3^-) - (Ca^{++} + Mg^{++})$$

(e) Magnesium Hazard

Magnesium Hazards (Mg-Hazards) is determined by using the formula:

$$\textbf{Magnesium Hazard} = \frac{Mg \times 100}{Ca + Mg}$$

In Thandla study area computed value of Mg-Hazards value is within range of 34.404 (Timarwani village) to 67.818 (Madalda village, Table 6.6).

- ## WILCOX DIAGRAM

Wilcox (1948, 1955) proposed a diagram to classify the water suitability for irrigation applications. The ground water has been classified into five categories:

(1) Excellent to good, (2) Good to permissible, (3) Permissible to doubtful, (4) Doubtful to unsuitable, (5) Unsuitable.

The plots of 30 ground water samples on Wilcox diagram indicate that all 30 samples are of Excellent to good class of water. The ground water of study area is favourable for the irrigation use (Figure 6.5).

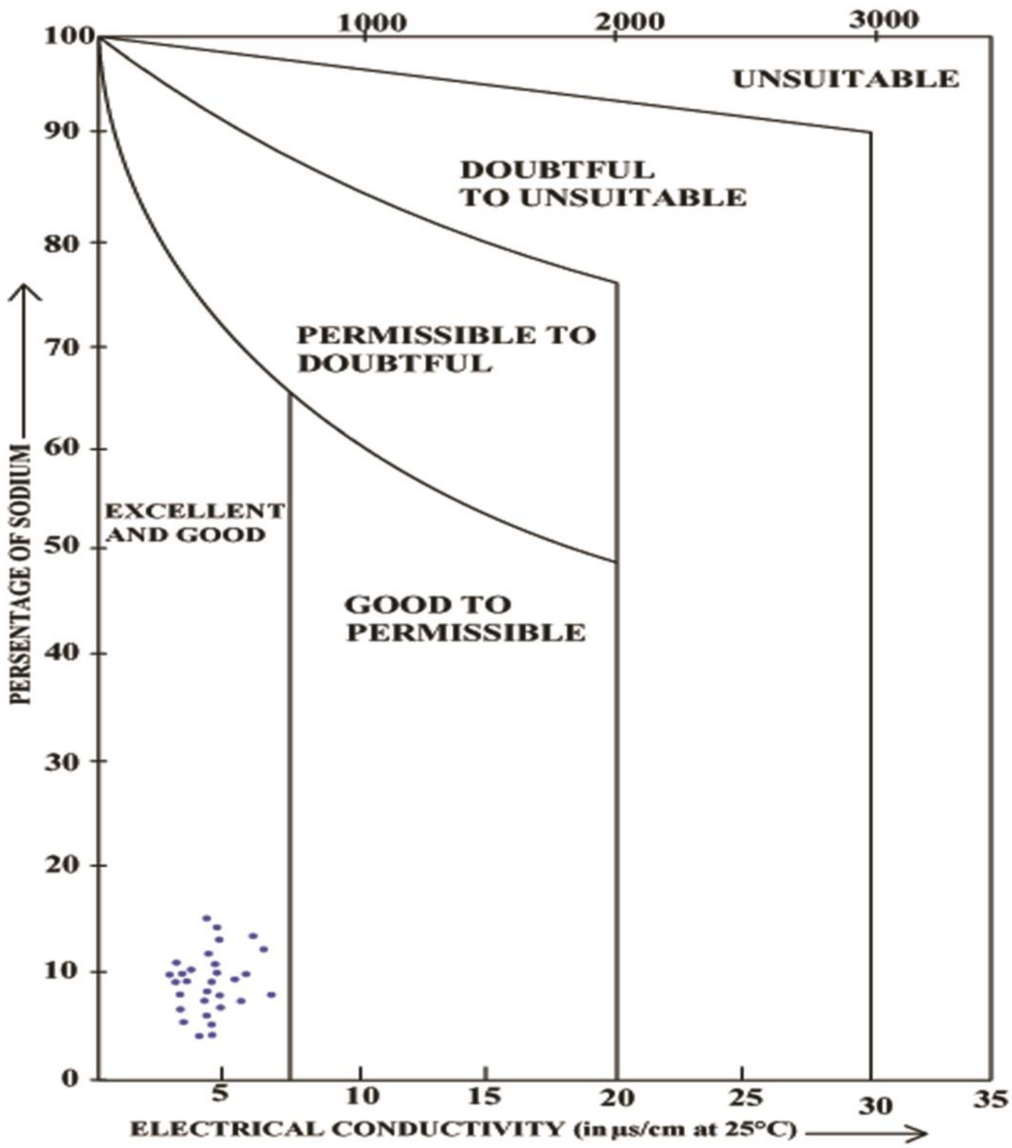


Figure 6.5 Wilcox diagram for water analysis of Thandla study area, Jhabua.

- **U.S. SALINITY HAZARD DIAGRAM**

U.S. Department of Agriculture (1954) used a diagram for the classification of ground water for agriculture purpose. In this diagram the values of Sodium Absorption Ratio (SAR) and specific conductivity are plotted are Y and X axis respectively. The Plots of 30 samples are exhibited on U.S. Salinity diagram. 8 samples belong to C_2 S_1 (C_2 = Medium salinity water, with S_1 = Low sodium water), 20 samples refer to C_2 S_2 (C2 = Medium salinity water, S_2 = Medium sodium water), and 2 samples represent C_2 S_3 (C_2

= Medium salinity water, S_3 = High sodium water). In general, the ground water is suitable for irrigation purpose (Figure 6.6).

