GROUNDWATER RECHARGE PLANNING FOR DHAMTARI, BALOD AND BEMETARA DISTRICTS OF CHHATTISGARH STATE USING SATELLITE DATA AND GIS TECHNIQUE

M. Tech. (Agril. Engg.) THESIS

by

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CERTIFICATE – I

This is to certify that the thesis entitled **"Groundwater Recharge Planning for Dhamtari, Balod and Bemetara Districts of Chhattisgarh State Using Satellite Data and GIS Technique"** submitted in partial fulfilment of requirements for the degree of **"Master of Technology in Agricultural Engineering"** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Ku. Jyotsana Khakha** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate award *etc.*) or has been published/Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

Date: 22/07/2013

Chairman

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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CERTIFICATE – II

This is to certify that the thesis, entitled **"Groundwater Recharge Planning for Dhamtari, Balod and Bemetara Districts of Chhattisgarh State Using Satellite Data and GIS Technique"**, submitted by **Ku. Jyotsana khakha,** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur in partial fulfilment of the requirements for the degree of **M. Tech. (Agricultural Engineering)** in the Department of Soil and Water Engineering, has been approved by the external examiner and Student's Advisory Committee after oral examination.

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Place: Raipur

Date: *(Jyotsana Khakha)*

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LIST OF ABBREVIATIONS

Abbreviation	Description
Agri.	Agriculture
Agril. Engg.	Agricultural Engineering
AICRP	All India Coordinated Research Project
CD	Check Dam
C.G.	Chhattisgarh
CGWB	Central Ground Water Board
DEM	Digital Elevation Model
Eq.	Equation
FAE	Faculty of Agricultural Engineering
Fig.	Figure
GIS	Geographic Information System
GPS	Global Positioning System
GW	Groundwater
GWARA	Ground Water Assessment and Recharge Analysis
GWU	Groundwater Utilization
ICAR	Indian Council of Agricultural Research
IGKV	Indira Gandhi Krishi Vishwavidyalaya
MSL	Mean Sea Level
M. Tech.	Master of Technology
NCCR	North Central Chhattisgarh Region
NRSA	National Remote Sensing Agency
PT	Percolation Tank
RS	Remote Sensing
SWE	Soil and Water Engineering
SLNA	State Level Nodel Agency

LIST OF SYMBOLS

Symbols		Description
^{o}	-	Degree
%	-	Percent
θ	-	Degree radian
A	-	Area of the watershed
mbgl	-	Meter below ground level
^{o}C	-	Degree Centigrade
cm	-	Centimeter
D	-	Depth
D_d	-	Drainage density
Dwt	-	Depth to water table in the pre-monsoon season
Dwte	-	Depth to water table in the pre-monsoon season
Dwto	-	Depth to water table in the post-monsoon season
E	-	East
F	-	Rainfall infiltration factor
hr	-	Hour
ha	-	Hectare
km	-	Kilometer
km^2	-	Square kilometer
lps	-	Litres per second
m	-	Meter
m^2	-	Square meter
m^2/ day	-	Square meter per day
m^3	-	Cubic meter
mm	-	Millimeter
N	-	North
Sy	-	Specific yield
Rrf	-	Recharge from rainfall
S	-	Storage Coefficient

CHAPTER I

INTRODUCTION

Groundwater is a precious resource with limited availability. Groundwater plays an important role in sustaining India's economy, environment, and standard of living. It is not only the main source for water supply in urban areas for domestic uses, but also is the largest and most productive source of irrigation water. The relentless increases in population and the resulting spurt in the demand for water requirement, carefully planning and management of this limited water resources is urgently needed.

There have been continued efforts for development of groundwater resource to meet the increasing demands of water supply, especially in the last few decades. In uncertain high demand areas, groundwater development has already reached a critical stage, resulting in acute scarcity of the resource. Over development of groundwater resources results in declining groundwater levels, shortage in water supply, intrusion of saline water in coastal areas and increased pumping lifts necessitating deepening of groundwater structures in ensuring added cost.

Artificial recharge of aquifer systems is gaining importance as one of the strategies of water management in the context of ever growing demands of water resources. It is the process by which groundwater is augmented at a rate exceeding that of natural conditions of replenishment. The aim of artificial recharge of groundwater has been to reduce or even reverse the declining levels of groundwater, to protect fresh ground water in coastal aquifers against saline water intrusion and to store surplus surf**a**ce water including monsoon runoff and waste water for future use.

A plan of an artificial recharge of groundwater can help to (1) enhance the sustainable yield in areas where over development has depleted the aquifers, (2) support conservation and storage of excess surface water for future requirements which often change within a season over a period and (3) improve the quality of existing groundwater through dilution.

The country’s average annual rainfall is 1194 mm, which when considered over a geographical area of 328 Mha amounts to a total volume of about 400 Mham. Out of this the utilizable potential is only 67 Mham of surface water and 26.5 Mham of groundwater. So, there is an urgent need for augmentation of the limited groundwater resources by taking appropriate measures including suitable management interventions.

The Chhattisgarh state receives adequate rainfall (average annual rainfall is 1324 mm). About 87 % area of the state is covered by hard rocks. Groundwater availability is largely influenced in these rocks by the topography and rainfall. Because of varied topography and hydrogeological condition in the state, the groundwater potential is not uniform and it changes from one area to another. Out of 146 blocks in the state, 15 have been categorized as semi-critical from groundwater development point of view as the stage of groundwater development is more than 70% but less than or equal to 90 %. Out of these 15 blocks, 3 fall in Durg, 3 in Dhamtari,1 in Rajnandgaon,1 in Kawardha, 1 in Janjgir-Champa, 1 in Raigarh, 2 in Bemetara, 2 in Balod and 1 in Bilaspur District.

The average groundwater development of Dhamtari, Balod and Bemetara districts are reported to be 67.60, 65.8 and 63.24 per cent, respectively. The lack of effective groundwater recharge structures in a region usually brings about adverse effects. The relentless increases in population and the resulting spurt in the demand for water requirement, carefully planning and management of the limited water resources is urgently needed.

A large amount of rain water is lost through runoff, a problem compounded by the lack of rainwater harvesting practices. Exploitation of sub-surface water from deep aquifers, also deplenishes resources have taken decades or centuries to accumulate and on which the current annual rainfall has no immediate effect. Few sustained efforts have been made to identify zones where artificial-recharge techniques can be implemented to conserve groundwater. Remote sensing and Geographic Information System are playing a significantly increasing role in the field of hydrology and water resources development. Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface. One of the greatest advantages of using remote sensing data for hydrological investigations and monitoring, is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation. GIS technology provides suitable alternatives for efficient management of large and complex databases.

Remotely sensed data provides unbiased information on geology, geomorphology, structural pattern and recharging conditions, which logically define the groundwater regime of an area. GIS overlaying analysis is highly helpful in locating the groundwater resources. In order to implement artificial groundwater recharge, it is essential to delineate potential groundwater recharge zones. Conventionally, remote sensing and GIS methods are deployed to select favorable sites for implementation of artificial recharge. Satellite Remote Sensing

techniques are also extremely useful techniques for groundwater exploration, especially for delineating
hydrogeomorphological units. Lineaments plays a major role in identifying suitable sites for artificial recharge of groundwater because they reflect rock structures through which water can percolate and travel up to several kilometers.

In recent years, the use of satellite data and GIS application has been found increasing in a wide range of resources inventory, mapping, analysis, and monitoring and environmental management. Remote sensing provides very useful methods of survey, identification, classification, and monitoring several forms of earth resourses, and helps in acquisition of data in a time at periodic intervals.

It provides the real time and accurate information related to distinct geological formation, landforms and helps in identification of drainage channels, which are altered by natural forces of human activities. GIS is an effective tool to analyze spatial and non spatial data on drainage, geology, landuse, lineament, soil map, slope map, well location forms parameters to understand their interrelationship. The concept of integrated remote sensing and GIS has proved to be an indispensable tool in planning and ground water studies

Since delineation of groundwater prospect zone and identification of artificial recharge sites is based on the combined role being played by various factors, it is necessary to use Remote sensing and GIS. The present study is an attempt to identification of artificial recharge sites, Dhamtari Balod and Bemetara districts of Chhattisgarh, using satellite data and Geographic Information System.

Looking to the status of groundwater development and alarming situation of water table there is urgent need of groundwater recharging. Since, there is no appropriate recharge plan available for the districts especially for the block which comes under semi critical category, there is need of plan for groundwater recharge.

Therefore, the present study involves to prepare the Plan for artificial groundwater recharge for Dhamatri, Balod and Bemetara districts with following specific objectives:

1. To analyse various information to prepare thematic maps of the study area.
2. To identify the appropriate locations for groundwater recharge structures and estimate the potential of these structures for groundwater recharge.
3. To develop groundwater recharge plan for the study area.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the review of literature related to the present study. It includes a brief account of published literature on estimation of groundwater recharge carried out in different parts of India and abroad. The efforts has been made to group the available literature accordingly and divided into different relevant groups and presented in this chapter. The literature related to planning of artificial groundwater recharge, remote sensing and GIS, groundwater availability and groundwater recharge structure are also included in this chapter. Nevertheless, the work of literature survey is endless even through exhaustive survey has been done and come out with clear cut need of plan for groundwater recharging.

2.1 Artificial Recharge

Tompson *et al*. (1999) analyzed groundwater migration from artificial recharge in a large urban aquifer. They review about the development and initial application of a detailed numerical model of groundwater flow and migration in a region encompassing a large groundwater recharge operation in Orange County, California. The model was based upon a novel representation of geologic heterogeneity, which has long been known to influence local flow and transport behavior in the subsurface. The model and complementary series of isotopic analyses provide an improved scientific basis to understand flow paths, migration rates, and residence times of recharged groundwater, as well as to identify the source composition of water produced in wells near the recharge operation. From a management perspective these issues need to be confronted in order to respond to proposed regulatory constraints that would govern the operation of recharge facilities and nearby production wells. While model calibration is greatly aided by isotopic source and residence time analyses, the model also provides unique insights on the interpretation of isotopic data themselves. Isotopic estimates of groundwater age help discriminate between several equally acceptable simulations calibrated to head data only.

Khepar *et al.* (2000) concluded that intensive agriculture in various countries had resulted in over-exploitation of ground water resources leading to a decline in the water table. Artificial ground water recharge offers a good method of preventing the water table from declining further. The Indo-Gangetic plain was currently facing the problem of a declining water table. A model was developed to determine the optimum discharge to be released at the head of drains under natural flow conditions and with interruption in the flow by providing check structures across the drains at suitable intervals. In the proposed method, water was released in such a way that outflow becomes zero at the outfall of the drain. The results obtained revealed that the strategy developed could be adopted for recharging the declining water table through surface drainage systems.

Scanlon (2002) reported that various techniques are available to quantify recharge; however, choosing appropriate techniques is often difficult. Important considerations in choosing a technique include space/time scales, range, and reliability of recharge estimates based on different techniques; other factors may limit the application of particular techniques. Typical study goals include water-resource evaluation, which requires information on recharge over large spatial scales and on decadal time scales; and evaluation of aquifer vulnerability to contamination, which requires detailed information on spatial variability and preferential flow. The range of recharge rates that can be estimated using different approaches should be matched to expected recharge rates at a site. The reliability of recharge estimates using different techniques is variable. Techniques based on surface-water and unsaturated-zone data provide estimates of potential recharge, whereas those based on groundwater data generally provide estimates of actual recharge. Uncertainties in each approach to estimating recharge underscore the need for application of multiple techniques to increase reliability of recharge estimates.

Singh *et al.* (2002) conducted study on artificial recharge of groundwater in the upper catchment area of Kumari river basin, India. Artificial recharge of groundwater in the upper catchments area of the Kumari river basin has been carried out in an area by latitude 22^{o}55' to 23^{o}15' N and longitude 86^{o}08' to 86^{o}38'E situated in the western part of the Purulia District, West Bengal. The Kumari River is the main tributary of the Kasai River that is finally drains its water into the Bay of Bengal. Rain and snow being the primary renewable source of water and rain water harvesting viewed in wider prospective forms the primary source of water for artificial groundwater recharge. The wider prospective of rain water harvesting includes water from perennial or ephemeral streams regulated with dams, storm runoff including that of urban areas, ponds and lakes. In fact any source of surplus water directly originated from snow or rain. The other sources of recharge water may originate from aqueducts or other water conveyance facilities, irrigation areas, drinking water treatment plants and sewage water treatment plants. Artificial recharge of groundwater is expected to play an increasing role in reuse of wastewater because movement of water through soils and aquifers provides a means of geo-purification of water through the process known as Soil –Aquifer-Treatment (SAT).

Sophocleous (2005) worked on groundwater recharge and sustainability in the high plains aquifer in Kansas, USA. His work highlights some key groundwater recharge studies in the Kansas high plains at different scales, such as regional soil-water budget and groundwater modeling studies, county-scale groundwater recharge studies, as well as field-experimental local studies, including some original new findings, with an emphasis on assumptions and limitations as well as on environmental factors affecting recharge processes. The general impact of irrigation and cultivation on recharge is to appreciably increase the amount of recharge, and in many cases to exceed precipitation as the predominant source of recharge. The imbalance between the water input (recharge) to the high plains aquifer and the output (pumpage and stream baseflows primarily) is shown to be severe, and responses to stabilize the system by reducing water use, increasing irrigation efficiency, adopting water-saving land-use practices, and other measures are outlined. Finally, the basic steps necessary to move towards sustainable use of groundwater in the high plains are delineated, such as improving the knowledge base, reporting and providing access to information, furthering public education, as well as promoting better understanding of the public's attitudinal motivations; adopting the ecosystem and adaptive management approaches to managing groundwater; further improving water efficiency; exploiting the full potential of dry land and biosaline agriculture; and adopting a goal of long-term sustainable use.

Nivasarkar and Verma (2009) conducted a study to know the groundwater development and artificial recharge prospectus of Mahasamund district in Chhattisgarh. They observed that the groundwater could be developed through dug wells and bore wells. The optimum development of balance ground water resources can supply assured irrigation to 85467 ha of land and side by side there was huge scope exists for artificial recharge.

Saxena et al. (2010) studied on conservation of groundwater by artificial recharge in Delhi and Haryana State of India. In this study author reviewed and summarized different studies to suggest a variety of methods to recharge groundwater. The groundwater recharge process in relation to the climatic and geographical conditions had been studied and prepared a list of pros and cons for different methods with secondary date available in literature. They have also narrated the case studies of two states (Site–1 and Site–2) to explain the conservation of groundwater by artificial recharge. The overall efficiency of the methods used to artificially recharge groundwater have sufficiently explained.

Bhattacharya (2010) reported that the artificial groundwater recharge is a process by which the groundwater reservoir is augmented at a rate exceeding the augmentation rate under natural conditions of replenishment. It was reported that in some parts of India, due to over exploitation of groundwater, decline in groundwater levels resulting in shortage supply of water, and intrusion of saline water in coastal areas had been observed. In such areas, there was a need for artificial recharge of groundwater by augmenting the natural infiltration of precipitation or surface-water into underground formations by methods such as water spreading, recharge through pits, shafts and wells. The choice of a particular method was governed by local topographical, geological and soil conditions; the quantity and quality of water available for recharge; and the technological-economical viability and social acceptability of such schemes. He also discusses various issues involved in the artificial recharge of groundwater.

Gautam *et al.* (2010) reported that the indiscriminate use of water results in fast decline of available water resource. Integration of remotely sensed data and field survey data on a GIS platform provides convergent analysis of diverse data sets for decision making in groundwater management. Speck Spatial Tech Limited (SST) adopted a multi-disciplinary approach for developing a comprehensive tool for planning watershed development through artificial recharge of groundwater and rainwater harvesting in 2500 km^2 area spanning across 3 districts in Chhattisgarh, India. In total thirty two (32) watersheds of various sizes (ranging from 16 to 248 km^2) falling in Mahanadi basin were delineated. An integrated analysis on a GIS platform was carried out to identify sites suitable for artificial recharge and rainwater harvesting. Water resource development plan was generated for each identified site, describing type of recharge structure, detailed engineering design.

Dripps and Bradbury (2010) worked on the spatial and temporal variability of groundwater recharge in a forested basin in Northern Wisconsin. A simple, daily soil-water balance model was developed and used to estimate the spatial and temporal distribution of groundwater recharge of the Trout Lake basin of northern Wisconsin for 1996-2000 as a means to quantify recharge variability. Results of 5 years of study revealed that the annual recharge varied spatially by as much as 18 cm across the basin; vegetation was the predominant control on this variability. Recharge also varied temporally with a threefold annual difference over the 5-year period. Intra-annually, recharge was limited to a few isolated events each year and exhibited a distinct seasonal pattern. The results suggested that ignoring recharge variability may not only be inappropriate, but also, depending on the application, may invalidate model results and predictions for regional and local water budget calculations, water resource management, nutrient cycling, and contaminant transport studies. Recharge is spatially and temporally variable, and should be modeled as such.

Chowdhury *et al*. (2010) worked on delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques. Different themes and their corresponding features were assigned proper weights based on their relative contribution to groundwater recharge in the area, and normalized weights were computed using the Saaty's analytic hierarchy process (AHP). These thematic layers were then integrated in the GIS environment to delineate artificial recharge zones in the study area. It was found that about 46% of the study area falls under 'suitable' zone, whereas 43% falls under the 'moderately suitable' zone. The western portion of the study area was found to be unsuitable for artificial recharge. The artificial recharge zone map of the study area was found to be in agreement with the map of mean groundwater depths over the area. Forty possible sites for artificial recharge were also identified using RS and GIS techniques. Based on the available field information, check dams were suggested as promising artificial recharge structures. The results of this study could be used to formulate an efficient groundwater management plan for the study area so as to ensure sustainable utilization of scarce groundwater resources.

Kavuri et al. (2011) worked on new methods of artificial recharge of aquifers. They reviewed about the existing methods of artificial recharge of aquifers such as infiltration basins and canals, water traps, cut waters, surface run off drainage wells, and diversion of excess flow from irrigation canals etc. with the help of various case studies conducted in the recent past at various places.

- hideDawes et al. (2012) quantified the change in groundwater recharge in

response to a range of future climate and land cover patterns across south-west Western Australia.Modeling the impact on the groundwater resource of potential climate change was achieved with a dynamically linked unsaturated/saturated groundwater model. A vertical flux manager was used in the unsaturated zone to estimate groundwater recharge using a variety of simple and complex models based on climate, land cover type, soil type, and taking into account the groundwater depth.

In the area centered on the city of Perth, Western Australia, the patterns of recharge change and groundwater level change are not consistent spatially, or consistently downward. In areas with land-use change, recharge rates have increased. Where rainfall had declined sufficiently, recharge rates were decreased, and where compensating factors combined, there was little change to recharge. In the southwestern part of the study area, where the combination of native vegetation and clayey surface soils restricted possible infiltration, recharge rates were very sensitive to reductions in rainfall. In the northern part of the study area, both climate and land cover strongly influence recharge rates. Recharge under native vegetation was minimal and was relatively higher where grazing and pasture systems have been introduced after clearing of native vegetation.

Sharma and Kujur (2012) conducted a study in a hard rock of Precambrian/Archaean with some part occupied by sedimentary rocks. The intersection zones of lineaments provide potential for ground water accumulation and ground water recharge. Occurrence of groundwater in such rocks is essentially confined to fractured and weathered zones. They were established basic information for site selection of rainwater harvesting /artificial recharge structures to the aquifer systems by preparing various thematic maps such as geology, geomorphology, drainage pattern, drainage density, lineaments, landuse/cover etc. which have been prepared on visual interpretation techniques using the remote sensing data with the help of GIS techniques and topographic information along with secondary information and limited field checks of the study area, that falls in and around Gola block, Ramgarh district, Jharkhand, India. It was an attempt to suggest for maintaining the proper balance between the groundwater quantity and its exploitation.

Hashemi *et al*. (2013) estimated the change in groundwater recharge from an introduced artificial recharge system is important in order to evaluate future water availability. There was an inverse modeling approach to quantify the recharge contribution from both an ephemeral river channel and an introduced artificial recharge system based on floodwater spreading in arid Iran. The study used the MODFLOW-2000 to estimate recharge for both steady and unsteady-state conditions. The model was calibrated and verified based on the observed hydraulic head in observation wells and model precision, uncertainty, and model sensitivity were analyzed in all modeling steps. The results showed that in a normal year without extreme events the floodwater spreading system is the main contributor to recharge with 80% and the ephemeral river channel with 20% of total recharge in the studied area. Uncertainty analysis revealed that the river channel recharge estimation represents relatively more uncertainty in comparison to the artificial recharge zones. The model is also less sensitive to the river channel. The results of this study showed that by expanding the artificial recharge system the recharge volume can be increased even for small flood events while the recharge through the river channel increases only for major flood events.

2.2 Planning of Groundwater Recharge

Harned *et al*. (1999) worked on ground-water recharge rates - a land-use planning tool for the Piedmont. The number of ground-water users in the Piedmont continues to increase with suburban development that is not tied to available surface water supplies. The USGS conducted studies from 1995 to 1997 to estimate groundwater recharge rates in Guilford and Orange Counties in the central Piedmont of North Carolina. Ground-water flow in streams was estimated by using hydrograph separation and long-term USGS records from 33 gauging stations with drainage areas that range in size from 7.54 to 1,310 square miles. The local minimum method of hydrograph separation by Pettyjohn and Henning (1979) was used to estimate values of daily mean ground-water discharge. Assumed that there has been no long-term change in groundwater storage, groundwater discharge is equal to groundwater recharge. Recharge hydrographs and duration tables were generated for each basin and sub basin within the counties. The median groundwater recharge for 27 basins and sub basins within Guilford and Orange Counties ranges from 80.7 to 723 gallons per day per acre. The difference in recharge rates generally correlated with hydrogeological units of the region. The recharge values combined with knowledge about other factors that affect recharge rates, such as land use and slope, can be used by planners to estimate the size of a recharge area needed to meet a water demand.

Jha *et al*. (2002) worked on groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. A detailed survey of literature revealed six major areas of RS and GIS applications in groundwater hydrology: (i) exploration and assessment of groundwater resources, (ii) selection of artificial recharge sites, (iii) GIS-based subsurface flow and pollution modeling, (iv) groundwater pollution hazard assessment and protection planning, (v) estimation of natural recharge distribution, and (vi) hydrogeologic data analysis and process monitoring. Although the use of these techniques in groundwater studies has rapidly increased since early nineties, the success rate is very limited and most applications are still in their infancy. Based on this review, salient areas in need of further research and development are discussed, together with the constraints for RS and GIS applications in developing nations. More and more RS- and GIS-based groundwater studies are recommended to be carried out in conjunction with field investigations to effectively exploit the expanding potential of RS and GIS technologies, which will perfect and standardize current applications as well as evolve new approaches and applications. It is concluded that both the RS and GIS technologies have great potential to revolutionize the monitoring and management of vital groundwater resources in the future, though some challenges are daunting before hydrogeologists/hydrologists.

Shah (2008) India's Master Plan for Groundwater Recharge: An Assessment and Some Suggestions for Revision. The Government's groundwater recharge master plan reflects belated recognition of the growing criticality of groundwater for the Indian economy. The plan aims to raise post-monsoon groundwater levels to three meter below ground level through annual "managed artificial recharge" of 36.4 km3 by constructing some four million spreading-type recharge structures at a cost of Rs 25,000 crore. While this was a step in the right direction, the revised master plan under preparation needs to incorporate socio-economic, institutional and administrative parameters that underpin the implementation of any major change intervention. This study provided an assessment of the existing plan and offers suggestions for revision.

Jha and Sinha (2009) worked towards better management of ground water resources in India. The highly uneven distribution and its utilization make it impossible to have single management strategy for the country as a whole. Any strategy for scientific management of ground water resources should involve a combination of supply side and demand side measures depending on the regional setting. There was a need to critically analyze the underlying factors responsible for the imbalances in terms of technical and socio-economic considerations. These should also be taken for consideration while formulating any comprehensive water resources management initiatives for the country. There was urgent need for coordinated efforts by various Governments and non-governmental agencies, social service organizations and the stakeholders for evolving implementable plan for effective management of this precious natural resource.

Anshuman (2011) reported that water resources faces multiple pressures with increasing complexities of peaking demand, unscrupulous use and additional likely risks due to climate change. With the multifarious stress on their source, the pursuit for its conservation and efficient management was indispensable. This study highlighted an integrated approach of groundwater management that involved a preliminary diagnostic assessment of the groundwater resources for Neelamangala watershed (India) using GIS and modeling tools and subsequent identification and implementation of suitable intervention for conservation and efficient management of groundwater resources in the region.

Kumar (2012) conducted a study on planning of groundwater recharge for Durg district using Remote Sensing and GIS. Increasing demands for fresh water in different sectors especially in agriculture and restriction of water resources necessitated the planning of ground water recharge. The average ground water development of Durg district was reported to be 77 per cent. A satellite image IRS P6 LISS IV, of the year 2007 was classified using sopncised classification method to generated landuse map of the area. Different structures and their size had been decided on the basis of topography and drainage pattern. It was concluded that suitable sites for artificial recharge structures in study area was found to be 83 per cent and finally 107 locations were identified for check dams, where as 59 location were identified for percolation tanks. The vadose zone of 32.47 Mm^3 is available for artificial recharge in the study area. The actual volume (43.18 Mm^3) of surface water required for saturating the vadose zone, the net amount of source water available had been calculated. It was found that sufficient volume of water required for artificial recharge was available. Availability of source water to recharge the subsurface reservoir had been found to be 882.75 Mm^3 in the form of non-committed surplus runoff out of which 30 per cent (264.82 Mm^3) was considered as surplus monsoon runoff which was available for artificial recharge.

2.3 Assessment of Groundwater Recharge

Sukhija *et al*. (1997) worked on a method for evaluation of artificial recharge through percolation tanks using Environmental Chloride. For meeting the growing demand on ground water in hard rock areas of India, man-made percolation tanks have become important structures for augmenting ground-water recharge. Keeping in view their increasing number and cost involved in their construction and their temporal variation in percolation due to silting or desilting operations if undertaken, it was vital to develop proper methodology to evaluate the performance of these structures. A method employed the mass balance of environmental chloride in the tank had been developed for this purpose. The results obtained using this method at one experimental site indicated that an average of 30–35% of impounded water was recharged through this structure situated in granitic gneissic terrain of a semiarid region of India. The remainder was lost through evaporation. The method developed was simple, inexpensive, and sensitive enough to observe the temporal variation in the recharge rate through such tanks.

Shentsis *et al*. (1999) worked on assessment of transmission losses and groundwater recharge from runoff events in a wadi under shortage of data on lateral inflow, Negev, Israel. A hydrological–lithostratigraphical model was developed for assessment of transmission losses and groundwater recharge from runoff events in arid water courses where hydrological and meteorological records were incomplete. Water balance equations were established for reaches between hydrometric stations. In this study, the transmission losses were of the same order of magnitude as the flow at the major hydrometric stations. The losses were subdivided into channel moistening, which subsequently evaporates, and deep percolation, which recharges groundwater. For large runoff events, evaporation was substantially smaller than the losses. The mean annual recharge of groundwater from runoff events in the Tsin watershed was $4{\cdot}1\times10^6$ m^3, while the mean annual flow volume at the major stations ranged from 0·6 to $1{\cdot}5\times10^6$ m^3. Once in 100 years, the annual recharge may be seven times higher than the mean annual value, but the recharge during most years was very small.

Kashaigili *et al*.(2003) worked on groundwater management by using mathematical modeling: case of the Makutupora groundwater basin in Dodoma Tanzania. The computer code Visual MODFLOW was employed in this study. The study intended at developing a groundwater management model for Makutupora groundwater basin through mathematical modeling. The model was calibrated using a set of observed dynamic water levels, aquifer parameters until the best fit between the observed and simulated heads was obtained. The model was then verified using parameters that gave the least Root Mean Square Error (RMSE). The developed model was then used to simulate the dynamic water table elevations for the next twenty years under the different management scenarios and pumping policies from the year 2000 to 2020. The model revealed that a pumping scenario that considers a 10 % of rainfall as recharge could ensure aquifer sustainability for the planned period.

Sander *et al*. (2005) worked on groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana. A rural groundwater project within the Voltaian Sedimentary Basin in Central Ghana was the focus of a study to develop better well-siting strategies, based on interpretations of remote-sensing data and Geographic Information System (GIS) analyses. Lineaments were examined in the field and integrated with information from several hundred GPS-positioned boreholes. GIS analyses focused on the identification of phenomena that contributed to successful wells, in order to develop optimal strategies for future well siting. Remote-sensing data allowed effective mapping of features that were conducive to groundwater development. Lineaments identified on Landsat TM imagery had the greatest correspondence to well success. The integration of data in a GIS was valuable for effective analyses but also exposed the necessity of accounting for spatial reference and accuracy of data from different sources. GPS technology proved very useful to increase the spatial accuracy of the various data integrated in the GIS.

Suryawanshi and Pendke (2009) worked on groundwater recharge assessment through modeling technique in a watershed. Wagarwadi watershed of Parbhani district falls under semi arid tropics of basaltic terrain. The water balance components were analyzed to find out the ground water recharge, which was the main input to the aquifer MODFLOW. The percentage of mean annual ground water recharge and surface runoff to rainfall worked out to be 13.22 and 30.3 percent , respectively . In the observation wells which are in the close vicinity of soil and water conservation measures the observed water levels were closely matching with the computed water levels. While in the wells located at the downstream side of the harvesting structures the observed water level were found to be higher by 1 to 3 m as compared to computed were level due to additional seepage for restricted area.hide

Jha *et al*. (2010) conducted groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. The hydrologic parameters-based groundwater potential zone map indicated that the ‘good’ groundwater potential zone covers 27.14% of the area, the ‘moderate’ zone 45.33%, and the ‘poor’ zone 27.53%. A comparison of this map with the groundwater potential map based on subsurface parameters revealed that the hydrologic parameters-based map accurately delineates groundwater potential zones in about 59% of the area, and hence it was dependable to a certain extent. More than 80% of the study area had moderate-to-poor groundwater potential, which necessitates efficient groundwater management for long-term water security. Overall, the integrated technique was useful for the assessment of groundwater resources at a basin or sub-basin scale.

Pedretti *et al*. (2011) worked on Probabilistic analysis of maintenance and operation of artificial recharge ponds. They developed a probabilistic modeling framework that quantifies the risk of a pond’s infiltration capacity falling below its target value due to soil heterogeneity and clogging. This framework could act as a tool to aid managers in optimally selecting and designing maintenance strategies. Our model enables one to account for a variety of maintenance strategies that target different clogging mechanisms. The framework was applied to an existing pond in Barcelona, Spain as well as to several synthetic infiltration ponds with varying statistical distributions of initial infiltration capacity. They found that physical clogging mechanisms induce the greatest uncertainty and that maintenance targeted at these can yield optimal results. However, considering the fundamental role of the spatial variability in the initial properties, they concluded that an adequate initial characterization of the surface infiltration ponds is crucial to determining the degree of uncertainty of different maintenance solutions and thus to made cost-effective and reliable decisions.

Gontia and Patil (2012) Assessed groundwater recharge through rainfall and water harvesting structures in Jamka Micro watershed using remote sensing and GIS. The natural groundwater recharge through rainfall in the study area was found varying from 11 to 16 per cent of annual rainfall. The total groundwater recharge in the study area was estimated 390.29 ha m, in which the contribution of recharge through water harvesting structures was about 38.53%; this revealed that the water harvesting structures played an important role in increasing the groundwater recharge in the region.

Acar *et al*. (2013) estimated groundwater and contaminant discharges from fractured rock. Fractured rock aquifers were recognized as highly complex flow and transport systems, and the fractured rock passive flux meter (FRPFM) was a recently tested device to simultaneously measure cumulative water and contaminant mass fluxes in fractures intersecting an observation well (boring). Furthermore, the FRPFM is capable of indicating orientations and directions of flow in hydraulically active ("flowing") fractures. They developed a discharge estimator for when FRPFM measurements of fracture fluxes in the direction perpendicular to transect (control plane) along one or more observation wells were available. It was found that discharge uncertainty decreases proportionally with the number of fluxes measured. Results were validated, and an example problem illustrated practical application and performance.

2.4 Remote Sensing and GIS

Sarup *et al.* (2000) performed a study to delineate groundwater prospect zones and identification of artificial recharge sites using Indian remote sensing satellite (IRS) 1D PAN geocoded data on 1:12,500 scale and Survey of India (SOI) topographical sheets. Four-artificial recharge sites were identify out of which the moderate and poor categories occupied more than 42% area and these were mainly plateau, ridges and buried pediment shallow. The most suitable artificial recharge sites occupied less area about 19% and mainly confined to buried pediplain and river terraces. The residual hill and linear ridge with steep slope (covering about 39% areas) was not suitable for artificial recharge sites. This vital information could be used effectively for identification of suitable location for groundwater potential and artificial recharged sites. The good interrelationship was found among the geological units, hydromorphological units and lineament density. The field data had further helped in quantifying various lithological and hydromorphological units with reference to their potential for groundwater occurrence.

Srivastava (2000) studied and worked on mapping of groundwater prospect using remote sensing, GIS and geoelectrical resistivity techniques – a case study of Dhanbad district, Jharkhand, India. Mapping and management strategies for groundwater resources had been studied, by analyzing IRS LISS II multi band remote sensing data along with geological as well as geophysical resistivity sounding data carried out at places in GIS environment. Based on the integrated thematic maps, weighted analysis in Arc GIS groundwater resource prospect map of the area had been prepared and discussed. The study had brought out that the high groundwater potential zones were confined along lineaments and in pediment areas. Also alluvial fills, valley fills formed potential zones. The other geomorphic units like buried pediplain, peniplains and denundational hills formed zones of moderate to good groundwater prospects. Dissected pediments, inselberg complex, undulating upland and buried pediment with intermountain valley were zones of poor prospects. Very poor regions occupied a small part of total study area and were mainly confined to undulating upland and residual hills.

Cunningham and Daniel III (2001) investigated groundwater availability and quality in Orange County, North Carolina. A countywide inventory was conducted of 649 wells in nine hydrogeologic units in Orange County, North Carolina. It was concluded that two areas of the Country were more favorable for high-yield wells a west-southwest to east-northeast trending area in the northwestern part of the County, and a southwest to northeast trending area in the southwestern part of the County. Well yields in Orange Country showed little correlation with topographic or hydrogeologic setting.

Balachandar *et al.* (2010) prepared digital geological data from geological survey of India (GSI) for the study area. P 143 R 52 Date: 15052001, P 143 R 53 Date: 15052001,Geological Data Satellite: TM and SRTM, SOFTWARE USED ArcGIS 9.3 version. ENVI: 4.3 versions. In this study various thematic maps were prepared by visual interpretation of satellite imagery, SOI Top sheet. All the thematic maps were prepared on 1:250,000, 1:50,000 scale. For the study area, artificial recharge sites had been identified based on the number of parameters loaded such as 4, 3, 2, 1 & 0 parameters. Again, the study area was classified into priority I, II, III suggested for artificial recharge sites based on the number of parameters loaded using GIS integration. These zones were then compared with the Landuse and Landcover.

Adham *et al.* (2010) studied groundwater recharge potentiality of Barind Tract, Rajshahi District, Bangladesh using GIS and Remote Sensing technique The groundwater recharge potentiality in Barind Tract in Rajshahi district, Northwest Bangladesh was studied based on Geographical Information System (GIS) and Remote Sensing technique. In this connection satellite images (Landsat 7 ETM and

SPOT) and aerial photos were subjected to several treatment processes using software like ERDAS Imagine and ESRI's Arc View. The degree of effect was determined for each factor to assess the total groundwater recharge potentiality for two categories (moderate to low). The resultant map showed that 85% of the area has low, and rest had moderate groundwater recharge potentiality. Finally only 8.6% of the total average annual precipitated water (1685mm) percolated into subsurface and ultimately contributed to recharge the groundwater.

Machiwal *et al*. (2011) reported that remote sensing (RS) and geographic information system (GIS) are promising tools for efficient planning and management of vital groundwater resources, especially in data-scarce developing nations. In this study, a standard methodology was proposed to delineate groundwater potential zones using integrated RS, GIS and multi-criteria decision making (MCDM) techniques. Four groundwater potential zones were identified and demarcated in the study area, viz., 'good', 'moderate', 'poor' and 'very poor' based on groundwater potential index values. In the 'good' zone, the mean annually exploitable groundwater reserve was estimated at 0.026 million cubic meters per km^2 (MCM/km^2), whereas it was 0.024 MCM/km^2 in the 'moderate' zone, 0.018 MCM/km^2 in the 'poor' zone, and 0.013 MCM/km^2 in the 'very poor' zone. The groundwater potential map was finally verified using the well yield data of 39 pumping wells, and the result was found satisfactory.

Agarwal *et al*. (2012) conducted a study on remote sensing and GIS based approach for identification of artificial recharge site. In this study, the SCS-CN model, groundwater depth data and morphological parameters (bifurcation ratio, elongation ratio, drainage density, ruggedness number, relief ratio, and circulatory ratio) had been used to delineate the recharge sites for undertaking water conservation measures. Augmentation of water resource was proposed in the watershed by constructing runoff storage structures, like check dam, percolation tank and nala bund. The site suitability for these water harvesting structures was determined by considering spatially varying parameters, like runoff potential, slope, groundwater fluctuation data and morphometric information of the watershed. GIS had been used as an effective tool to store, analyze and integrate spatial and attribute information pertaining to runoff, slope, drainage, groundwater fluctuation and morphometric characteristics for such studies.

