DELINEATION OF GROUNDWATER POTENTIAL ZONES AND SITE SELECTION FOR ARTIFICIAL RECHARGE USING GEO SPATIAL TECHNOLOGIES

A Thesis submitted to

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfilment of the requirements for the degree

Of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

in

SOIL AND WATER CONSERVATION ENGINEERING

by

Mr. PATIL DEEPAK RAVINDRA

(ENDPM 2019/168)

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA)
September, 2021

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I hereby declare that this thesis or part there of has not been submitted

by me or any other person to any other

University or Institute

For a Degree or

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This is to certify that the thesis entitled "**Delineation of groundwater potential zones and site selection for artificial recharge using geo spatial technologies"** submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.- Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering,** embodies the results of bonafide research work carried out by **Mr. Patil Deepak Ravindra (ENDPM 2019/168)** under guidance and supervision of **Dr. H. N. Bhange,** Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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Dated: / /2021

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Place: Dapoli
Dated: / /2021

(Patil Deepak R.)
ENDPM 2019/168

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LIST OF ABBREVATIONS AND SYMBOLS

Abbreviations	**Description**
<	Less than
>	Greater than
%	Per cent
AHP	Analytical Hierarchy Process
bgl	Below ground level
CAET	College of Agricultural Engineering and Technology
cm	Centimetre
CN	Curve number
DEM	Digital Elevation Model
E	East
et al.	And others
etc.	Etcetera
FAO	Food and Agricultural Organization
Fig.	Figure
g	Gram
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectares
hr	Hour
IMSD	Integrated Mission for Sustainable Development
ISRO	Indian Space Research Organization
i.e.	That is
kg	Kilo gram
km	Kilo meter
km^2	Square kilo meter
LANDSAT ETM +	Landsat Enhanced Thematic Mapper plus
LISS	Linear Imaging Self Scanner
LU/LC	Land use/ land cover

M	Million
m	Meter
m^3	Cubic meter
mm	Millimetre
mm/hr	Millimetre per hour
MCM	Million Cubic Meters
Mha-m	Million hectare meter
N	North
No.	Number
RS	Remote sensing
SOI	Survey of India
SRTM	Satellite Radar Topography Mission
USGS	Unites States Geographical Survey
viz.	Namely
yr	Year

ABSTRACT

"DELINEATION OF GROUNDWATER POTENTIAL ZONES AND SITE SELECTION FOR ARTIFICIAL RECHARGE USING GEO SPATIAL TECHNOLOGIES"

By

Patil Deepak Ravindra
Department of Soil and Water Conservation Engineering,
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2021

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Groundwater is emerging as the critical issue all over the world. Due to overuse of groundwater, water level from deep aquifers that have taken decades to accumulate have been diminishing. The study of groundwater has remained difficult, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters. Various technique can be used to provide information about potential occurrence of groundwater. Remote sensing has been practiced for about three decades in groundwater exploration. An integrated approach of remote sensing (RS) and GIS technique is very useful in demarcation of various groundwater potential zones. Remote Sensing and GIS are one of the advanced technologies which understands sub-surface water condition with their advantages of spectral, spatial, temporal nature of data and analyse of data

Asond is small watershed situated in Dapoli tehsil of Ratnagiri district, Maharashtra. The total area of Asond watershed is 510.76 ha. The average annual rainfall of nearby rain gauge station Wakavali is 2860 mm. Even though in every summer, it faced severe water scarcity due to improper water management. Therefore, there was need to delineate groundwater potential zones and suitable sites for artificial recharge to increase the groundwater level.

Five thematic maps such as lithology, geomorphology, drainage density, slope and land use/land cover were generated to demarcate different groundwater potential zones of the Asond watershed. Each thematic map plays a significant role in delineation of groundwater potential zone. All the thematic maps were integrated using weighted overlay method in spatial analyst tool. In weighted overlay analysis, the ranking has been given to each individual parameter of each thematic map and weights were assigned according to the influence characteristics such as geomorphology – 30%, Lithology – 20%, slope – 15%, Land use/land cover-15% and drainage density – 20% to find out the potential zones of study area. The groundwater potential zone map was delineated and classified into three zones, 'Poor', 'Moderate' and 'Good'. About 15.18% of the study area falls under poor potential zone category; 62.80% area falls under moderate category and 22.01% area falls under good potential category.