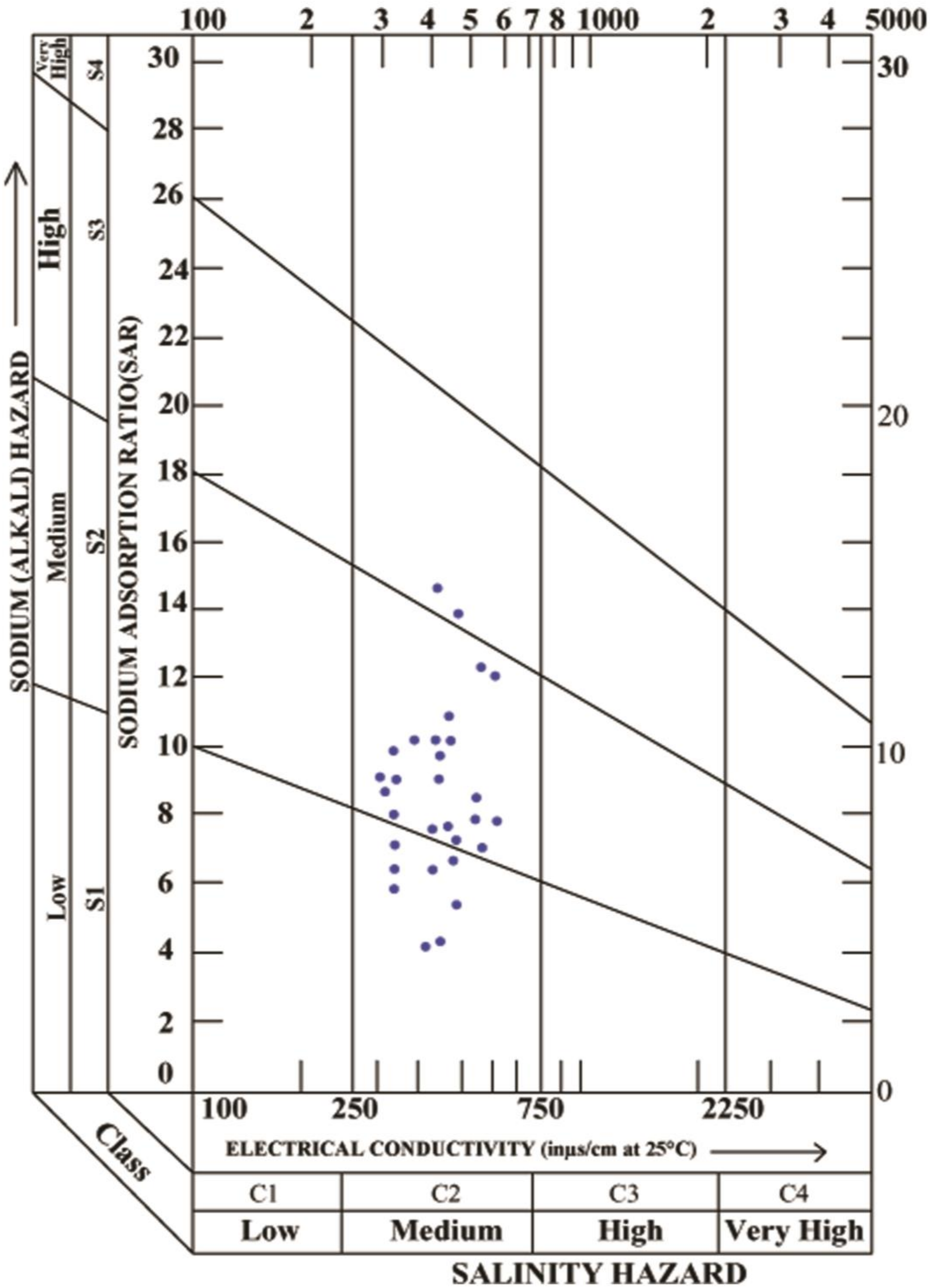


Figure 6.6 U.S. Salinity Hazard diagram for water analysis of study area.

6.5 QUALITY ASSESSMENT OF GROUND WATER

The chemical quality of ground water has been determined on the basis of 30 samples collected from the study area located in Thandla study area of Jhabua district, Madhya Pradesh. Based on the results of determined physical and chemical parameters of water samples collected from open dug wells. The comparative analysis of determined parameters with the recommended values of the Bureau of Indian Standards and World Health Organizations reveal that the ground water of Thandla study area, in general, is favourable for domestic, drinking and irrigation purposes.

CHAPTER - 7

GROUND WATER DEVELOPMENT AND MANAGEMENT

7.1 CONCEPT OF WATER RESOURCE

Water resources are generally surface water and sub-surface (Ground water). Surface water resources are not adequate to meet out the requirement of the country. This resource is mainly substituted by the ground water. In the life of present trends of population rapid explosion, increase in population, organization, industrialization, energy and sport sectors are generating immense pressure on ground water resource. As a result, the ground water is depleting at a fast speed, which is resulting into shortage of water ground water supply. Hence it is essential to increase development ground water resource.

In India, Madhya Pradesh is one of the states which are facing problem of sustained water supply, that causes even drought situation most of the parts of the country. Madhya Pradesh region is well-known for a good net work of rivers, however, it is having the problem of water crisis, because most of the rivers are seasonal and hence resulting into the scarcity of regular supply of water in most of the district of the states. Hence it is necessary to implement a scheme for augmentation of water resources.

Sustainable development is a reasonable process that increases both the current and future potential to meet human requirements and aspirations. The sustainable development involves the optimum realization of different economic, environmental and social objectives of the society at one and same time. Ground water is a renewable natural resource, however, it has limited extent and hence, only a definite quantity of water must be withdrawn annually from a ground water basin. Artificial recharge is a main globally adopted technique to augment the ground water system (Singh and Dev, 2012).

7.2 GROUND WATER DEVELOPMENT

Development of ground water requires energy, except where artesian conditions are develop the existence of free flowing wells and springs. Ground water has also certain disadvantages and its inadequate water supply in some areas, due to presence of impervious rocks or saline water. In recent years, the phenomenal increase in ground water use for domestic, irrigation, industrial and municipal supplies have resulted, in a large area, in extraction of ground water for in excess of not natural recharge. Grave local water shortages have developed under these conditions adverse effects such as persistent water level declines and consequent increase in pumping costs, development of adverse salt balance, subsidence of land surface and saline water intrusion into fresh water aquifers (Davis and Dewiest, 1966, Todd, 1980, Karanth, 1994).

According to Todd and Mays (2005) ground water development dates from ancient times. The old evidence contains numerous references to ground water, springs, and wells. According to Garg (1973), development plan for water resource has been defined as a detailed study of the pros and cons of different promising behavior of harnessing this amazing resource and finally writing down the means and ways of achieving the best and optimum benefits. Nagabhushaniah (2001) considered that ground water is almost always in movement in spite of very small, velocities, in the analysis of ground water movement. Ground water movement, the direction and quantity of which have been supposed to be under minable has been treated as the percolation. The sub-surface stream flow takes place generally by percolation and rarely by turbulent flow, which occurs chiefly in solution conduits.

Artificial recharge technique controls the infiltration of surface water into the ground water reservoir altering natural conditions, is one of the procedures adopted to restore or enhance supplies from depleted aquifers, control or prevent subsidence of land surface, improve quality of native water and renovate quality of waste water. Recharging is done by pounding water in specially prepared or natural land surfaces, injecting water into wells or by capturing stream flow (Karanth, 2003).

Karanth (2003) described in detail, the problem of ground water development. The assessment of development potentialities of an aquifer, require the following information, is required:

(a) Geometry of reservoir defining dimensions and boundaries.

(b) Conditions at boundaries, in particular sources of the recharge.

(c) Lithology and aquifer characteristics.

(d) Hydrodynamic conditions (phreatic, confined or semi confined).

(e) Order of the magnitude of reserves.

(f) Average natural recharge and discharge.