Narendra *et al*. (2013) worked on integrating remote sensing and GIS for identification of groundwater prospective zones in the Narava basin, Visakhapatnam region, Andhra Pradesh**.** It deals with the integrated approach of remote sensing and Geographical Information System (GIS) to delineate groundwater prospective zones in Narava basin, Visakhapatnam region. Various thematic maps generated for delineating groundwater potential zones were geomorphology, geology, lineament density, drainage density, slope and land use/land cover (LULC). Weighted index overlay (WIO) technique was used to investigate a number of choice possibilities and evaluate suitability according to the associated weight of each unit. The integrated map of the area showed different zones of groundwater prospects, viz. very good (18.9% of the area), good (26.4% of the area), moderate (17.1% of the area) and poor (37.6% of the area). The categorization of groundwater potential was in good agreement with the available water column in the basin area.

2.5 Ground Water Availability

Tripathi *et al.* (2006) conducted a study to present the overall availability of groundwater in Chhattisgarh. Effort has also been made to suggest scientific methods for proper development and effective management of groundwater. They concluded that total groundwater available in Chhattisgarh is 13684.80 Mm^3.

Watson *et al*. (2013) worked on groundwater availability as constrained by hydrogeology and environmental flows. This study explored how both hydrogeologic and environmental flow limitations might constrain groundwater availability in the Great Lakes Basin. A methodology for calculating maximum allowable pumping rates was presented. The results were sensitive to factors such as pumping time, regional and local hydrogeology, streambed conductance, and stream flow depletion limits. Understanding how these restrictions constrain groundwater usage and which hydrogeologic characteristics and spatial variables had the most influence on potential stream flow. Depletions had important water resources policy and management implications.

2.6 Artificial Groundwater Recharge Structure

Nedunchezhian *et al.* (2002) worked on efficacy of artificial recharge structures. They concluded that the groundwater flow was towards Northwest and West directions and follows the natural ground slope. The water level fluctuation method and norms recommended by Ground Water Estimation Committee 1998 was used for water budgeting of the study area. The study identified a large amount of inflow coming into this basin from the Northeast and Eastern boundaries.

Perrin *et al*. (2010) worked on contribution of percolation tanks to total aquifer recharge: the example of Gajwel watershed, southern India. The modeling approach consists in a first component which simulated runoff from daily rainfall as well as volumetric storage in tanks. A second component computed deep percolation from tanks based on a tank water balance approach. The model was validated by field observations in part of the watershed (temporal variations of tank volumetric storage).

Estimation of the recharge with the water table fluctuation method was about 21% of the monsoon rainfall whilst estimations of the additional artificial recharge, inferred from the tank water balance and the runoff model, ranged from 5 to 8%.

Renganayaki and Elango (2012) reviewed on Managed Aquifer Recharge by check dams. The study revealed that proper maintenance of check dams would result in the sustainable replenishment of groundwater resources in a region. In general the MAR through check dam was found to be one of the efficient methods to improve the groundwater head and quality which in turn improve the livelihood of community as indicated by most of the studies. MAR by check dam could be considered as a best option for efficient and sustainable management of groundwater resources.

2.7 Critics of Review of Literature

The review of literature reveals the importance of artificial groundwater recharge and need to identify the appropriate place for constructions of structure for groundwater using remote sensing and GIS, and computer software. The remote sensing and the Geographical Information System (GIS), is confined to advanced countries only. However, some of ground water recharge in study on planning the management of some of the countries are site specific very few study has been done in India, Chhattisgarh in particular.

Looking to the importance of groundwater planning, management and use of recently technique i.e. GIS is need of present area. This study will be very much useful for planning artificial groundwater recharge. Further, it will derive information for artificial recharging of ground water for enhancing sustainable livelihood security of poor farmers.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the description of the study area, data acquisition and methods used for data processing. Furthermore, methodologies for extracting some of the data using GIS for planning of groundwater recharge for Balod, Bematara and Dhamtari districts are described in detail. In this study RS data and GIS techniques were used for planning of groundwater recharge of Dhamtari, Balod and Bematara districts. This chapter deals with the materials and methods adopted to achieve the specific objective of the study. Materials used and methodology adopted are presented in following text of the chapter.

3.1 Description of Study Area

Most of the Blocks of Dhamtari**,** Balod and Bematara districts of Chhattisgarh are semicritical as per report published by CGWB, NCCR, Raipur. Also most of the data including meteorological, hydrological and hydrogeological are available hence these districts were chosen for the present study. These districts are the part of the middle agroclimatic zone known as Chhattisgarh plains. Location of the study area is shown in Fig. 3.1. The brief description including location and salient features of these districts is given below.

3.1.1 Dhamtari district

Dhamtari is located between 81°23'17" to 82°10'35" E longitude and 20°2'30" to 21°a1'32"N latitude and covers an area of 4081.93 km^2. The average altitude of the Dhamtari district is about 321.5 m above mean sea level (MSL). The district is bounded by Raipur district in the north, Balod district in the west, Kondagaon district in the south and Gariaband district in the east.

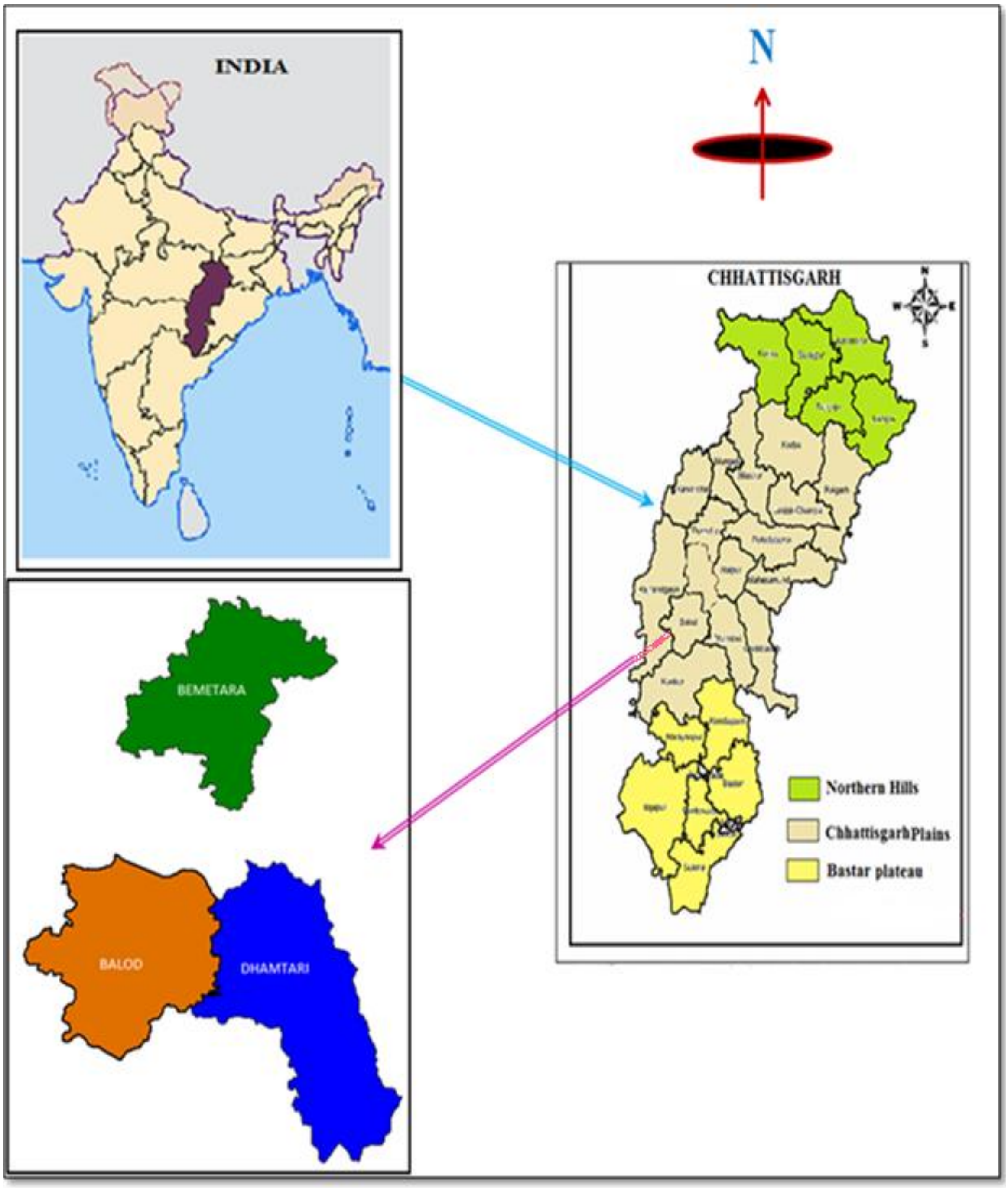

Fig. 3.1: Location of the study area in India and Chhattisgarh

3.1.2 Balod district

Balod district is located between 80°48'2" to 81°31'22" E longitude and 20°31' 22" to 21°25'03" N latitude and covers an area of 3385.11 km^2. The average altitude of the Balod district is about 324 m above mean sea level (MSL). The district is bounded by Durg district in the north, Rajnandgaon district in the west, Kanker district in the south and Dhamtari district in the east.

3.1.3 Bemetara district

Bemetara district was carved out by division of Durg district. It is situated on the North side of the Durg district. District Bemetara is located between 81°56'56" to 82°24'49" E longitude and 21°20'37" to 22°15'05" N latitude and covers an area of 2872 km^2. The average altitude of the Bemetara district is about 317 m above mean sea level (MSL). The boundary of the district touches 6 districts *i.e.*, Durg, Raipur, Baloda Bazar, Mungeli, Kawardha and Rajnandgaon of the Chhattisgarh State.

3.2 Data Acquisition

Satellite image for the Dhamtari, Balod and Bemetara districts procured from National Remote Sensing Agency (NRSA), Hyderabad by the All India Coordinated Research Project (AICRP) on Groundwater Utilization (GWU), Department of Soil and Water Engineering (SWE), Faculty of Agricultural Engineering (FAE), Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur. These satellite data were used in this study. Meteorological and hydrological parameters are being monitored under AICRP on GWU sponsored by Indian Council of Agricultural Research (ICAR), New Delhi and the same were used in the present study. Some hydrogeological data were collected from the Central Ground Water Board, (CGWB), NCCR, Raipur. Thematic maps including depth to water level (per monsoon), depth to water level (post monsoon) and lineament maps were prepared under the assistance of Central Ground

Water Board, Senior Scientist. Drainage and water bodies map was prepared with the help of topographic map and MapInfo Professional 8.5 GIS. Watershed map was collected from State Water Resource Department, Government of Chhattisgarh which were rectified with the help of GIS.

3.2.1 Agroclimate of Dhamtari district

The district experiences sub-tropical climate characterized by extreme cold in winter and extreme hot in summer. On the basis of rainfall and temperature the year may be divided into three distinct season namely rainy season (from June to October), winter season (mid November to Feberaury) and summer season (from March to May). Dhamtari District receives rainfall of 1096 mm annually with 65 rainy days (Table 3.1). Monthly rainfall of Dhamtari district is given in Table A_1 of Appendix A. About 91.2% of annual average rainfall occurs during monsoon season. Most of the precipitation is due to south west monsoon during the month of June to October. The monsoon normally enters Dhamtari district around 10^{th} June and withdraws by 15^{th} September. The long term trend analysis of the rainfall for the last 32 years shows a gentle falling trend. The annual temperature varies from 10° C in winter to 46° C in summer. May is the hottest month when maximum temperature reaches to 48^oC and December is the coolest month when minimum temperature reaches 5^oC. The climate is characterized by bright sunshine hours of more than 9 hrs the day time temperature during peak summer season are usually very high in the entire area varying from 45^o C to 48.5^o C in the second weeks of May. The relative humidity is very low in summer (45 - 49%) and reaches above 90% during monsoon, the sunshine hours during monsoon month *i.e.*, July and August are very less (3-5 hrs per day). Often zero sunshine hrs is observed for 8-15 days in the month of August. The winds are moderate and blow with average speed of 2-8 km per hour. In general wind blows from East to West and South East to North West during June to November but it blows from West to East and North West to South East during December to May. Hot winds are experienced only after mid of April to first week of June.

3.2.2 Agroclimate of Balod district

The Balod district experiences sub-tropical climate and is characterized by extreme summer and winter seasons. The summer months are from March to May and the months of April and May are the hottest. The rainy season extends from the month of June to September with well distributed rainfall through southwest monsoon. Monsoon generally breaks in the third week of June and maximum in the months of July and August. Winter season is marked by dry and cold weather with intermittent showers during the months of December and January. The Balod district receives rainfall mainly from south-west monsoon. It sets in third/fourth week of June and continues till mid August/September with heaviest showers in the months of July and August. The mean annual rainfall for the past 6 years is 984.1 mm, out of which 97% occurred during the monsoon period (Table 3.1). Monthly rainfall of Balod, Gunderdehi, Gurur, Dondi and Dondi Lohara Blocks are given in Table A_2, Table A_3, Table A_4, Table A_5 and Table A_6, respectively of APPENDIX A. The temperature in the district changes continuously with the season and even in day and night. The temperature decreases progressively after October. The winter season lasts till February. January is the coldest month with mean daily maximum temperature at 30°C and the minimum is around 10°C. During winter season, the night temperature sometimes may drop below 10°C. The temperature increases rapidly from mid February till May and sometimes up to mid-June (summer season). The mean daily maximum temperature in summer season goes up to 46°C and nights are slightly warmer during May and mid June. The monsoon period is generally pleasant. With the withdrawal of the monsoon by the end of September, day temperature rises a little and then both day and night temperatures begin to drop rapidly. The atmospheric humidity is usually low during summer months around 25%. However, humidity slowly starts building up from third week of May and it reaches maximum around 85% during monsoon period. The humidity again decreases in winter season and it varies between 30 to 40% during winter season. The wind flows easterly or westerly during the South-West monsoon period. During post-monsoon and winter seasons the wind directions are between north and east and sometimes westerly. The wind speed of more than 10 km/hr is recorded during the monsoon months (from June to September). In the post-monsoon and winter months (from October to February), the wind speed is less than 5 km/hr and in the summer months (from March to May) the wind speed is more than 7 km/hr.

3.2.3 Agroclimate of Bemetara district

The Bemetara district experiences tropical climate and is characterized by extreme hot in summer and extreme cold in winter seasons. The summer months are from March to 1st week of June and the months of April and May are the hottest. The rainy season extends from the month of June to September with well distributed rainfall through southwest monsoon. Monsoon generally breaks in the third week of June and is maximum in the months of July and August. Winter season is marked by dry and cold weather. The Bemetara district receives average rainfall of 968.50 mm with 55-56 rainy days (Table 3.1). The southwest monsoon brings average rainfall during rainy season. The monsoon normally enters Bemetara district around 15th June and withdraws by 15th September. The temperature in the district changes continuously with the season and even in day and night. In the summer, temperature rises upto 47^{o} C and in winter temperature reaches upto 10^{o} C. The monsoon season starts immediately after summer till late September. The temperature decreases progressively after October. The southwest monsoon brings average rainfall during rainy season. The atmospheric humidity is usually low during summer months around 23%. However, humidity slowly starts building up from third week of May and it reaches maximum around 85% during monsoon period. The humidity again decreases in winter season and it varies between 35 to 40% during winter season. The winds are moderate and blow with average speed of 4-10 km/hr. In general wind blows from East to West and South East to North West during June to November but it blows from West to East and North West to South East during December to May. Hot winds are experienced only after mid of April to 10^{th} of June. Monthly rainfall of Bemetara, Berla, Nawagarh and Saja Blocks are given in Table A_7, Table A_8, Table A_9 and Table A_{10}, respectively of APPENDIX A.

Table 3.1:Average annual rainfall of Dhamtari, Balod and Bemetara districts in (mm)

Year	Dhamtari	Balod	Bemetara
2005	1153.4	1292.8	1494.1
2006	1309.3	933.54	1055.7
2007	1120.7	1186.6	1059.1
2008	802.6	876.6	950.14
2009	915.4	709.1	970
2010	1276.6	809.7	826.12
Total	1096.33	1059.19	968.50

3.2.2 Soil resource data

Generally, soils are classified on the basis of texture, mineral content and presence of salts and alkalies. However, in present context the classification and distribution is adopted as per the soil orders in US soil taxonomy and their Indian equivalents. There are 12 orders in US soil taxonomy but only four orders are found in these districts. They are given in Table 3.2

Table 3.2: Soil texture classification of the study area

S. No.	US Soil Taxonomy	Indian Equivalents
1	Ultisols	Lateritic soil
2	Alfisols	Red Loamy soil
3	Vertisols	Deep black soil
		Medium black soil
4	Inceptisol	Humic gley soil

Soil texture map of the study was prepared through GIS using available soil resource data of the area (sources: National atlas maps Survey of India maps, Central Ground Water Board, Census of India, Geological Survey of India, other government agencies and field surveys 1991). Four types of soil texture are found in the study area as describe below:

Kanhar**:** This type of soil is black in color and comes under *vertisols*. Depending on the parent material and the climate, they can range from grey or red to the more familiar deep black. Vertisols contain high level of plant nutrients, but, owing to their high clay content, they are not well suited to cultivation without painstaking management. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Rainfaid farming is very difficult because vetisols can be worked only under a very narrow range of moisture conditions as they become very hard when dry and become very sticky when wet.

Dorsa**:** This type of soil is medium in nature and it comes under *vertisols*. Vertisol is a soil in which the content of clay size particles is 30%. They are characterized by a high content of expanding and shrinking clay known as montmorillonite. They may also be characterized by salinity and well defined layers of calcium carbonate or gypsum. Evidence of strong vertical mixing of the soil particles over many periods of wetting and drying can be observed in this type of soil.

Bhata: There are also two types of Indian equivalent of this soil is found in these districts namely red loamy and red sandy soil. Alfisols is a fertile leached soil found in humid areas which is alkaline in nature and contains clay-rich layer. They are less extensively leached of metal ions and develop in cooler climates. These soils formed where annually dropping leaves form a thick humus layer with the time, under which by decomposition processes the characteristic loam layers are formed which generally refers high age of the soil. They are considered as very fertile soils and are frequently used for agriculture. This soil exhibit well developed contrasting soil horizons depleted in calcium carbonate but enriched in aluminum and iron bearing minerals.

***Matasi*:** The Indian equivalent of this soil found is Lateritic soil. It is the ultimate product of continuous weathering of minerals in a humid climate. This is a highly weathered and leached acid soil with high levels of clay below top layer. They are characterized by a humus rich surface horizon and by a layer of clay that has migrated below the surface horizon. This soil has variety of clay minerals but in many cases the dominant mineral is Kaolinite. This clay has good bearing capacity and has no shrinkage property. They are red to yellow in colour and are quite acidic having pH less than 5. The red and yellow color results from the accumulation of iron oxide which is highly insoluble in water.

3.2.3. Topographic data

Topographic maps of the study area were collected for use from the Department of Survey of India (SOI), Raipur. The Dhamtari district is covered in topographic map No. 64H, 64L and very small portion lies in 64F on 1: 2,50,000 scales. The Balod district is covered in topographic map No. 64D and 64H and the Bemetara district is covered in topographic No. 64G on 1:2,50,000 scales.

3.2.4 Satellite data

Satellite image taken by IRS-P6 (Resourcesat-I) have three type of sensor including LISS IV (high resolution sensor), LISS VI (medium resolution sensor) and AWIFS (advance wide field sensor). The satellite data for preparing the landuse/cover map was procured from National Remote Sensing Agency, Hyderabad in the form of CD-ROM format. LISS IV sensor considered for this study. The resolution, path, row and date of pass are given in Table 3.3

Table 3.3: Details of satellite image used for the study

Satellite	Sensor	Resolution (m)	Path	Row	Date of Pass
IRS-P6	LISS-IV	5.8	102	057	25.10.2007

3.2.5 Geological data of Dhamtari, Balod and Bemetara districts

The Dhamtari district is underlain mainly by three distinct geological formations range in age from Achaean to recent. The crystalline basement occupy major part of the district comprising of granite and granitic rocks belonging to Dongargarh group, severally intruded by Chhattisgarh Super group are unconformably overlying the basement crystalline and are represented by the sandstone, limestone and shale sequence occupying the north central and central part of the district. A thin layer of alluvium/laterite belongs to Quaternary age occur along the flood plains of major rivers and its tributaries. Geologically, Balod and Bemetara districts comprises of rocks of Archaean basement of Meso to Neo-Proterozoic ages. The oldest rocks belong to Archaean anbeld mainly comprise the basement granite gneiss with meta-sedimentary and meta-igneous enclaves belonging to the Bengal group. The overlying Bailadila group includes Banded Iron formation, Shale and

Phyllite belonging to Archaean-Lower Proterozoic age. It is unconformably overlain by the rocks of the Nandgaon group belonging to the Paleo-Proterozoic age comprising Rhyolite, Rhyolitic tuffs, Basic pyroclastics, Basalt, Dolerite and Gabbro etc.

The Meso to Neo-Proterozoic sequence is represented by the Chhattisgarh Supergroup, which comprises the Chandrapur and Raipur groups. Chandrapur group consists of sandstone, siltstone and conglomerate. Shale and siltstone occur as interbands within sandstone. Raipur group comprises Charmuria formation, Gunderdehi formation, Chandi formation, Tarenga formation, Hirri formation and Maniyari formation. Charmuriya formation mainly comprises grey bedded limestone with minor phosphatic clay bands.

3.3 Data Processing for the Software

3.3.1 Hardware used

All the facilities regarding hardware and software have been provided by the Department of SWE, FAE, IGKV, Raipur has been used in this study. Hardware including computer (Intel Pentium-IV processor 2.66 GHz, 2GB DDR-2 RAM, 50x DVD ROM Drive and 320 GB Hard Disc Drive), scanner (CONTEX wide image scanner), printer (coloured and black and white), Global Positioning System (GPS) Garmin, digital camera, software including MS Office and other statistical package has been used.

3.3.2 Software

MapInfo Professional 8.5 software is used for generating digital input maps. MapInfo Professional 8.5 software is well-known and widely used image processing software. The same has been used for image interpretation, classification and further analysis.

3. 4 Preparation of Base Map

To prepare the base map of the study areas the Survey of India (SOI) topographic map 64D, 64H, 64G and 64L on 1:2,50,000 scale were scanned using A0 scanner and it was imported in MapInfo Professional 8.5 software. Subsequently toposheet was georeferenced (Projection and Coordinate System) using conic Geographic Coordinate System (GCS) Indian 1986 and World Geology System (WGS) 1984.

3.5 Creation of Digital Maps

Vector digitization of Dhamtari, Balod and Bemetara districts boundary, block boundary, drainage map, watershed boundary, slope map, soil texture map, geology map, lineament map, water bodies map, depth to water level (per and post monsoon) and landuse/cover map was done to generate digital input maps. The drainage was initially digitized from SOI topographic map and later updated using IRS-P6 LISS IV False Colour Composite FCC. The digitized district boundaries and updated maps were used for further overlaying and analysis.

3.5.1 District boundary

For the preparation of district Boundary of Dhamtari, Balod and Bemetara districts topographic map was open in the MapInfo Professional 8.5 software and registered by selecting the four points and putting the value of latitude and longitude of those points before registration. This administrative map of the study area was collected from the districts official websites as per the guidance of the district authority.

Image to image registration process was adopted to register the district administrative map. The district boundary was digitized using on screen digitization facilities given in the GIS software. Digitized boundaries were scoured for further use in this study. Similar to district boundaries, the block boundaries were digitized. Polygons of each block boundaries were given different colour for easer visualization.

3.5.2 Preparation of drainage map and canal network map

The drainage map was also digitized using the topographic map. Each and every drainage channel within the district boundary has taken for further use. Similar procedures were adapted for the preparation of water bodies and canal network maps. In this case also polygons for water bodies and lines for canal network map were drawn and used.

3.5.3 Preparation of slope map

The slope map was prepared with the help of district development maps of Dhamtari, Balod and Bemetara districts collected from Survey of India (SOI). MapInfo Professional 8.5 GIS software is used to registered slop map from district development map. Standard procedure was adopted for preparation of slope map.

3.5.4 Preparation of soil texture map

The soil texture map of these districts was digitized block wise using soil resource data. Similar procedure has been adopted as used for preparation of slope map.

3.5.5 Preparation of geological map

With the help of geological information available from the Central Ground Water Board, NCCR, Raipur. Block wise information derived from geological map was used in this study.

3.5.6 Preparation of lineament map

Lineament map was collected from the Central Ground Water Board, NCCR, Raipur. This map was registered in respect to these districts boundary with the help of MapInfo Professional 8.5 GIS software and used in this study. This map was important since lineament plays major role in artificial groundwater recharging of an area.

3.5.7 Preparation of watershed map

The watershed boundaries were digitized manually by delineated boundaries on the basis of topography (contours) and drainage lines. Same procedure was adopted as in case of preparation of lineament map which is described in the previous section.

3.5.8 Preparation of land use /cover map

The land use/cover map which was previously generated in the Soil and Water Engineering (SWE) department, Faculty of Agricultural Engineering (FAE), Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur was used in this study. Land use/cover classification was being done under AICRP on “Ground Water Utilization” (GWU) sponsored by Indian Council of Agricultural Research (ICAR), New Delhi.

3.6 Morphology of Watershed

3.6.1. Drainage density (D_d)

Drainage density is one of the important indicators of the linear scale of land form in stream eroded topography, and is defined as the ratio of total length of the streams of all orders of basin to the area of basin. The drainage density, expressed in km/km^2, indicates closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Further, it also gives an idea of the physical properties of the underlying rocks. Low drainage density occurs in regions of highly resistant and permeable subsoil materials with dense vegetation and low relief, whereas, high drainage density is prevalent in weak regions, if permeable subsurface materials which are sparsely vegetated and have high relief.

The standard formula was used for determination of drainage density as mentioned below.

$$Dd = \frac{L}{A} \qquad \dots (3.1)$$

Where, L is length of the streams of all orders in m and A is area of watershed

3.6.2. Stream frequency (F_u)

Stream frequency is the number of streams per unit area of the basin. It mainly depends upon the lithology of the basin and reflects the texture of the drainage network. The stream frequency was determined using following formula;

$$Fu = \frac{\sum Nn}{A} \qquad \dots (3.2)$$

Were, Nn is number of streams of all orders in m and A is area of watershed in m^2.

3.6.3. Runoff depth by using Runoff Coefficient

$$Q = K \times P \qquad \dots (3.3)$$

Where, Q = Runoff (mm)

P = Precipitation (mm)

K= Runoff coefficient

3.6.4. Estimation of available storage space

The estimation of subsurface storage space is based on the thickness of available unsaturated zone (below 3 mbgl) in post-monsoon and the specific yield of phreatic aquifer, the limit to saturate the vadose zone below 3 m is kept with a view to avoid water logging and soil salinity. The total volume of unsaturated strata is estimated and actual amount of water required to recharge the aquifer upto 3 m has been calculated by multiplying with specific yield of the area *i.e.* 0.03%. Volume of surface water Q_s required is calculated by using the formula given below (GEC 2007).

$$Q_s = A \times B \times S \qquad \dots (3.4)$$

Where,

A = Demarcated area for artificial recharge (km^2)

B = Post-monsoon average depth to water level – 3 m in every zone

S = Specific yield of the particular formation

3.7 Identification of Appropriate Site for Artificial Recharge Structures

3.7.1 Investigations for proper planning

Various inputs are necessary for proper and scientific planning of artificial recharge in any terrain. Scientific investigations leading to a better understanding of the characteristics of subsurface formations are to be taken up for realistic determination of these inputs. These can be broadly grouped into two categories namely general studies and detailed studies.

3.7.1.1 General studies

These studies are aimed at assessing the need and scope of artificial recharge in an area. The procedure to be followed for establishing the need for artificial recharge in an area to augment the groundwater resources has already been described in detail in an earlier section of this chapter.

Once the case of overexploitation of groundwater is proved, the need for augmentation of groundwater resources through artificial recharge is justified. In case of entire study area, overlaying of maps depicting the long-term decline in water levels and cumulative departure of rainfall from the normal can help in identification of areas requiring recharge augmentation.

3.7.1.2 Detailed studies

Once the need and suitability of the area for artificial recharge to groundwater are identified on the basis of data collected from the general studies, areas identified as suitable for recharge augmentation are studied in detail using remote sensing techniques and through hydrometeorological, hydrological and hydrogeological investigations to ascertain the scope and feasibility of artificial recharge. These studies are to be oriented in such a way as to collect and analyze necessary data, which are to be used as inputs for proper planning of artificial recharge. The major inputs expected to be provided by the studies mentioned are given in proceeding section of this chapter.

3.7.1.2.1 Remote sensing studies

Remote sensing, with its advantages of spatial, spectral and temporal availability of data has now become a very useful tool in assessing, monitoring and conserving groundwater resources. Satellite data provides quick and useful baseline information on various parameters controlling the occurrence and movement of groundwater such as drainage, landuse/land cover, soil, lineament, and geological map etc. All these parameters used to be studied earlier independently due to non availability of data and lack of integrating tools and modelling techniques. A systematic study of these factors leads to better delineation of areas suitable for artificial recharge, which are then studied in detail through hydrogeological investigations. Visual interpretation of satellite imagery, with emphasis on terrain analysis is being used widely for selection of sites suitable for recharge augmentation. Aspects, which are given special attention for the study, usually carried out with satellite imagery or False Colour Composites (FCC) on 1:2,50,000 scale include stream course delineation, land form analysis, outcrop pattern analysis, fracture pattern analysis and land use analysis. These studies can provide valuable information on drainage density and lineament intensity, which helps in the identification of suitable sites for recharge.

Various thematic layers such as land use/cover, soil, lineament, and geology etc. can be integrated with slope, drainage density and other collateral data in a Geographic Information System (GIS). Overlaying of various maps and analysis of different data with logical conditions provides suitable sites for artificial recharge.

3.7.1.2.2 Hydrometeorological Studies

Rainfall and evaporation are two of the most important parameters, which are required for proper planning of artificial recharge. Long-term average rainfall is an important parameter for assessing the storage capacity of various artificial recharge structures. Different hydro- meteorological data viz. temperature, humidity, rainfall, wind speed has been taken from the Department of Agrometrology, IGKV, Raipur and used in this study.

3.7.1.2.3 Hydrological studies

Hydrological investigations are useful for ascertaining the availability of source water for recharge. These investigations are required to be carried out in the watershed/sub-watershed where the artificial recharge is envisaged.

3.7.1.2.4 Hydrogeological studies

A detailed understanding of the hydrogeology of the area is of prime importance in artificial recharge. Maps providing information on regional hydrogeological units, their groundwater potential and general pattern of groundwater flow are also necessary.

A detailed hydrogeological study, aimed at supplementing the regional picture of hydrogeological setup available from previous studies, is imperative to have precise information about the promising hydrogeological units for recharge and to decide the location and type of structures to be constructed (CGWB 2007).

3.8 Ground Truth Location of Artificial Recharge Structures

3.8.1 Allocation of recharge structure

Location of all recharge structures in Dhamtari, Balod and Bemetara districts were observed by field survey and noted by using the device named Global Positioning System (GPS) (Plate 3.1). Location of all the recharge structures of these districts are shown in Fig 4.38, Fig 4.40 and Fig 4.42, respectively and given in Table B_1, Table B_1 and Table B_1 of Appendix B. Recharge structures existing in the study area which includes check dam and percolation tank are shown in Plate 3.1, Plate 3.2, Plate 3.3 and Plate 3.4.

3.8.2 Stage of groundwater development

Stage of groundwater development is defined as the ratio of using groundwater draft for all uses to the net annual groundwater availability. This can be determined using the following formula:

$$\text{Stage of Groundwater Development} = \frac{\text{Existing Groundwater Draft for all use}}{\text{Net Annual Groundwater Availability}} \times 100 \quad \ldots (3.5)$$

Net annual groundwater availability refers to the available annual recharge after allowing for natural discharge in the monsoon season in terms of baseflow and subsurface inflow/outflow. Existing groundwater draft for all uses refers to the total of existing groundwater draft for irrigation and all other purposes.

Plate 3.1: Location of check dam in the study area (Parasgaon Village)

Plate 3.2: Location of check dam in the study area (Badagaon Village)

Plate 3.3: Location of check dam in the study area (Navin Gatapara Village)

Plate 3.4: Location of percolation tank in the study area (Mandraud Village)

3.8.3 Categorization of assessment units

The assessment units have been categorized for groundwater development based on two criteria (a) stage of groundwater development and (b) long-term trend of pre and post monsoon water levels. The long term groundwater level trends have been computed generally for the period of 10 years. The significant rate of water level decline has been taken between 10 to 20 cm/hr depending upon the local hydrogeological conditions. There are four categories namely 'Safe' areas which have groundwater potential for development, 'Semi-critical' areas where cautious groundwater development is recommended, 'Critical-areas' and 'Over-exploited' areas where there should be intensive monitoring and evaluation and future groundwater development be linked with water conservation measures. The details of criteria for categorization of assessment units are given in Table 3.4.

Table 3.4: Criteria for categorization of assessment units

S. No.	Stage of ground water development	Significant long term decline		Categorization
		Pre-monsoon	Post-monsoon	
1	Upto 70%	No	No	Safe
2	>70% to ≤90 %	No	No	Safe
		YES/No	YES/No	Semi-critical
3	>90% to ≤100%	YES/No	YES/No	Semi-critical
		YES	YES	Critical
4	>100%	YES/No	YES/No	Over-exploited
		YES	YES	Over-exploited

3.9 Planning of Artificial Recharge

3.9.1 Preparation of recharge plan for suitable groundwater recharges structure

The plan for artificial recharge has been prepared considering the hydrogeological parameters and hydrological data base. The following aspects were considered for preparation of the plan. Identification and prioritization of need based areas for artificial recharge to groundwater. Estimation of subsurface storage space and quantity of water needed to saturate the unsaturated zone (to 3 mbgl). Quantification of surface water requirement and surplus annual runoff availability as source water for artificial recharge in each watershed. Areas of poor chemical quality of groundwater and scope of improvement by suitable recharge measures. Working out design of suitable recharge structures, their numbers, type, storage capacity and efficiency considering the estimated storage space and available source water for recharge. Percolation tank and check dam are suitable structures for groundwater recharge. Structure have been tested previously for Gajra watershed management project of Patan Block in Durg district as shown in Fig. 3.2 and number of structure are given in Table 3.5.

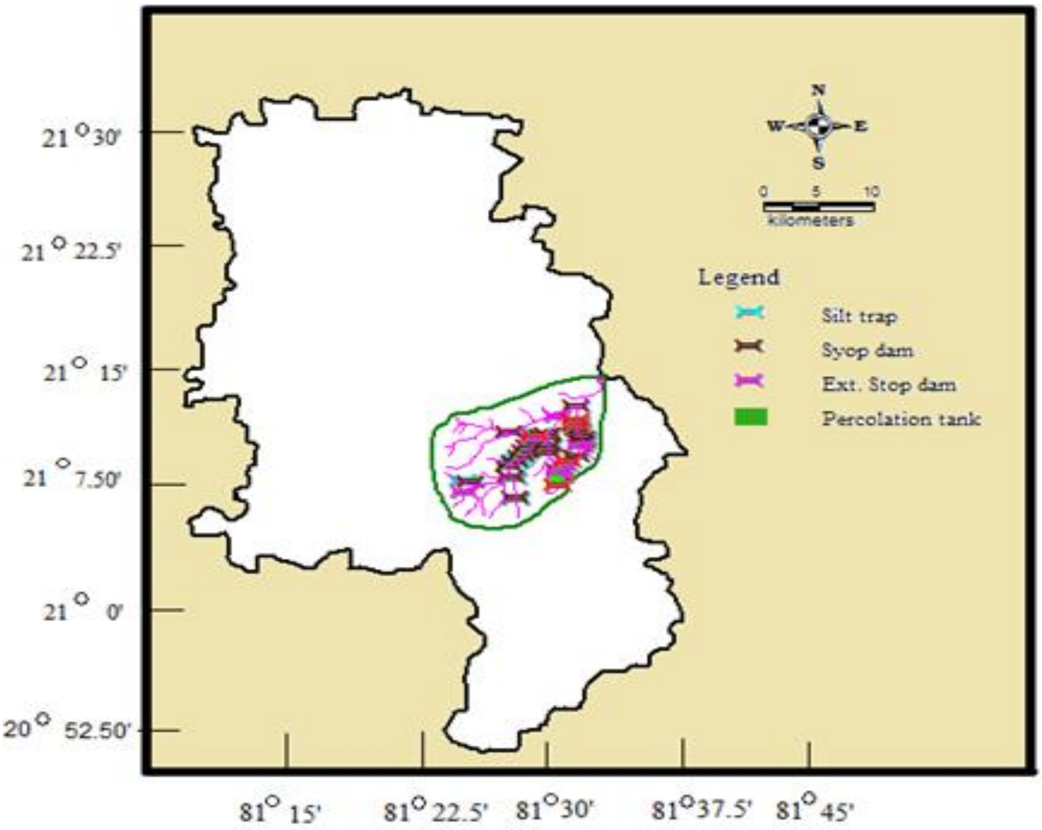

Fig. 3.2: Location of recharge structure in the Gajra Watershed

Table 3.5: Structure present in the Gajra Watershed

S. No.	Structure name	Structure number
1	Stop dam	20
2	Silt trap	7
3	Ext. stop dam	7
4	Boulder check dam	5
5	Percolation tank	1

3.9.1.1 Requirement of source water

After assessing the volume of water required for saturating the vadose zone, the actual requirement of source water is to be estimated. Based on the experience gained in the pilot/experimental projects implemented in different hydrogeological situations, an average recharge efficiency of 75% of the individual structure is considered. The volume of source water required for artificial recharge was calculated by multiplying a factor of 1.33 (*i.e*. reciprocal of 0.75). In few cases different values are taken depending upon the regional scenario prevailing there upon.