For the sustainable groundwater resource management, artificial recharge structures play a vital role in hard rock regions. By considering this aspect, zones favourable for artificial recharge of groundwater were to be demarcated. Ranking was assigned to each class of thematic map and all the thematic maps were integrated using weighted overlay method. Based on the artificial recharge potential zone map, the favourable artificial recharge sites were selected in the watershed. Three types of recharge structures, namely percolation tanks, check dams and recharge ponds were suggested to augment the groundwater.

Keywords: RS and GIS, Thematic maps, Groundwater potential zone, Artificial recharge.

I. INTRODUCTION

Water is most essential and existing resource on the earth. Water resource is more than anything else, which makes the Earth unique in the solar system. About 71% of the Earth’s surface is covered by water, still there is a severe crisis of freshwater for drinking, agriculture and industries because 97% water on the earth is salt water in the form of seas and oceans, about 2% water is glaciers in the polar region, and remaining 1% is a form of stream channels and groundwater (WWAP, 2009). This shows that the greater part of the Earth’s water is saline. The fresh water in lakes and rivers has very little proportion of the Earth’s water. Surface water is highly vulnerable to various pollutants. Hence, surface water in many places is not a good option for the human consumption and economic activities. Insufficient water availability in arid and semi-arid areas causes repeated drought condition. Hence, management of freshwater is very significant in order to prevent severe water scarcity in arid and semi-arid regions.

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity because of its several inherent qualities. It has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries. In India, 30% urban and about 90% population living in rural areas depends on groundwater for their daily needs (Agarwal *et al.* 2015). Groundwater is referred as subsurface water in the saturated zone that occupies all the pore spaces of soils and geologic formations below the water table (Manap *et al.* 2013). It is formed by rainwater or snowmelt water that seeps down through the soil into the underlying rocks (Banks *et al.* 2002). Seepage water flows in the aquifer layer towards the point of discharge, which includes wells, springs, rivers, lakes, and the ocean (Manap *et al.* 2013). Currently groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development it requires. Groundwater is emerging as the critical issue all over the world. Due to overuse of groundwater, water level from deep aquifers that have taken decades to accumulate have been diminishing.

Despite the extensive research and technological advancement, the study of groundwater has remained more risky, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters. The availability of groundwater depends on several factors such as geology, geomorphology, slope, drainage density, land use of an area. Hence, an assessment of these parameters can provide a clear understanding regarding the groundwater potential of a region. Additionally, assessment of these parameters develops a general knowledge regarding the importance of each and every factor for groundwater potential in different areas around the world.

In India 65 percent of the total geographical area is covered by hard rock formation with low porosity (less than 5%) and very low permeability (10-1 to 10-5 m/day) (Saraf *et al.* 1998). Many efforts have been made to increase the groundwater level by identifying potential zones for conservation of sub surface water. But availability of groundwater in hard rock terrain is very limited. Therefore, effective management and planning of groundwater in these areas is very importance.

Ratnagiri is one of the coastal districts of Maharashtra and forms part of Konkan region. It is situated in between the Western Ghats and the Arabian sea and lies between north latitudes 16^0 30' and 18^0 4' and east longitudes 73^0 20' and 73^0 52'. The District has geographical area of 8208 sq. km, out of which about 60 sq. km is covered by forest, whereas cultivable area is 4010 sq. km and net sown area is 2630 sq. km (CGWB, 2014). The falling trend of water level in the range of 0 to 0.20 m/year is observed in northern eastern parts of the district (in parts of Khed and Chiplun talukas) and in southern part of the district (in Rajapur taluka). Net Ground Water Availability is 466.05 MCM and Existing Ground Water Draft for all uses is 52.49 MCM. After making provision for Domestic and Industrial Supply for next 25 Years as 24.37 MCM, Ground Water Availability for future Irrigation is 401.36 MCM (CGWB, 2014).

Dapoli is a Taluka of Ratnagiri district, lies in coastal strip with Net Annual Ground Water Availability 37.6962 MCM and Existing Gross Ground Water Draft for Irrigation 5.8746 MCM. The groundwater level till January 2017 was 2.70 m bgl which is -0.088 less than November 2016. In the last 10 years (2007-2017) January, groundwater level is decreased to -60 m bgl. Even though district receives rainfall in excess of 3500 mm/year, but water scarcity in non-monsoon season is reported in many villages. Over all Stage of Ground Water development of the district is 11.26% indicating there is ample scope for ground water development in the district. Rain water harvesting and water management techniques are solution for combating water scarcity problem.