(g) Quality of the water.

7.3 DETERMINATION OF GROUND WATER POTENTIAL

Evaluation of ground water potential is very essential for planned development of study area (Jeyaram *et.al* 1996). Sudarsana (1994) remarked that Spatial variation in the ground water potential within area can be brought by modeling techniques in Geographical Information System (GIS) employing satellite derived thematic maps and collateral data.

Ground water potential of an area has been estimated by methods, which are based on analyzed rainfall data and aquifer parameters obtained from aquifer analysis. Relationship of rainfall infiltration and hydrodynamic methods determine ground water recharge of an study area. Ground water recharge is determined as per following methods: (A) Rainfall Infiltration method, and (B) Hydrodynamic method.

(A) Rainfall Infiltration Method

Determination of ground water recharge is described as:

Total area of study basin (A) = 366.58 sq.km. = 366.58 x 10^6 sq. m.

Annual Average Rainfall of study area = 964.324 m. m. = 0.964 m.

Rainfall Infiltration Index (RII) = 10 % Assumed value (after Charlu and Dutt, 1982)

Ground Water Recharge = A x RII x AR (Average Rainfall)

$$= 366.58 \times 10^6 \times (10/100) \times 0.964$$

$= \quad 366.58 \times 10^6 \times 0.1 \times 0.964$

$= \mathbf{3533.83} \times \mathbf{10^4\ m^3}$

(B) Hydrodynamic Method

Hydrodynamic method has been considered dependable by Central Board of Irrigation and Power (CBIP, 1976), and Adyalkar and Rao (1979). This method considers the effects of ground water level variations which reveals a real picture of ground water system. Hence, the hydrodynamic method is more reliable as it involves the value of annual average water level fluctuation in the formula for estimation of ground water recharge. The procedure of computation of hydrodynamic method of is described as follows:

Total study area (A) = 366.58×10^6 sq. m.

Average annual water level fluctuation = 4.59 m. (b.g.l.)

Level fluctuation specific field of hard = 3 % Assumed value (Charlu and Dutt, 1982).

Ground water recharge = A x Water level fluctuation x Specific yield

$= 366.58 \times 10^6 \times 4.59 \times (3/100)$

$= 366.58 \times 10^6 \times 4.59 \times 0.03$

$= \mathbf{5047.80} \times \mathbf{10^4\ m^3}$

7.4 ASSESSMENT OF GROUND WATER BALANCE

Ground water quantity in the reservoir has been estimated on the basis of average saturated thickness of the aquifers derived from the open dug wells examination by using following procedure:

Area under investigation (A) = 366.58×10^6 sq. m.

Average Saturated Thickness (AST) = 15 m.

Specific yield = 3 % Assumed value (Charlu and Dutt, 1982)

Ground water Storage = A x AST x Specific yield

$$= 366.58 \times 10^6 \times 15 \times (3/100)$$

$$= 366.58 \times 10^6 \times 15 \times 0.03$$

$$\mathbf{= 16496.1} \times \mathbf{10^4\ m^3}$$

Ground water annual draft of the present study area has been calculated by observing the average annual decline in the water levels. Annual ground water draft of study area has been determined as per following procedure:

Area under study (A) = 366.58 x 10^6 sq. m.

Annual decrease in water level from post-monsoon to pre-monsoon period (D) = 9.7

Specific yield of hard rock aquifers = 3 % Assumed value (Charlu and Dutt, 1982)

$$\text{Annual draft} = A \times D \times \text{Specific yield}$$

$$= 366.58 \times 10^6 \times 9.7 \times (3/100)$$

$$= 366.58 \times 10^6 \times 9.7 \times 0.03$$

$$\mathbf{= 10667.47} \times \mathbf{10^4\ m^3}$$

(1) Ground water Balance = Ground water recharge **-** Annual draft

$$= 3533.83 \times 10^4\ m^3 - 10667.47 \times 10^4\ m^3$$

$$\mathbf{= -\ 7133.64} \times \mathbf{10^4\ m^3}$$

(2) Ground water Balance = Ground water recharge **-** Annual Draft

$$= 5047.80 \times 10^4\ m^3 - 10667.47 \times 10^4\ m^3$$

$$\mathbf{= -\ 5619.67} \times \mathbf{10^4\ m^3}$$

The determined values of ground water recharge **(5047.80×10^4 m^3)** and annual draft **(10667.47×10^4 m^3)** indicate that there is an over draft of ground water is **(-5619.67×10^4 m^3)** and even causing acute water crisis particularly during summer season.

7.5 GROUND WATER MANAGEMENT

The concept of management has been described by Bear and Levin (1967) that basic thought is to observe the aquifer as a system that has to be operated in an best possible manner. Burdon (1972) considered that ground water management includes the technical ground water management and in general, integrated ground water management (*vide etiam*, Karanth, 2003).

The management of a ground water basin concerns with the development and utilization of ground water for main purpose, commonly of a social or economic nature. Usually the preferred objective is to obtain the maximum quantity of water to meet the predetermined quality requirements at least cost (Todd, 1980).The optimum development of ground water (sub-surface water) resources for valuable use involves planning of an total ground water basin (Todd, op.cit). Hence, the ground water management requires the quantity as well as quality of water.

Karanth (1994, 2003) explained the assessment for development of aquifer potentialities, the following are essential requirements - (1) Reservoir geometry (dimension and boundaries), (2) Condition at the boundaries (the sources of recharge), (3) Lithology and aquifer characteristics, (4) Hydrodynamic conditions (phreatic, condition and semi confined), (5) Order of magnitude of the reserves, (6) Average natural recharge and discharge, and (7) Quality of water.

Fetter (1990) remarked that study of ground water development essentially encompasses several aspects of surface water flow, drainage basin, topographic boundaries, flow in direction towards land surface is sloping not topographic divides. Development and management of ground water is more complicated than that of surface water, simply on the basis of mode of occurrence. According to Nagabhushaniah (2001) established that the proposal of ground water management in a basin is to augment optimum ground water to assure the requirements of all users within basin and to meet up specific predetermined conditions, for example the water quality, cost of development and operation, certain legal, social, and political constraints.

Hence, the ground water management implies development and utilization of aquifer water in order to obtain maximum quantity of ground water at the least cost.

7.6 GROUND WATER RECHARGE

The main source of ground water recharge is the Rainfall factor. The Rain from sky to earth moves to surface of the earth, which is occupied by the cover of soil, which absorbs the water from ground surface followed by the infiltration. If the infiltration process is in permeable zone, than water moves downward through the soil and sub-soil or rock. The infiltration process, continues in permeable zone downwards, through the unsaturated zone, until the infiltrating water reaches to the water level (upper layer of saturated zone).