3.9.1.2 Availability of source water

The surface water resources available in various basins and subbasins utilized for preparation of plan was based on information mostly provided by state government. In few cases information from other Government Agencies were considered. The data availability for source water availability for each subbasin includes committed runoff, provision for future planning and surplus water available. The availability of source water per annum was worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out for the entire subbasin and not exclusively for the requirement of the areas identified for artificial recharge. The source water availability for areas identified for artificial recharge was apportioned from total water availability in the basin.

Blockwise groundwater resources availability, utilization and stage of groundwater development of Dhamtari, Balod and Bemetara districts are shown in Table 3.6, Table 3.7 and Table 3.8.

Table.3.6: Block-wise groundwater resources availability, utilization and stage of development of Dhamtari district.

S.No.	Blocks	Total annual replanishable ground water resources (ham)	Natural losses (ham)	Available ground water (ham)	Gross ground water draft (ham)	Stages of ground water development	Category
1	Dhamtari	9966.40	996.64	8969.76	6785.28	75.76	Semicritical
2	Kurud	9168.99	642.34	8526.65	6138.14	73.07	Semicritical
3	Nagri	4471.87	447.19	4024.68	3381.45	80.51	Semicritical
4	Magarlod	4820.58	482.06	4338.52	1780.91	41.09	Safe
Total		28427.84	2568.23	25859.61	18085.78	67.60	-

Table 3.7: Block-wise groundwater resources availability, utilization and stage of development of development of Balod district

S. No.	Blocks	Total annual replanishable groundwater resources (ham)	Natural losses (ham)	Available groundwater resources (ham)	Stages of groundwater development (%)	Category
1	Bemetara	6107.44	610.74	5496.69	75.38	Semicritical
2	Berla	8108.23	810.82	7297.40	62.71.54	Safe
3	Saja	7362.206	76.58	6685.61	75.78	Semicritical
4	Nawagarh	4820.58	482.06	4338.52	42.06	Safe
Total		26585.94	2407.16	24178.76	63.24	-

Table 3.8: Block-wise ground water resources availability, utilization and stage of development of Bemetara district

S. No.	Blocks	Total annual replanishable groundwater resources (ham)	Natural losses (ham)	Available groundwater resources (ham)	Gross groundwater draft (ham)	Category
1	Balod	7598.23	759.82	6838.40	4975.18	Semicritical
2	Gunderdehi	8505.74	850.57	7655.16	4659.16	Safe
3	Gurur	4925.37	492.54	4432.83	422.47	Semicritical
4	Dondi	5556.6	304.23	5252.37	1896.41	Safe
5	Dondilohara	9044.22	904.42	8139.79	3994.62	Safe
Total		35630.16	3311.58	32318.79	15947.84	-

3.9.1.3 Capacity of recharge structures

The capacity of recharge structures was worked out based on the findings of various artificial recharge studies under taken in different states and the same was used for planning the recharge structures. Maximum storage capacity (single filling) and gross capacity due to multiple fillings during rainy season were taken into consideration for designing percolation tanks, cement plugs, check dams and other surface storage structures.

3.9.1.4 Number of recharge structures

The numbers of recharge structures required to store and recharge the groundwater reservoir have been worked out as follows:

$$\text{No. of recharge structures} = \frac{\text{Total surface water considered}}{\text{Average gross capacity of water spreading recharge structures (considering multiple fillings)}} \quad ...(3.6)$$

The type and design of different types of structures like percolation tanks, check dams, recharge shafts *etc.* in a particular block/watershed would be guided by prevailing hydrogeological situation, existing density and number of structures, land availability etc. The planning of type and design of proposed structures should accordingly be decided. The allocation of source water for recharge through specific type of artificial recharge structures should be done considering these aspects.

3.9.1.5 Dimension of artificial recharge structures

A wide spectrum of techniques is in vogue which is being implemented to recharge the groundwater reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques feasible too, would vary accordingly. The artificial recharge structures, which are feasible in varied hydrogeological situation are described as follows:

3.9.1.5.1 Percolation tanks

Percolation tank is an artificially created surface water body, submerging in its reservoir highly permeable land areas, so that the surface runoff is made to percolate and recharge the groundwater storage. In areas where land is available in and around the stream channel section, a small tank is created by means of earthen dams across the stream. The tank can also be located adjacent to the stream. The percolation tank should have adequate catchment area. The hydrogeological condition of site for percolation tank is of utmost importance. The rocks coming under submergence area should have high permeability. The degree and extent of weathering of rocks should be uniform and not just localized. The percolation tank should be located downstream of runoff zone, preferably towards the edge of piedmont zone or in the upper part of transition zone (land slope between 3 to 5%). The purpose of percolation tank is to conserve the surface runoff and diverts the maximum possible surface water to the groundwater storage. Thus, the water accumulated in the tank after monsoon should percolate at the earliest, without much evaporation losses. Normally a percolation tank should not retain water beyond February. The size of a percolation tank should be governed by the percolation capacity of the strata in the tank bed rather than yield of the catchment. In case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses, thus depriving the downstream area of the valuable resource.

3.9.1.5.2 Determination of recharge from percolation tanks

Recharge from percolation tanks was determined by taking 50% of gross storage, considering the number of fillings, with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season. The gross storage area of percolation tank was determined by using the following formula:

$$Gross\ storage\ area\ = \frac{A \times d}{0.4} \qquad \ldots (3.7)$$

where, A is the submerged area of percolation tank in m^2, d is depth of the tank in m.

3.9.1.5.3 Check dam/cement plug/nala bund

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within for short span of time. The water stored in these structures is mostly confined to stream course and the height is normally around 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess runoff, water cushions are provided at downstream side. To harness the maximum runoff in the stream, series of such check dams can be constructed to have recharge on a regional scale. A nala bund acts like a mini percolation tank with water storage confined to stream course.

3.9.1.5.4 Determination of recharge due to check dams

Recharge due to check dams was determined by taking 50% of gross storage (assuming annual desilting maintenance exists) with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season (GEC 2007). The gross storage area of percolation tank was determined by using the following formula:

$$A = \frac{1}{2} \times length \times depth \times width \qquad \ldots (3.8)$$

Where, all dimensions were in m and A is gross storage area of check dam in m^2.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results related to planning of groundwater recharge in Dhamtari, Balod and Bemetara districts. Various maps including, block map, drainage, soil, slop, water bodies, lineament map, watershed, depth to water level (per and post monsoon) and land use/cover map are given in this chapter. Various input data required for MapInfo Professional 8.5 GIS software included in this chapter. Research findings include the possibility of use of groundwater enhanced due to recharging in the study area are also given in this chapter. This chapter presents the results obtained in the research work along with discussion wherever required.

4.1 Preparation of Thematic Maps

4.1.1 Boundary of Dhamtari, Balod and Bemetara districts

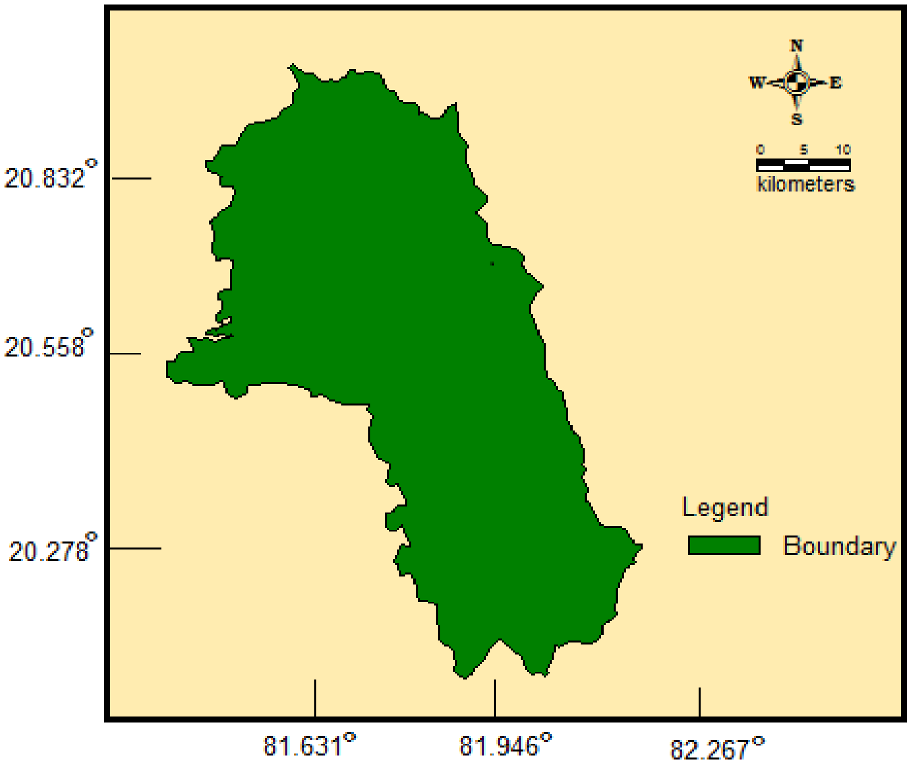

Fig. 4.1: Administrative boundary of Dhamtari district

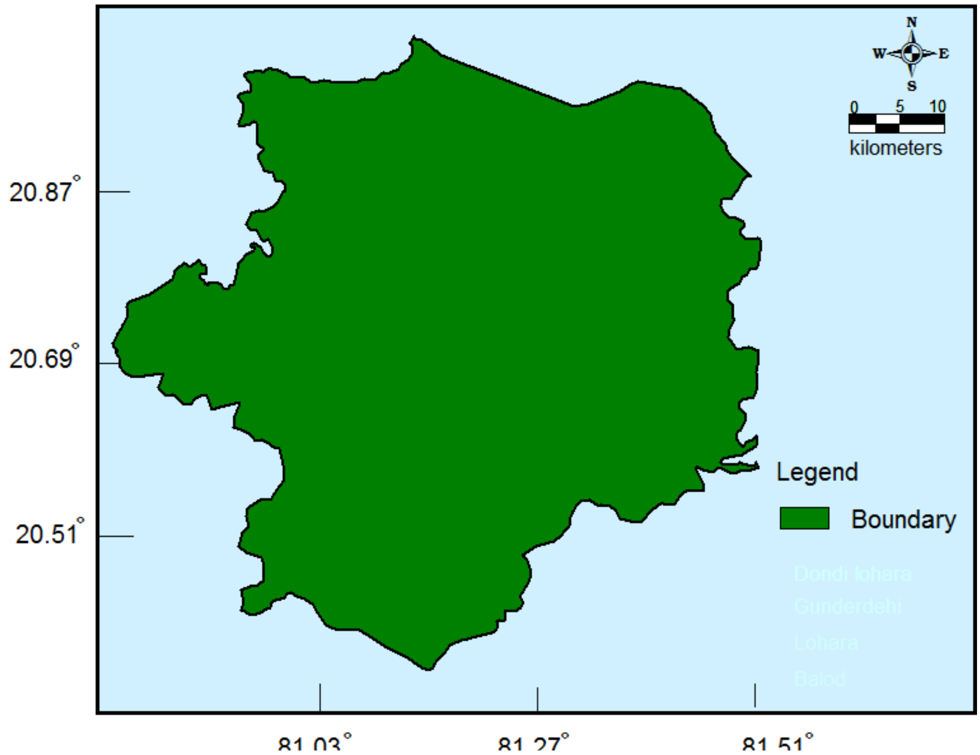

Fig. 4.2: Administrative boundary of Balod district

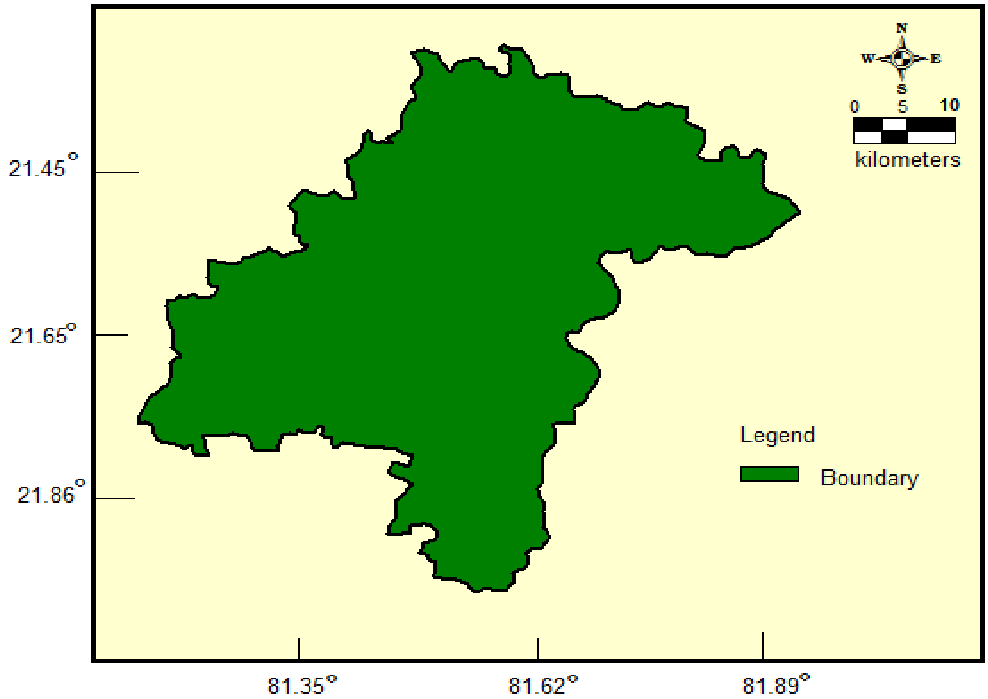

Fig. 4.3: Administrative boundary of Bemetara district

The geographical area of Dhamtari, Balod and Bemetara districts are 4081 km^2, 3385 km^2 and 2872.2 km^2, respectively. The boundaries were digitized as described previously in Chapter III. The maps of district boundaries are shown in Fig. 4.1, Fig. 4.2 and Fig. 4.3.

4.1.2 Different blocks of the of Dhamtari, Balod and Bemetara districts

Similar to the district boundary, block boundaries of Dhamtari, Balod and Bemetara districts has been digitized and shown in Fig. 4.4, Fig 4.5 and Fig 4.6, respectively. The blockwise area is given in Table 4.1, Table 4.2 and Table 4.3.

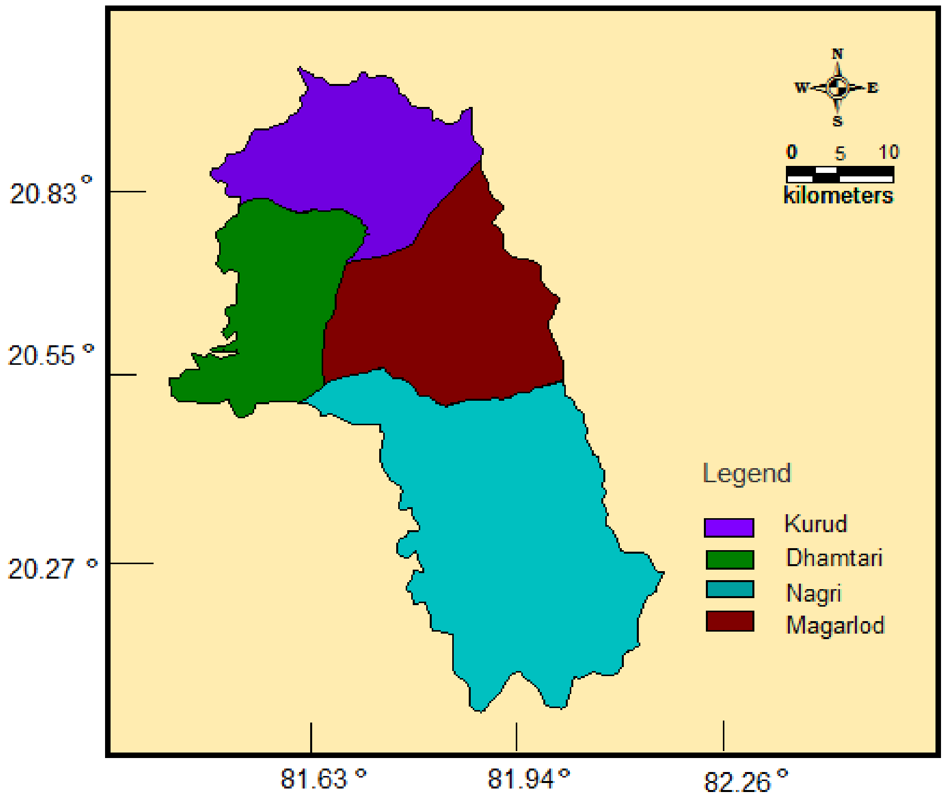

Fig. 4.4: Different blocks of Dhamtari district

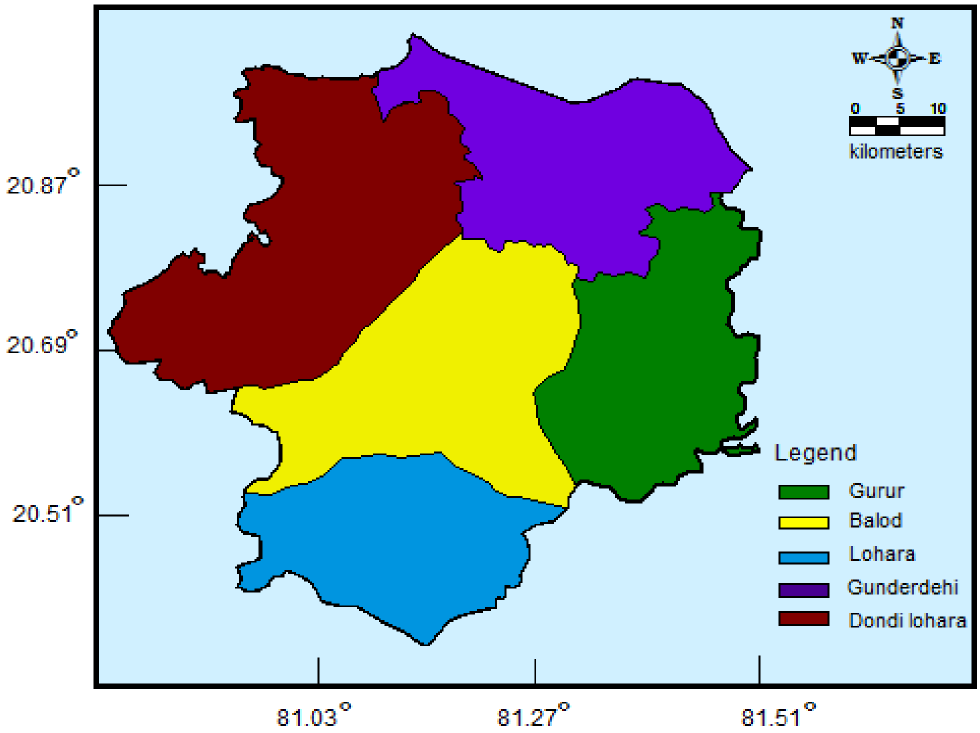

Fig. 4.5: Different blocks of Balod district

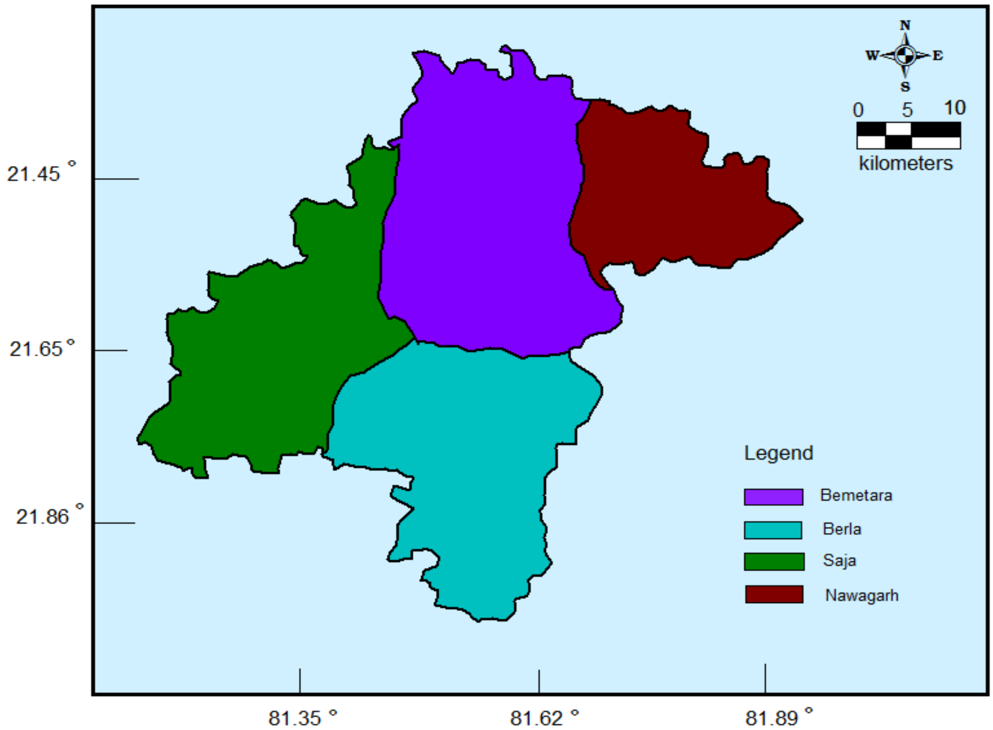

Fig. 4.6: Different blocks of Bemetara district

Table 4.1: Area of different blocks of Dhamtari district

S. No.	Block name	Area in km^2
1	Dhamtari	646.97
2	Kurud	747.72
3	Nagri	1732.96
4	Magarlod	940.42
Total		4068.87

Table 4.2: Area of different blocks of Balod district

S. No.	Block name	Area in km^2
1	Balod	738.66
2	Gurur	604.24
3	Gunderdehi	624.18
4	Dondi	522.14
5	Dondi Lohara	895.87
Total		3385.11

Table 4.3: Area of different blocks of Bemetara district

S. No.	Block name	Area in km^2
1	Bemetara	899.50
2	Berla	775.18
3	Saja	747.72
4	Nawagarh	450.65
Total		2872.09

4.1.3 Watersheds map

The watershed maps of the study area were prepared using drainage network and topography of the area, Fig. 4.7, Fig. 4.8 and Fig. 4.9 represents the watershed maps of Dhamtari, Balod and Bemetara districts, respectively. Watersheds codes of these districts along with area of each code are given in Table 4.4, Table 4.5 and Table 4.6. There are 7, 7 and 10 watersheds delineated in Dhamtari, Balod and Bemetara districts, respectively and used in this study for the analysis and interpretation of the results.

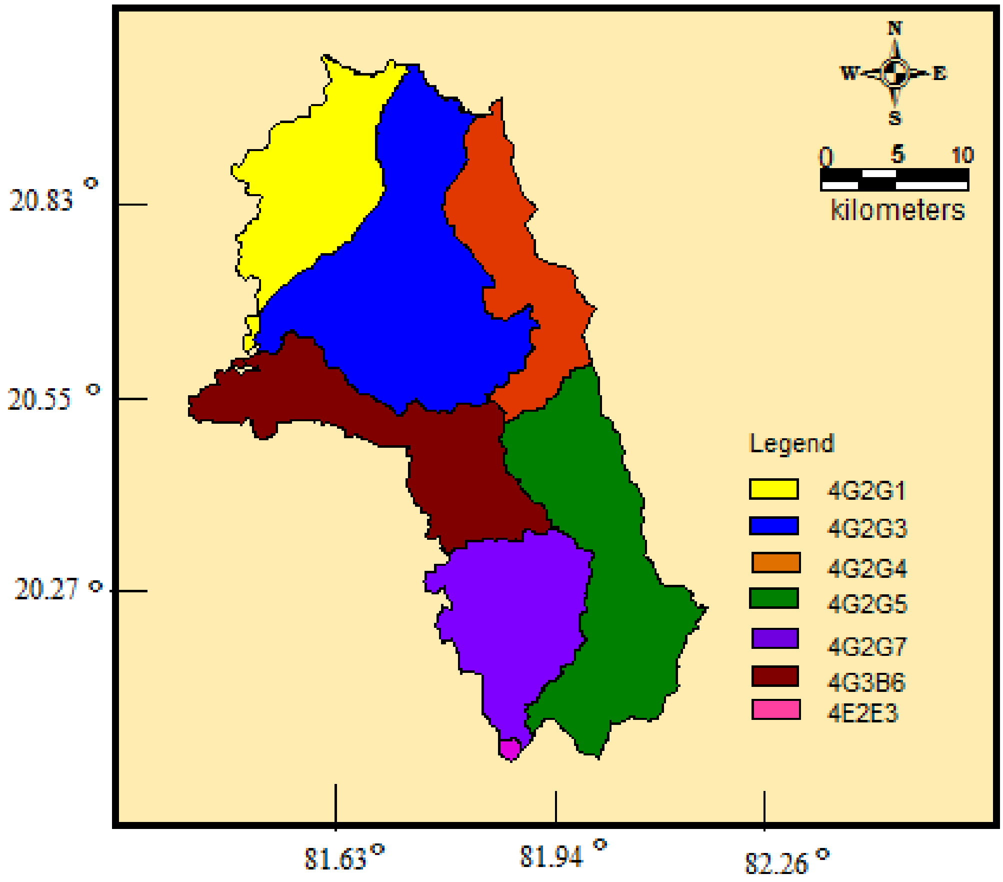

Fig. 4.7: Watershed map of the Dhamtari district

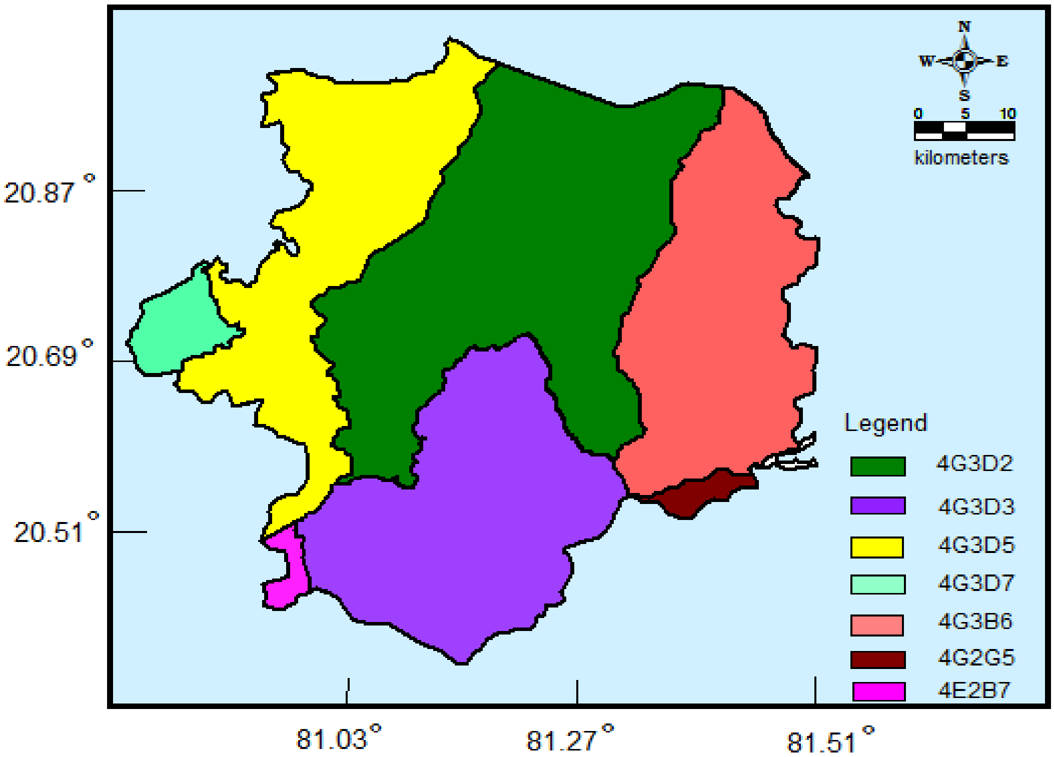

Fig. 4.8: Watershed map of the Balod district

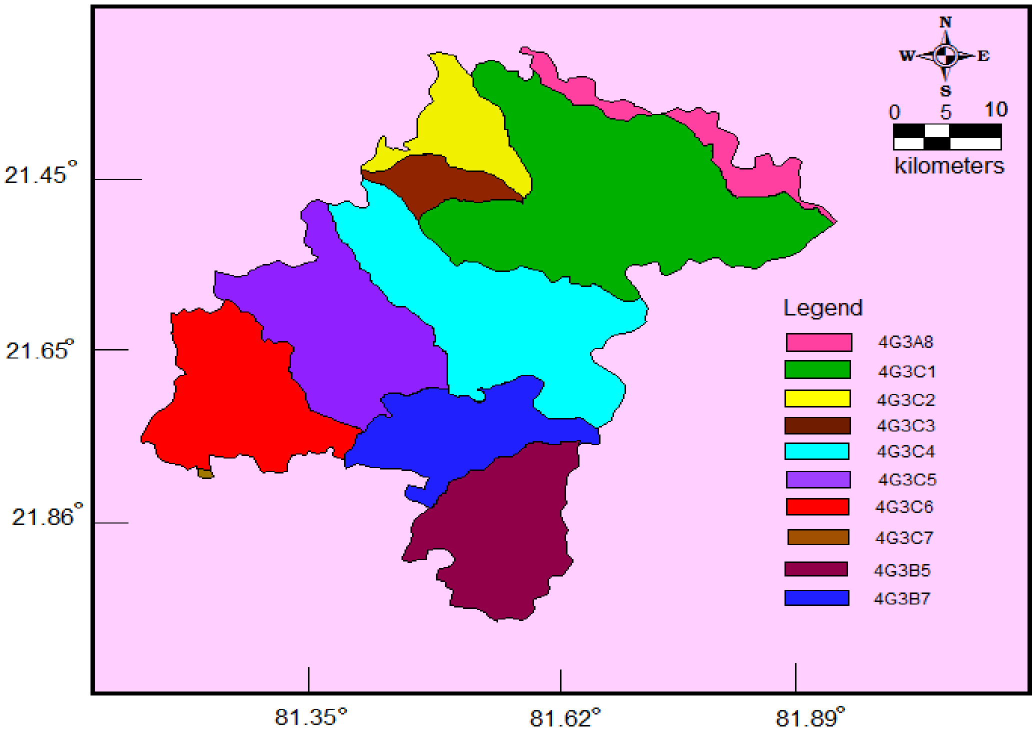

Fig. 4.9: Watershed map of the Bemetara district

Table 4.4: Area in ha falls under different watersheds in Dhamtari

S. No.	Watershed code	Area in ha
1	4G2G1	46801
2	4G2G3	84822
3	4G2G4	106526
4	4G2G5	64050
5	4G2G7	52499
6	4G3B6	53509
7	4E2E3	925

Table 4.5 Area in ha falls under different watersheds in Balod

S. No.	Watershed code	Area in ha
1	4G3D2	111862
2	4G3D3	75265
3	4G3D5	586218
4	4G3D7	8725
5	4G3B6	67702
6	4G3G5	3170
7	4E2B7	2916

Table 4.6: Area in ha falls under different watersheds in Bemetara

S. No.	Name of watershed	Area in ha
1	4G3AB	11021
2	4G3B5	31442
3	4G3B7	24822
4	4G3C1	74307
5	4G3C2	14548
6	4G3C3	7910
7	4G3C4	50867
8	4G3C5	38539
9	4G3C6	33618
10	4G3C7	188

4.1.4 Drainage map

4.1.4.1 Drainage map of the Dhamtari district

Drainage map was prepared by using Survey of India Topographic maps on 1:2,50,000. All the streams existing in this district are marked in Fig 4.10. The entire area of the district is drained by river Mahanadi and its tributaries *i.e.*, Sondur, Kharun and Pairi river. Mahanadi originates in the Sihawa hills flows northwest throughout its length in the district. The tributaries for Sondur are Sita nala, Kajal nala and Sukha nala whereas Safari Ama and Bagbura nala directly joins with river Mahanadi. The drainage pattern is typically dendritic and is controlled by initial slope. The drainage density is very high in the hilly areas of south and southeast indicating that the infiltration rate is low.

The morphometric analysis has been done for the district and values of different parameters are given in Table 4.7. It can be seen that, there were a total of 307 streamlets found in this study area out of which 243 streamlets are of 1st order, 52 are of 2nd order, 10 are of 3rd order, 1 is of 4th order and 1 is of 5th order (Table 4.7). The total length of the streams was found to be 2764.24 km. Drainage density of the area was found to be 0.67 km/km^2 which was indicating low runoff potential of the study area. Similarly, stream frequency (the total number of channels required to drain a unit area of the watershed) of the area was found to be 0.075, which is also low showing more or less plain topography of the area and lack of structural control.

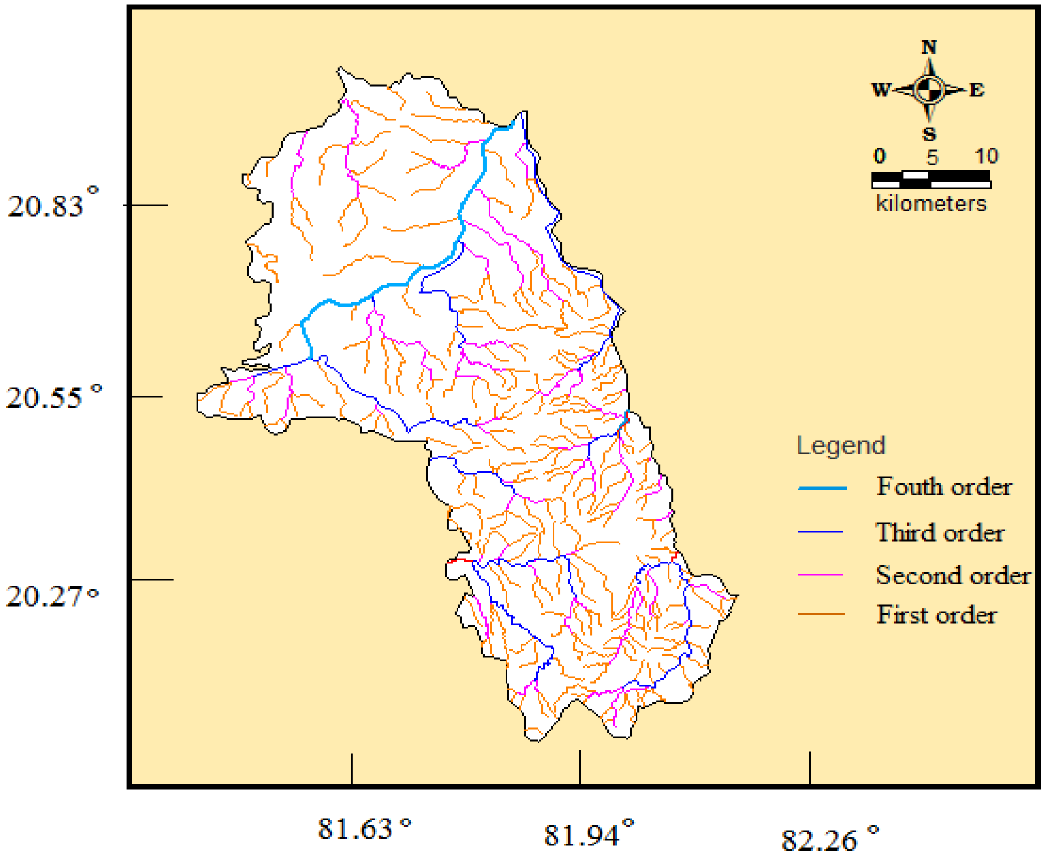

Fig. 4.10: Drainage map of the Dhamatri district

Table 4.7: Stream analysis of watersheds of Dhamtari district

WS No.	Number of Stream					Stream length (km)					Cumulative stream length (km) (watershed wise)				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
1	13	1	-	-	-	93.22	32.70	-	-	-	93.2	126	126	126	126
2	33	7	1	-	1	308.7	69.20	-	45.1	60.9	308	378	378	423	484
3	28	6	1	1	-	943.3	69.48	8.30	-	-	943	1012	1021	1021	1021
4	35	10	2	-	-	167.5	43.03	67.4	-	-	167	210.5	278	278	278
5	98	18	4	-	-	362.0	99.24	50.1	4.52	-	362	461.2	511.4	516	516
6	36	10	2	-	-	184.7	225.6	54.9	-	-	184	410	465	465	465
7	-	-		-	-	-	-	-	-	-	-	-	-	-	-

4.1.4.2 Drainage map of the Balod district

All the streams in this district are marked in Fig. 4.11. The district is mainly drained by Seonath river, Tandula river and their tributaries. Tandula river system comes under Mahanadi River basin. Tandula river flows through the central periphery to northern part of the district along with its tributaries district. Seonarh river flows through the western periphery to upper western part of the district. It can be seen that, the drainage pattern of the area is dendritic to subdendritic in nature. Drainage density is more or less same in most of the part of the district except in western part. The drainage density was found comparatively high in western part of the district. High drainage density is reflective of somewhat high runoff and lower infiltration.