Various technique can be used to provide information about potential occurrence of groundwater. Remote sensing has been practiced for about 3 decades in groundwater exploration. An integrated approach of remote sensing (RS) and GIS technique is very useful in demarcation of various groundwater potential zones. Remote Sensing and GIS are one of the advanced technologies which understands sub-surface water condition with their advantages of spectral, spatial, temporal nature of data and analyze of data. It can be available for even inaccessible areas within a short span of time. RS has become a very handy tool for accessing, preserving and monitoring the groundwater resources (Gupta and Srivastava 2010). To judge the groundwater status of region, we should generate thematic map of distribution of vegetation, land use land cover, drainage pattern, slope, density of drainage pattern and types of rocks. Integration of these thematic layers can give precise and quick demarcation of groundwater potential zones for artificial recharge.

Artificial recharge to groundwater is a process by which the groundwater is augmented at a rate exceeding that obtained under natural conditions of replenishment. Any man-made attempt or facility that adds water to an aquifer may be considered to be an artificial recharge to the groundwater system. Due to rapid growth in urbanization, infiltration of rain water into the sub-soil has decreased drastically due to land use changes and recharging potential to groundwater has diminished. Rain water harvesting gained importance due to various problems like when surface water is inadequate to meet the demand and to depend on groundwater. There are two main techniques of rain water harvesting and those are a) storage of rain water on surface for future use and b) recharge to the groundwater system. The storage of rain water on surface is a traditional technique and structures used were tanks, ponds, check dams, weirs, etc. Artificial Recharge to groundwater is a new concept of rain water harvesting and the structures generally used are 1) Pits 2) Trenches 3) Dug wells 4) Hand pumps 5) Recharge wells 6) Recharge

Shafts 7) Lateral shafts with bore wells and 8) Spreading techniques. (Dhakate *et al.*, 2013)

Due to the highly variable geological conditions in the hard-rock region, groundwater potential mapping is more complex and challenging. Many scholars carried out their researches to explore groundwater potential in basaltic terrain. However, the demarcation of the groundwater prospect areas in the Deccan Trap region of Maharashtra, covered by good basalt, is still not studied well. Hence, an attempt has been made in this study to demarcate different groundwater potential areas of Asond village of Dapoli taluka by using muti-criteria decision modelling (influencing factor and frequency ratio) in GIS environment. Several environmental criteria such as geology, geomorphology, drainage, regional slope and land-use pattern have been evaluated to prepare the groundwater potential maps for future planning, management, utilization and conservation of groundwater resources with following objectives-

1. To identify the groundwater potential zones in Asond watershed.
2. To suggest suitable locations for artificial recharge of groundwater.

II. REVIEW OF LITERATURE

This chapter deals with review of study carried out by various researchers on identification of groundwater potential zones in particular watershed and suggest suitable sites for artificial recharge of groundwater. The review of literature indicates the importance of remote sensing and geographic information service (GIS), particularly with application to hydrological problems.

2.1. Identification of groundwater potential zones-

Kumar *et al.* (2007) used remote sensing and GIS for the delineation of groundwater potential zones of a river basin in state of Kerala. It was found that valley fills, pediments and moderately dissected plateaus of the basin were favourable geomorphological units for groundwater exploration, whereas structural hills, residual hills, residual mounts, and linear ridges were of poor groundwater potential. The study shows that basin was demarcated as poor to moderate groundwater potential zones due to high drainage density and steep slope.

Nagarajan *et al.* (2009) conducted the case study on demarcation of groundwater potential zones in Kattakulathur block of Tamilnadu state. Different thematic maps like geology, geomorphology, land use /land cover and drainage map were prepared. Digital Elevation Model (DEM) was generated from SOI toposheet (1:25000). Groundwater potential zones were obtained by integrating and overlaying all the thematic maps by weighted overlay method. The village wise groundwater potential zones were obtained with 3 categories such as good, moderate and poor zones. The results of study were validated by randomly selecting wells in different potential zones and results were closely associated.

Dar *et al.* (2010) studied deciphering groundwater potential zones in hard rock terrain by using geospatial technology in Mamun Diyar basin. The study showed that to demarcate the groundwater availability of the Mamun Diyar basin, various thematic maps such as geological map, lineament map, geomorphology map, and drainage map were prepared from remote sensing data and topographic maps, geology maps, and geomorphology maps using Arc GIS and ERDAS software. All maps were integrated for preparing groundwater potential map. The geomorphologic units such as valley fill and buried pediplain were prospective zones for groundwater exploration and development. The presence of lineaments in the area would enhance the potential of groundwater.