Nagabhushaniah (2001) remarked that the precipitation reaching the water table is called recharge, because it is helping to replenish the store of ground water. The ground water in a certain basin is recharged from either surface water within the basin or ground water percolating from another basin. The recharge may be of two types - (1) Natural recharge or (2) Artificial recharge.

7.6.1 NATURAL RECHARGE

Natural recharge of ground water system includes deep percolation from precipitation, seepage from streams, lakes, and sub-surface under flow. Natural discharge or out flow from the ground water body consists of seepage to streams, flow from springs, sub-surface under flow, transpiration, and evaporation.

7.6.2 ARTIFICIAL RECHARGE

Artificial recharge has been described as a process of infiltration of the surface water into ground water system. This phenomenon is augmented by changing natural condition of renewable of ground water is being achieving significance as one of the strategies of water management (Karanth, 2003). Artificial recharge operations undertaken for a specified purpose may achieve beneficial results other than those contemplated. The main aim of artificial recharge helps in the conservation of ground water resources.

Numerous techniques of artificial recharge are in practice, the choice being dictated by local condition. The techniques have been described by Muckel (1948); Todd (1959, 1980, 2010); Chow (1964); Karanth (1994, 2003); Nagabhushaniah (2001) and others. The commonly used techniques of artificial recharge are: (1) Spreading method, (2) Pit method, (3) Induced-recharge method, (4) Well method.

(1) Spreading method

The spreading methods are most widely adopted. These methods have been categorized as basin, ditch or furrow, flooding, natural channel and irrigation, water is either pounded or allowed to flow into channels or ground surfaces. The principle of spreading methods is to increase the detention time of an area of contact with water, in order to increase recharge to ground water. The spreading methods are used to recharge phreatic aquifers and semi confined aquifers. It is essential that materials in zone of aeration have good vertical permeability to aid percolation and aquifer has good transmissivity for transport of water away from spreading area. Presence of layers having low hydraulic conductivity in vadose zone, forms perched zones of saturation and retards deep percolation of water (Karanth, 1994, 2003).

(2) Pit method

This method is used to construct a pit or shaft to expose permeable formation. Recharge pits are usually provided with a layer of filtering material for protection against silt intrusion of aquifer. The gravel pits and excavation in permeable formations with minor modification may be used to save excavation costs. The silt-laden water increase rate of recharge in pits steep side slopes. Pits in Sweden are constructed on tops of eskers are used to recharge aquifers. Recharged water is extracted by wells located at the fringe of the aquifer. The infiltration rate in pits ranges from 1.5 to 15 m / day (Karanth, 2003).

(3) Induced-recharge method

Induced recharge implies to the diversion process of surface flow to the aquifer. It also

refers to water, which is diverted to an aquifer from a surface-water body by extraction of ground water. The induced recharge does not increase amount of ground water in storage, however, it permits withdrawals at higher than normal rates. Diversion of water is accomplished by diminution in stream flow, due to a reduction in ground water contribution and diversion of surface water (Karanth, 2003).

(4) Well method

Recharge well is used for purpose of increasing ground water supply by feeding surface water into an aquifer. Recharge well may be called an inverted well as the movement of water in a recharge well is in the reverse direction to that in ordinary wells (Meinzer, 1923). A few recharge wells (diffusion wells), do not extent down to the zone of aeration precludes the adoption of spreading methods. When a well is recharged, a recharge cone or cone of impression is formed, which is similar in shape to but the reverse in configuration of a cone of depression around a pumping well (Karanth, 2003).

7.6.3 ARTIFICIAL RECHARGE STRUCTURE CONSTRUCTION

Artificial recharge structures are constructed to increase water in a well for sustained supply. The following structure are generally constructed :

(a) Pits and Trenches, (b) Shafts, (c) Nala Bunds and Contour Bunds, (d) Ponds, (e) Check Dam, (f) Percolation Tank, (g) Gully Plug, (h) Sub-surface Dyke, (i) Injection Wells, and (j) Rainwater Harvesting structures.

(a) Pits and Trenches

A pit is excavated structure in a permeable formation which serves as an ideal artificial recharge structure. Cost of excavation and removal of materials is high, use of abandoned excavations, such as gravel pits, is most economic (Todd, 1980, 2010).The pit may be of 14 m. in length and width of 2 m. A view of pit contracted in the study area is illustrated in figure (Figure 7.1).

Figure 7.1 A view of large pit constructed near Junwaniya Bara village, Thandla study area, Jhabua district, Madhya Pradesh.

Figure 7.2 A view of trenches constructed at Junwaniya Bara village,Thandla area.

Recharge trenches are also known as infiltration trenches and are used for shallow application. These trenches (Figure 7.2) are excavated from the surface using conventional excavation technique. Recharge trench method is used in unconfined aquifers with water tables near ground level, and allowing shallow trenches to be used.

(b) Shafts

Recharge shafts are commonly deeper and of smaller diameter than pits (Figure 7.3). There purpose is also to penetrate low permeability layers. Shafts may be lined or unlined open or filled with coarse materials, and large or small. They are constructed by hand, drilled or bored. Where the recharge water contains sediment, shafts may become plugged rapidly. Generally, recharge shafts are used in conjunction with pits (Nagabhushaniah, 2001).

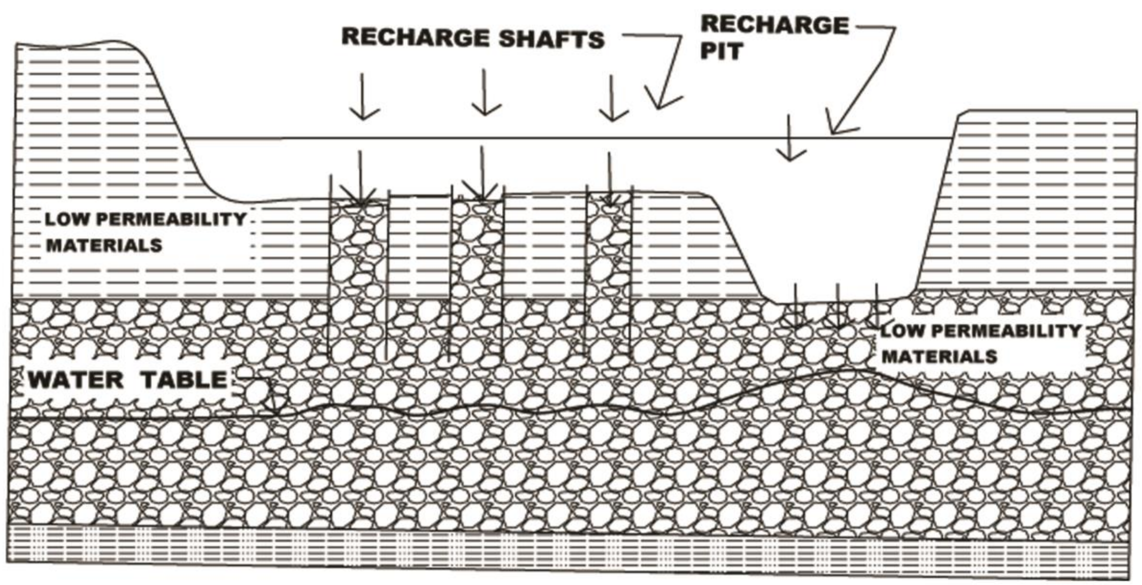


Figure 7.3 Diagram illustrating a view of construction of shaft (Modified after Nagabhushaniah, 2001).