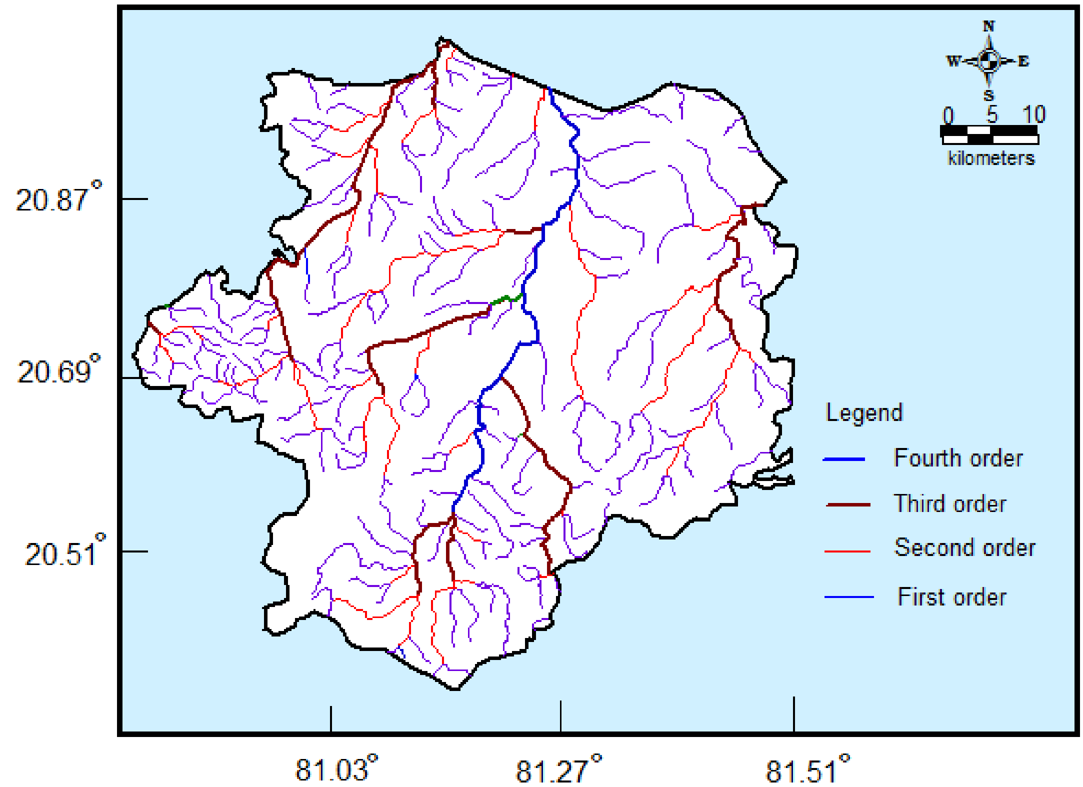

Fig. 4.11: Drainage map of the Balod district

The morphometric analysis has been done for this district and is given in Table 4.8. It can be seen that, there were a total of 221 streamlets found in the entire Balod district out of which 175 streamlets are of 1st order, 35 are of 2nd order, 9 are of 3rd order and 2 are of 4th order. The total length of the streams was found to be 1536.68 km. Drainage density of the area was found to be 0.45 km/km^2 which was indicating low runoff potential of this district. Similarly, stream frequency (the total number of channels required to drain a unit area of the watershed) of the area was found to be 0.065 which is also low showing more or less plain topography of the area and lack of structural control.

Table 4.8: Stream analysis of watersheds of Balod district

WS No.	Number of Stream				Stream length (km)				Cumulative stream length (km) (watershed wise)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1	24	5	-	-	202	52	22	35	202	254	276	311
2	45	9	2	1	345	90	30	-	345	435	465	465
3	49	10	2	-	448	56	52	-	448	504	556	556
4	12	2	1	-	39	47	1.8	-	39	86	87.8	87.8
5	45	9	3	1	44	-	49	23.86	44	44	93.02	117
6	-	-	-	-	-	-	-	-				-
7	-	-		-	-	-	-	-	-	-	-	-

4.1.4.3 Drainage map of the Bemetara district

The district is mainly drained by Sheonath, Kharun and Hanp rivers and their tributaries. These rivers system comes under Mahanadi river basin. Sheonath river flows through the eastern periphery to central and south western part of the district along with its tributaries. Kharun river flows through the southern periphery and eventually joins the Sheonath river in the southeastern part of the district. The Hanp river along with its tributaries flows through the northern part of the district and also joins Sheonath river in north-eastern part of the district. This entire drainage network is governed by the master slope in the district. The drainage map is prepared and presented in Fig 4.12. It can be seen that, the drainage pattern of the area is dendritic to subdendritic in nature. Drainage density is more or less same in most of the part of the district.

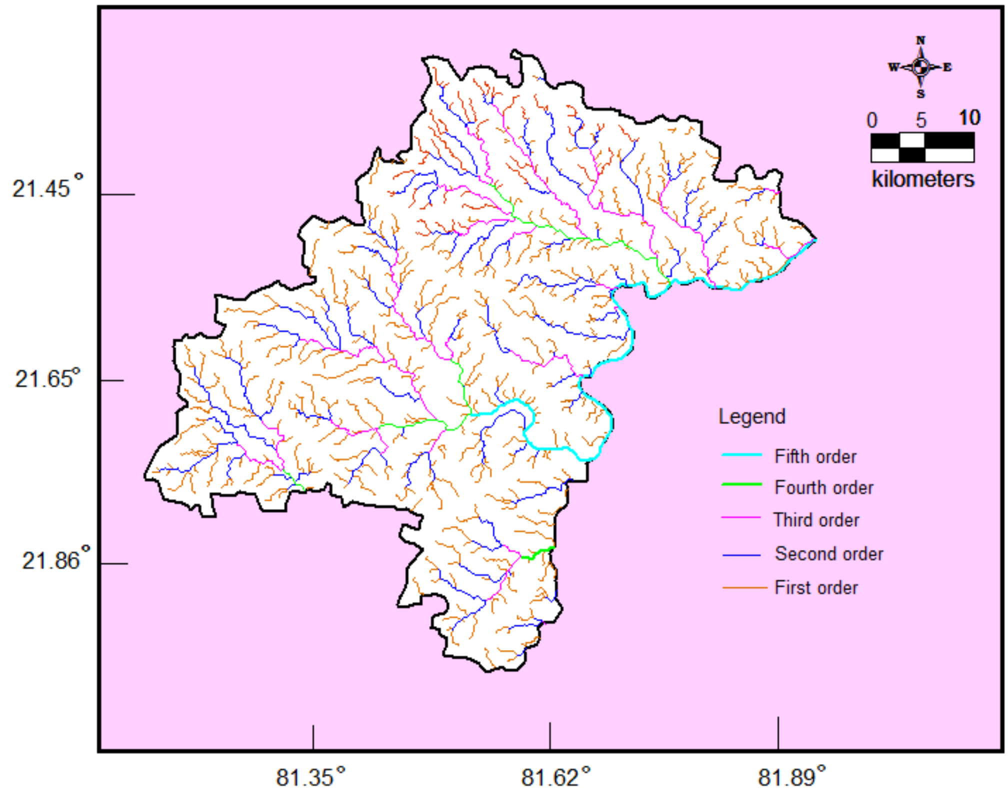

Fig. 4.12: Drainage map of the Bemetara district

The morphometric analysis has been done for this district and is given in Table 4.9. It can be seen that, there was a total of 575 streamlets found in the entire Bemetara district out of which 452 streamlets are of 1st order, 95 are of 2nd order, 18 are of 3rd order, 7 are of 4th order and 3 are of 5th order . The total length of the streams was found to be 1528 km. Drainage density of the area was found to be 0.532 km/km^2 which was indicating low runoff potential of this district. Similarly, stream frequency (the total number of channels required to drain a unit area of the watershed) of the area was found to be 0.20 which is also low showing more or less plain topography of the area and lack of structural control.

Table 4.9: Stream analysis of watersheds of Bemetara district

WS No.	Number of Stream					Stream length (km)					Cumulative stream length (km) (Watershed wise)				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
1	16	5	1	-	-	22	8	2	-	-	22	30	32	32	32
2	119	27	7	1	1	268	22	94	17	25	268	290	384	401	426
3	21	6	2	1	-	52	24	13	3	-	52	76	89	92	92
4	11	3	1	-	-	20	14	12	-	-	20	34	46	46	46
5	85	18	2	1	1	96	63	36	11	33	96	159	195	206	239
6	52	8	2	1	-	110	46	34	5	-	110	156	190	195	195
7	54	10	1	1	-	127	54	17	4	-	127	181	198	202	202
8	40	7	1	1	1	73	31	4	5	1	73	104	104	113	114
9	54	11	1	1	-	123	44	10	5	-	123	167	177	182	182
10	-	-	-	-	-	-	-	-	-		-	-	-	-	-

4.1.5 Lineament map

The lineament map was prepared as mentioned in the Chapter III. Lineaments are the linear, rectilinear, curvilinear features of tectonic origin observed in satellite data. These lineaments normally show tonal, textural, soil tonal, relief, drainage and vegetation linearity and curvilinerities in satellite data. All these linear features were interpreted from the satellite data and the lineament map of the study area was prepared. Lineaments are any linear features that can be picked out as lines (appearing as such or evident because of contrasts in terrain or ground cover on either side) in aerial or space imagery. In geological term these are usually faults, joints, or boundaries between stratigraphic formations. Most of these lineaments were attributed either to faults or to fracture systems that were controlled by joints (fractures without relative offsets). Fig. 4.13, Fig. 4.14 and Fig. 4.15 shows the lineaments present in the Dhamtari, Balod and Bemetara districts, respectively and the information about the length of lineaments present in these districts is given in Table 4.10, Table 4.11 and Table 4.12, respectively.

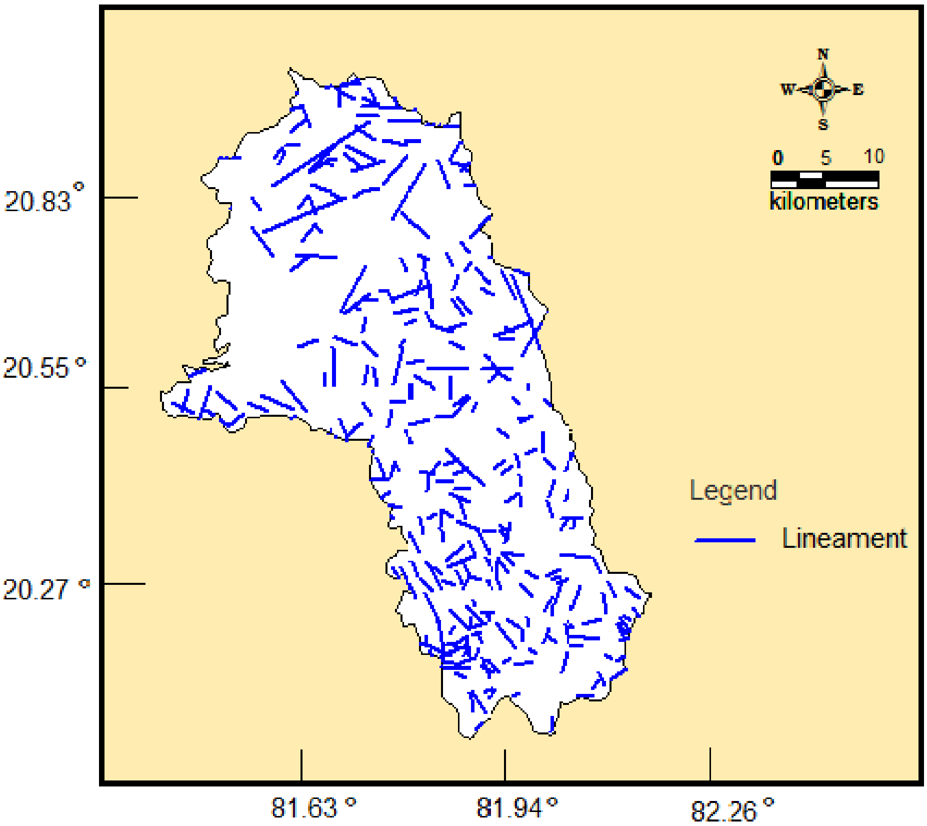

Fig. 4.13: Lineament map of the Dhamtari district

Table 4.10: Lineament map of the Dhamtari district

S. No.	Block	Length (km)
1	Dhamtari	110
2	Kurud	224
3	Nagri	204
4	Magarlod	152
Total		592

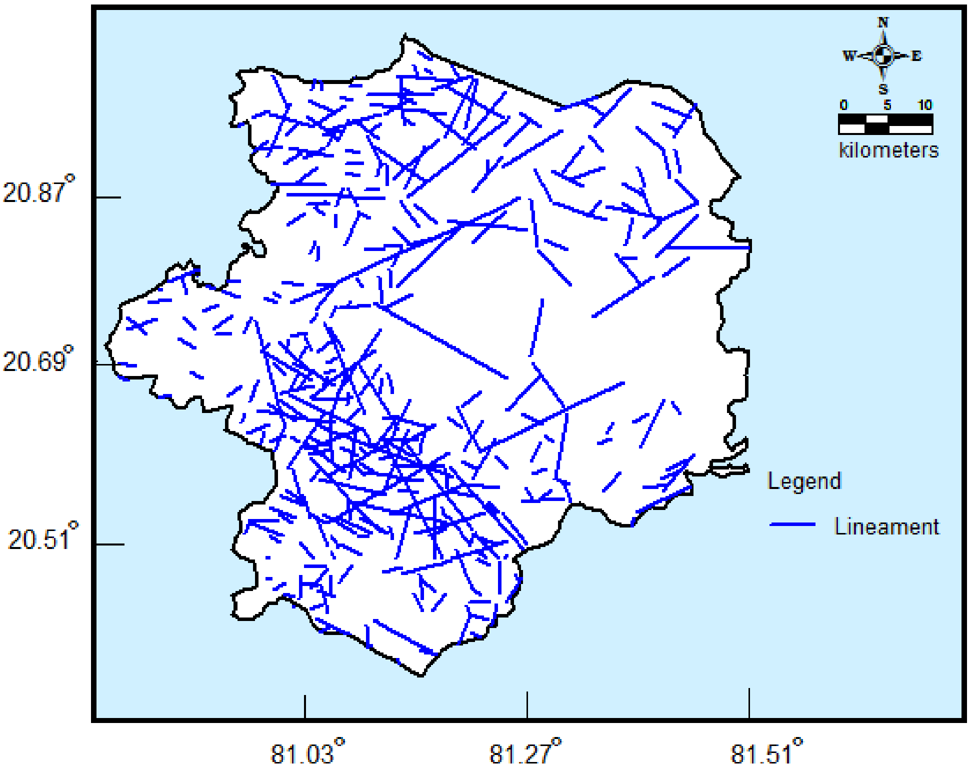

Fig. 4.14: Lineament map of the Balod district

Table 4.11: Lineament map of the Balod district

S. No.	Block	Length (km)
1	Balod	153
2	Gurur	121
3	Gunderdehi	103
4	Dondi	219
5	Dondi lohara	186
Total		784

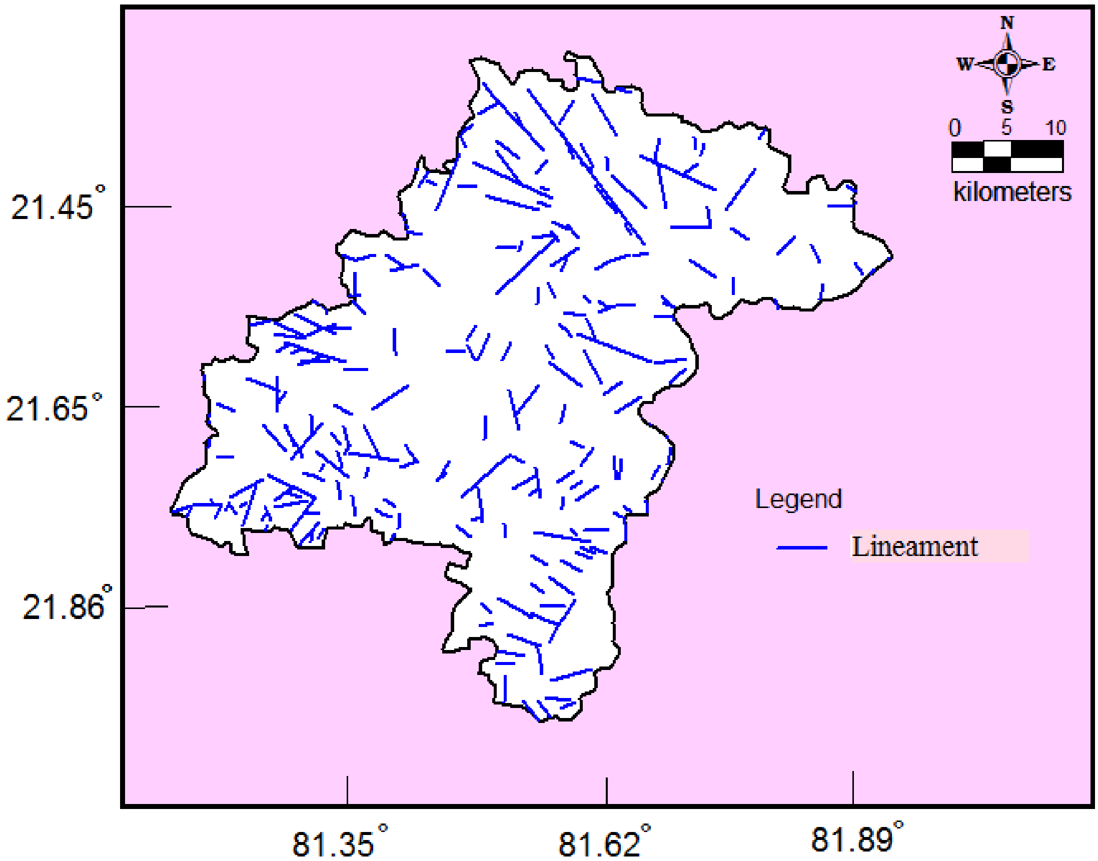

Fig. 4.15: Lineament map of the Bemetara district

Table 4.12: Lineaments of the Bemetara district

S. No.	Block	Length (km)
1	Bemetara	116.1
2	Berla	224.6
3	Saja	178.4
4	Nawagarh	138.2
Total		658.3

4.1.6 Geological map

The digitized geological map of Dhamtari Balod and Bemetara districts are shown in Fig 4.16, Fig 4.17 and Fig 4.18, respectively, which indicated that the geology of study area has varied formations. Dhamtari district has four formations viz. Gunderdehi, Charmuriya, Chandrapur and Dongargarh. Balod district has four formations viz. Gunderdehi, Charmuriya, Chandrapur, Nandgaon, Bailadila group and Basement Genesis. And Bemetara district has five formations viz. Maniyari, Hirri, Tarenga, Chandi and Khamaria formation. The geological information, lithology and area occupied by the different formations are given in Table 4.13, Table 4.14 and Table 4.15.

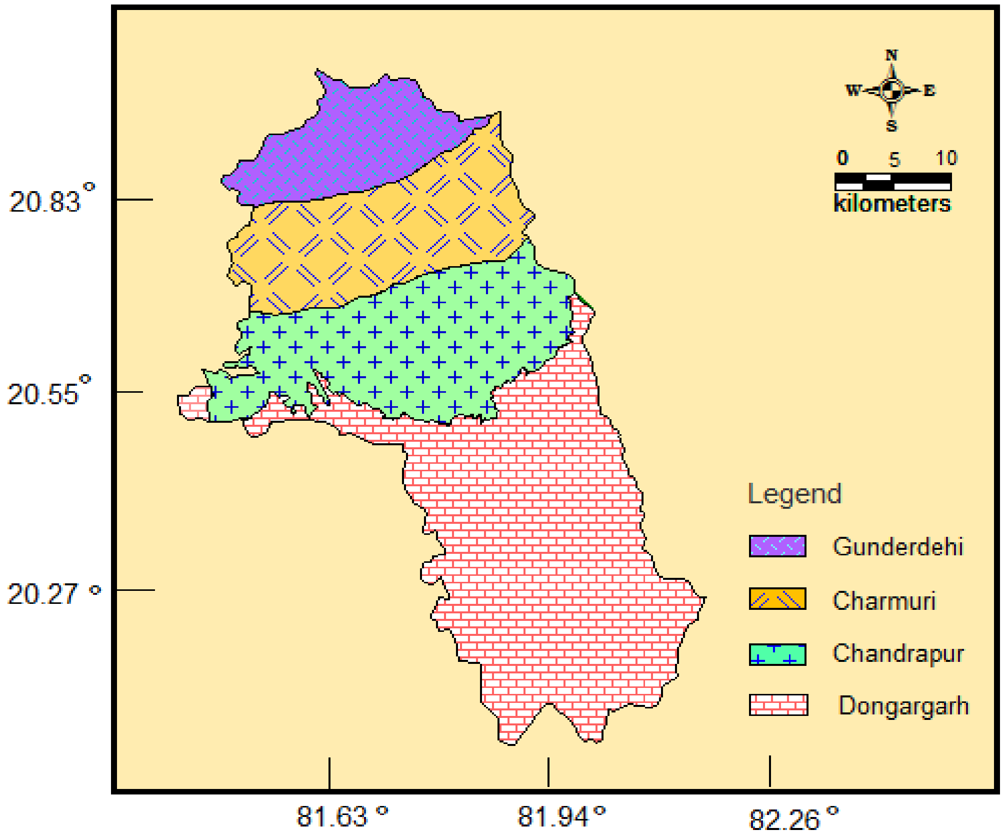

Fig. 4.16: Geology map of the Dhamtari district

Table 4.13: Geological information of Dhamtari district

S. No.	Name of formation	Lithology	Area in ha.
1	Gunderdehi formation	Shale	44988
2	Charmuri formation	Dolomite	76301
3	Chandrapur formation	Sandstone	101838
4	Dongargarh formation	Granite	187567

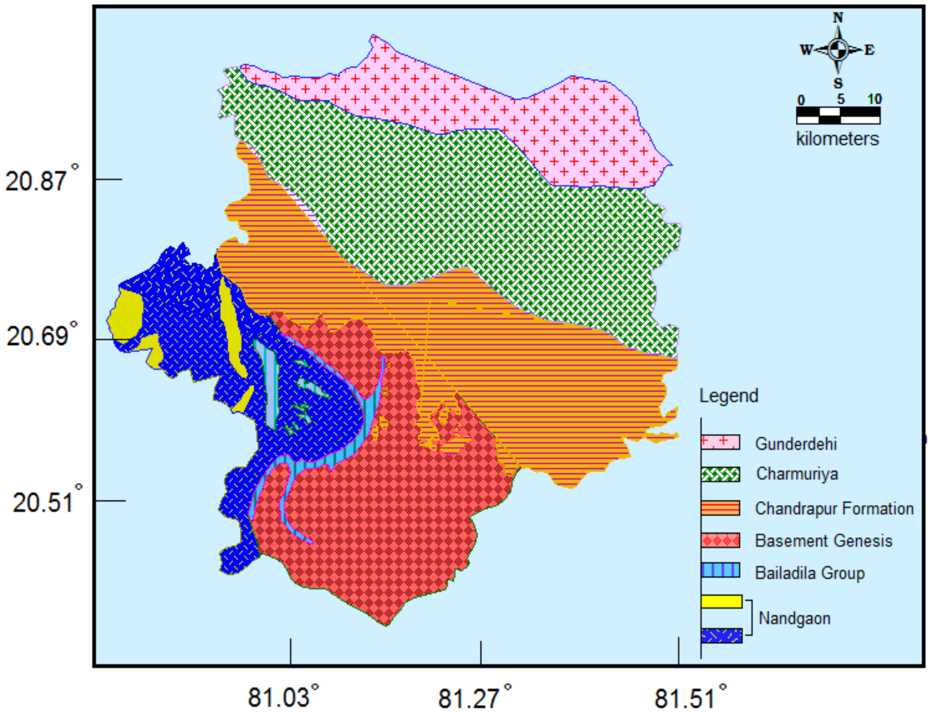

Fig. 4.17: Geology map of the Balod district

Table 4.14: Geological information of Balod district

S. No.	Name of formation	Lithology	Area in ha.
1	Gunderdehi Formation	Shale	39730.41
2	Charmuri Formation	Dolomite	96684.25
3	Chandrapur formation	Sandstone	33403.07
4	Nandgaon	Rhyolite	44240.62
5	Bailadila Group	Shale	6873.54
6	Basement Genesis	Granite	66101.67

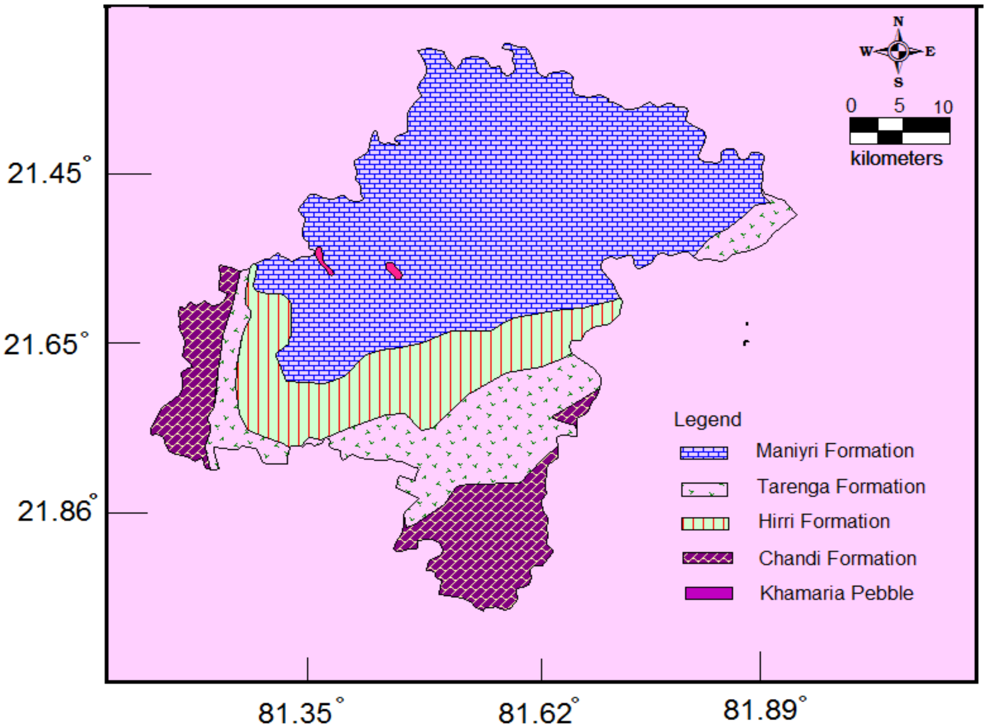

Fig. 4.18: Geology map of the Bemetara district

Table 4.15: Geological information of Bemetara district

S. No.	Name of formation	Lithology	Area in ha.
1	Maniyari formation	Shale	158879
2	Hirri formation	Dolomite	44366
3	Tarenga formation	Shale	46853
4	Chandi formation	Sandstone	36643
5	Khamaria formation	Pebble bed	534

4.1.7 Soil texture map

Soil texture map of the Dhamtari, Balod and Bemetara districts is shown in Fig. 4.19, Fig. 4.20 and Fig. 4.21, respectively which were prepared through GIS using available soil resource data of the area. The area occupied by the soil texture identified in the study areas are given in Table 4.16, Table 4.17 and Table 4.18, respectively for Dhamtari, Balod and Bemetara districts.

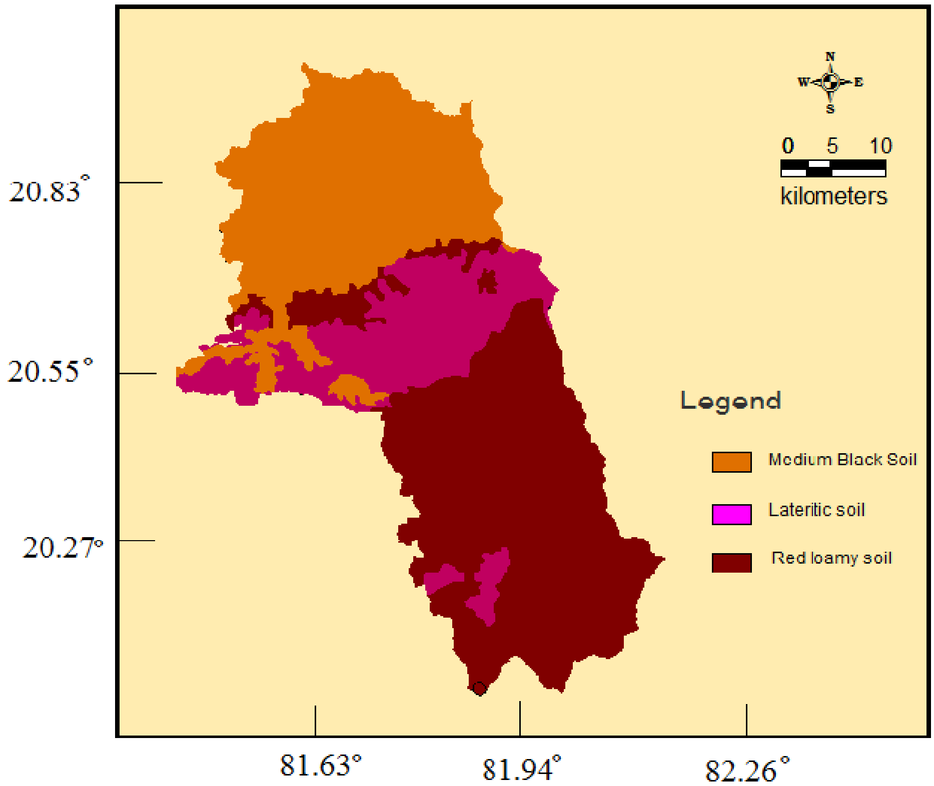

Fig. 4.19: Soil texture map of the Dhamtari district

Table 4.16: Area under different soil texture prevailing in Dhamtari district

S. No.	Soil type	Local name	Area (ha)	% Total area
1	Medium black soils	Dorsa	2196.72	54
2	Red loamy soils	Bhata	651	16
3	Laterite soil	Matasi	1220.66	30

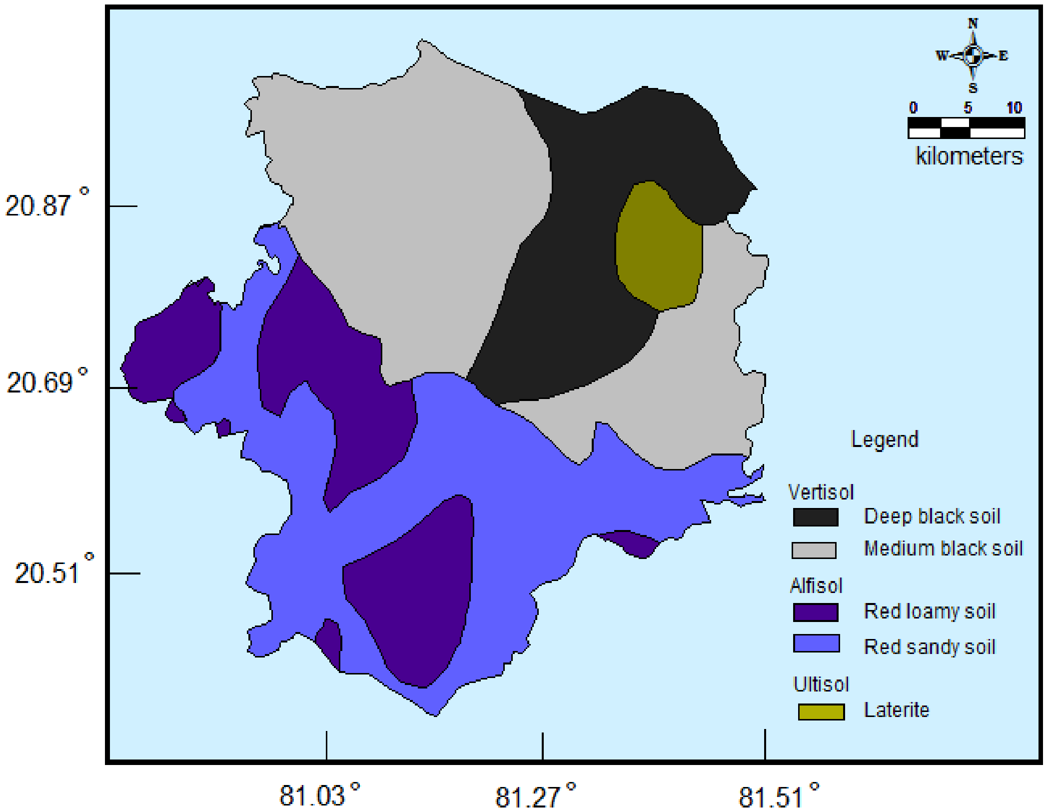

Fig. 4.20: Soil texture map of the Balod district

Table 4.17: Area under different soil texture prevailing in Balod district

S. No.	Soil type	Local name	Area (ha)	% Total area
1	Deep black soils	Kanhar	54053.05	16.04
2	Medium black soils	Dorsa	117430.06	34.83
3	Red loamy soils	Bhata	55096.07	16.35
4	Red sandy soils	Bhata	99709.34	29.59
5	Lateritic soils	Matasi	10813.20	3.20

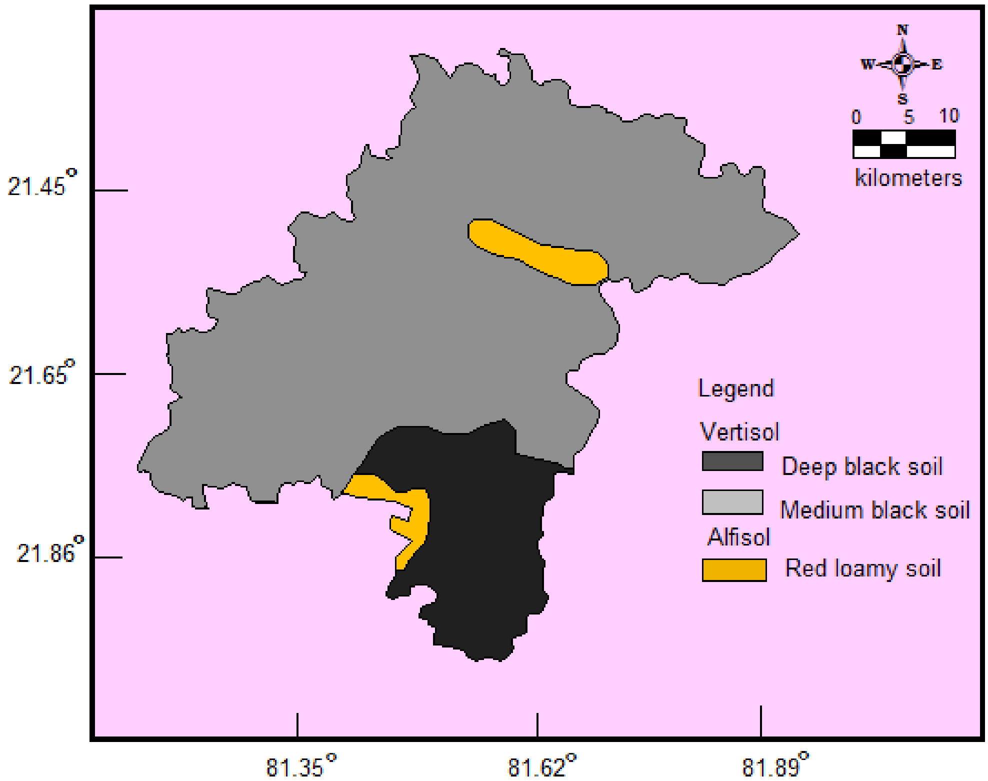

Fig. 4.21: Soil texture map of the Bemetara district

Table 4.18: Area under different soil texture prevailing in the Bemetara district

S. No.	Soil type	Local name	Area (ha)	% Total area
1	Deep black soils	Kanhar	45687	16.0
2	Medium black soils	Dorsa	236984	82.5
3	Red loamy soils	Bhata	4594	1.6

4.1.8 Depth to water level map of pre and post monsoon

The water levels in all these districts are monitored four times a year during the month of January, May, August and November through National Hydrograph Network Stations (NHNS). During the month of May along with the water level measurements, the water samples are also collected from the observation wells for quality analysis.

4.1.8.1 Depth to water level map of Dhamtari district

Details of depth to water level (pre monsoon) of Dhamtari district is given in Table 4.19, it can be seen that in pre-monsoon period, the lowest water level was recorded as 1.17 mbgl and the deepest water level was recorded as 10.91 mbgl. The depth to water level map as shown in Fig.4. 22 indicated that the pre-monsoon depth to the water level in the range of 1.17 to 5.0 m covers an area of about 29%. The depth to water level in the range of 5.0 to 10.0 m covers an area of about 70%. The depth to water level in the range of 10.0 to 10.91 m covers an area of about 0.49%. While it shows that in the district the depth to the water level during pre-monsoon period is less than 10 m in almost 99% of the total area.

Details of depth to water level (post monsoon) of Dhamtari district is given in Table 4.20, indicated that during post-monsoon period, the depth to water level was less than 0.70 m (minimum value) whereas maximum depth to the water level was found to be 5.29 m. The depth to water level map as shown in Fig. 4.23, indicated that almost 18.7% area was occupied the water level which ranged between 0.70 to 2.0 m and 39.04% area comes under the depth to the water level which ranged between 2.0 to 4.5 m while nearly 35.71 % of the area was covered between 4.5 to 5.29 m of water level. The water levels increases and decreases during the post-monsoon and pre-monsoon period, respectively.