Machiwal *et al.* (2010) studied identification of groundwater potential in a semi-arid region of Rajasthan using remote sensing, GIS and MCDM technique. In study area four groundwater potential zones were identified and demarcated such as good, moderate, poor and very poor based on groundwater potential index values. The area falling in 'good' zone was about 2,113 km^2 (17% of the total study area), 'moderate' zone, which consist an area of 3,710 km^2 (about 29%). The 'poor' zone was dominant in the study area which covers an area of 4,599 km^2 (36% of the total area) and 'very poor' groundwater potential zone covers an area of 2,273 km^2 (18%). The study observed that mean annually exploitable groundwater reserve estimated in good, moderate, poor and very poor zone was 0.02, 0.024, 0.018, and 0.013 MCM/km^2 , respectively.

Adiat *et al.* (2012) studied the accuracy of GIS-based multi criteria decision analysis as a spatial prediction tool for mapping. In order to find out effectiveness of MCDA a total of five set of factors believed to be influencing groundwater storage potential in the area was selected. Appropriate weight based on Saaty's 9-point scale were assigned to each factor and the weights was normalized by using the analytic hierarchy process (AHP). The groundwater potential prediction map of the study area was delineated and it was found to be 81.25% accurate. The study revealed that if the set of factors were coherent the GIS based MCDA gives better accurate and reliable prediction.

Kuria (2012) carried out study on groundwater potential zone mapping using remote sensing and GIS in kitui district of Kenya. Land use land cover and lineaments maps from landsat data were generated. Various parameters were evaluated by using DRASTIC model and groundwater potential zone were delineated. The study shows that the central and eastern regions of Kitui district were highly suitable for groundwater exploitation.

Magesh *et al.* (2012) determined the groundwater potential zone in the Theni district of Tamilnadu state with help of RS, GIS, MIF technique. The information on geology, lithology, lineaments, slope and land use/land cover were gathered from IRS-1C satellite data and Survey of India (SOI) toposheets of scale 1:50,000. The groundwater potential map obtained were categories into 4 zones, such as very poor, poor, good, and very good zones. The groundwater potential map indicate that the excellent groundwater potential was due to the distribution of alluvial plains and agricultural land with high infiltration ability.

Dhakate *et al.* (2013) studied the integrated approach of RS and GIS for identifying suitable sites for rainwater harvesting for increasing groundwater at Indore city, (M.P.). It was found that water level ranges from 0.12-19.17 m (bgl) and 1.41–23.89 m (bgl) during August 2010 and October 2010. Geophysical investigations reveal that top layer was clay soil, clayey soil with boulder formation in some part and very hard boulder formation in elevated area. The comparison of groundwater balance under natural conditions with groundwater balance computed for water harvesting structures was carried out. The relative contribution from the water harvesting structures showed that check dams would contribute about 20–48 % of impounded water depending on the location of lineaments. The net enhancement of groundwater recharge from proposed water harvesting would be about 0.11 mcm/year.

Goodarzi *et al.* (2013) studied identification of potential sites for artificial groundwater recharge using GIS and MCDM techniques in Oshtorinan plain, Iran. The different thematic maps considered in this study are the thickness of the unsaturated zones, Groundwater quality, aquifer transmissivity, hydraulic gradient, storage coefficient, slope, geology, land use and distance from surface water resources. The thematic maps were arranged by Analytic Hierarchy Process (AHP) and weighted by an adhoc method. The artificial recharge map obtained were divided into 3 classes: suitable, moderately suitable and unsuitable according to their suitability for artificial recharge.

Suganthi *et al.* (2013) studied the zonation of groundwater potential by remote sensing and GIS technique and its relation to the groundwater level. The study was carried out in the coastal part of Arani and Koratalai river basin where the pumping of water was extreme. Thematic layers have been generated by SOI toposheet and (IRS-1D LISS III) satellite imagery. The thematic layers were integrated and assigned by appropriate weightage to demarcate groundwater potential zone. The delineated zones within this region were classified as very high, high, moderate and low groundwater potential zones. The study concluded that in very high groundwater potential zones the groundwater table was reasonably flat.