(c) Nala Bunds and Contour Bunds

Generally, Nala bunds are fairly large structures and commonly constructed across Nalas. It is essential that Nala bed must have a good permeable soil. In study area, important Nala bund exists over Chhota Nala near village of Munjal, Thandla area (Figure 7.4).

Figure 7.4 A view of Nala bund construction near Munjal village, Thandla area.

Contour Bunds

Contour bunds are mainly constructed along contour lines. They are typically prepared by employing stones or soil, and rarely in variation with crop remains. The contour bunds are constructed along a contour in order to best check water flowing downwards slope, which augmented green water pool of soil and prevents erosion (Figure 7.5).

Figure 7.5 A view of contour bunds near Lalgarh village, Thandla study area.

(d) Ponds

Ponds are well-known as a man-made or natural water body ranging from 1 m^2 and 2 ha (~5 acres or 20,000 m^2) in area, that holds water for the four months of a year or more. Pond's water is also facing pollution as like other water bodies are getting polluted due to discharge of effluents from various industries, domestic waste, land and agricultural drainage resulting in degradation of water quality of water resources (Figure 7.6 A, B).

Figure 7.6 (A) A view of Pond constructed near Ratanpura village, Thandla area.

Figure 7.6 (B) A view of Pond constructed near Dhawrapara village, Thandla area.

(e) Check Dam

Check dams are usually constructed to augment recharge from existing streams or temporary channels (Petty john, 1988). Check dams are generally 10 to 15 m long, 1 to 3 m wide and 2 to 3 m in height and these are constructed in a trapezoidal from. Site selection for check dam construction should have sufficient thickness of permeable soil or weathered materials to make easy recharge of stored water within a short span. Water stored in these structures is mostly confined to stream course and height is generally less than 2 m. (Figure 7.7 A, B). Check dams are designed based on stream width and excess water is allowed to flow over the wall (Singh and Dev, 2012).

Figure 7.7 (A) A view of Check Dam near Rundipara village, Thandla area.

Figure 7.7 (B) A view of Check Dam near Devigarh village, Thandla area.

(f) Percolation Tank

Construction of percolation tank is one of most significant artificial recharge structures to augment ground water reservoir. It helps in providing water supply during summer season. Percolation tanks are generally made on streams having a sizeable catchment area. Site is selected at place having adequate sub-surface storage space (Figure 7.8). The suitable site for contraction of percolation tank in Padmavati River basin is suggested at Devigarh village of Thandla area.

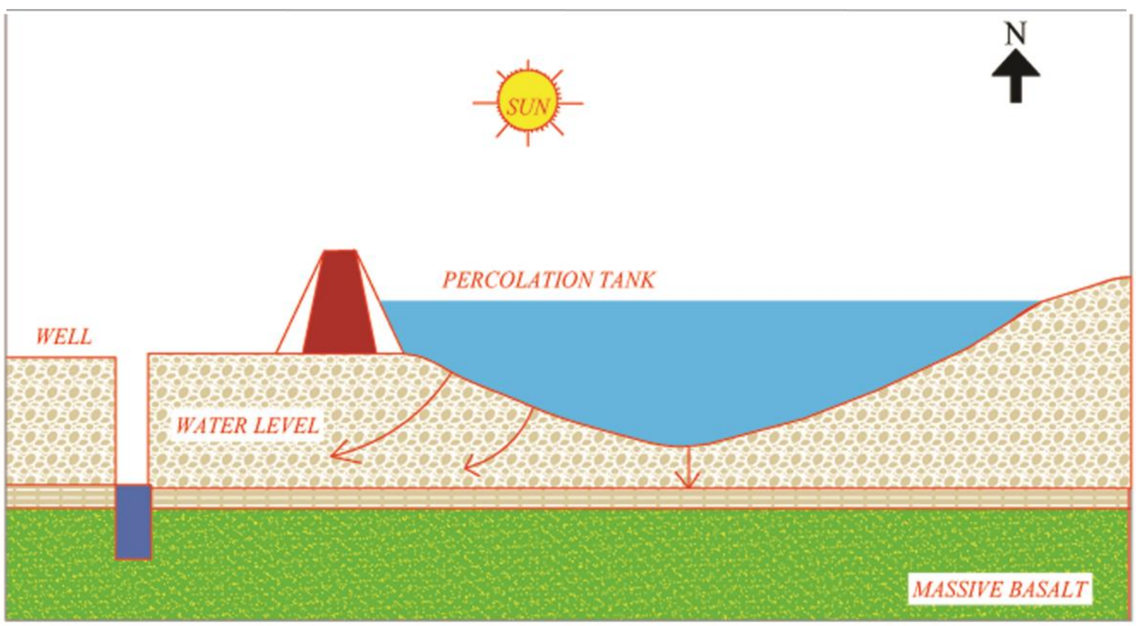


Figure 7.8 A general view of Percolation tank recommended for construction in study area, (Modified after, www.Google.com).

(g) Gully Plug

Gully plugs are commonly constructed across first order streams (Figure 7.9), Nala bunds and Check dams are mainly built across large streams and in area having gentle slopes. Capable civil and agro-engineering methods are to be applied in design, plan and construction of permanent check dams to ensure proper storage and adequate out flow of surplus water for long-term stability of dam (Centre Science and Environment, 2003).