Table 4.19: Depth to water level of Dhamtari during the month of May

S. No.	Depth (Meter below ground level)	Area in ha
1	1.17 – 5.0	105671.51
2	5.0 – 10.0	296294.63
3	10.0 – 10.9	2014.23

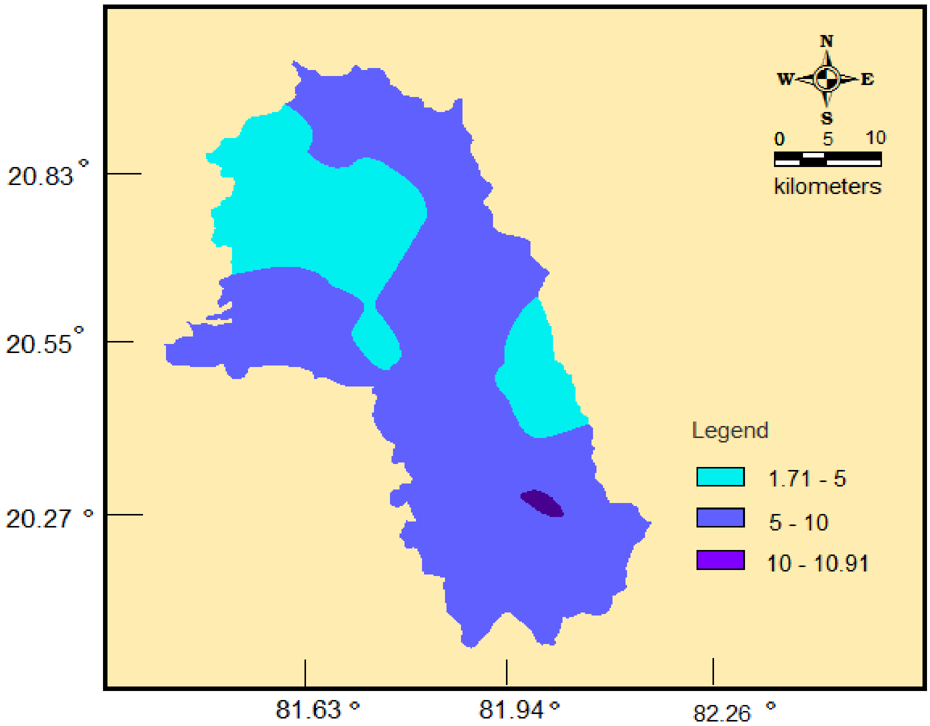

Fig. 4.22: Water level map of Dhamtari district (before monsoon)

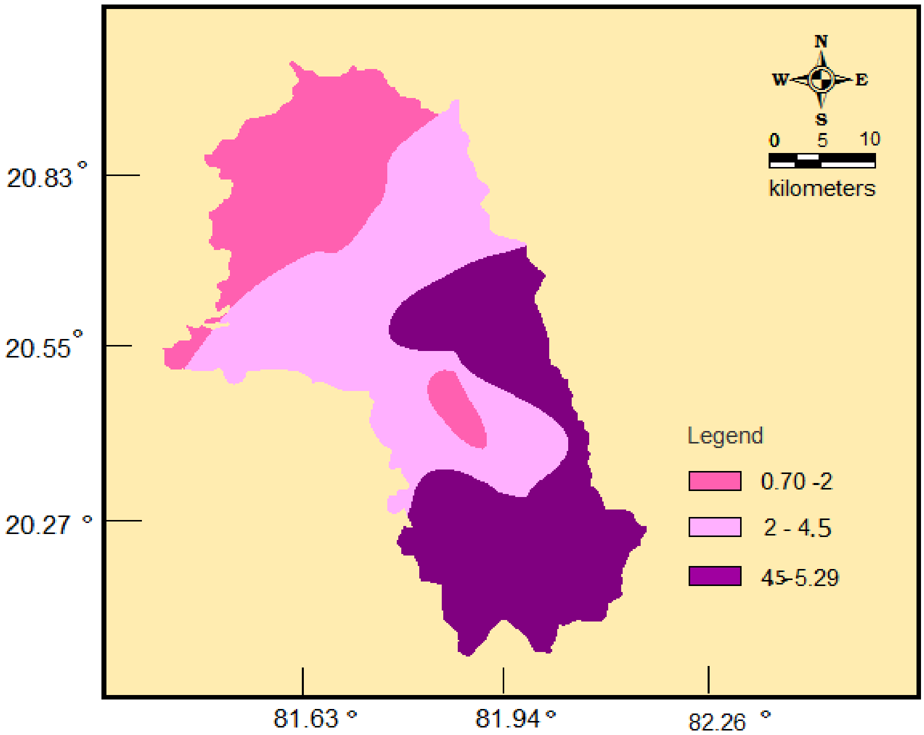

Fig. 4.23: Water level map of Dhamtari district (after monsoon)

Table 4.20: Depth to water level of Dhamtari during the month of November

S. No.	Depth (mbgl)	Area in ha
1	0.7 – 2.0	73970
2	2.0 – 4.0	159077
3	4.0 – 5.3	145324

4.1.8.2 Depth to water level map (pre and post monsoon) of Balod district

During pre-monsoon period, the lowest water level was recorded as 5 mbgl and the deepest water level was recorded > 20 mbgl (Table 4.21). The pre-monsoon depth to the water level in the range of 5.0 to 10.0 m covers an area of about 31% (Fig. 4.24). The depth of water level in the range of 10.0 to 15.0 m covers an area of about 64%. The depth of water level in the range of 15.0 to 20.0 m covers an area of about 59%. However, the depth to water level greater than 20.0 m is observed as 4.8%. Fig. 4.24 also shows that the depth to the water level during pre-monsoon period is less than 10 m in almost 31% of the total area in the district.

Table 4.22, indicated that the minimum depth to water level was 3 m whereas maximum depth to the water level was found to be 20 m during post monsoon. Almost 43 % area was occupied in the water level ranging between 3.0 to 5.0 m and 48.7% the area comes under the depth to the water level which ranged between 5.0 to 10.0 m while, nearly 6.20% of the area was covered with the water level ranging from10.0 to 15.0 m (Fig. 4.25). The water level increases and decreases during the post-monsoon and pre-monsoon period, respectively.

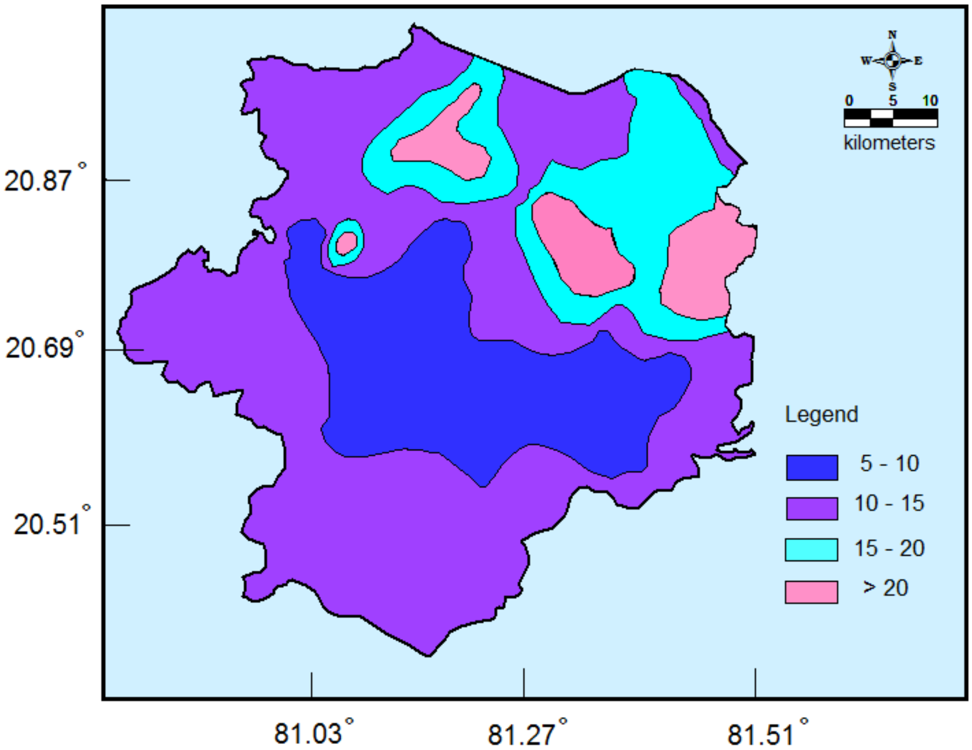

Fig. 4.24: Water level map of Balod district (before monsoon)

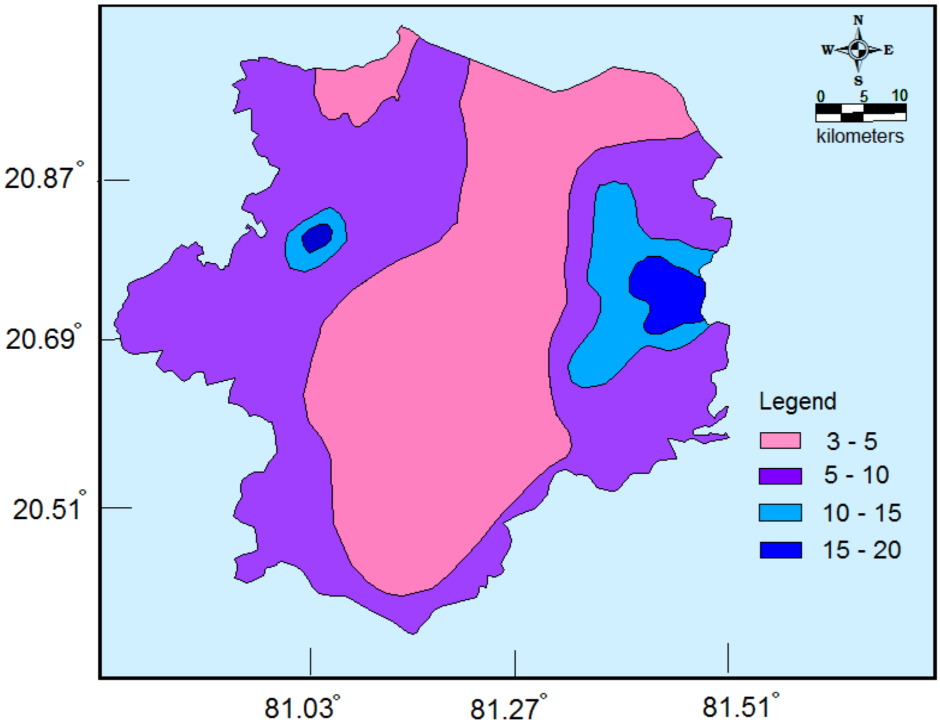

Fig. 4.25: Water level map of Balod district (after monsoon)

Table 4.21: Depth to Water level of Balod in the month of May

S. No.	Depth (mbgl)	Area in ha
1	5.0 – 10.0	105671.51
2	10.0 – 15.0	296294.63
3	15.0 – 20.0	2014.23
4	>20.0	16249.07

Table 4.22: Depth to water level of Balod in the month of November

S. No.	Depth (mbgl)	Area in ha
1	3.0 – 5.0	145710.14
2	5.0 – 10.0	165059.94
3	10.0 – 15.0	20957.40
4	15.0 – 20.0	6747.69

4.1.8.3 Depth to water level map (pre and post monsoon) of Bemetara district

The depth to water level (pre monsoon) of Bemetara district is given in Table 4.23. It can be seen from the Table 4.23 that during pre-monsoon period, the lowest water level recorded in the district was 1 mbgl and the deepest water level recorded was 15 mbgl. Fig. 4.26 shows that the pre-monsoon depth to the water level in the range of 1.0 to 5.0 m covers an area of about 5%. The depth to water level in the range of 5.0 to 10.0 m covers an area of about 40 %. The depth to water level in the range of 10.0 to 15.0 m covers an area of about 55%, while the depth to the water level during pre-monsoon period is less than 10.0 m in almost 45% of the total area (Fig. 4.26).

The depth to water level (post monsoon) as given in Table 4.24, indicated that during post-monsoon period, lowest water level recorded was 3 mbgl whereas, maximum depth to the water level was found to be 15 m. It can be seen in the Fig. 4.27 that almost 57.84 % area was occupied the water level ranging between 3.0 to

5.0 m, and 25.578 % area comes under the depth to the water level ranged between 5.0 to 10.0 m, while nearly 16.60% of the area was covered between 10.0 to 15.0 m of water level. The water level increases and decreases during the post-monsoon and pre-monsoon period, respectively.

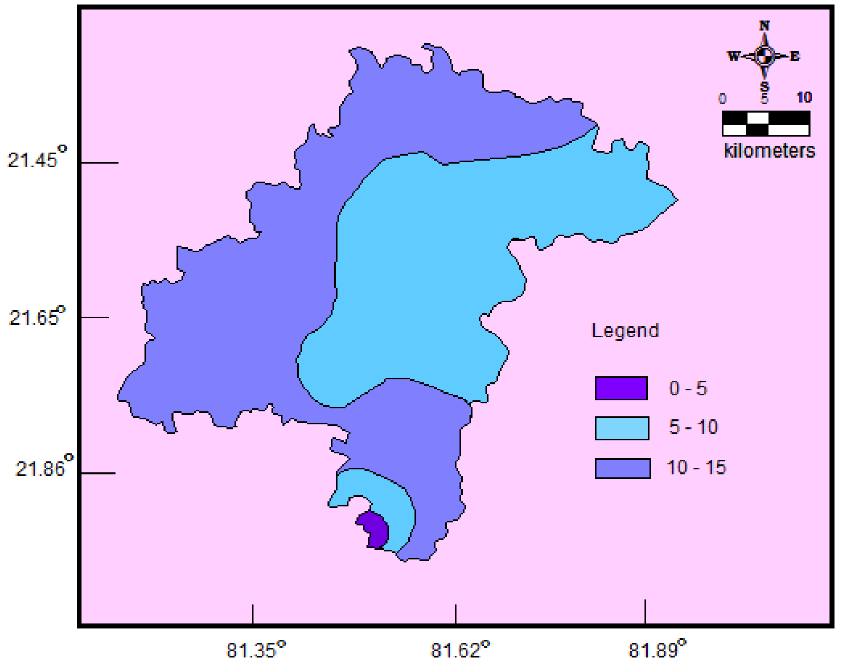

Fig. 4.26: Water level map of the Bemetara district (before monsoon)

Table 4.23: Depth to water level of Bemetara during the month of May

S. No.	Depth (mbgl)	Area in ha
1	0.0 – 5.0	1655.77
2	5.0 – 10.0	127417.05
3	10.0 – 15.0	158300.07

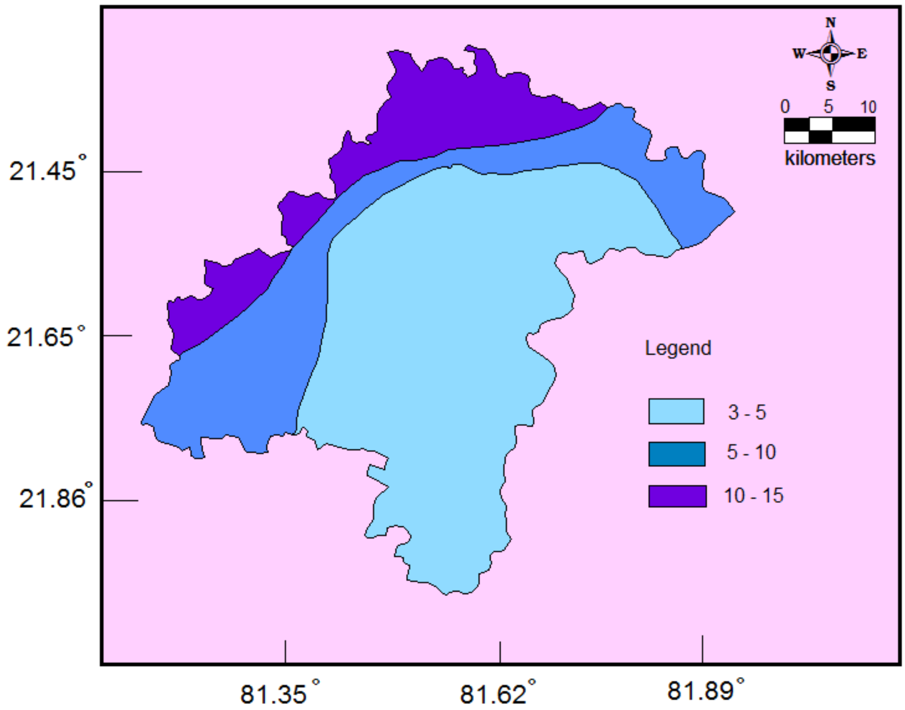

Fig. 4.27. Water level map of Bemetara district (after monsoon)

Table 4.24: Depth to water level of Bemetara during the month of November

S. No.	Depth (mbgl)	Area in ha
1	3.0 – 5.0	166147.73
2	5.0 – 10.0	73452.06
3	10.0 – 15.0	47681.68

4.1.9 Slope Map

The central Chhattisgarh (plain) is represented by Structural Plain on Proterozoic rocks which cover major area in the northern and central part of the district. This unit is developed over rocks of Purana sedimentary basin of Chhattisgarh. This unit has extensive cris-crossed fractures and joints. They are having gently sloping erosional surfaces and thin to moderate cover of soil. The slop map of Dhamtari, Balod and Bemetara districts are show in Fig. 4.28, Fig. 4.29 and Fig. 4.30, respectively.

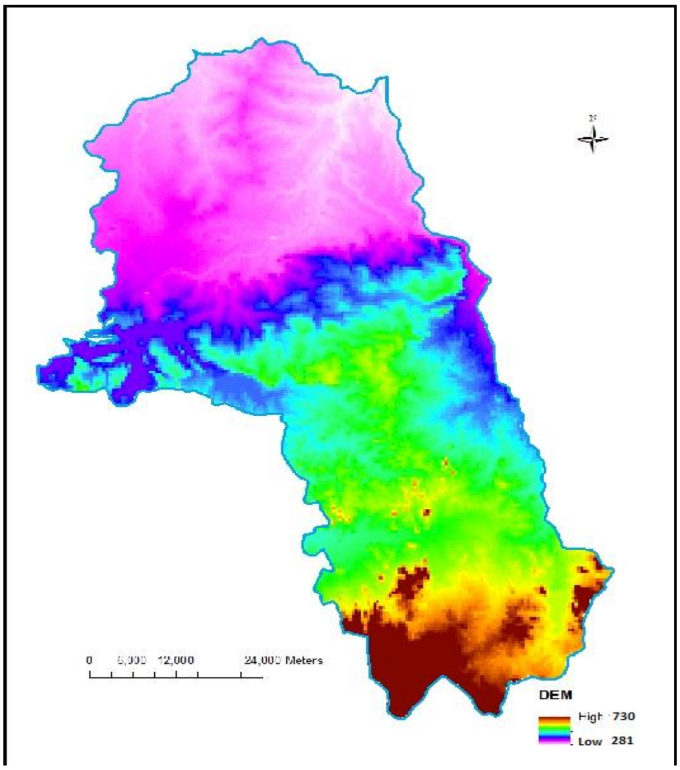

Fig. 4.28: Slope map of the Dhamtari district

Overall the topography in the Dhamtari district varies between 281 m to 730 m above MSL. The area has general slope towards north-east direction with average elevation of 505 m above MSL. The highest elevation recorded in the district is 730 m above MSL and the lowest point is 281 m above MSL. Topography of the Balod district varies between 287 m to 701 m above MSL. The area has general slope towards north and north-west direction with average elevation of 495 m above MSL. The highest elevation recorded in the district is 701 m above MSL and the lowest point is 287 m above MSL. The topography of Bemetara district varies between 238 m to 324 m above MSL. The area has general slope along east direction with average elevation of 281 m above MSL. The highest elevation recorded in the district is 324 m above MSL and the lowest point is 238 m above MSL.

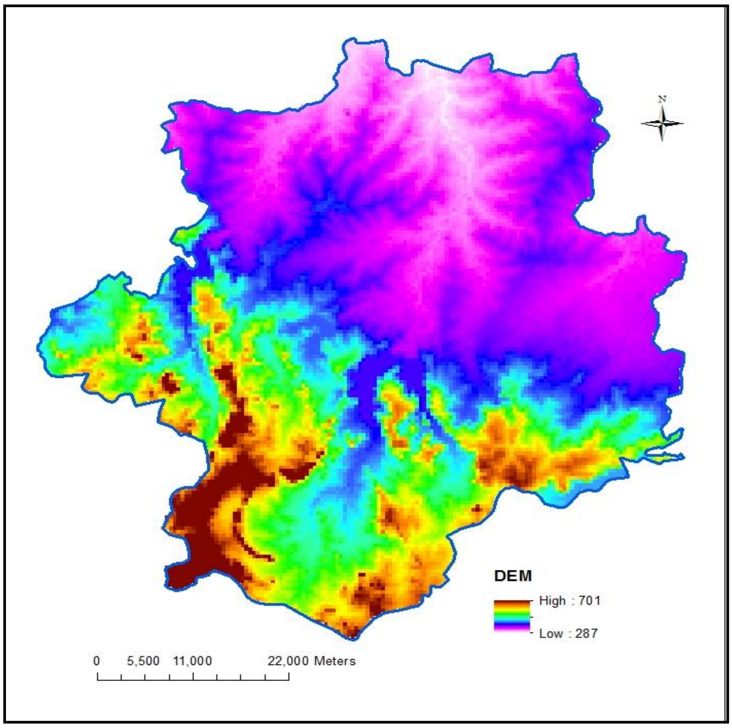

Fig. 4.29: Slope map of the Balod district

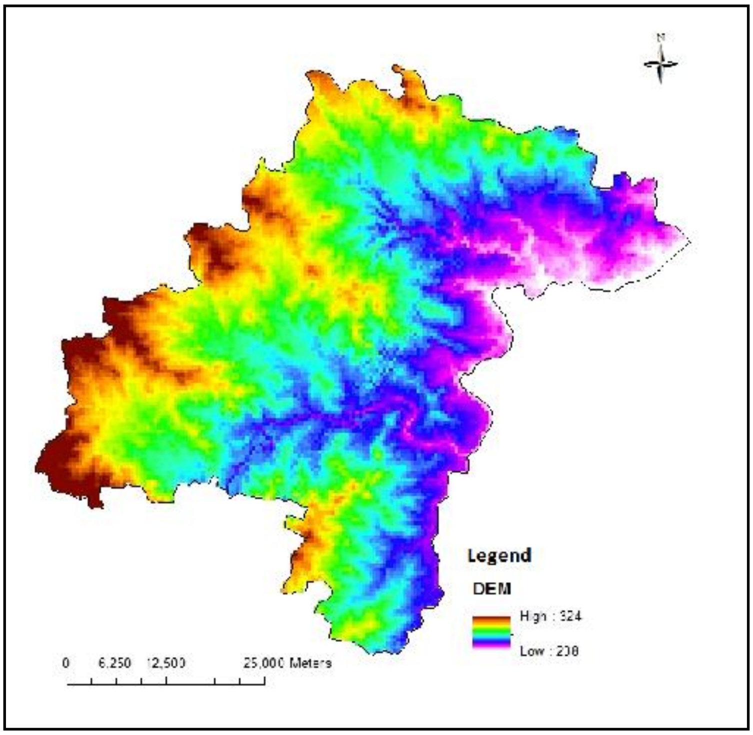

Fig. 4.30: Slope map of the Bemetara district

4.1.10 Canal distributaries map

The canal network of the study area was digitized using topography map. The procedure as described in Chapter III was adopted for digitization of canal network. The digitized canal network of Dhamtari, Balod and Bemetara districts are shown in Fig. 4.31, Fig.4.32 and Fig.4.33, respectively.

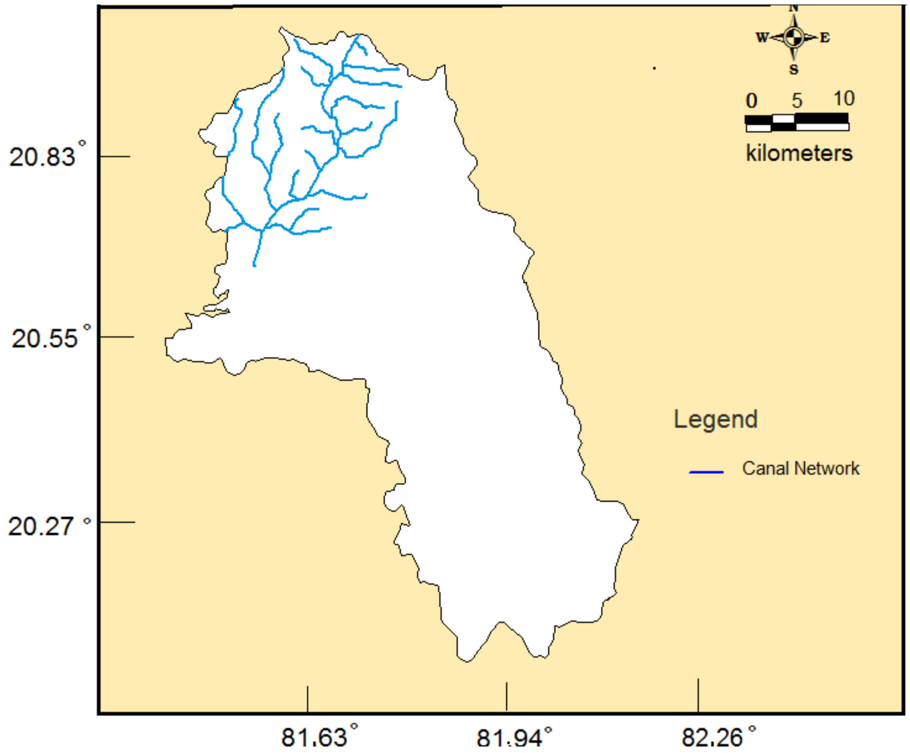

Fig. 4.31: Canal network map of Dhamtari district

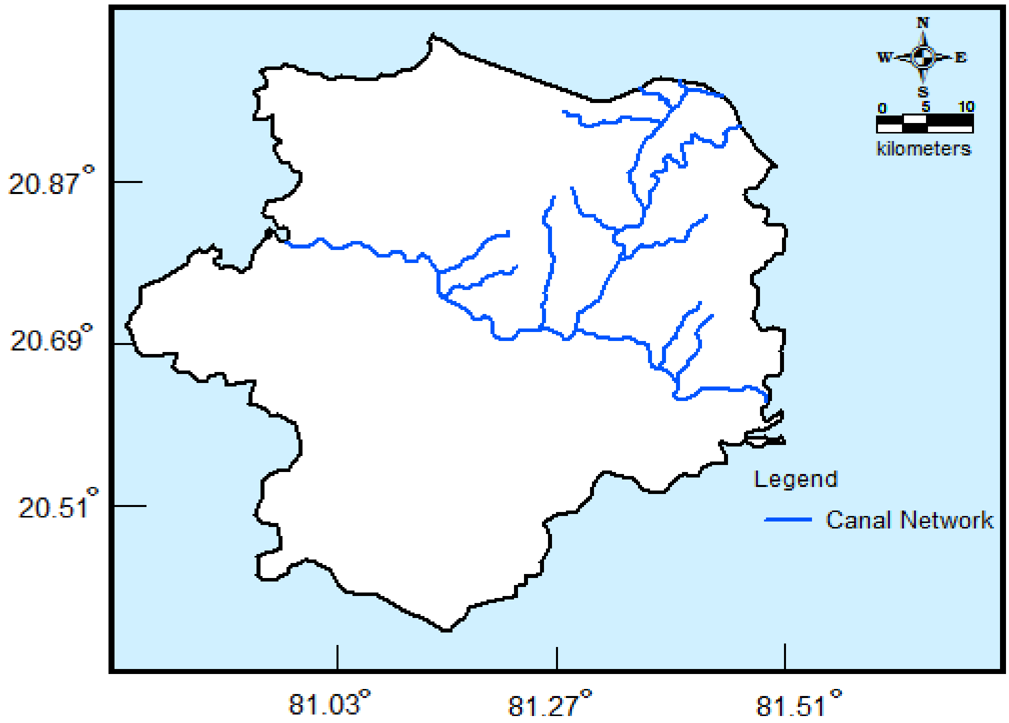

Fig. 4.32: Canal network map of the Balod district

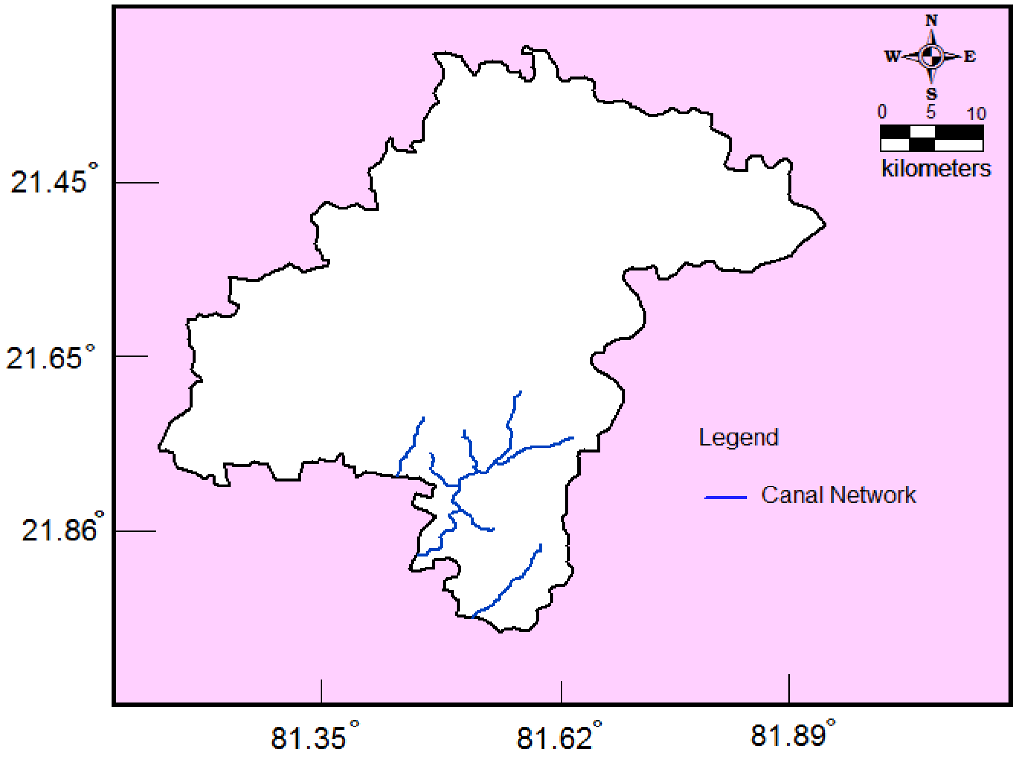

Fig. 4.33: Canal network map of the Bemetara district

4.1.11 Land use/cover map

The cloud free geocoded digital data of IRS- P6 (LISS-IV) in CD ROM was obtained from the NRSC Data Centre, Hyderabad. The imagery, which covers Dhamtari, Balod and Bemetara districts, was used in this study. Area under different land use classes are given in Table 4.25, Table 4.26 and Table 4.27. The total geographical area of the Dhamtari district is 4081.93 ha. Nearly 38.37 % *(i.e.* 1561 ha.) of the total area is arable land, reserved forest covers 2303 ha, protected forest covers 7.23 ha area, whereas shrubs and grasses (wastelands) covers 132 ha. The total geographical area of the Balod district is 3385.11 ha. Nearly 76.96 % (*i.e.* 2605.18 ha.) of the total area is arable land, reserved forest covers 342.23 ha, protected forest covers 247.45 ha area, whereas shrubs and grasses (Wastelands) covers 190 ha. The total geographical area of the Bemetara district is 2872.29 ha. Nearly 92.26 % (*i.e.* 2649.97 ha.) of the total area is arable land and shrubs and grasses (wastelands) covers 222 ha area.

Table 4.25: Area under different land use classes in the Dhamtari district

S. No.	Description	Area in ha	Area in (%)
1	Arable land	1561	38.37
2	Reserves forest	2304	56.62
3	Protected forest	7.2	1.77
4	Shrubs and grass land	132	3.24

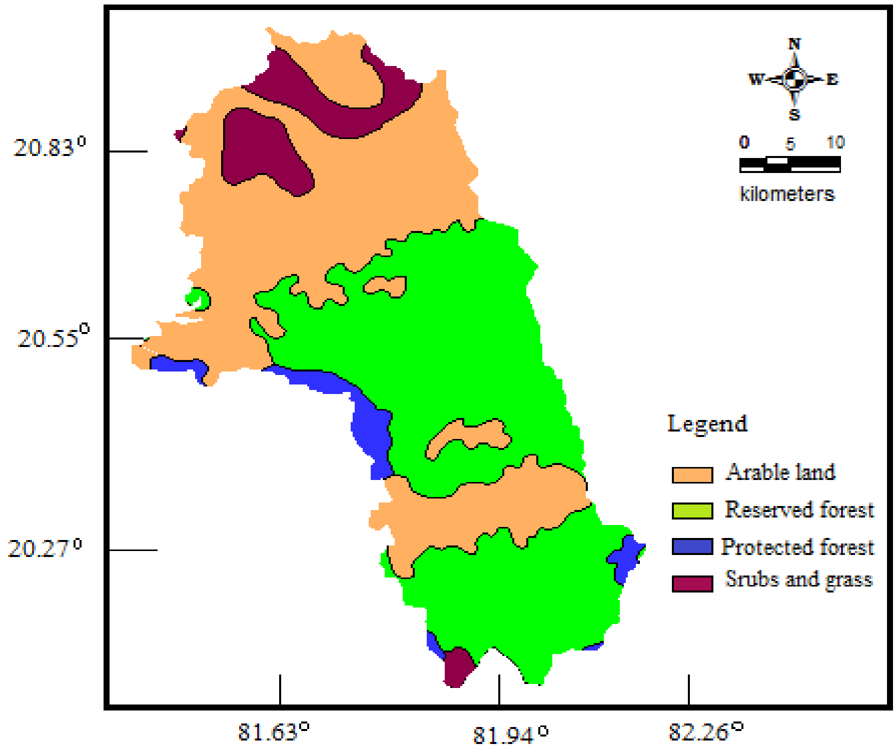

Fig. 4.34: Land use/cover map of the Dhamtari district

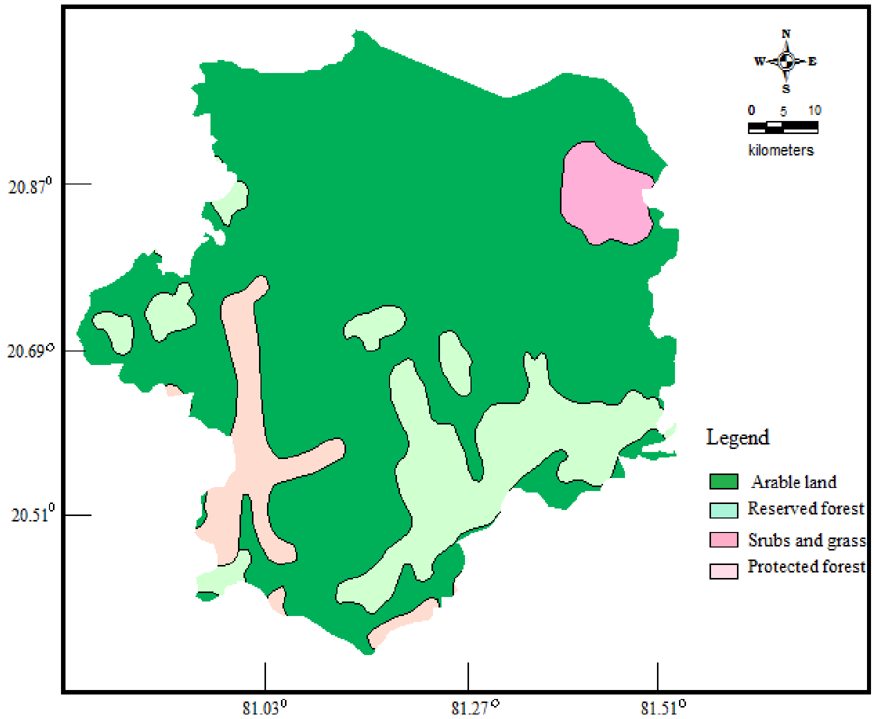

Fig. 4.35: Land use/cover map of the Balod district

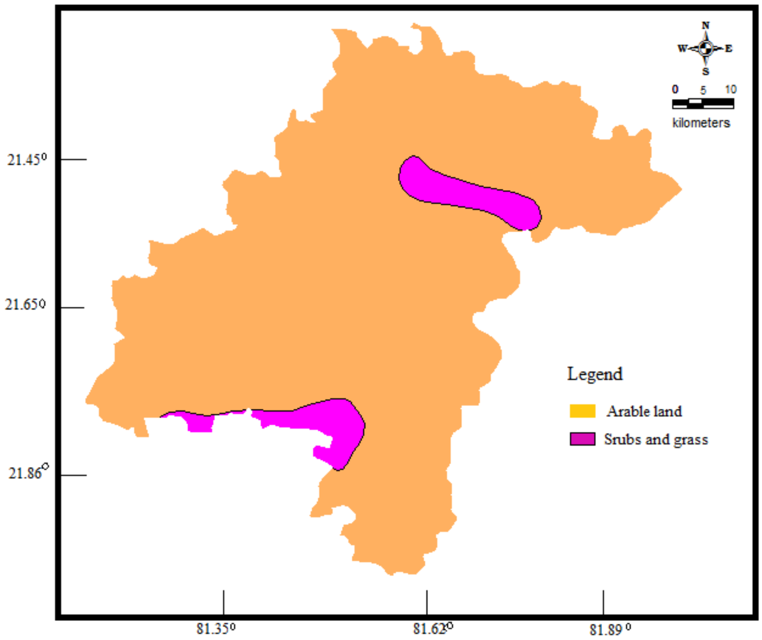

Fig. 4.36: Land use/cover map of the Bemetara district

Table 4.26: Area under different land use classes in the Balod district

S. No.	Description	Area in ha	Area in (%)
1	Arable land	2605	76.96
2	Reserves forest	342	10.11
3	Protected forest	247	7.31
4	Shrubs and grass land	190	5.62

Table 4.27: Area under different land use classes in the Bemetara district

S. No.	Description	Area in ha	Area in (%)
1	Arable land	2650	92.26
2	Shrubs and grass land	222	7.74

4.2. Identification of Location for Groundwater Recharge Structures

4.2.1 Overlaying of different thematic maps

Thematic map including drainage, geology, lineament, soil and slope maps were considered to identify the location of groundwater recharges structures. The suitable recharge sites were suggested accordingly for these districts. Overlaying of different thematic maps are shown in Fig. 4.37, Fig.4.39 and Fig.4.41 for Dhamtari, Balod and Bemetara districts, respectively.