Patil and Mohite (2014) studied delineation of groundwater recharge potential zones for watershed using remote sensing and GIS for a watershed in Pune district. Groundwater potential zones were categorized into 3 zones ‘poorly suitable’, ‘moderately suitable’, ‘most suitable’. The study indicated that most suitable groundwater potential zones were found in the area having alluvium soil, buried pediplain and agricultural land have high infiltration ability. The least suitable zone for recharge of groundwater is found at steep sloping topography and mountain soil spread.

Shekhar and Pandey (2014) studied the demarcation of groundwater potential zone using geospatial technologies and Analytic Hierarchy Process (AHP) techniques in hard rock terrain of India. The final groundwater prospect map has GWPI values ranging from 6.79 to 27. The study shows that only 3.22% (136 km^2) of the study area have excellent groundwater potential, 5.87% (248 km^2) area showed very good groundwater potential in addition to 2.51% (106 km^2) area with good groundwater potential, whereas 13.27% (561 km^2) was classified as having moderate groundwater potential, 36.89% are within poor groundwater potential and 38.23% are within very poor groundwater potential. The groundwater potential zone map delineated in the study was verified by using well yield data available from Rajiv Gandhi National Drinking Water Mission atlas.

Waikar and Nilawar (2014) made an attempt in identification of groundwater potential zones using GIS and remote sensing technique. The study was carried out in Parbhani district of Maharashtra which has natural boundaries of the Penganga river with area 160.93 km^2. In this study groundwater potential zones were delineated by integrating and assigning weight to the thematic maps according to the importance of factors in demarcating groundwater potential. The delineated potential zones were categorized into four zones such as excellent, good, moderate, poor and very poor. The study shows that area having slope 0^0 to 1^0, lineament density 2.11 to 2.69, drainage density 0 to 1.2 under Pediment-pediplain complex and cover with crop land was observed as excellent groundwater potential zone. Area having slope 10^0 to 15^0, lineament density 0 to 0.34, drainage density 4.8 to 6 under Moderately dissected plateau and cover with crop, scrub, barren land is observed as very poor groundwater potential zone.

Agarwal and Garg (2015) delineated groundwater potential and recharge zone maps for Loni and Morahi watershed. Thematic maps like geology, geomorphology, slope, drainage density were prepared and integrated using weighted overlay method. The delineated potential map was divided into five zones such as very poor, poor, good, very good and excellent. The area under excellent zone is about 150.93 km^2 which is 7.06 % of the total study area, which covers a major portion of the Ganga river. However, the area under very poor zone is about 372.03 km^2 (17.42 % of the total study area). Groundwater recharge map was classified into four zones namely; 'most suitable', 'moderately suitable', 'poorly suitable' and 'not suitable'. Yield data of the 40 pumping wells were used to verify the groundwater potential zone map.

Jesiya and Gopinath (2015) studied identification of groundwater potential zones in urban and peri-urban clusters of Kozhikode District of Kerala. In this study various thematic maps like base map, geomorphology map, slope map, soil map, geology map, LULC map and groundwater level map of the study area had been prepared and integrated using overlay analysis. The results showed that there are four categories of groundwater prospect zones ranging from very good to poor, in which the moderate to good prospective zone (68%) dominated the entire study area.

Lalbiakmawia (2015) carried out groundwater potential zone mapping of Kolasib district of Mizoram state. The study showed that 5 thematic layers viz., LULC, slope, geomorphology, lithology, geological structures like faults and lineaments were generated. These thematic layers were given ranked and weighted based on their relative importance in deriving the potentiality of ground water.

Bhange *et al.* (2016) used remote sensing and GIS techniques for delineation of groundwater potential zones of Dapoli taluka of Ratnagiri district. Different thematic maps like geological, drainage, drainage density, lineament, lineament density, DEM, and slope map were generated from the conventional maps and SRTM DEM data to demarcate the groundwater potential zones. Weight was assigned to each and every feature of thematic map according to its contribution in groundwater potential. The potential zones were categorized into 5 classes viz. poor, moderate, good, very good and excellent. Excellent groundwater potential was available in 1.16 per cent, very good groundwater potential was in 13.22 per cent, good groundwater potential 32.18 per cent, moderate in 42.62 per cent and poor in 10.83 percent which shows greater part of study area lies in moderate to good potential for groundwater.

Kadam *et al.* (2016) studied the assessment of groundwater potential zones using GIS technique at shivganga river basin, pune. The weighted overlay analysis was found suitable in assessment of groundwater potential zones. The thematic layers viz. Geomorphology, Geology, Drainage Density and Slope (%) were prepared to obtain the groundwater potential zone map. This map was categorized into five different zones, Excellent to Very good (29.11%), Very good to Good (20.96%), Good to Moderate (22.31%), Moderate to Moderately poor (23.07%) and Moderately Poor to Poor (4.55%).