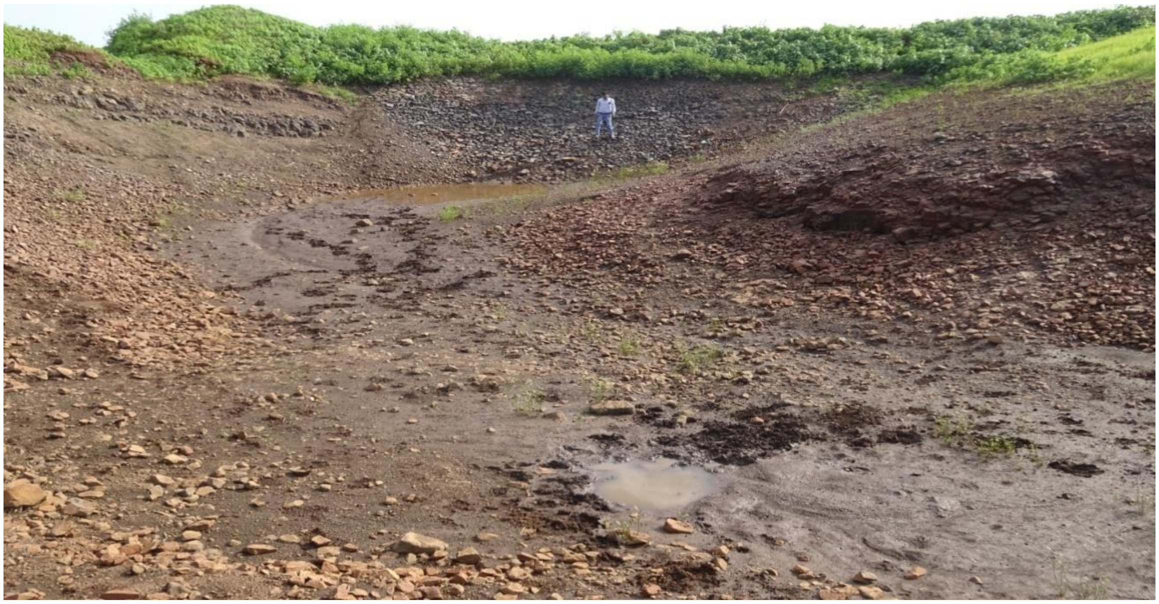


Figure 7.9 A view of Gully Plug structure near Madalda village, Thandla area.

(h) Sub-surface Dyke

Subsurface dyke is a recognized structure which is constructed in an aquifer with objective of obstructing natural flow of subsurface water. Therefore, increasing ground water level and augmenting amount of stored water in an aquifer (Figure 7.10 A, B).

Subsurface dyke has established that it is one of the most practicable techniques for conservation and exploitation of ground water resource. These dykes are presently largest rainwater harvesting structure. The suitable site for construction of sub-surface dyke is recommended in Padmavati River basin at Rundipara village.

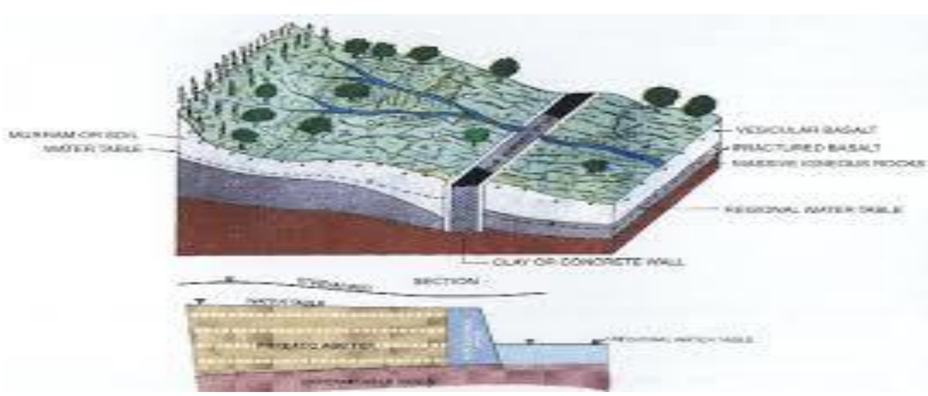


Figure 7.10 (A) A view construction of Sub-surface dyke (www.google.com).

Figure 7.10 (B) A view of Sub-surface dyke construction in study area (www.google.com).

(i) Injection Wells

Injection wells are structures generally constructed on dry lands for aquifer augmentation by transmitting contamination free surface water (Figure 7.11). It has been regarded that injection wells are drilled downstream of a dam and water released from spillway is conveyed into wells (Raghunath,1982). Operation of recharge by injection wells involves treatment of balanced matter so that aquifer should be clean.

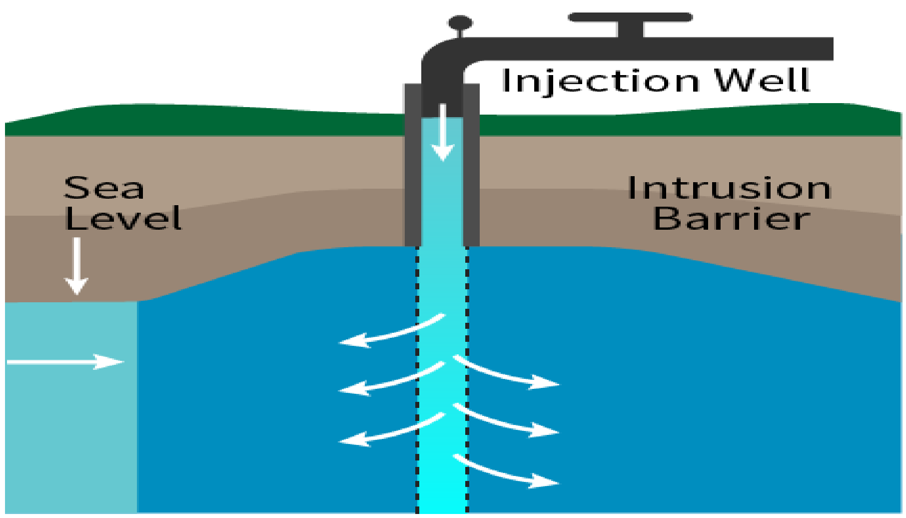


Figure 7.11 A view of Injection Well (www.google.com).

(j) Rainwater Harvesting

Rainwater harvesting involves tapping rainwater where it falls. A major portion of rainwater that falls on earth's surface is runoff into streams, rivers, and finally in the sea. Rainwater harvesting technique involves collecting rain from localized catchment surfaces e.g, roofs, plain or sloping surfaces, either for direct use or to augment ground water system (Figure 7.12). Roof top rainwater harvesting is one of most suitable options for increasing ground water recharge / storage in urban areas. Simplest technique of roof top rainwater harvesting involves collection of rainwater in a large pot /vessel kept beneath edge of roof. Water accordingly collected can meet immediate domestic needs. In this process, water is collected from roof using drain pipes or gutters fixed to roof edge. Several organization including Central Ground Water Board are already implementing roof top rainwater harvesting scheme in diverse parts of country.