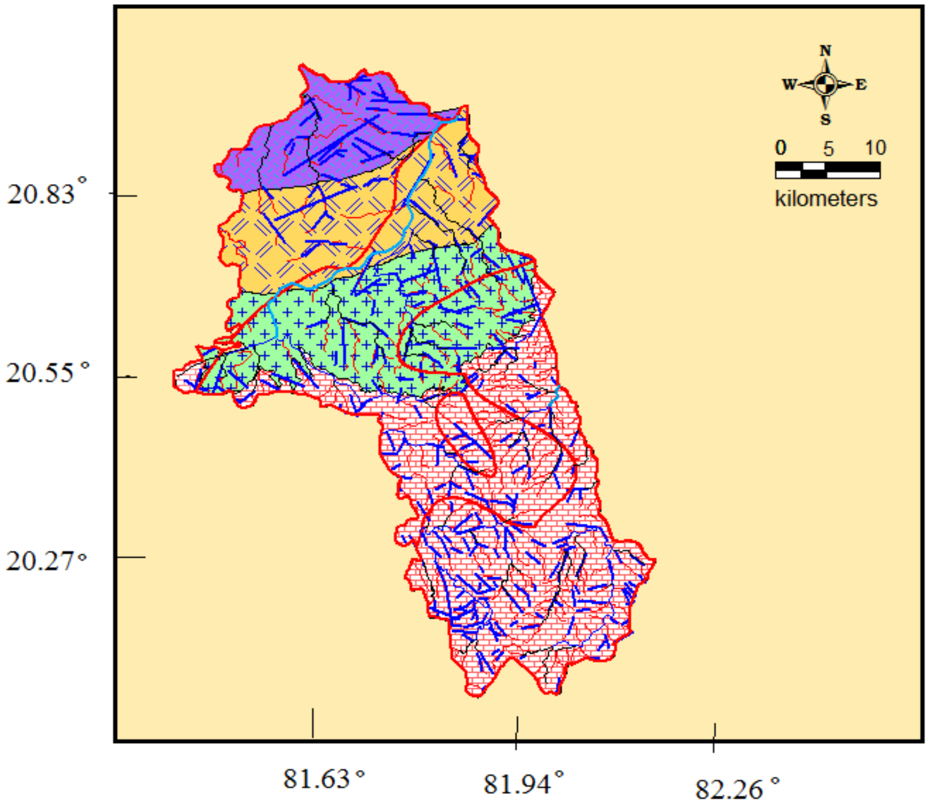

Fig. 4.37: Overlay of drainage, geology, lineament map of Dhamtari district

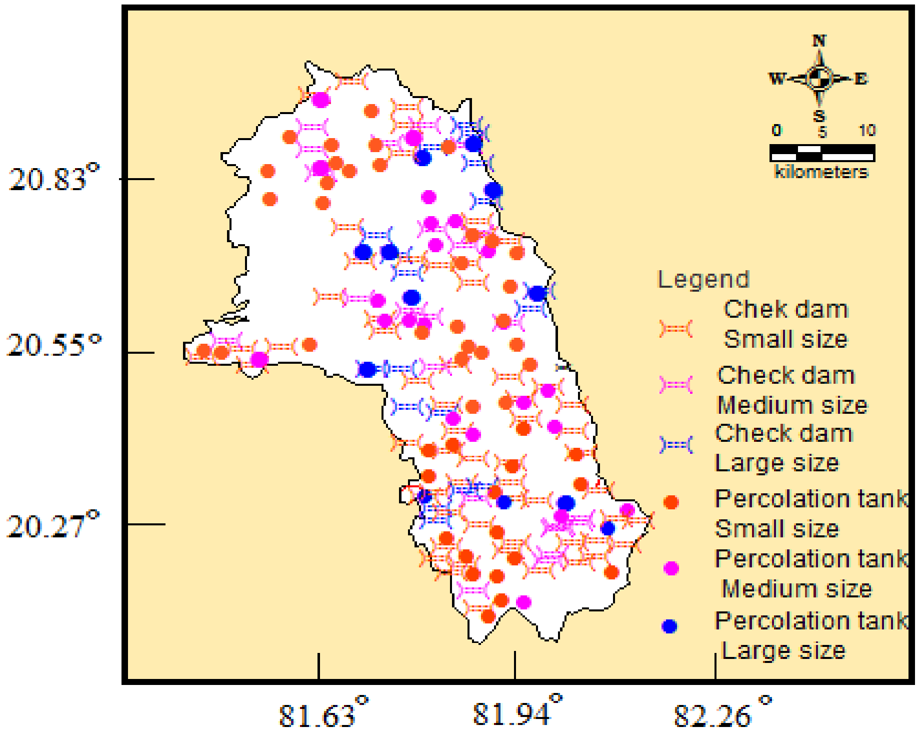

Fig. 4.38: Identified site for groundwater recharge structures in Dhamtari district

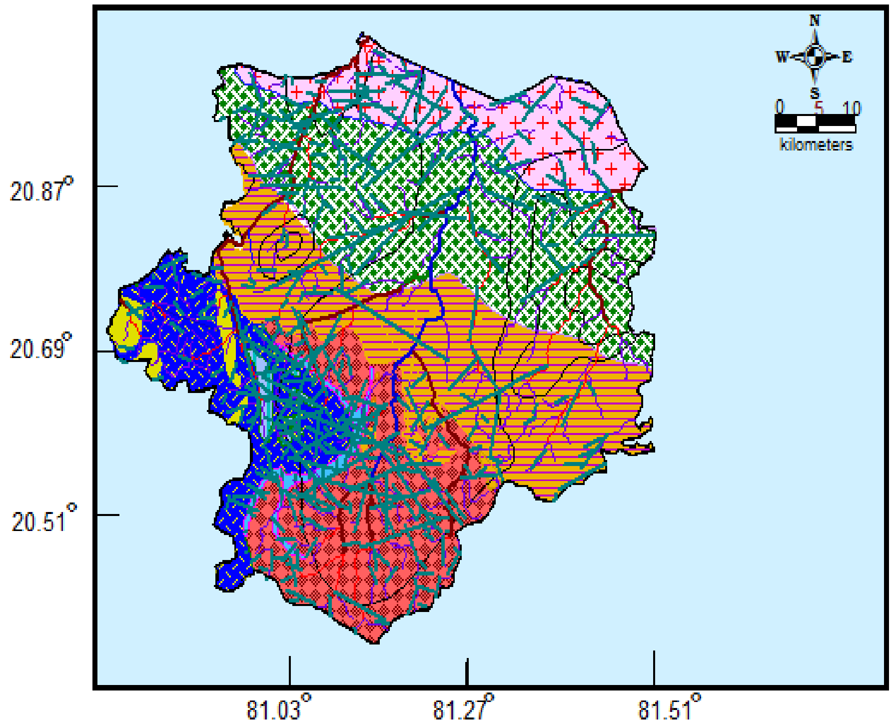

Fig. 4.39: Overlay of drainage, geology, lineament map of Balod district

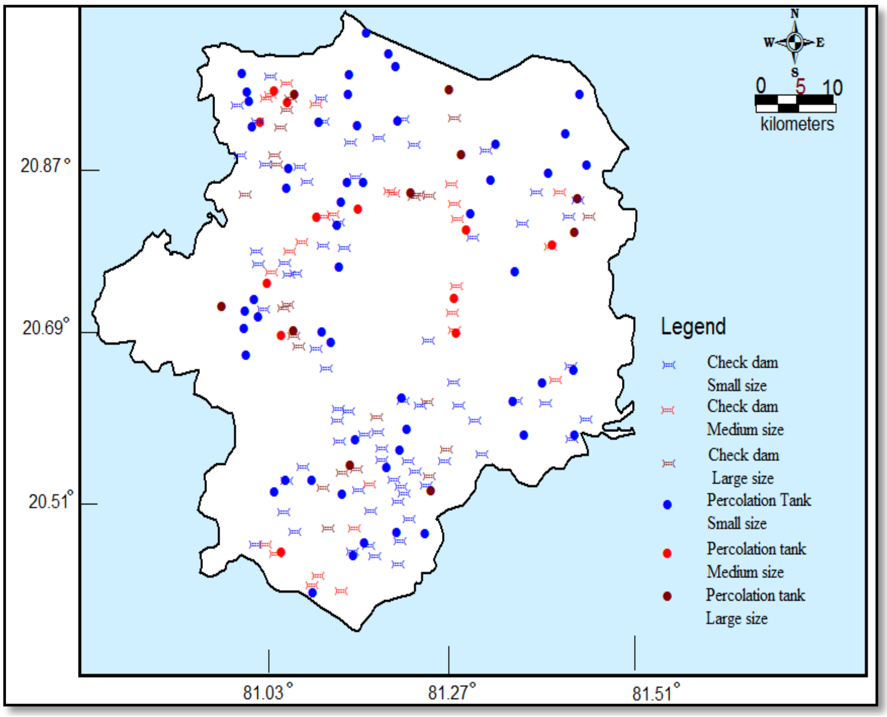

Fig. 4.40: Identified site for groundwater recharge structures in Balod district

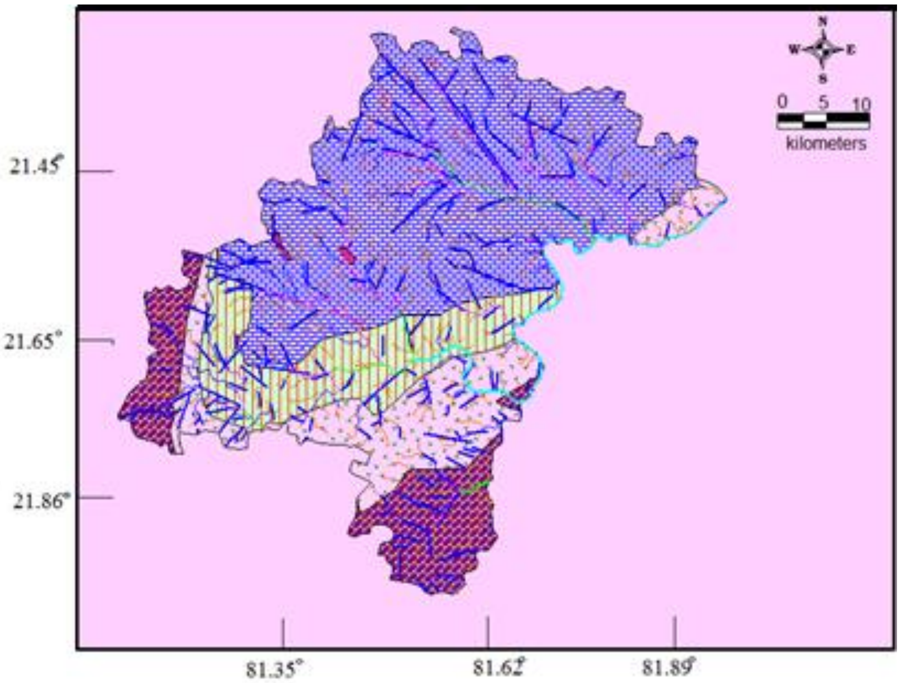

Fig. 4.41: Overlay of drainage, geology, lineament map of Bemetara district

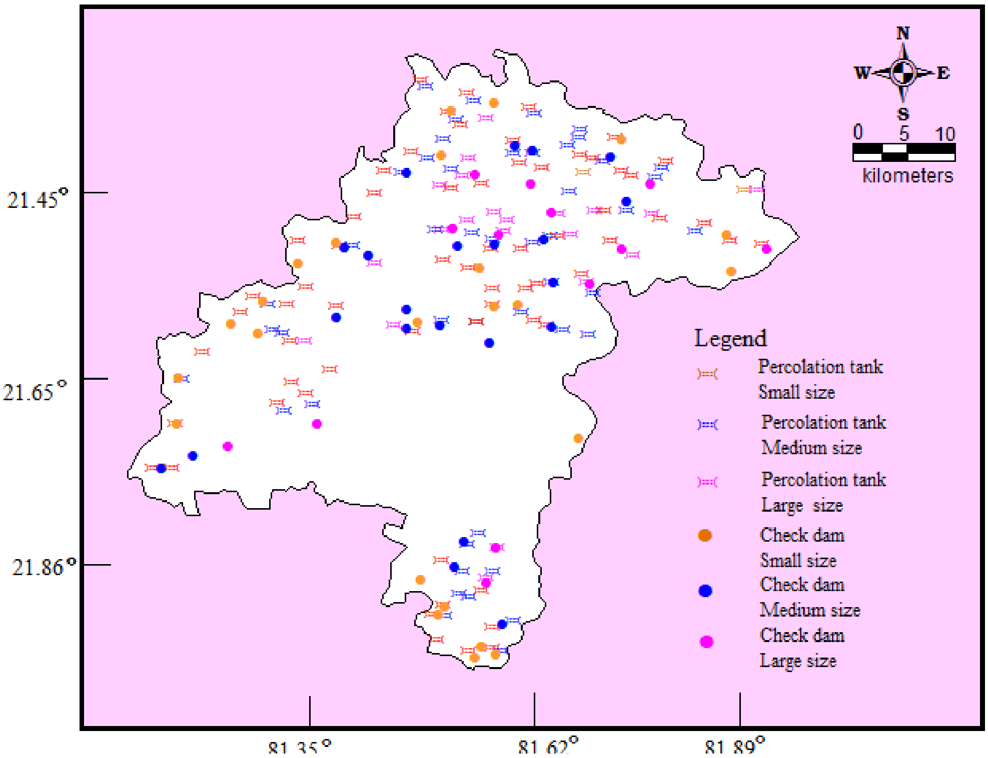

Fig. 4.42: Identified site for groundwater recharge structures in Bemetara district

4.3 Preparation of Groundwater Recharge Plan

4.3.1 Artificial recharge in Dhamtari district

The plan for artificial recharge has been prepared by considering the hydrogeological parameters and hydrological data. The following steps have been taken into consideration.

1. Identification of need based area for artificial recharge to groundwater.
2. Estimation of subsurface storage space and quantity of water needed to saturate the unsaturated zone (upto 3 mbgl).
3. Quantification of surface water requirement and surplus annual runoff availability for artificial recharge.
4. Determination of suitable recharge structures in terms of their numbers, type and size.

The standard methodology was adopted for placing artificial recharge structures. The average post-monsoon depth to water level was prepared. Based on post-monsoon depth to water level area feasible for artificial recharge has been demarcated and put into 3 categories, namely;

i. Area showing water level 0.70 to 2.0 mbgl

ii. Area showing water level 2.0 - 4.5 mbgl

iii. Area showing water level 4.5 - 5.29 mbgl

4.3.1.1 Identification of need based area for artificial groundwater recharge

The field survey of study area was also carried out to find out the suitability and appropriate location of proposed artificial groundwater recharge structures. It is observed that about 75.45 percent area was suitable for locating the artificial recharge structures in the Dhamtari district. Since, water level during post monsoon season is 3 m for remaining 24.55 % area of the district. Identification of need based area for artificial groundwater recharging shown in Fig. 4.43.

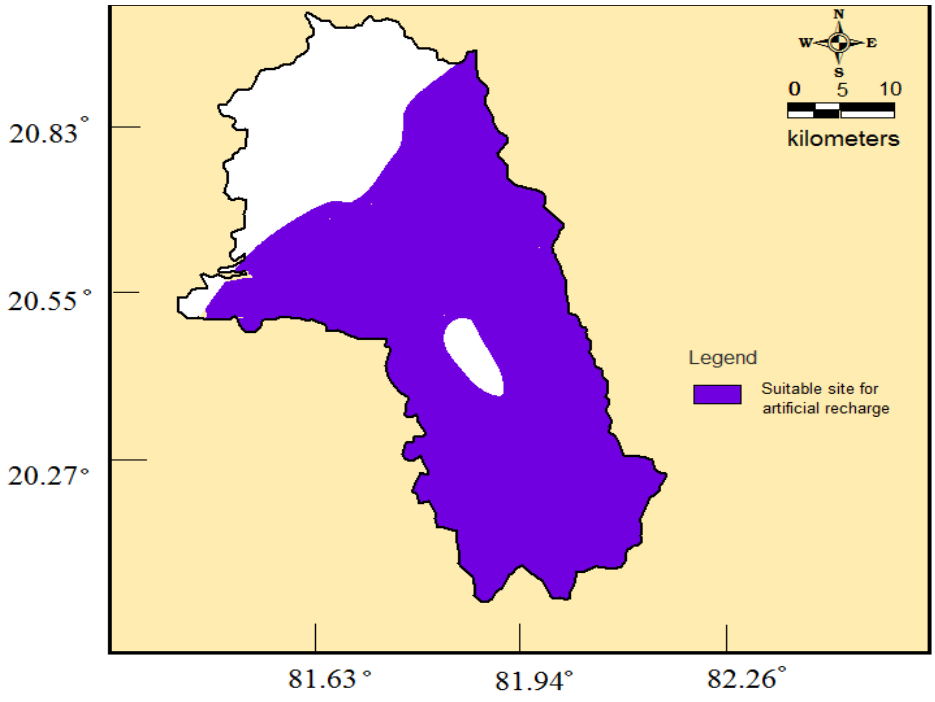

Fig. 4.43: Identification of need based area for artificial groundwater recharge in Dhamtari district

4.3.1.2 Estimation of available storage space

The estimation of subsurface storage space is based on the thickness of available unsaturated zone (below 3 mbgl) in post-monsoon season and the specific yield of phreatic aquifer. The limit to saturate the vadose zone below 3 m is kept with a view to avoid water logging and soil salinity. The total volume of unsaturated strata was estimated and actual amount of water required to recharge the aquifer upto 3 m has been calculated by multiplying with specific yield of the area i.e. 0.03% (Verma 2008). Volume of surface water required is calculated by using the standard formula and given in Table 4.28. The vadose zone of 94.54 Mm^3 is available for artificial recharge in the study area.

Table 4.28: Estimated volume of sub-surface storage capacity in Dhamtari district

Project area	Geographical area (km^2)	Area identified for artificial recharge (km^2)	Depth to water level (post monsoon) below cut-off level (m)	Volume of unsaturated zone ($Mm^{3)}$	Average specific yield	Total storage potential as volume of water (Mm^3)
Dhamtari	4081.93	1590.77	0.25	397.69	0.03	11.93
		1453.24	1.89	2753.88	0.03	82.61

4.3.1.3 Surface water requirement

After assessing the actual volume of water required for saturating the vadose zone, the net amount of source water available has been calculated by considering 75 percent efficiency of the artificial recharge structure (Verma 2008). The value obtained was multiplied by 1.33 (A reciprocal of 75 percent efficiency). The volume of water required for artificial recharge was found to be 125.73 M m^3.

4.3.1.4 Availability of surplus water for recharge

Availability of source water to recharge the subsurface reservoir in the each Block has been assessed in the form of non-committed surplus runoff. The runoff was estimated by using Stranger's Table for the normal monsoon rainfall of the area. The normal monsoon rainfall of the area is being 978.36 mm. The availability of surface water for recharge has been calculated for each Block as given in Table 4.29. The total volume of runoff generated from Dhamtari district having 4081.93 km^2 area worked out to be 1585.68 Mm^3. Runoff 475.69 Mm^3, which is 30 % of the total runoff considered as surplus for artificial recharge (Verma 2008).

Table 4.29: Availability of surplus water for recharge in Dhamtari district

S. No.	Block	Area of block (km^2)	Monsoon rainfall	Coefficient (K)	Runoff (Q=rainfall x Coefficient) (mm)	Volume (area x runoff) (Mm^3)	30 % of the total runoff (Mm^3)
1	Dhamtari	646.97	1054.32	0.422	444.93	287.85	86.35
2	Kurud	747.72	1044.68	0.414	432.49	323.38	97.01
3	Nagri	1732.96	883.57	0.402	355.19	615.53	184.66
4	Magarlod	940.42	930.88	0.410	381.66	358.92	107.67
Total		4086.87	---	---	---	1585.68	475.69

4.3.1 Artificial recharge in Balod district

The standard methodology was adopted for placing artificial recharge structure. The average post-monsoon depth to water level is prepared. Based on post-monsoon depth to water level area feasible for artificial recharge has been demarcated and put into 4 categories, namely;

i. Area showing water level 3.0 – 5.0 mbgl

ii. Area showing water level 5.0 – 10.0 mbgl

iii. Area showing water level 10.0 – 15.0 mbgl

iv. Area showing water level 15.0 – 20.0 mbgl

4.3.1.1 Identification of need based area for artificial groundwater recharge

The field survey of study area was also carried out to find out the suitability and location of proposed artificial groundwater recharge structures. It is observed that 57.95 percent area was suitable for locating the artificial recharge structures in this district. Since water level during post-monsoon season is 3 m for remaining 42.05 % area of Balod district. Identification of need based area for artificial ground water recharging shown in Fig.4.44.

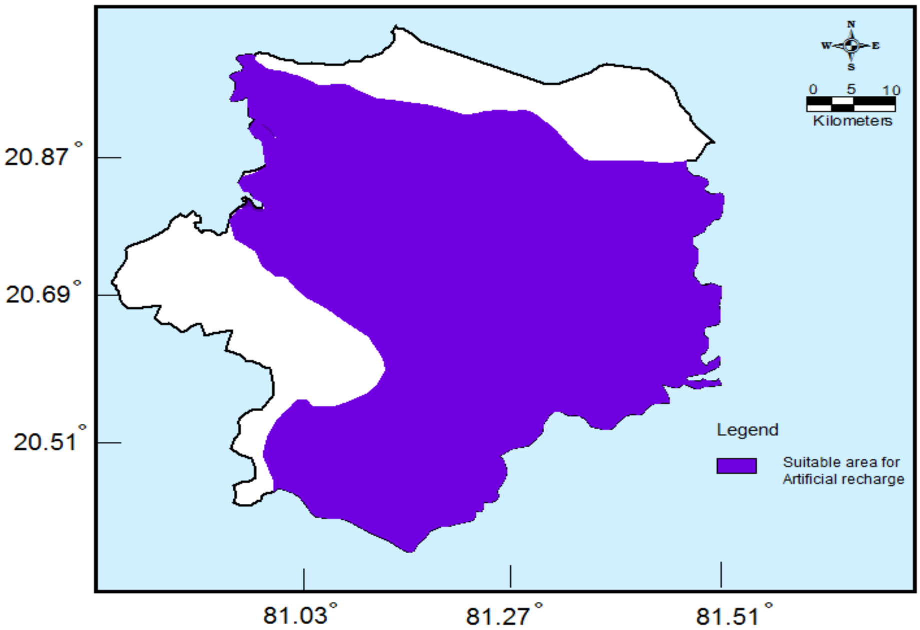

Fig. 4.44: Identification of need based area for artificial groundwater recharge in Balod district

4.3.1.2 Estimation of available storage space

The estimation of subsurface storage space is based on the thickness of available unsaturated zone (below 3 mbgl) in post-monsoon and the specific yield of phreatic aquifer. The limit to saturate the vadose zone below 3 m is kept with a view to avoid water logging and soil salinity. The total volume of unsaturated strata was estimated and actual amount of water required to recharge the aquifer upto 3 m has been calculated by multiplying with specific yield of the area *i.e.* 0.03% (Verma 2008). Volume of surface water required is calculated by using the standard formula and given in Table 4.30. The vadose zone of 357.62 Mm^3 is available for artificial recharge in the study area.

Table 4.30: Estimation of sub-surface storage capacity in Balod district

Project area	Geographical area (km^2)	Area identified for artificial recharge (km^2)	Depth toWater level (post monsoon) below cut-off level (m)	Volume of unsaturated zone (Mm^3)	Average specific yield	Total storage potential as volume of water (Mm^3)
Balod	3385.11	1457.10	1.0	1457.10	0.03	43.71
		1650.59	4.5	7427.65	0.03	222.82
		209.57	9.5	1990.91	0.03	59.72
		67.47	15.5	1045.78	0.03	31.37

4.3.1.3 Surface water requirement

After assessing the actual volume of water required for saturating the vadose zone, the net amount of source water available has been calculated by considering 75 per cent efficiency of the artificial recharge structure (Verma 2008). The value obtained was multiplied by 1.33 (A reciprocal of 75 per cent efficiency). The volume of water required for artificial recharge was found to be 475.63 Mm^3.

4.3.1.4 Availability of surplus water for recharge

Availability of source water to recharge the subsurface reservoir in the each Block has been assessed in the form of non-committed surplus runoff. The runoff is estimated by using Stranger's Table for the normal monsoon rainfall of the area. The normal monsoon rainfall of the area is being 1005.5 mm. The availability of surface water for recharge was calculated for each Block as given in Table 4.31. The total volume of runoff generated from Balod district having 3385.11 km^2 area worked out to be 1318.63 Mm^3. Runoff 395.58 Mm^3, which is 30 % of the total runoff considered as surplus for artificial recharge.

Table 4.31: Availability of surplus water for recharge in Balod district

S. No.	Block	Area of block (km^2)	Monsoon rainfall (mm)	Coefficient (K)	Runoff (Q=rainfall x coefficient) (mm)	Volume (area x runoff) (Mm^3)	30 % of the total runoff (Mm^3)
1	Balod	738.6	782.97	0.326	255.24	188.53	56.56
2	Gunderdehi	624.18	961.90	0.391	376.10	234.75	70.42
3	Gurur	604.24	1354.40	0.339	459.14	277.43	83.23
4	Dondi	522.14	1023.68	0.463	473.96	247.47	74.24
5	Dondilohara	895.9	904.83	0.457	413.50	370.44	111.13
Total		3385.11	---	---	---	1318.63	395.58

4.3.1 Artificial recharge in Bemetara district

The standard methodology was adopted for placing artificial recharge structure. The average post-monsoon depth to water level is prepared. Based on post-monsoon depth to water level area feasible for artificial recharge has been demarcated and put into 3 categories, namely;

i. Area showing water level 3.0 – 5.0 mbgl

ii. Area showing water level 5.0 – 10.0 mbgl

iii. Area showing water level 10.0 – 15.0 mbgl

4.3.1.1 Identification of need based area for artificial groundwater recharge

The field survey of study area was also carried out to find out the suitability and location of proposed artificial groundwater recharge structures. It is observed that 68.25 percent area was suitable for locating the artificial recharge structures in study area. Since water level during post monsoon season is that 3 m for remaining 31.742 % area of Bemetara district. Identification of need based area for artificial groundwater recharging shown in Fig. 4.45.

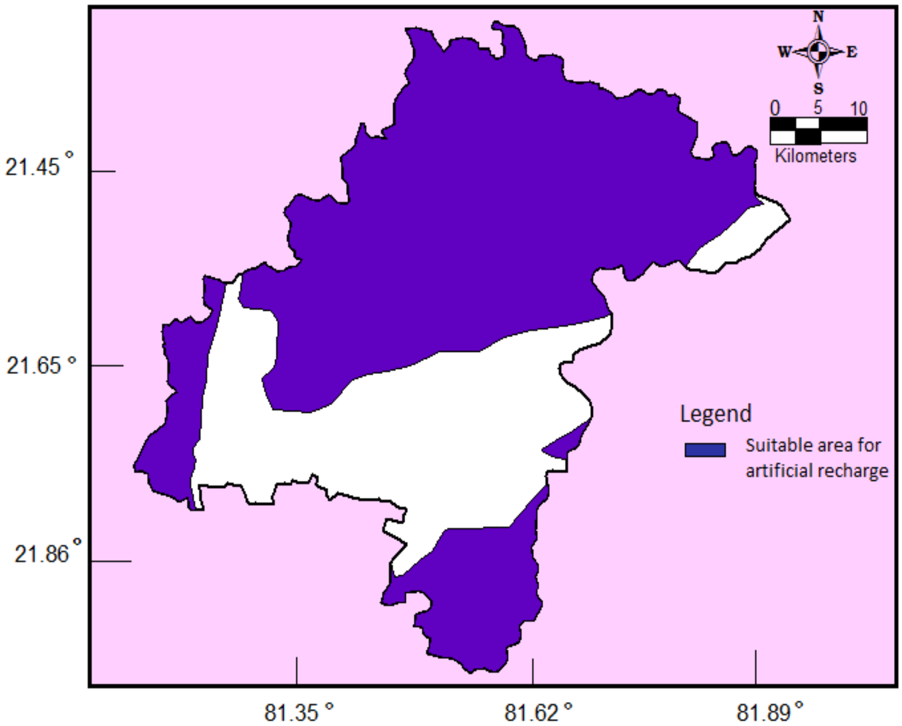

Fig. 4.45: Identification of need based area for artificial groundwater recharge in Bemetara district

4.3.1.2 Estimation of available storage space

The estimation of subsurface storage space is based on the thickness of available unsaturated zone (below 3 mbgl) in post-monsoon and the specific yield of phreatic aquifer. The limit to saturate the vadose zone below 3 m is kept with a view to avoid water logging and soil salinity. The total volume of unsaturated strata was estimated and actual amount of water required to recharge the aquifer upto 3 m has been calculated by multiplying with specific yield of the area *i.e.* 0.03%. Volume of surface water required is calculated by using the standard formula and given in Table 4.32. The vadose zone of 284.89 Mm^3 is available for artificial recharge in the study area.

Table 4.32: Estimated volume of sub-surface storage capacity in Bemetara district

Project area	Geographical area (km^2)	Area identified for artificial recharge (km^2)	Depth to waterlevel (post monsoon) below cut-off level (m)	Volume of unsaturated zone (Mm^3)	Average specific yield	Total Storage potential as volume of water (Mm^3)
Bemetara	2872.29	1661.47	1.0	1661.47	0.03	49.84
		734.52	4.5	3305.34	0.03	99.16
		476.81	9.5	4529.69	0.03	135.89

4.3.1.3 Surface water requirement

After assessing the actual volume of water required for saturating the vadose zone, the net amount of source water available has been calculated by considering 75 percent efficiency of the artificial recharge structure. The value obtained was multiplied by 1.33 (A reciprocal of 75 percent efficiency). The volume of water required for artificial recharge was found to be 378.90 Mm^3.

4.3.1.4 Availability of surplus water for recharge

Availability of source water to recharge the subsurface reservoir in each Block has been assessed in the form of non-committed surplus runoff. The runoff is estimated by using Stranger's Table for the normal monsoon rainfall of the area. The normal monsoon rainfall of the area is being 983.75 mm. The availability of surface water for recharge has been calculated for each Blocks as given in Table 4.33. The total volume of runoff generated from Bemetara district having 2238.36 km^2 area worked out to be 1098.93 Mm^3. Runoff 329.67 Mm^3 which is 30% of the total runoff considered as surplus for artificial recharge.

Table 4.33: Availability of surplus water for recharge in Bemetara district

S. No.	Block	Area of block (km^2)	Monsoon rainfall (mm)	Coefficient (K)	Runoff (Q=rainfall x coefficient) (mm)	Volume (area x runoff) (Mm^3)	30 % of the total runoff (Mm^3)
1	Bemetara	899.50	1261.34	0.403	512.10	422.30	126.69
2	Berla	775.18	883.57	0.433	382.58	286.62	85.98
3	Saja	747.72	752.48	0.339	265.21	223.96	67.18
4	Nawagarh	450.65	1037.76	0.386	400.57	166.05	49.81
Total		2238.36	---	---	---	1098.93	329.67

4.3.4 Suitability of recharge structures as per their type/size

4.3.4.1 Suitable recharge structures

The sizes of recharge structures as per the slope were selected on the basis of information available in the manual of groundwater recharge structure suitable for different slope is given in Table 4.34. Suitable recharge structures given in Table C_1 of Appendix C.

Table 4.34: Suitable recharge structures for different slope

S. No.	Topographic slope	Check dam	Percolation tank
1	Moderate to gentle slope (2 to 5%)	Small size and medium size	Small size and medium size
2	Gentle slope (< 2%)	Large size	Large size

4.3.4.2 Types and feasible numbers of recharge structures

The various recharge structures have suggested by keeping in view the various geological and hydrogeological parameters and feasibility of site in the area. The suitable artificial recharge structures in the area which are proposed to construct are mainly Percolation Tank (PT), and Check Dam (CD).

Table 4.35: Recommended groundwater recharge structures in Dhamtari district

S. No.	Structure size	Dhamtari		Kurud		Nagri		Magarlod		Total
		CD	PT	CD	PT	CD	PT	CD	PT	
1	Small	6	5	5	10	39	20	10	12	107
2	Medium	5	1	6	3	9	8	7	10	45
3	Large	1	0	3	2	8	5	7	5	30
Total		7	6	14	15	56	33	24	27	**182**

The Dhamtari district comprises of four blocks namely Dhamtari, Kurud, Nagri, and Magarlod and each Block was found to have two types of structures *i.e.,* check dam and percolation tank of different sizes (small, medium and large) (Table.4.35). In Dhamtari Block, check dam and percolation tank were found to be 6 and 5, 5 and 1, 1 and 0 numbers of small, medium and large size, respectively. In Kurud Block, check dam and percolation tank were found to be 5 and 10, 6 and 3, 3 and 2 numbers of small, medium and large size, respectively. In Nagri Block, check dam and percolation tank were found to be 39 and 20, 9 and 8, 8 and 5 numbers of small, medium and large size, respectively. In Magarlod Block, check dam and percolation tank were found to be 10 and 12, 7 and 10, 7 and 5 numbers of small, medium and large size, respectively. Locations of identified groundwater recharge structure for the Dhamtari district are given in Table D_1, Appendix: D.

Table 4.36: Recommended groundwater recharge structures in Balod district

S. No.	Structure size	Balod		Gunderdehi		Gurur		Dondi		Dondilohara		Total
		CD	PT	CD	PT	CD	PT	CD	PT	CD	PT	
1	Small	4	5	6	11	11	6	20	11	21	19	124
2	Medium	3	2	5	11	3	1	7	1	9	7	39
3	Large	6	1	4	3	1	2	3	2	7	2	31
Total		23	8	15	15	15	9	30	14	37	28	**194**

The Balod district comprises of five Blocks namely Balod, Gunderdehi, Gurur, Dondi and Dondilohara and each Block was found to have two types of structure *i.e.*, check dams and percolation tank of different sizes (small, medium and large) (Table 4.36). In Balod block, check dam and percolation tank were found to be 14 and 5, 3 and 2, 6 and 1 numbers of small, medium and large size, respectively. In Gunderdehi block, check dam and percolation tank were found to be 6 and 11, 5 and 1, 4 and 3 numbers of small, medium and large size, respectively. In Gurur block, check dam and percolation tank were found to be 11 and 6, 3 and 1, 1 and 2 numbers of small, medium and large size, respectively. In Dondi block, check dam structure and percolation tank were found to be 20 and 11, 7 and 1, 3 and 2 numbers of small, medium and large size, respectively. In Dondilohara block, check dam and percolation tank were found to be 21 and 19, 9 and 7, 7 and 2 numbers of small, medium and large size, respectively. Locations of identified groundwater recharge structure for the Balod district are given in Table D_2 of Appendix D.

Table 4.37: Recommended groundwater recharge structures in Bemetara district

S. No.	Structure size	Bemetara		Berla		Saja		Nawagarh		Total
		CD	PT	CD	PT	CD	PT	CD	PT	
1	Small	23	7	7	7	19	7	15	3	88
2	Medium	22	12	9	3	7	5	8	2	68
3	Large	11	5	2	2	1	2	6	4	33
Total		56	24	18	12	27	14	29	9	**189**

The Bemetara district comprises of four blocks namely Bemetara, Berla, Saja and Nawagarh and each block was found to have two types of structure *i.e.,* check dams and percolation tank of different sizes (small, medium and large) (Table 4.37). In Bemetara block, check dam and percolation tank were found to be 23 and 7, 22 and 12, 11 and 5 numbers of small, medium and large size, respectively. In Berla block, check dam and percolation tank were found to be 7 and 7, 9 and 3, 5 and 2 numbers of small, medium and large size, respectively. In Saja Block, check dam and percolation tank were found to be 19 and 7, 7 and 5, 1 and 2 numbers of small, medium and large size, respectively. In Nawagarh block, check dam and percolation tank were found to be 15 and 3, 8 and 2, 6 and 4 numbers of small, medium and large size, respectively. Locations of identified groundwater recharge structure for the Bemetara district are given in Table D_3 of Appendix D.

4.3.4.3 Specification of artificial recharge structures

These structures are based on similar principle as that of nala bund. The difference being the larger size of the reservoir area. In area where uncultivated land is available in and around the stream channel section, which show sufficient permeability for sub-surface percolation, small tank are created by making low elevation stop dam across the stream. The tank can also be located adjacent to the steam by excavation and connecting it to the stream through a delivery canal. These percolation tanks are thus artificially created surface water bodies submerging a highly permeable land area so that the surface runoff is made to percolate and recharge the groundwater storage.

Site characteristics and design guidelines

The following guide lines are recommended for the site selection and design of recharge structure (Verma 2008)

1. The hydrogeological condition of site for percolation tank is of utmost important. The rocks coming under submergence area should have high permeability. The degree and extent of weathering of rocks should be uniform and not just localized.
2. Proper study of catchment area and rainfall pattern should be made to ensure that the percolation tank get filled every year. The soils in the catchment area should be light sandy to avoid silting up of tank bed.
3. As the yield of catchment in low rainfall area generally varies between 0.44 to 0.55 Mm^3/km^2 the catchment area for small tank may be between 2.5 to 4 km^2 and for the larger tank between 5 to 8 km^2.
4. Depending on occurrence of good precipitation storms during the rainy season (which may vary between 2 to 4 in low rainfall region) the percolation tank gets fully filled up to two to three times during the rainy season. The enhanced percolation caused due to repeated filling may lead to the total percolation getting enhanced up to one and half times of percolation expected through a single filling.

5. The nala chosen for bunding to create a percolation tank should have adequate catchment area to yield between 3 to 8 Mm^3 runoff during rainy season. The nala should be influent in nature (non perennial).

6. The size of a percolation tank should be governed by the percolation capacity of the strata in the tank bed rather than yield of the catchment. In case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses, thus depriving the downstream area of a valuable resource. Therefore larger capacity tank should be constructed only if percolation capacity is established to be good. Otherwise under moderate percolation tank, tanks of smaller capacity may be constructed. Normally percolation tanks are designed for storage capacity from 2-3 to 5-7 Mm^3.

7. The depth of impounded water provides the recharge head and hence it is necessary to design the tank to provide a minimum height of pounded water column to be 3 to 4.5 m above the bed level. This would imply construction of larger capacity tanks in steeper gradient area.

8. The purpose of percolation tank is to conserve the surface runoff and divert the maximum possible surface water to the ground storage. Thus the water accumulated at the earliest without much evaporation losses. Normally, a percolation tank should not retain water beyond February.

9. The percolation tank should be located downstream of runoff zone, preferably towards the edge of piedmont zone or in the upper part of transition zone (land slope 3-5 per cent).

10. The benefited area should have good phreatic aquifer with lateral continuity upto the percolation tank. The depth to water level in the area should remain more than 3 to 5 m below ground level in the post monsoon period.

11. The village falling under the benefited zone of the percolation tank should have adequate number of groundwater structures of fully utilize this addition recharge. Generally a well density of 3 to 5 per km^2 is desired.

12. The percolation tanks are mostly earthen dams with masonry structure only for the spillway. An earthen dam is a structure constructed with combination of soil, silt, clay, loam, sand, gravel suitably disposed and laid in layers and water tightness. The practical considerations in the height of earth dam may be summed up as under:

(a) The dam should not be over topped. This is done by providing adequate length of waste weir and sufficient free board.

(b) The line of saturation should be well within downstream toe.

(c) There should be no piping or opportunity for the free passage of water from upstream side (U/S) to downstream (D/S) toe.

(d) The water passes through and under the dam, when it rises to the surface, should have so small pressure and velocity that it is incapable of moving any material from the dam foundation.

(e) The sliding of dam should be prevented by properly bounding the main body of the dam to the foundation.

(f) U/S and D/S slope should not be so steep as to include shear stress in foundation beyond the permissible limits.

(g) The U/S slope should be properly protected against erosion by wave by means of rubble pitching and D/S slope from rain by turning etc.

(h) The alignment of the dam should be so fixed that the quantity of earth work for the given height is minimum. They can be best fixed after preparing a counter map of a strip of area, about 150 m U/S and 150 m D/S of the probable dam centre line.

Table 4.38: Guidelines for Dam profile based on empirical method

S. No.	Height of dam	Top width	Free board	Slope	
				U/S	D/S
1	Up to 10 m	3.0 m	2.0 m	2.5:1 3:1	2:1 (2.5:1)
2	10 to 12 m	3.5 m	2.0 m	2.5:1	Cover 2 m (3 m)

a. Percolation tank recharge structures

The design of percolation tank depends upon the location, which is suitable for construction. A schematic diagram of a percolation tank is shown in Fig. 4.46. Different size including medium and large size of percolation tank along with specification are show in Fig. 4.47 and Fig. 4.48. This type of percolation tank can be construction at proposed locations accordingly.

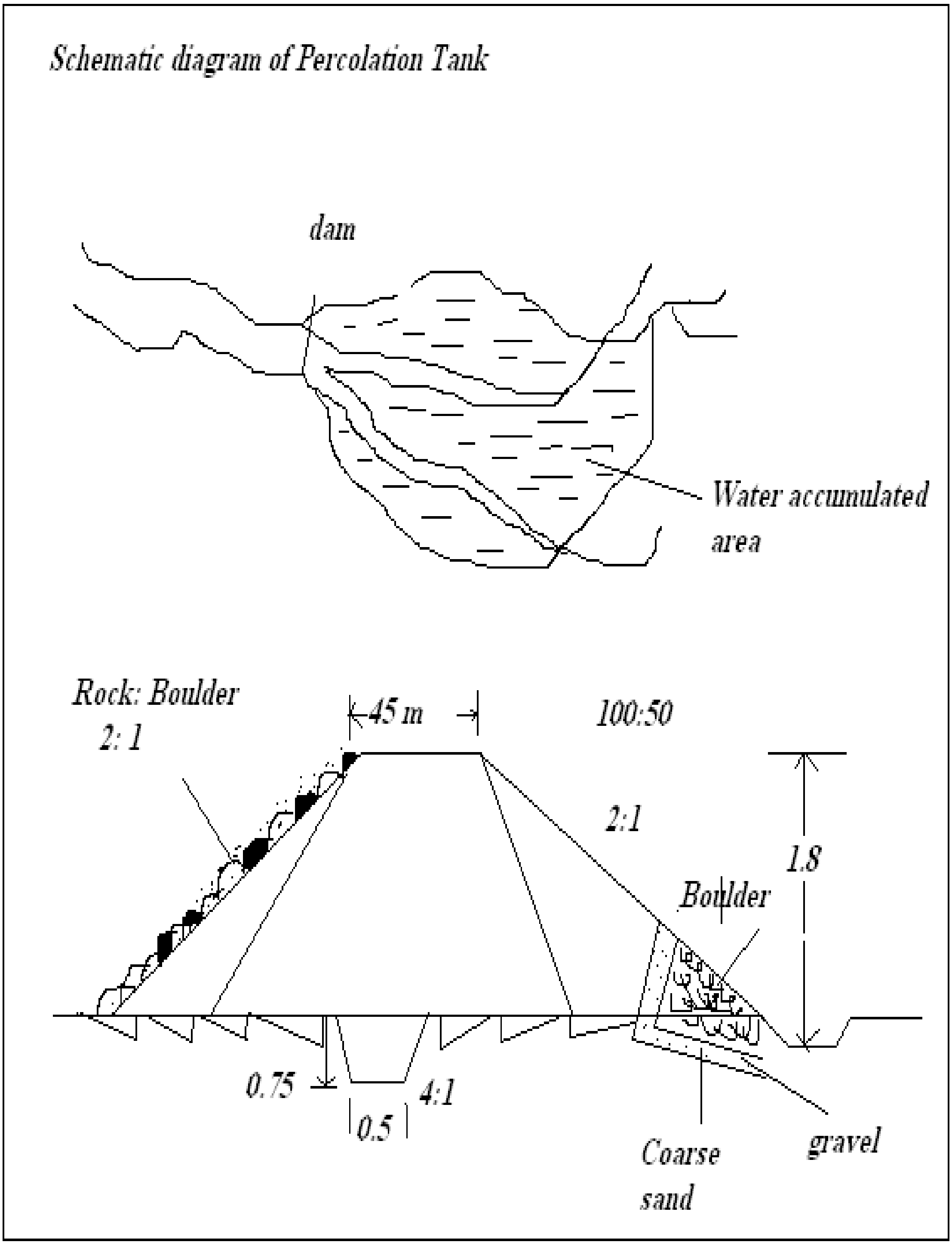

Fig. 4.46: Schematic diagram of percolation tank for groundwater recharge

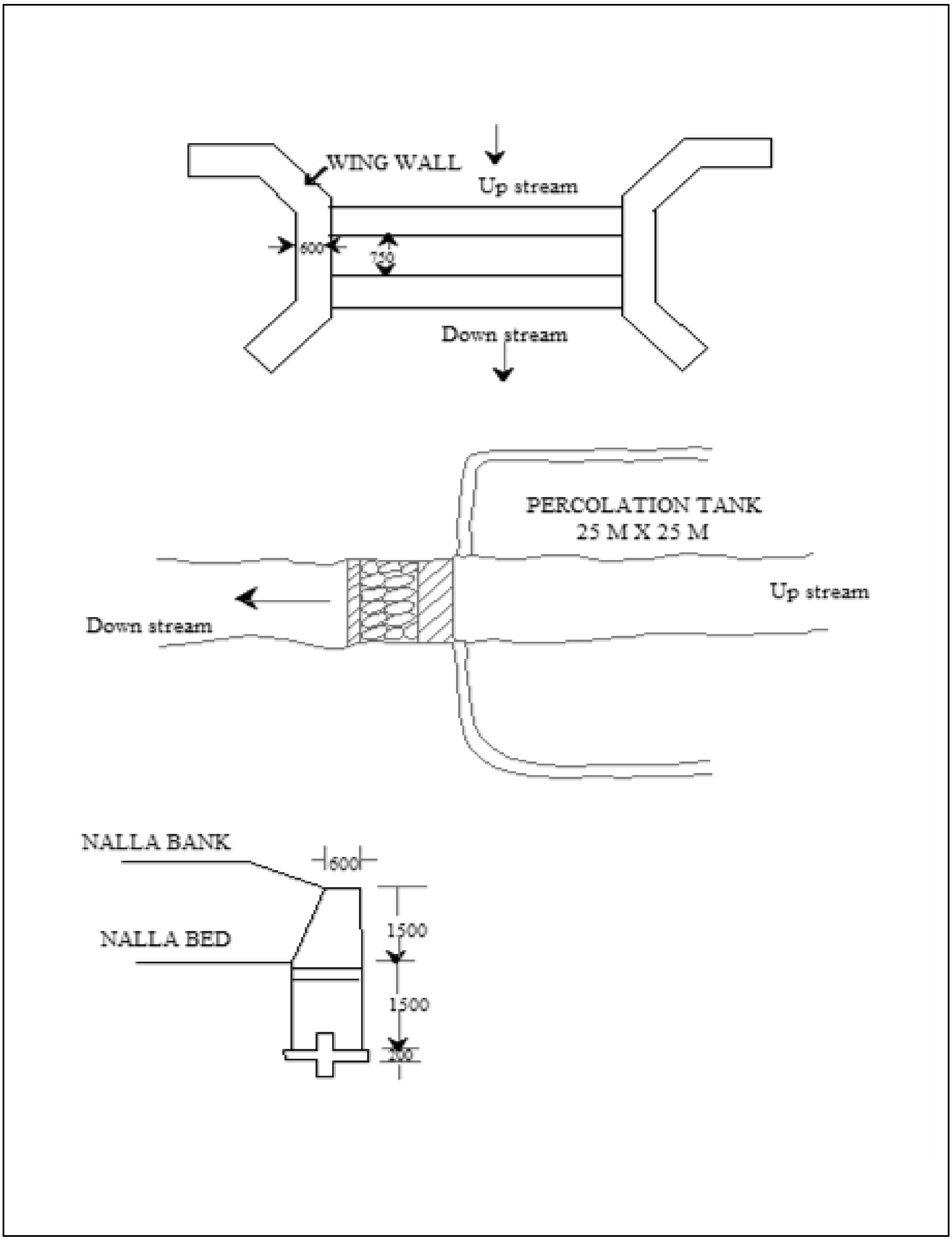

Fig. 4.47: Medium size percolation tank for groundwater recharge

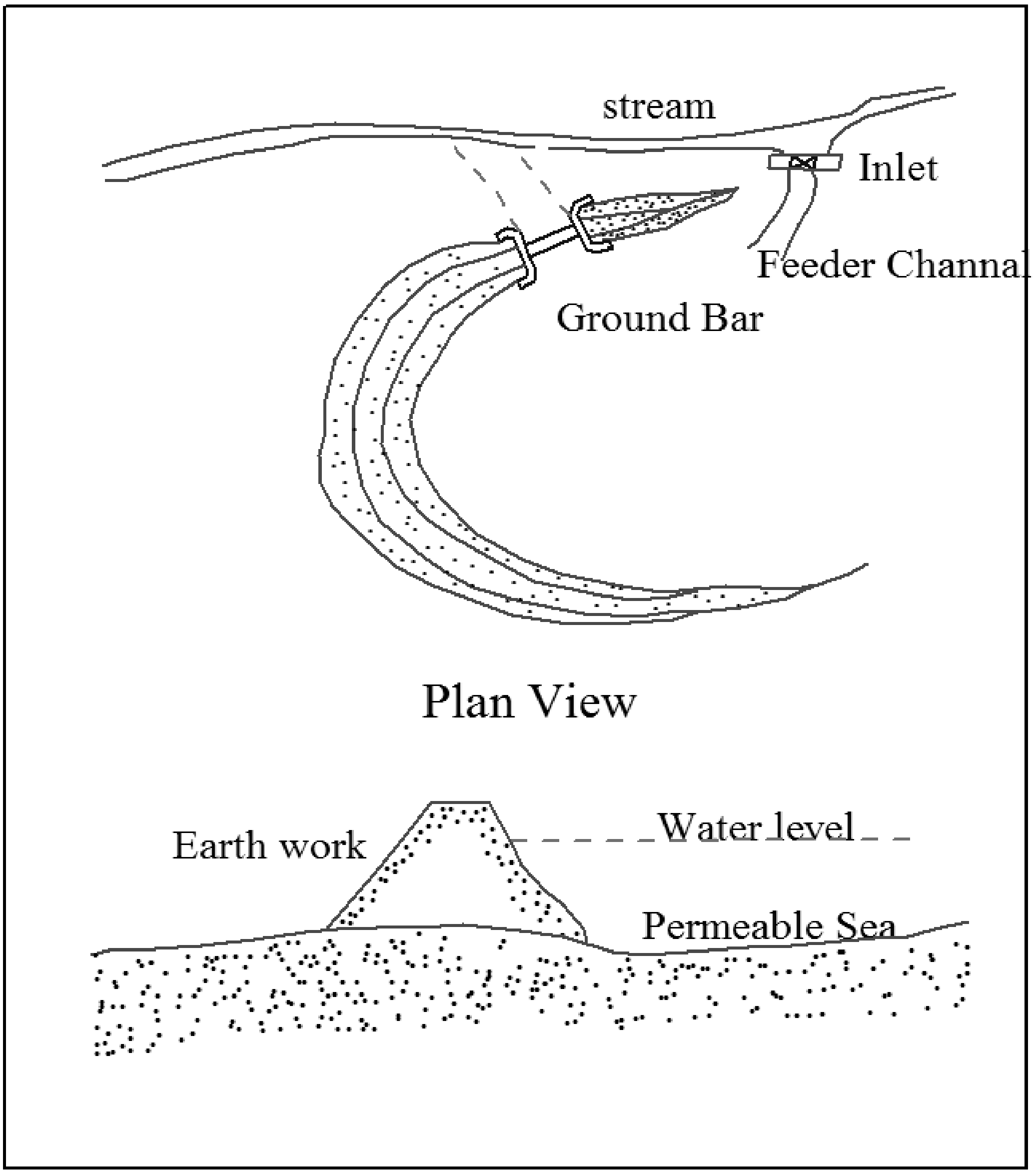

Fig. 4.48: Large size percolation tank for groundwater recharge

b. Check dam recharge structures

Three sizes small, medium and large for different location of streams are proposed. Three type of check dam along with specification are shown in Fig. 4.25, Fig. 4.26 and Fig. 4.27, respectively for small, medium and large recharge.

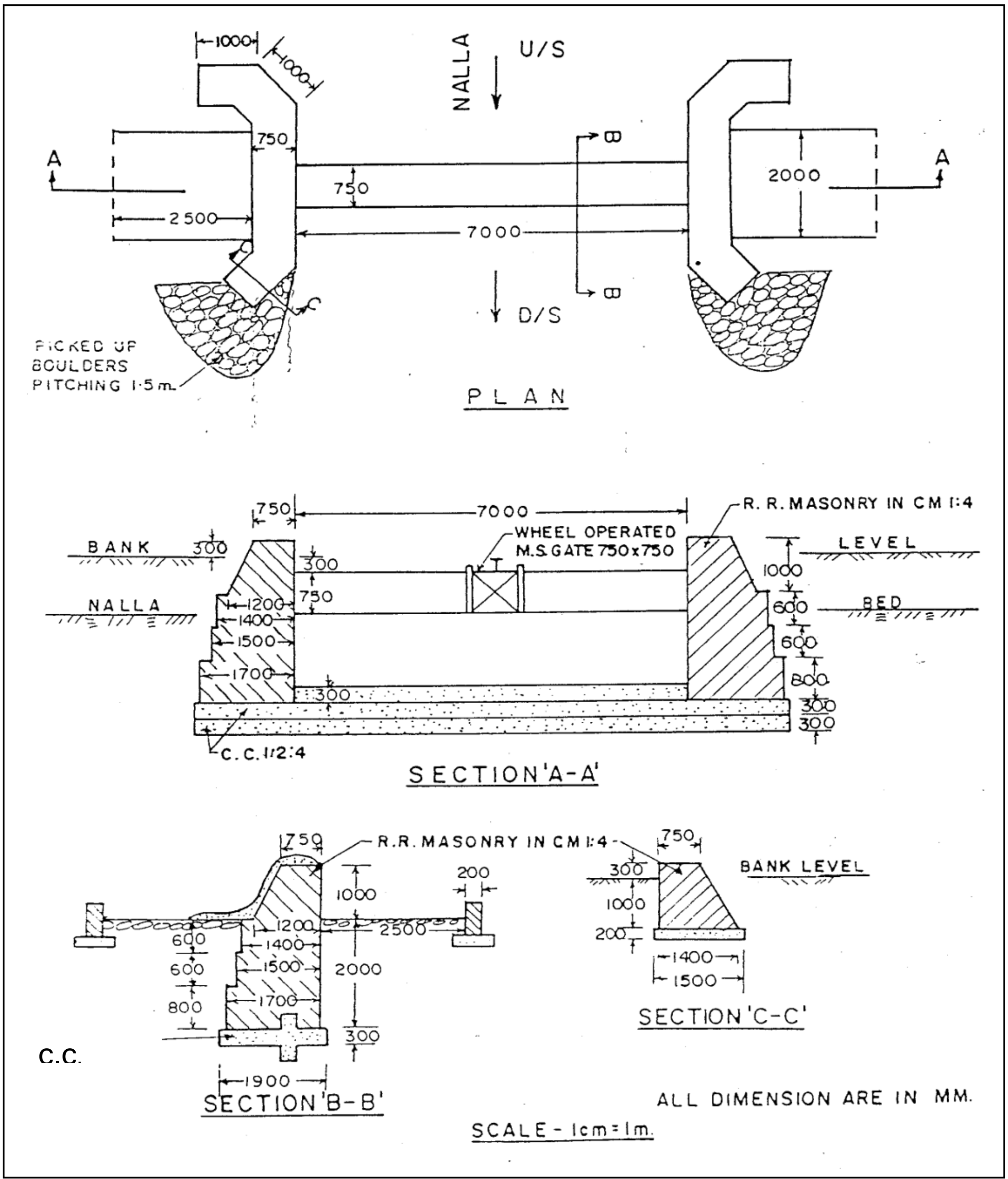

Fig. 4.49: Small size check dam for groundwater recharge

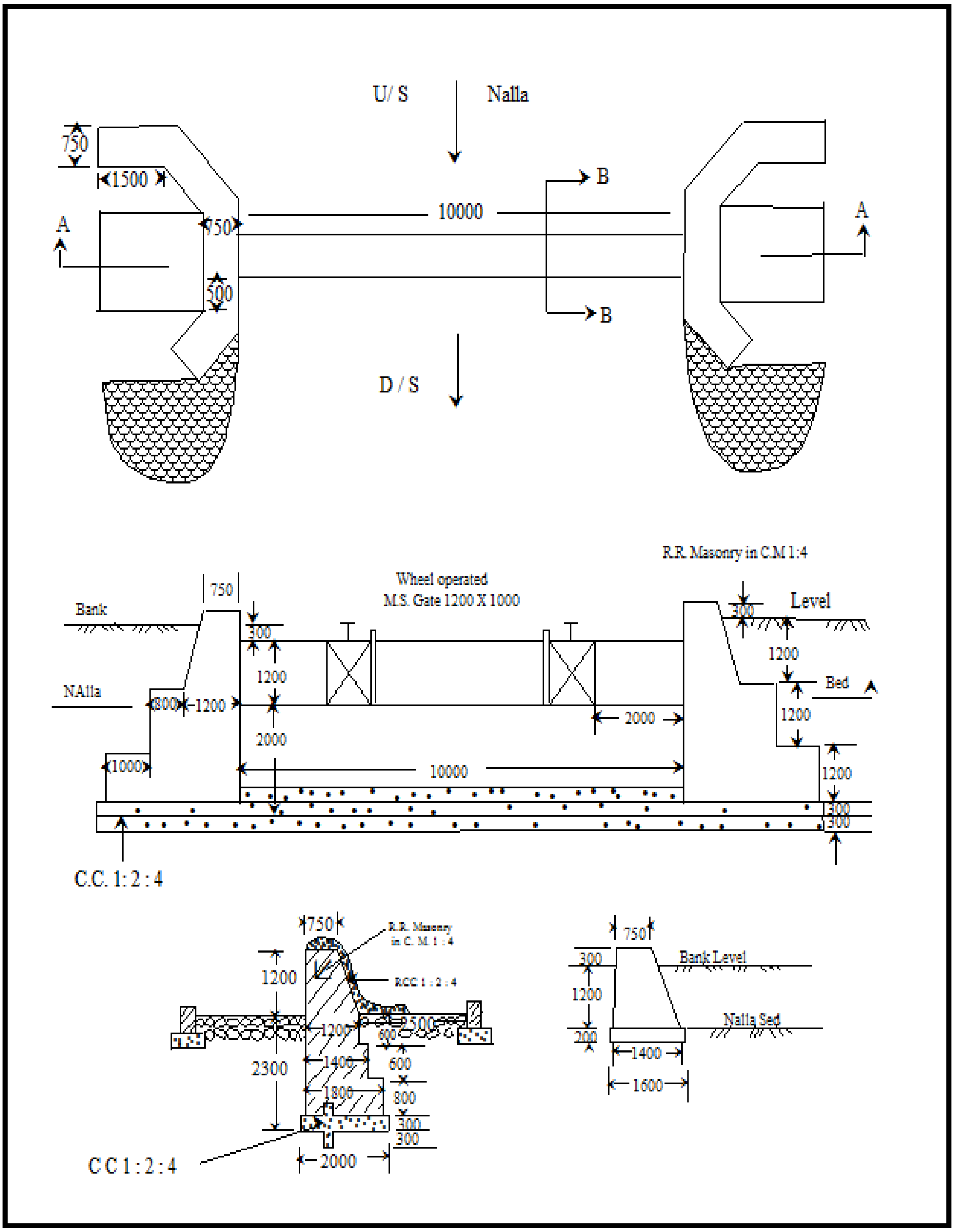

Fig. 4.50: Medium size check dam for groundwater recharge

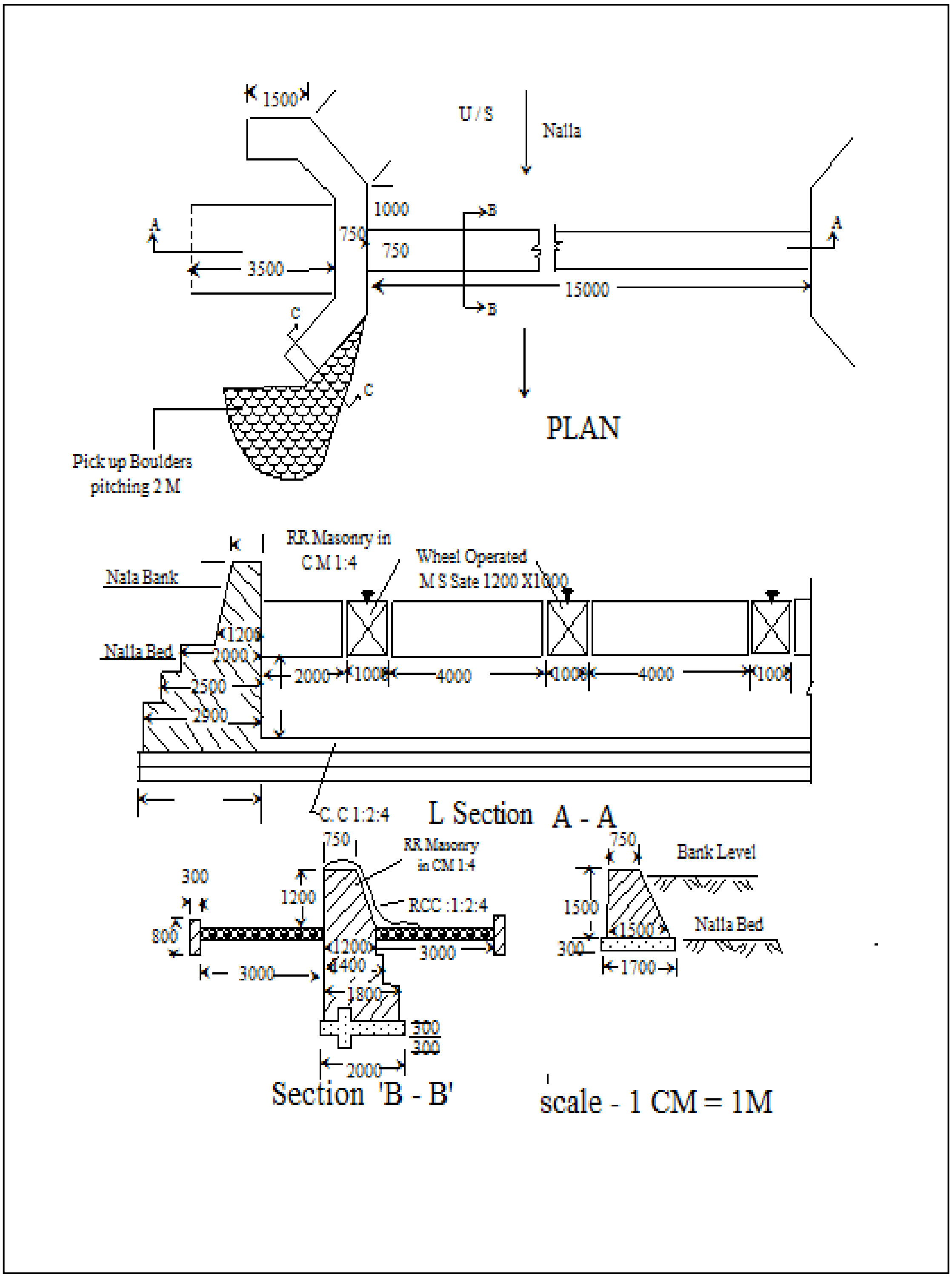

Fig. 4.51: Large size check dam for groundwater recharge

CHAPTER V

SUMMARY AND CONCLUSIONS

Groundwater studies are important for the optimization of groundwater use in all respect. Groundwater utilization is as old as human history. Over the years, it has continued to play a major role in augmenting existing water supply to meet the requirements and increasing demands for agricultural, domestic, and industrial use. In order to assure the water supply to the growing population under human activities, changes in climate variability, growing demands and catchment degradation, groundwater recharge investigation is one of the main concerns for water managers in the coming decades.

Artificial groundwater recharge can be an interesting option in an integrated strategy to optimize total water resource management. Artificial recharge, by definition, is feeding water to a permeable formation with the purpose of recharging groundwater table. Plan of a groundwater basin recommends a variety of recharge structures to various management regimes. Artificial recharge is the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface water into the groundwater aquifers. Presently many states do not have plan for groundwater recharging. The groundwater recharge structure which can be constructed are percolation tanks, check dams, cement plugs and nala bunds, Gabian structures, village tanks, recharge shaft, sub-surface dykes or groundwater dams, dried up or disused dug wells, injection wells in alluvial aquifers, and roof top water harvesting structures.

An earth scientist can provide a suitable method of recharging the groundwater with the aid of spatial tools like Remote Sensing, GIS and GPS technology. Using these technologies, the artificial recharge methods can be adopted to a site depending upon the local topographic, geologic and soil conditions.

It provides the real time and accurate information related to distinct geological formation, landforms and helps in identification of drainage channels, which are altered by natural forces of human activities. GIS is an effective tool to analyze spatial and non spatial data of drainage, geology, lineament, land use, soil, slope and well location from the extracted parameters can be interrelated in digital form as per requirement using standard methods. The concept of integrated remote sensing and GIS has proved to be an indispensable tool in groundwater studies, planning and management.

Looking to the importance of satellite data and GIS technology groundwater recharge plan for the semi critical districts i.e. Dhamtari, Balod and Bemetara of Chhattisgarh state was proposed. The respective objective of the research was to develop a groundwater recharge plan for these districts by superimposing various thematic maps including classified satellite image, lineament map, drainage map, slope map and groundwater fluctuation map. Also various recharge structure along with their sizes has to be suggested for the study area.

Dhamtari is located between 81° 23’17’’ to 82°10’35’’E longitude and 20°2’30’’ to 21°a 1’32’’N latitude and covers an area of 4081.93 km^2. The altitude of the Dhamtari district is 321.54 m above mean sea level (MSL). It falls in the Survey of India’s Topographic map Nos. 64H and 64L (1:2,50,000 scale). The district receives an average annual rainfall of 1095 mm.

The Balod district covers an area of 3385.11 km^2. It is situated in the western part of Chhattisgarh. It falls in the Survey of India's Topographic map Nos. 64D and 64H (1:2,50,000). It is located between 80°48'32'' to 81°31'22'' E longitude and 20°31' 22'' to 21°25'03'' N latitude and the average altitude of the Balod district is about 324 m above mean sea level (MSL). The district receives an average annual rainfall of 984.1 mm.

The Bemetara is located between 81°56'56'' to 82°24'49'' E longitude and 21°20'37''to 22°15'05'' N latitude and covers an area of 2872 km^2. The altitude of the Bemetara district is 317 m above mean sea level (MSL). It falls in Topographic map Nos. 64G (1:2,50,000 scale). The district receives an average annual rainfall of 968.50 mm.

Satellite image of these districts was procured from the National Remote Sensing Agency, Hydrabad which was provided by Department of Soil and Water Engineering (SWE), Faculty of Agricultural Engineering (FAE), Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur. Meteorological and hydrological parameters are being monitored under AICRP on "Ground Water Utilization" (GWU), IGKV, Raipur centre were used in this study. Some hydrogeological data were collected from the Central Ground Water Board (CGWB), NCCR, Raipur. Some of the maps like depth to water level (per and post monsoon) and well location map were prepared under the supervision of scientist working in the Central Ground Water Board, NCCR, Raipur. Drainage and water bodies map was prepared with the help of topographic map and GIS (MapInfo Professional 8.5). Watershed map and lineament map collected from the State Water Resource Department, Government of Chhattisgarh, Raipur were used, which has been modified as per required file format with the help of GIS. Several hardware including computer, scanner, printer, digital camera and GPS and softwares including MS-Office, GIS (MapInfo Professional 8.5) and other statistical packages were used in this study.

The delineated watersheds in the Dhamtari district namely 4G2G1, 4G2G3, 4G2G4, 4G2G5, 4G2G7, 4G3B6 and 4E2E3, having 46801 ha, 84822 ha, 106526 ha, 64050 ha, 52499 ha, 53509 ha and 925 ha, area. The delineated watersheds in the Balod district namely 4G3D2, 4G3D3, 4G3D5, 4G3D7, 4G3B6, 4G3G5 and 4E2B7, having 111862 ha, 75265 ha, 586218 ha, 8725 ha, 67702 ha, 3170 ha and 2916 ha, area. The delineated watersheds in the Bemetara district namely 4G3AB, 4G3B5, 4G3B7, 4G3C1, 4G3C2, 4G3C3, 4G3C4, 4G3C5, 4G3C6 and 4G3C7, having 11021 ha, 31442 ha, 24822 ha, 74307 ha, 14548 ha, 7910 ha, 50867 ha, 38539 ha, 33618 ha and 188 ha, area in the watershed.

Drainage map was prepared by using Survey of India Topographic maps on 1:2,50,000. All type of the streams existing in the study area. Dhamtari district is drained by river Mahanadi and its tributaries *i.e.,* Sondur, Kharun and Pairi river. Mahanadi flows northwest throughout its length in the district. The tributaries for Sondur are Sita nala, Kajal nala and Sukha nala whereas Safari Ama and Bagbura nala directly joins with river Mahanadi. Balod district is mainly drained by Seonath river, Tandula river and their tributaries. Seonarh river flows through the western periphery to upper western part of the district. Tandula river flows through the central periphery to northern part of the district along with its tributaries district. Drainage density is more or less same in most of the part of the district except in western part. The drainage density is found comparatively more in western part of the district. Bemetara district is mainly drained by Sheonath, Kharun and Hanp river and their tributaries. Sheonath river flows through the eastern periphery to central and western part of the district along with its tributaries. Kharun river flows through the eastern periphery from south east to south and eventually join the Sheonath river in the eastern part of the district. The Hanp river along with its tributaries flows through the northern part of the district and also joins Sheonath River in north-eastern part of the district. Drainage density is more or less same in most of the part of the district. All these river systems come under Mahanadi river basin. Low drainage density is reflective of somewhat low runoff and higher infiltration. This entire drainage network is governed by the master slope of the districts.

The morphometric analysis has been done for all these districts. It may be seen that, there were a total of 307 streamlets found in Dhamtari district out of which 243 streamlets are of 1^{st} order, 52 are of 2^{nd} order, 10 are of 3^{rd} order, 1 is of 4^{th} order and 1 is of 5^{th} order. The total length of the streams was found to be 2764.24 km. Drainage density of the area was found to be 0.67 km/km^2. Similarly, stream frequency of the area was found to be 0.075, which is also low showing more or less plain topography of the area and lack of structural control. There were a total of 221 streamlets found in the entire Balod district out of which 175 streamlets are of 1^{st} order, 35 are of 2^{nd} order, 9 are of 3^{rd} order and 2 are of 4^{th} order. The total length of the streams was found to be 1536.68 km. Drainage density of the area was found to be 0.45 km/km^2. Stream frequency of the area was found to be 0.065. There were a total of 575 streamlets found in the entire Bemetara district out of which 452 streamlets are of 1^{st} order, 95 are of 2^{nd} order, 18 are of 3^{rd} order, 7 are of 4^{th} order and 3 are of 5^{th} order . The total length of the streams was found to be 1528 km. Drainage density of the area was found to be 0.532 km/km^2. Stream frequency of the Bemetara district was found to be 0.20 which is also low showing more or less plain topography of the area and lack of structural control.

The geology of study area has varied formations. Dhamtari district is underlain mainly by three distinct geological formations range. The crystalline basement occupy major part of the district comprising of granite and granitic rocks belonging to Dongargarh group, severally intruded by Chhattisgarh Super group are unconformably overlying the basement crystalline and shale sequence occupying the north central and central part of the district. Geologically, Balod district comprises of Charmuria formation, Gunderdehi formation, Chandrapur, Baliladila and Nandgaon formation. Bemetara district comprises of Chandi formation, Tarenga formation, Hirri formation and Maniyari formation. The groundwater recharge was suitable in all formation except in Biladila, Tarnga, Hirri, Nandgaon and Gunderdehi formations.

Area under different land use classes were obtained after classification. The total geographical area of the Dhamtari district is 4081.93 km^2. Nearly 38.37 % *(i.e.* 1561 km^2) of the total area is arable land, reserved forest covers 2303 km^2, protected forest covers 7.23 km^2 area, whereas shrubs and grasses (Wastelands) covers 132 km^2. The total geographical area of Balod district is 2238.36 km^2. Nearly 76.96 per cent (*i.e*., 2605 km^2) of the total area is covered by arable land. Beside arable land other land used also occupied the entire area. Reserve forest (342 km^2), Protected forest (247 km^2), Shrubs and grass land (190 km^2). In Bemetara district nearly 92.26 per cent (*i.e.*, 2650 km^2) of the total area is covered by arable land and 7.74 % area is covered by Shrubs and grass land.

Soil texture map of the Dhamtari, Balod and Bemetara districts was prepared through GIS using available soil resource data.The area occupied by different soil texture in these districts was determined. Soil texture map of Dhamtari district indicated that the medium black soil (Dorsa) occupied 54 percent area, Laterite soil (Matasi) occupied 30 percent area whereas red loamy soil (Bhata) covers only 16 per cent area in the district. Balod district occupied four type of soil viz. Kanhar, Dorsa, Bhata and Matasi. Kanhar occupied 16.04 percent area, Dorsa occupied 34.83 per cent area, Bhata occupied 45.95 per cent area and Matasi covers only 3.20 per cent area in the district. Soil texture map of Bemetara district indicated that the deep black soil occupied 15.90 percent area whereas medium black soil occupied 82.49 per cent area and red loamy soil covers only 1.6 per cent area in the district.