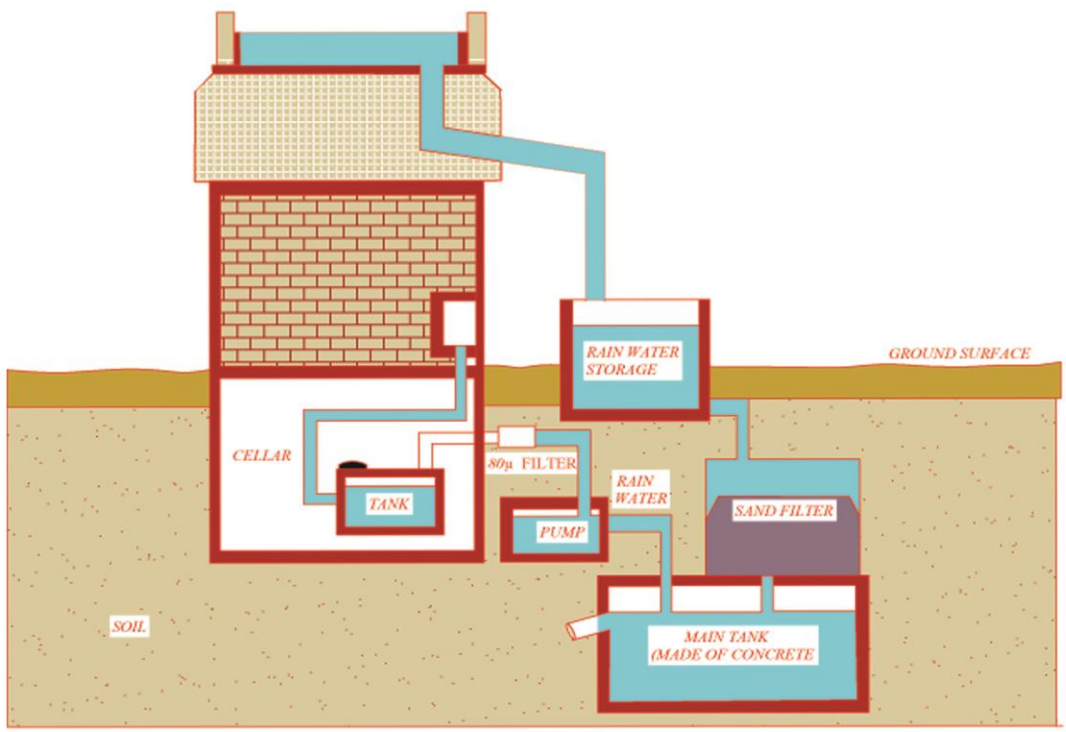


Figure 7.12 A view of Rainwater harvesting structure (After, www.Google.com).

CHAPTER - 8

SUMMARY AND CONCLUSION

8.1 SUMMARY OF RESEARCH STUDY

The present study entitled ***"Characterization and Management of Shallow Ground Water Resource of Thandla Area, Jhabua District, Madhya Pradesh"*** has been undertaken in Thandla vicinity, within latitude 23^0 0' to 23^0 10' N and longitude 74^0 30' to 74^0 40' E. (Survey of India Toposheet no. 46 I/12).

Ground water is a dynamic, renewable and valuable natural resource of the earth, which is significant as a sole substitute for the surface water supply. Presently, ground water resources are being over exploited due to population explosion, urbanization, industrialization, irrigation energy and sports sector are causing pressure on ground water resource, resulting into rapid depletion of ground water levels. In India, Madhya Pradesh is one of the states, which is facing the problem of scarcity of water supply in spite of a fairly good network of rivers. In view of the existing facts, it is priority need of the augmentation of ground water development and management strategy in order to obtain sustained water supply to resolve present need of water accessibility.

In view of foregoing facts, it has been considered to undertake a hydrogeological investigation in Thandla area, Jhabua district, Madhya Pradesh, which is facing the problem of water crisis. Present investigation has been carried out to generate relevant geoscientific data for characterization of hydrogeological regime of Thandla area. Research study has been conducted both in the field and laboratories, data analyses, and interpretations have been incorporated herein. The important characteristics of research work presented in seven chapters are being described.

8.1.1 INTRODUCTION

Chapter 1 has been designed to include general information about occurrence and importance of water, selection of research area, location of area, physiographic environment, fauna and flora; previous work and scope of future work. The study area is located within latitude 23^0 0' to 23^0 10' N and longitude 74^0 30' to 74^0 40' E in Thandla area of Jhabua district, Madhya Pradesh. Main objectives of the research work have been recorded.

A review of the previous investigations carried out in Thandla area, Jhabua district, has been included. The outlines of methodology have been incorporated. Based on the results of present study the scope of future research work has been discussed.

8.1.2 REGIONAL GEOLOGY AND STRATIGRAPHIC SETTING OF STUDY AREA

The chapter 2 deals with a concise description of Regional Geology and Stratigraphic setting of Thandla study area. Study area is dominated by the occurrence of Deccan Traps (Upper Cretaceous to Lower Eocene age). Deccan Traps are resting over the Aravalli Super group of Rajasthan (Achaean Group) with unconformable contact.

Diagnostic characters of various lithounits such as Phyllites, Quartzites, Lava flows, Soils and alluvium are described and illustrated. The structural features such as vertical, columnar joints, fractures, and spheroidal weathering have been observed in Thandla study area.

8.1.3 GEOMORPHOLOGICAL ANALYSIS

Chapter 3 presents an account of the qualitative and quantitative geomorphological analyses of Thandla drainage basin. Qualitative aspects including hills, valleys, plateau, and plains have been described. Quantitative morphometric analysis involves computation of linear, areal and relief aspects of Thandla drainage basin. These parameters include Stream order, Stream number, Stream length, Bifurcation ratio (1 to 10), Drainage density (2.76 to 4.91 1/km), Stream frequency (2.799 to 6.257 1/km^2), Form factor (0.348 to 2.829), Circularity ratio (0.509 to 1.143), Elongation ratio (13.331 to 107.888), Lemniscates ratio (0.069 to 0.718), Length of overland flow (0.101 to 0.181 km), Basin relief (2 to 120 m), Relief ratio (0.754 to 16), Ruggedness number (0.008 to 0.583) and Ground surface slope (0.016 to 1.166). Quantitative analysis indicates that the study area is characterized by presence of dendritic drainage pattern indicating ground water potential zones. Relationships among morphometric parameters have been determined. Hypsometric analysis has been carried out to illustrate the development stages of Thandla drainage basin.

8.1.4 RAINFALL DATA ANALYSIS

Chapter 4 describes results and interpretation of rainfall data analysis of Thandla area for a period of 25 years (1992 - 2016). Rainfall data reveal a range of 423.0 mm to 2086.2 mm. Mathematical analysis indicates the annual average value of rainfall as 964.324 mm. Variation trends of monthly, yearly and cumulative departure from the annual average value have been determined.