Overall the topography in the Dhamtari district varies between 281 m to 730 m above MSL. The area has general slope towards north-east direction with average elevation of 505 m above MSL. The highest elevation recorded in the district is 730 m above MSL and the lowest point is 281 m above MSL. Topography in the Balod district varies between 287 m to 701 m above MSL. The area has general slope towards north and north-west direction with average elevation of 495 m above MSL. The highest elevation recorded in the district is 701 m above MSL and the lowest point is 287 m above MSL. The topography of Bemetara district varies between 238 m to 324 m above MSL. The area has general slope along east direction with average elevation of 281 m above MSL. The highest elevation recorded in the district is 324 m above MSL and the lowest point is 238 m above MSL

In Dhamtari district, depth to water level measured during the pre-monsoon (May) and post-monsoon (November). It may be seen that in pre-monsoon period, the lowest water level was recorded as 1.17 mbgl and the deepest water level was recorded as 10.91 mbgl. The depth to the water level during pre-monsoon period is less than 10 m in almost 99% of the total area. It may be seen that in post-monsoon period, the depth to water level was less than 0.70 m (minimum value) and the maximum depth to the water level was around 5.29 m. The water levels increases and decreases in post-monsoon and pre-monsoon period.

In Balod district, depth to water level measured during the pre-monsoon (May) and post-monsoon (November). It may be seen that in pre-monsoon period, the lowest water level was recorded as 5 mbgl and the deepest water level was recorded more than 20 mbgl. Depth to the water level in the district during pre-monsoon period is less than 10 m in almost 31% of the total area. It may be seen that in post-monsoon period, the depth to water level was less than 0.70 m (minimum value) and the maximum depth to the water level was around 5.29 m. The water levels increases and decreases in post-monsoon and pre-monsoon period.

In Bemetara district, depth to water level measured during the pre-monsoon (May) and post-monsoon (November). It may be seen that in pre-monsoon period, the lowest water level was recorded as 3 mbgl and the deepest water level was recorded more than 15 mbgl. Depth to the water level in the district during pre-monsoon period is less than 10 m in almost 45% of the total area.It may be seen that in post-monsoon period, the depth to water level was less than 3 m (minimum value) and the maximum depth to the water level was around 15 m. The water levels increases and decreases in post-monsoon and pre-monsoon period.

Various thematic layers including drainage, land use/cover, soils, lineaments, slope and geology were generated which has been integrated each other in the environment of GIS. Other collateral data were also integrated with GIS for developing the recharge plan for Dhamtari, Balod and Bemetara districts.

The Dhamtari, Balod and Bemetara districts have four, five and four blocks, respectively and each was found with two types of structure *i.e.* Check Dam and Percolation tank of different size (small, medium and large) respectively. The number of check dam structure and percolation tank in Dhamtari block of Dhamtari district was found to be 6 and 5, 5 and 1, 1 and 0 numbers of small, medium and large size, respectively. In Kurud block, check dam and percolation tank were found to be 5 and 10, 6 and 3, 3 and 2 numbers of small, medium and large size, respectively. In Nagri block, check dam and percolation tank were found to be 39 and 20, 9 and 8, 8 and 5 numbers of small, medium and large size, respectively. In Magarlod block, check dam and percolation tank were found to be 10 and 12, 7 and 10, 7 and 5 numbers of small, medium and large size, respectively.

In Balod block, check dam and percolation tank were found to be 14 and 5, 3 and 2, 6 and 1 numbers of small, medium and large size, respectively. In Gunderdehi block, check dam and percolation tank were found to be 6 and 11, 5 and 1, 4 and 3 numbers of small, medium and large size, respectively. In Gurur block, check dam and percolation tank were found to be 11 and 6, 3 and 1, 1 and 2 numbers of small, medium and large size, respectively. In Dondi block, check dam structure and percolation tank were found to be 20 and 11, 7 and 1, 3 and 2 numbers of small, medium and large size, respectively. In Dondilohara block, check dam and percolation tank were found to be 21 and 19, 9 and 7, 7 and 2 numbers of small, medium and large size, respectively.

In Bemetara block, check dam and percolation tank were found to be 23 and 7, 22 and 12, 11 and 5 numbers of small, medium and large size, respectively. In Berla block, check dam and percolation tank were found to be 7 and 7, 9 and 3, 5 and 2 numbers of small, medium and large size, respectively. In Saja Block, check dam and percolation tank were found to be 19 and 7, 7 and 5, 1 and 2 numbers of small, medium and large size, respectively. In Nawagarh block, check dam and percolation tank were found to be 15 and 3, 8 and 2, 6 and 4 numbers of small, medium and large size, respectively.

The site for percolation tank has been identified. The field survey of study area was also carried out to find out the suitability of proposed artificial groundwater recharge structures. It is concluded that suitable sites for artificial recharge structures in the Dhamtari, Balod and Bemetara district was found to be 75, 58 and 68 per cent and finally 101 locations were identified for check dams, whereas 59 location were identified for percolation tanks in Dhamtari District, 120 locations for check dam and 74 locations for percolation tank in Balod district and 130 locations for check dam and 59 locations for percolation tank in Bemetara district were identified. The subsurface storage space was estimated based on the thickness of available unsaturated zone (below 3 mbgl) in post-monsoon and the specific yield of phreatic aquifer. The limit to saturate the vadose zone below 3 m is kept with a view to avoid water logging and soil salinity. So the vadose zone of 94.54, 357.62 and 284.89 Mm^3 is available for artificial recharge in the Dhamtari, Balod and Bemetara districts, respectively.

After assessing the actual volume of water required for saturating the vadose zone, the net amount of source water available has been calculated by taking 75% efficiency of the artificial recharge structure. The value obtained was multiplied by 1.33 (A reciprocal of 75% efficiency). The quantum of water required for artificial recharge in Dhamtari, Balod and Bemetara districts was 125.73 Mm^3, 475.63 Mm^3 and 379 Mm^3, respectively.

Availability of source water to recharge the subsurface reservoir in these districts has been assessed in the form of non-committed surplus runoff. The runoff is estimated by using Stranger's Table for the normal monsoon rainfall of the area. The normal monsoon rainfall of the Dhamtari, Balod and Bemetara districts are 978.36 mm, 1005.54 mm and 983.75 mm, respectively. The total yield of runoff generated from Dhamtari district having 4081.93 km^2 area workout to be 1585.68 Mm^3 and 30 per cent of the total runoff *i.e.* 475.69 Mm^3 is considered as surplus monsoon runoff available for artificial recharge. The total yield of runoff generated from Balod district having 3385.11 km^2 area workout to be 1318.63 Mm^3 and 30 per cent of the total runoff *i.e.,* 395.58 Mm^3 is considered as surplus monsoon runoff available for artificial recharge. The total yield of runoff generated from Bemetara district having 2872.29 km^2 area workout to be 1099 Mm^3 and 30 per cent of the total runoff *i.e.*329.67 Mm^3 is considered as surplus monsoon runoff available for artificial recharge.

Study revealed that percolation tanks and check dams will be suitable for the study area for recharge the groundwater. These structures were suggested after overlaying various thematic layers. Study clearly indicated that the groundwater recharge planning for Dhamtari, Balod and Bemetara districts will be adequate for sustainable agriculture development.

CONCLUSIONS

On the basis of this study following conclusions can be drawn:

1. Various thematic maps including slope, land use/cover, drainage, soil texture, lineaments, geology and depth to water level (pre and post monsoon) can be generated using GIS technique and image processing software which can be further utilized for groundwater recharge planning and management.
2. Overlay techniques is proved to be useful for identification of locations for diffident groundwater recharge structures. Overlay of the drainage map, slope map, land use/cover map, drainage map, soils map, lineaments map, geology map and depth to water level map, resulted in identification of fairly accurate locations for artificial groundwater recharge
3. Nearly 182, 194 and 189 numbers of groundwater recharge structures can be constructed in the Dhamtari, Balod and Bemetara districts, respectively. Total 475.69 Mm^3, 395.58 Mm^3 and 329.26 Mm^3 water is available for recharge in Dhamtari, Balod and Bematara districts, respectively.

SUGGESTIONS FOR FUTURE WORK

- In the present study the GPS used for taking locations was having ±10 percent variation, in future, these locations can be identified again by having less than ±10 percent variation.
- The dimensions of different structure were considered on the basis of recommendations of state government agencies, these dimensions could be changed according to the dynamics of the area.
- Such study should be done for other districts of Chhattisgarh falling under critical or semicritical categories with more accuracy using latest satellite imagery.

Groundwater Recharge Planning for Dhamtari, Balod and Bemetara Districts of Chhattisgarh State Using Satellite Data and GIS Technique

By
Jyotsana Khakha

ABSTRACT

Groundwater is a precious resource with limited availability. The relentless increases in population and the resulting spurt in the demand for water requirement, careful planning and management of this limited water resources is urgently needed. The lack of effective groundwater recharge structures in a region usually brings about adverse effect on groundwater utilization. The average groundwater development of Dhamtari, Balod and Bemetara districts are reported to be 67.60, 65.8 and 63.24 percent, respectively. Looking to the need of groundwater recharge plan for these districts a study on groundwater recharge planning was carried out in the Department of Soil and Water Engineering, Faculty of Agricultural Engineering, IGKV, Raipur. Proper groundwater recharging may drastically change the scenario of groundwater availability of these areas. It needs appropriate groundwater recharge locations, which can be prepared by using satellite data and GIS. The present study was aimed to identify appropriate location for artificial recharge structures in these districts.

Accordingly thematic maps were superimposed to identify the appropriate locations for artificial groundwater recharge structures. Various thematic maps including District and Block boundaries, drainage, slope, soil texture, lineaments, geology and water level depth were generated in the environment of GIS. A satellite image IRS P6 LISS IV, was classified using supervised classification method to generated landuse map of the area.

Different structures and their sizes were decided on the basis of topography and drainage pattern. The upper, middle and lower reaches of drainage lines were considered for different sizes of check dam. The site for percolation tank was identified for groundwater recharge. The field survey of study areas was also carried out to find out the suitability of proposed artificial groundwater recharge structures. It is concluded that suitable sites for artificial recharge structures in these districts was found to be 75, 58 and 68 percent, respectively. Finally 101 locations were identified for check dams, whereas 81 locations were identified for percolation tanks in Dhamtari district, 120 locations for check dam and 74 locations for percolation tank in Balod district and 130 locations for check dam and 59 locations for percolation tank in Bemetara district were identified. The subsurface storage space was estimated on the basis of thickness of available vadose zone. The vadose zone of 94.54 Mm^3, 357.62 Mm^3 and 285 Mm^3 are available for artificial recharge in the Dhamtari, Balod and Bemetara districts, respectively. The volume of water required for artificial recharge were found to be 125.73Mm^3, 475.63 Mm^3 and 379 Mm^3, respectively for these districts. It was found that sufficient volume of water required for artificial recharge is available. Availability of source water to recharge the subsurface reservoir were found to be 1585.68 Mm^3, 1318.63 Mm^3 and 1099 Mm^3, respectively in the form of non-committed surplus runoff out of which 30 percent (475.69 Mm^3, 395.58 Mm^3 and 329.67 Mm^3) is considered as surplus monsoon runoff which is available for artificial recharge. Design of varies recharge structures for different locations were also suggested in this study.

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Appendix A

Table A_1: Monthly rainfall of Dhamtari district of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	78.8	0	0	0	0	14.8
February	41	0	0	0	0	3
March	21	68	11.8	0	0	2
April	5.6	40	2.4	0	2	3
May	49.4	72.5	24.4	0	0	22.6
June	116.4	52.5	352.4	313.6	0	70.2
July	299.2	458.3	195	0	141.5	432.5
August	226.2	483.4	257.3	190.8	289.5	191.5
September	289	116.8	236	286.7	0	345.6
October	30.2	1.6	41.4	11.5	19.9	112.4
November	0	16.2	0	0	144.5	32.5
December	0	0	0	0	18	46.3

Table A_2: Monthly rainfall of Balod Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	187	0	0	0	0	0
February	36	0	0	16	0	0
March	0	19	0	0	7	22
April	0	0	0	0	5	13
May	0	0	0	0	0	0
June	60	12	261	214	68	52
July	211	173.7	304	164	198	148
August	270	368	384	277	113	291
September	310	125	0	264	62	114
October	0	0	0	0	32	22
November	0	0	0	0	115	0
December	0	0	0	0	0	0

Table A_3: Monthly rainfall of Gunderdehi Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	122	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	8
April	0	0	00	0	0	0
May	0	0	0	0	0	0
June	174	37	354	88	21	36
July	320	301	162	173.1	211	242
August	236	587	205	221	172	209
September	316	199	318.4	268	238	183
October	57	0	0	0	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

Table A_4: Monthly rainfall of Gurur Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	0	0	0	0	0	0
February	30.2	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	36.4	26.2	266	209.1	243	282
July	351.3	241.8	249.7	213	208	217
August	199.7	418.4	115	202	184	146
September	145.2	148.8	0	213	172	138
October	180	8	0	0	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

Table A_5: Monthly rainfall of Dondi Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	121	66	133	30	90	161
July	357	253	390	248.3	283	276
August	297	432	247	178	95	231
September	272.4	81	168	129	21	53
October	60	4	16	9	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

Table A_6: Monthly rainfall of Dondilohara Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	138	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	199	98	232	198	86	85
July	580	323	309	220	341	254
August	167	305	115	187	126	202
September	196	65	0	140	160	87
October	56	0	0	8	0	0
November	0	0	0	0	0	0
December	5	0	0	0	0	0

Table A_7: Monthly rainfall of Bemetara Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	127	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	00	0	0	0
May	0	0	0	0	0	0
June	119	86	245	265	722	356
July	596	337	425	139	296	206
August	196	456	170	180	187	152
September	214	102	0	255	156	129
October	0	15	0	0	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

Table A_8: Monthly rainfall of Berla Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	0	30.2	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	36.4	26.2	266.6	209.1	75	49
July	351.3	241.8	249.7	213	265	283
August	199.7	418.4	115	202	187	169
September	145.2	148.8	0	213	126	112
October	180	8	0	0	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0

Table A_9: Monthly rainfall of Nawagarh Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
January	138	24	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	00	0	0	0
May	0	0	0	0	0	0
June	199	98	232	198	0	0
July	580	323	309	202	278	291
August	167	305	115	187	218	163
September	196	65	0	140	96	106
October	56	0	0	8	0	0
November	0	0	0	0	0	0
December	5	0	0	0	0	0

Table A_{10}: Monthly rainfall of Saja Block of the years 2005 through 2010

	2005	2006	2007	2008	2009	2010
Jan	76	0	0	0	0	0
Feb	0	0	0	0	0	0
March	14	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	88	66	593	262	186	235
July	584	374	244	153	218	193
August	336	607	343	135	253	238
Sep	370	183	0	244	128	164
October	56	0	0	9	0	0
November	0	0	0	0	0	0
December	5	0	0	0	0	0

Appendix B

Table B_1: Location of artificial recharge structures in the Dhamtari district (ground truth).

S. No.	Recharge structure (code)	Location	
		Longitude	Latitude
1	Check dam (CD1)	E-81° 59' 37"	N-20° 40' 30"
2	Percolation tank (PT1)	E-81° 58' 29"	N-21° 33' 24"
3	Check dam (CD2)	E-81° 58' 51"	N-20° 04' 29"
4	Percolation tank (PT2)	E-81° 55' 06"	N-20° 43' 06"
5	Check dam (CD3)	E-81° 54' 02"	N-20° 45' 39"
6	Check dam (CD4)	E-81° 53' 51"	N-21° 10' 26"
7	Check dam (CD5)	E-81° 53' 32"	N-20° 40' 31"
8	Check dam (CD6)	E-82° 51' 39"	N-20° 11' 55"
9	Check dam (CD7)	E-81° 49' 26"	N-20° 36' 07"
10	Check dam (CD8)	E-81° 46' 21"	N-20° 52' 23"
11	Check dam (CD9)	E-81° 46' 01"	N-20° 30' 29"
12	Check dam (CD10)	E-81° 43' 28"	N-20° 57' 41"
13	Percolation tank (PT3)	E-81° 39' 37"	N-20° 53' 27"
14	Check dam (CD11)	E-81° 39' 22"	N-20° 38' 02"
15	Boulder Check dam (BCD1)	E-81° 37' 17"	N-20° 48' 04"
16	Percolation tank (PT4)	E-81° 22' 11"	N-20° 32' 30"

Table B_2: Location of artificial recharge structures in the Balod district (ground truth).

S. No.	Recharge structure (code)	Location	
		Longitude	Latitude
1	Check dam (CD1)	E-81° 42 52"	N-20° 29 37"
2	Check dam (CD2)	E-81° 41 04"	N-20° 46 17"
3	Check dam (CD3)	E-81° 29 16"	N-20° 53 16"
4	Percolation tank (PT1)	E-81° 26 16"	N-20°36 01"
5	Check dam (CD4)	E-81° 26 03"	N-20° 39 59"
6	Check dam (CD5)	E-81° 25 10"	N-20° 51 21"
7	Check dam (CD6)	E-81° 24 46"	N-20° 47 29"
8	Percolation tank (PT2)	E-81° 21 47"	N-20° 32 43"
9	Check dam (CD7)	E-81° 24 50"	N-20° 46 09"
10	Check dam (CD8)	E-81° 19 43"	N-20° 25 19"
11	Percolation tank (PT3)	E-81° 18 13"	N-20° 49 46"
12	Check dam (CD9)	E-81° 17 06"	N-20°2731"
13	Check dam (CD10)	E-81° 13 29"	N-20° 30 15"
14	Check dam (CD11)	E-80° 56 39"	N-20° 45 01"

Table B_3: Location of artificial recharge structures in the Bemetara district (ground truth)

S. No.	Recharge structure (code)	Location	
		Longitude	Latitude
1	Percolation tank (PT1)	E-81° 54' 09"	N-21° 52' 02"
2	Check dam (CD1)	E-81° 49' 08"	N-21° 49' 25"
3	Percolation tank (PT2)	E-81° 45' 31"	N-21° 52' 42"
4	Check dam (CD2)	E-81° 43' 43"	N-21° 55' 48"
5	Check dam (CD3)	E-81° 42' 36"	N-21° 50' 66"
6	Check dam (CD4)	E-81° 39' 59"	N-21° 43' 02"
7	Check dam (CD5)	E-81° 39' 27"	N-21° 50' 56"
8	Check dam (CD6)	E-81° 37' 58"	N-21° 57' 11"
9	Percolation tank (PT3)	E-81° 36' 43"	N-21° 44' 35"
10	Percolation tank (PT4)	E-81° 35' 02"	N-21° 28' 13"
11	Check dam (CD7)	E-81° 33' 57"	N-21° 29' 39"
12	Check dam (CD8)	E-81° 32' 25"	N-21° 52' 28"
13	Check dam (CD9)	E-81° 31' 03"	N-21° 22' 33"
14	Check dam (CD10)	81- 29' 11"	N-21 35' 02"
15	Percolation tank (PT5)	81 -12' 08"	N-21 39' 48"

Appendix C

Table C_1: Suitable Recharge Structures

Topographic slope	**Hydrogeologic Group**			**Aquifer situation**
	Consolidated	Semi-Consolidated	Un-consolidated	Confined/ Unconfined
Moderate Slope (10 to 5%) Runoff zone	Gravity Head Recharge Well	Gravity Head Recharge Well	Ditch & Furrow Pits & Shafts Contour Trench Gravity Head Recharge Well	Unconfined
	Deep Gravity Head Recharge Well Hydro fracturing Fracture Seal Cementation	Injection Well Recharge Shafts	Injection Well Recharge Shafts	Confined
Moderate to Gentle Slope (2 to 5%) Transition zone	*Nalah* Bunds Contour Bunding Percolation Tanks Recharge Pits Canal Irrigation Induced Recharge	Canal Irrigation Induced recharge Stream Channel Modification Recharge Pits	Flooding Stream Channel Modification Induced Recharge Gravity Head Recharge Well Canal Irrigation	Unconfined
	Gravity Head Recharge Well Hydro-fracturing Deep Fracture Seal Cementation	Recharge Shaft Gravity Head Recharge Wells Injection Wells Hydro-fracturing	Recharge Shafts Gravity Head Recharge Wells Injection Wells	Confined
Gentle Slope (< 2%) Storage Zone	Surface Irrigation Recharge Pits Gravity Head Recharge Wells	Recharge Pits Flooding Canal Irrigation Induced Recharge Surface Spreading Infiltration Gallery	Flooding Surface Spreading Infiltration Gallery	Unconfined
	Gravity Head Recharge Wells (On Lineaments or their intersections)	Injection Wells	Injection Wells Connector Wells	Confined

Appendix D

Table D_1: Locations of identified for artificial recharge structure in Dhamtari District

S. No.	Check Dam			Percolation Tank		
	Small	Medium	Large	Small	Medium	Large
1	E-81.690° N-20.690°	E-81.886° N-20.133°	E-81.819° N-20.188°	E-81.720° N-20.937°	E-81.813° N-20.791°	E-81.808° N-20.290°
2	E-81.744° N-20.974°	E-81.805° N-20.256°	E-81.727° N-20.732°	E-81.586° N-20.894°	E-81.856° N-20.750°	E-81.936° N-20.280°
3	E-81.752° N-20.969°	E-81.861° N-20.404°	E-81.766° N-20.506°	E-81.656° N-20.881°	E-81.911° N-20.702°	E-82.105° N-20.234°
4	E-81.722° N-20.956°	E-81.974° N-20.415°	E-81.722° N-20.506°	E-81.553° N-20.835°	E-81.817° N-20.748°	-
5	E-81.770° N-21.948°	E-81.972° N-20.423°	E-81.803° N-20.504°	E-81.557° N-20.788°	E-81.734° N-20.617°	-
6	E-81.762° N-20.919°	E-81.970° N-20.431°	E-81.780° N-20.441°	E-81.641° N-20.784°	E-81.742° N-20.585°	-
7	E-81.717° N-20.935°	E-81.965° N-20.455°	E-81.835° N-20.433°	E-81.650° N-20.817°	E-81.780° N-20.586°	-
8	E-81.727° N-20.898°	E-82.046° N-20.404°	E-81.832° N-20.435°	E-81.686° N-20.837°	E-81.805° N-20.578°	-
9	E-81.723° N-20.881°	E-81.893° N-20.755°	E-81.982° N-20.616°	E-81.662° N-20.850°	E-81.933° N-20.580°	-
10	E-21.713° N-20.876°	E-81.809° N-21.918°	E-81.978° N-20.610°	E-81.729° N-20.882°	E-82.019° N-20.408°	-
11	E-81.724° N-20.845°	E-81.795° N-20.915°	-	E-81.730° N-20.847°	E-82.008° N-20.466°	-
12	E-81.747° N-20.848°	E-81.748° N-20.887°	-	E-81.848° N-20.877°	E-81.968° N-20.446°	-
13	E-81.770° N-20.870°	-	-	E-81.946° N-20.640°	E-81.884° N-20.394°	-
14	E-81.858° N-20.853°	-	-	E-81.959° N-20.697°	E-82.029° N-20.256°	-
15	E-81.682° N-20.747°	-	-	E-81.916° N-20.718°	E-82.137° N-20.265°	-
16	E-81.648° N-20.751°	-	-	E-81.885° N-20.731°	-	-
17	E-81.625° N-20.734°	-	-	E-81.866° N-20.683°	-	-
18	E-81.614° N-20.728°	-	-	E-81.825° N-20.714°	-	-

19	E-81.682° N-20.563°	-	-	E-81.885° N-20.730°	-	-
20	E-81.679° N-20.607°	-	-	E-81.976° N-20.514°	-	-
21	E-84.745° N-20.567°	-	-	E-81.959° N-20.544°	-	-
22	E-81.872° N-20.585°	-	-	E-81.936° N-20.588°	-	-
23	E-81.944° N-20.493°	-	-	E-81.899° N-20.534°	-	-
24	E-81.919° N-20.605°	-	-	E-81.877° N-20.540°	-	-
25	E-81.959° N-20.641°	-	-	E-81.869° N-20.522°	-	-
26	E-81.989° N-20.648°	-	-	E-81.861° N-20.574°	-	-
27	E-81.982° N-20.665°	-	-	E-81.803° N-20.563°	-	-
28	E-82.004° N-20.398°	-	-	E-81.621° N-20.543°	-	-
29	E-82.055° N-20.364°	-	-	E-81.477° N-20.532°	-	-
30	E-82.095° N-20.293°	-	-	E-81.448° N-20.535°	-	-
31	E-82.025° N-20.244°	-	-	E-82.055° N-20.360°	-	-
32	E-82.011° N-20.236°	-	-	E-81.974° N-20.397°	-	-
33	E-82.641° N-20.160°	-	-	E-81.967° N-20.403°	-	-
34	E-82.036° N-20.145°	-	-	E-81.943° N-20.433°	-	-
35	E-81.993° N-20.170°	-	-	E-81.938° N-20.448°	-	-
36	E-81.928° N-20.152°	-	-	E81.885° N-20.439°	-	-
37	E-81.870° N-20.183°	-	-	E-82.061° N-20.311°	-	-
38	-	-	-	E-82.111° N-20.163°	-	-
39	-	-	-	E-81.971° N-20156°	-	-
40	-	-	-	E-81.932° N-20.118°	-	-
41	-	-	-	E-81.912° N-20.088°	-	-
42	-	-	-	E-81.923° N-20.157°	-	-

43	-	-	-	E-81.886° N-20.157°	-	-
44	-	-	-	E-81.864° N-20.173°	-	-
45	-	-	-	E-81.874° N-20.186°	-	-
46	-	-	-	E-81.839° N-20.219°	-	-
47	-	-	-	E-81.854° N-20.276°	-	-

Table D_2: Locations of identified for artificial recharge structure in Balod District

S. No.	Check Dam			Percolation Tank		
	Small	Medium	Large	Small	Medium	Large
1	E-81.442° N-20.838°	E-81.418° N-20.846°	E-81.457° N-20.821°	E-81.445° N-20.950°	E-81.409° N-20.789°	E-81.274° N-20.955°
2	E-81.430° N-20.821°	E-81.401° N-20.788°	E-81.248° N-20.842°	E-81.426° N-20.908°	E-81.297° N-20.805°	E-81.290° N-20.886°
3	E-81.388° N-20.846°	E-81.277° N-20.858°	E-81.233° N-20.843°	E-81.455° N-20.875°	E-81.280° N-20.732°	E-81.223° N-20.844°
4	E-81.369° N-20.813°	E-81.280° N-20.834°	E-81.228° N-20.843°	E-81.404° N-20.866°	E-81.155° N-20.828°	E-81.443° N-20.839°
5	E-81.321° N-20.891°	E-81.200° N-20.845°	E-81.281° N-20.926°	E-81.335° N-20.898°	E-81.100° N-20.819°	E-81.439° N-20.803°
6	E-81.305° N-20.798°	E-81.196° N-20.848°	E-81.066° N-20.947°	E-81.329° N-20.859°	E-81.061° N-20.941°	E-81.071° N-20.950°
7	E-81.227° N-20.897°	E-81.121° N-20.823°	E-81.060° N-20.935°	E-81.302° N-20.823°	E-81.045° N-20.955°	E-81.976° N-20.723°
9	E-81.214° N-20.921°	E-81.113° N-20.820°	E-81.053° N-20.916°	E-81.360° N-20.760°	E-81.026° N-20.921°	E-81.069° N-20.697°
10	E-81.181° N-20.904°	E-81.061° N-20.963°	E-81.045° N-20.886°	E-81.437° N-20.655°	E-81.035° N-20.748°	E-81.144° N-20.553°
11	E-81.144° N-20.899°	E-81.039° N-20.950°	E-81.048° N-20.872°	E-81.396° N-20.642°	E-81.053° N-20.692°	E-81.250° N-20.526°
12	E-81.151° N-20.863°	E-81.033° N-20.946°	E-81.006° N-20.844°	E-81.358° N-20.621°	E-81.053° N-20.460°	-
13	E-81.109° N-20.921°	E-81.121° N-20.823°	E-81.061° N-20.726°	E-81.438° N-20.586°	E-81.283° N-20.694°	-

14	E-81.105° N-20.947°	E-81.109° N-20.820°	E-81.057° N-20.722°	E-81.370° N-20.578°	-	-
15	E-81.039° N-20.970°	E-81.080° N-20.793°	E-81.069° N-20.692°	E-81.166° N-21.022°	-	-
16	E-81.995° N-20.939°	E-81.064° N-20.783°	E-81.076° N-20.681°	E-81.194° N-20.994°	-	-
17	E-81.021° N-20.955°	E-81.040° N-20.760°	E-81.245° N-20.622°	E-81.204° N-20.980°	-	-
18	E-81.000° N-20.886°	E-81.281° N-20.747°	E-81.178° N-20.605°	E-81.143° N-20.972°	-	-
19	E-81.032° N-20.876°	E-81.278° N-20.717°	E-81.151° N-20.550°	E-81.142° N-20.951°	-	-
20	E-81.077° N-20.874°	E-81.413° N-20.645°	E-81.133° N-20.546°	E-81.206° N-20.922°	-	-
21	E-81.086° N-20.857°	E-81.169° N-20.533°	E-81.109° N-20.529°	E-81.153° N-20.917°	-	-
22	E-81.127° N-20.814°	E-81.150° N-20.486°	E-81.109° N-20.529°	E-81.103° N-20.921°	-	-
23	E-81.108° N-20.789°	E-81.032° N-20.469°	-	E-81.002° N-20.973°	-	-
24	E-81.136° N-20.787°	E-81.046° N-20.459°	-	E-81.008° N-20.954°	-	-
25	E-81.021° N-20.783°	E-81.102° N-20.435°	-	E-81.016° N-20.916°	-	-
26	E-81.057° N-20.770°	E-81.094° N-20.426°	-	E-81.063° N-20.871°	-	-
27	E-81.023° N-20.769°	E-81.132° N-20.419°	-	E-81.060° N-20.850°	-	-
28	E-81.063° N-20.758°	-	-	E-81.161° N-20.856°	-	-
29	E-81.073° N-20.759°	-	-	E-81.140° N-20.857°	-	-
30	E-81.029° N-20.720°	-	-	E-81.131° N-20.835°	-	-
31	E-81.099° N-20.679°	-	-	E-81.127° N-20.810°	-	-
32	E-81.245° N-20.688°	-	-	E-81.129° N-20.765°	-	-
33	E-81.433° N-20.659°	-	-	E-81.018° N-20.731°	-	-
34	E-81.453° N-20.603°	-	-	E-81.005° N-20.699°	-	-
35	E-81.434° N-20.581°	-	-	E-81.007° N-20.672°	-	-
36	E-81.400° N-20.620°	-	-	E-81.167° N-20.696°	-	-
37	E-81.362° N-20.655°	-	-	E-81.115° N-20.685°	-	-
38	E-81.367°	-	-	E-81.211°	-	-

	N-20.602°			N-20.625°		
39	E-81.316° N-20.565°	-	-	E-81.150° N-20.580°	-	-
40	E-81.267° N-20.558°	-	-	E-81.133° N-20.522°	-	-
41	E-81.244° N-20.532°	-	-	E-81.093° N-20.537°	-	-
42	E-81.127° N-20.614°	-	-	E-81.059° N-20.537°	-	-
43	E-81.142° N-20.611°	-	-	E-81.045° N-20.525°	-	-
44	E-81.126° N-20.601°	-	-	E-81.095° N-20.417°	-	-
45	E-81.180° N-20.589°	-	-	E-81.148° N-20.457°	-	-
46	E-81.163° N-20.587°	-	-	E-81.162° N-20.740°	-	-
47	E-81.130° N-20.579°	-	-	E-81.204° N-20.481°	-	-
48	E-81.186° N-20.572°	-	-	E-81.241° N-20.477°	-	-
49	E-81.186° N-20.560°	-	-	E-81.209° N-20.569°	-	-
50	E-81.219° N-20.558°	-	-	-	-	-
51	E-81.244° N-20.532°	-	-	-	-	-
52	E-81.200° N-20.539°	-	-	-	-	-

Table D_3: Locations of identified for artificial recharge structure in Bemetara District

S. No.	Check Dam			Percolation Tank		
	Small	Medium	Large	Small	Medium	Large
1	E-81.878° N-21.866°	E-81.829° N-21.830°	E-81.894° N-21.867°	E-81.579° N-21.963°	E-81.718° N-21.904°	E-81.904° N-21.801°
2	E-81.829° N-21.830°	E-81.818° N-21.820°	E-81.767° N-21.839°	E-81.527° N-21.955°	E-81.624° N-21.911°	E-81.765° N-21.873°
3	E-81.860° N-21.809°	E-81.778° N-21.891°	E-81.699° N-21.844°	E-81.515° N-21.905°	E-81.603° N-21.917°	E-81.731° N-21.801°
4	E-81.899° N-21.807°	E-81.709° N-21.898°	E-81.744° N-21.793°	E-81.731° N-21.924°	E-81.737° N-21.854°	E-81.647° N-21.842°
5	E-81.785° N-21.899°	E-81.666° N-21.916°	E-81.660° N-21.834°	E-81.765° N-21.873°	E-81.473° N-21.886°	E-81.622° N-21.873°

6	E-81.742^o N-21.883^o	E-81.626^o N-21.951^o	E-81.655^o N-21.840^o	E-81.857^o N-21.817^o	E-81.637^o N-21.812^o	E-81.555^o N-21.585^o
7	E-81.731^o N-21.888^o	E-81.553^o N-21.966^o	E-81.643^o N-21.855^o	E-81.862^o N-21.776^o	E-81.578^o N-21.807^o	E-81.692^o N-21.763^o
8	E-81.723^o N-21.924^o	E-81.497^o N-21.969^o	E-81.628^o N-21.866^o	E-81.561^o N-21.780^o	E-81.535^o N-21.905^o	E-81.584^o N-21.817^o
9	E-81.699^o N-21.901^o	E-81.509^o N-21.928^o	E-81.570^o N-21.945^o	E-81.607^o N-21.739^o	E-81.428^o N-21.793^o	E-81.529^o N-21.824^o
10	E-81.681^o N-21.936^o	E-81.516^o N-21.923^o	E-81.548^o N-21.903^o	E-81.578^o N-21.737^o	E-81.400^o N-21.802^o	E-81.367^o N-21.606^o
11	E-81.880^o N-21.905^o	E-81.495^o N-21.101^o	E-81.514^o N-21.871^o	E-81.389^o N-21.808^o	E-81.648^o N-21.714^o	E-81.259^o N-21.582^o
12	E-81.683^o N-21.897^o	E-81.461^o N-21.887^o	E-81.575^o N-21.844^o	E-81.344^o N-21.784^o	E-81.572^o N-21.696^o	E-81.585^o N-21.462^o
13	E-81.711^o N-21.844^o	E-81.467^o N-21.886^o	E-81.579^o N-21.842^o	E-81.308^o N-21.740^o	E-81.512^o N-21.715^o	E-81.568^o N-21.428^o
14	E-81.636^o N-21.892^o	E-81.564^o N-21.830^o	E-81.514^o N-21.822^o	E-81.263^o N-21.718^o	E81.473^o N-21.734^o	-
15	E-81.524^o N-21.953^o	E-81.552^o N-21.819^o	E-81.546^o N-21.833^o	E-81.296^o N-21.706^o	E-81.389^o N-21.725^o	-
16	E-81.563^o N-21.873^o	E-81.508^o N-21.822^o	E81. 553^o N-21.834^o	E-81.487^o N-21.720^o	E-81.218^o N-21.571^o	-
17	E-81.435^o N-21.863^o	E-81.409^o N-21.804^o	E-81.563^o N-21.837^o	E-81.679^o N-21.590^o	E-81.179^o N-25.556^o	-
18	E-81.563^o N-21.873^o	E-81.289^o N-21.718^o	E-81.593^o N-21.833^o	E-81.201^o N-21.658^o	E-81.541^o N-21.474^o	-
19	E-81.435^o N-21.863^o	E-81.312^o N-21.711^o	E-81.569^o N-21.821^o	E-81.199^o N-21.606^o	E-81.530^o N-21.446^o	-
20	E-81.344^o N-21.810^o	E-81.325^o N-21.706^o	E-81.654^o N-21.815^o	-	-	-
21	E-81.390^o N-21.806^o	E-81.245^o N-21.680^o	E-81.688^o N-21.764^o	-	-	-
22	E-81.352^o N-21.757^o	E-81.202^o N-21.679^o	E-81.458^o N-21.715^o	-	-	-
23	E-81.389^o N-21.737^o	E-81.280^o N-21.616^o	E-81.351^o N-21.697^o	-	-	-
24	E-81.330^o N-21.738^o	E-81.183^o N-21.556^o	E-81.509^o N-21.602^o	-	-	-
25	E-81.291^o N-21.748^o	E-81.327^o N-21.621^o	E-81.412^o N-21.604^o	-	-	-
26	E-81.286^o N-21.705^o	E-81.601^o N-21.386^o	E-81.298^o N-21.587^o	-	-	-
27	E-81.334^o N-21.698^o	E-81.519^o N-21.392^o	E-81.298^o N-21.562^o	-	-	-
28	E-81.229^o N-21.686^o	E-81.536^o N-21.416^o	E-81.265^o N-21.569^o	-	-	-
29	E-81.336^o N-21.652^o	E-81.563^o N-21.435^o	E-81.256^o N-21.584^o	-	-	-
30	E-81.202^o	E-81.563^o	-	-	-	-

	N-21.606^{o}	N-21.435^{o}				
31	E-81.196^{o} N-21.607^{o}	-	-	-	-	-
32	E-81.226^{o} N-21.575^{o}	-	-	-	-	-
33	E-81.220^{o} N-21.558^{o}	-	-	-	-	-
34	E-81.171^{o} N-21.557^{o}	-	-	-	-	-
35	E-81.245^{o} N-21.545^{o}	-	-	-	-	-
36	E-81.294^{o} N-21.588^{o}	-	-	-	-	-
37	E-81.343^{o} N-21.555^{o}	-	-	-	-	-
38	E-81.341^{o} N-21.564^{o}	-	-	-	-	-
39	E-81.470^{o} N-21.536^{o}	-	-	-	-	-

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