Statistical analysis involves determination of Mean (976 mm), Median (960 mm), Mode (1140 mm), Standard deviation (412 mm), Co-efficient of variation (42.213), Co-efficient of dispersion (0.422) and Co-efficient of skewness (-0.398). An attempt has been made to forecast the expected future rainfall. Future trend has been computed on the basis of time series analysis, which indicates a negative trend of expected rainfall. Hence, it is the priority need to implement a scheme for augmentation of rainfall phenomena in order to enhance ground water recharge. Implementation of a scheme to increase rainfall recharge and aforestation is recommended to combat the requirement of sustained water supply.

8.1.5 HYDROGEOLOGICAL CHARACTERIZATION

Chapter 5 deals with hydrogeological characterization examined by the systematic hydrogeological analysis of Thandla study area, located in Jhabua district, Madhya Pradesh. During survey of study area, 197 open dug wells have been examined by recording relevant data such as location of wells, name of owner, bench mark, diameter, total depth of wells, seasonal static water levels, mode of lifting water and use of wells.

Based on dug wells data, 35 open dug wells have been selected as observation wells for monitoring of seasonal fluctuations in water levels. The collected dug wells data have been analyzed and described.

Seasonal ground water levels contour maps have been prepared on the basis of reduced water levels (Bench Mark – Static Water Level = Reduced Water Level). The patterns of ground water level contours help in demarcation of favourable ground water potential sites. Widely spaced contours at villages of Madalda, Karikura, Etankhera, Kadwali, Mujal, Walakhori, Panchpiplya, Kundla, Dhamni Chhoti, Chainpuri, Semlya, Machhlaimata, Kakarej, Junwaniya Chhota, Warlipara, Parwalya, Khandan, Manpur, Rupgarh, Miyati Ratanpura, and Timarwani indicates the ground water potential sites in study area. Closely spaced contours have been observed near villages of Angliyapara, Lalgarh, Bahadurpara, Kaldela, Koriyapara, Chirwa, Dhamni Bari and Jamda have a very low yield or almost dry.

The ground water level fluctuation has been noted from 1.3 to 11.0 m. (b.g.l.) during the post-monsoon to pre-monsoon interval. In general, ground water flow direction is towards "Padmavati" River.

8.1.6 GROUND WATER QUALITY ESTIMATION

The chapter 6 contains results of chemical analysis of selected 30 ground water samples from open dug wells existing in Thandla area, Jhabua district. Physical and Chemical analyses of ground water samples have been determined and recorded by using both tabular and graphic methods of representation. Physical analysis indicates that ground water is colorless, odorless, tasteless, with turbidity (0.89 to 4.91), pH value (7.05 to 8.30), electrical conductivity (307 to 600 mohos/cm), total dissolved solids (275 to 481), total hardness (230 to 340), and Alkalinity (132 to 198).

Chemical analysis includes determinations of major Cations- Ca (89-200), Mg (63-147), Na (22-60), K (0.30-3.60) and Anions- Cl^- (97-240), SO_4 (68-195), HCO_3 (120-235), NO_3 (21-50), F^- (0.20-4.00). Based on plots of ionic concentration on Piper's Trilinear diagram the ground water quality has been determined for drinking applications. The determined values of different chemical parameters have been compared with the recommended desirable and maximum permissible values indicate that the samples of Thandla ground water in general, are suitable for domestic and drinking purposes. Determinations of parameters such as sodium percent, sodium adsorption ratio, residual sodium carbonate, and magnesium hazards have been applied for quality delineation of ground water suitability for irrigation use. In general, ground water of Thandla area is suitable for domestic, drinking, and irrigation purposes. It should be used for drinking purposes after proper treatment at a few places.

8.1.7 GROUND WATER DEVELOPMENT AND MANAGEMENT

Chapter 7 incorporates the strategy for ground water development and management in Thandla area of Jhabua district. Thandla area exhibits a depleting trend of ground water which is causing a problem of shortage of sustained water supply, particularly during summer period to the inhabitants of study area. Most of open dug wells existing in the study area become almost dry during summer season. This condition is resulting mainly due to rapid depletion of ground water levels, resulting in the failure of sustained water supply to populace of Thandla study area.

Ground water management requires both quantity and quality of water for the well-organized water supply programmes. Ground water augmentation can be achieved by construction of artificial recharge structures such as pits, trenches, check dams, nala bunds, percolation tanks, gully plugs, sub-surface dykes, recharge wells and rainwater harvesting structures .

It is basic requirement to compute ground water potential of an area. Formulation of management plan is based on the estimation of recharge, annual draft, over draft, purpose of water supply, as well as availability of finance.

In Thandla study area, computation of ground water potential parameters have been determined with a view to prepare the ground water development and management plan. Computed values of ground water are recharge as $5047.80 \times 10^4 \, m^3$, and annual draft as $10667.47 \times 10^4 \, m^3$ indicate that the Thandla area is facing a situation of ground water over draft of $-5619.67 \times 10^4 \, m^3$.

It is suggested that optimum development and management plans may be executed by launching a proper scheme for plantation, aforestation, construction of artificial recharge structures, roof top harvesting structures, and adequate control on wastage of available water. The implementation of a strategy for judicious management of ground water supply in a particular area or region, is required to obtain sustained water supply.

8.2 CONCLUSION OF RESEARCH

The salient features of present research investigation are incorporated herein:

- ❖ Thandla study area is located in Jhabua district, Madhya Pradesh. Geologically, it is dominated by Deccan Traps, Phyllite, Quartzite and Alluvium soils.

- ❖ Drainage basin geomorphology reveals more or less elongated shape and dendritic pattern revealing ground water suitability.

- ❖ The analyzed rainfall data indicates a wide variation and indicating rather negative future trend. Environmental factors affecting the rainfall and it is recommended that rainfall recharge to ground water system needs to be essential.

- ❖ Systematic hydrogeological survey has been carried out in vicinity of Thandla area, which includes monitoring of ground water levels for constructing different maps depicting nature of ground water occurrence, movement and demarcation of new ground water potential sites.

- ❖ Quality estimation of ground water reveals that in general ground water is favourable for domestic, drinking and irrigation use except at a few villages of Bhimkund, Khokhar Khandan, Kaldela, Symlya, Ambapara, Kakarej, Panchpiplya, Devigarh, Borari, Bahadurpara, Munjal, Karikurna, and Khajuri.

- ❖ Estimation of ground water potential indicate over draft condition which can be reduced by construction of artificial recharge structure. Such as Pits, Trenches, Shafts, Nala bunds, Contour bunds, Ponds, Check dam, Percolation tank, Gully plug, Sub-surface dyke, Injection wells, and Rainwater harvesting structures.

- ❖ Development and management of ground water resource in present study area, may be obtained by implementation of a strategy including the augmentation of ground water by construction of artificial recharge structures, which would increase the recharge of ground water system and resolve the problem of water crisis.

- ❖ Results of present study reflect that guidelines would be favourable for implementation for the development and management in adjoining areas as well.

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