Kumar and Krishna (2016) carried out mapping of groundwater potential zones in hard-rock terrain of India by using geospatial and analytic hierarchy process approach. The weighted linear combination (WLC) method was used to prepare the groundwater potential index. The study revealed that excellent, very good and good groundwater potential zones respectively cover 148.3 km^2, 373.66 km^2 and 438.86 km^2 of the study area, whereas the poor groundwater potential zone covers 180.05 km^2. Final validation was done through a receiver operating characteristic (ROC) curve, which concluded that AHP had good prediction accuracy (AUC=75.45%).

Mandal *et al.* (2016) carried out study of groundwater potential zonation in the coastal region of Balasore district in state of Orissa. The demarcate of groundwater potential zones have been carried out using Multi-Criteria Decision-Making Technique.

All thematic maps were integrated by overlay weighted sum method to delineate groundwater potential map. Four zones have been identified for the coastal groundwater basin very good: 36.39 % (273.53 km^2), good: 43.57 % (327.47 km^2), moderate: 18.27 % (137.30 km^2) and poor: 1.77 % (13.27 km^2). The study indicated that possible location of the tubewells for groundwater extraction on a long-term sustainable basis in the area that can be planned very efficiently.

Kashouty (2017) studied the application of RS and GIS hydrogeological and hydrological studies in part of Golden Triangle project of central desert. The study shows that Satellite imageries (Landsat 8 ETM+), Digital Elevation Model (DEM), and geological map are used to prepare various thematic layers such as rainfall, geology, slope, lineament and drainage. The potential zones were categories into five zones as very high, high, moderate, low, very low. The GWPZ map indicates about 14 % (587 km^2) of the total area (4258 km^2) has highest recharge potential.

Varade *et al.* (2017) studied the insinuation of spatial database for realistic groundwater assessment in the Indian context. To plan the groundwater development programs in Nagpur region, an attempt was made to assess the groundwater recharge and withdrawal affecting parameters through spatial database generated by remote sensing technique. In this study, groundwater resources of the GEC norms and the approach through spatial database are compared which depicted differences in recharge of groundwater. This study concluded that role of spatial database was inevitable and should be made mandatory for realistic assessment. The data generated are also useful for the delineation of potential zones for targeting groundwater or selection of suitable sites for exploratory dug and bore wells.

Gurav *et al.* (2018) studied identification of groundwater potential zones and artificial recharge sites in the Vedganga river sub-basin using remote sensing and GIS techniques. The remote sensing and GIS techniques helped in delineating the groundwater potential zones in very short span. It shows that groundwater potential zones were highly influenced by factors like geomorphology, geology, slope, etc. The study indicated very less infiltration of rain water as most of area is hilly and impermeable in nature. The area of alluvial plain(120-130 cu. m./ day), Pediplain (agricultural land) yields good quantity of groundwater (50-70 cu. m./ day), Pediment area gives moderately good quantity of groundwater (40-50 cu. m./ day). The area of highly dissected plateau (30-40 cu. m./ day), denudation hill(20-30 cu. m./ day) and lateritic plateau are poor for groundwater prospecting.

Rajashekhar *et al.* (2018) identified various artificial recharge sites with the help of geospatial tools in Semi-Arid Region of Anantapur District of Andhra Pradesh. Eight different thematic maps such as land slope, geomorphology, geology, soil, drainage density, lineament density, land use/land cover, hydrogeomorphology were generated and weighted as per Satty's scale. The thematic maps were integrated by weighted linear grouping method in a GIS environment to create GWPZ. The study area is classified into four different groundwater potential zones such as 'good', 'moderate to good', 'moderate' and 'poor'.

Rusia *et al.* (2018) carried out the study on identification of potential groundwater zone by integrated geospatial techniques. The study concluded that geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments and slope, etc. that plays a significant role in determining groundwater potential zone. Also, various thematic layers such as rainfall, geology, slope, lineament and drainage are prepared using satellite imageries (Landsat 8 ETM+), Digital Elevation Model (DEM) and village geological map.

Singh *et al.* (2018) studied the accuracy of GIS-based Multi-Criteria Decision Analysis approaches in process of mapping the groundwater potential. In this study GIS-based Multi-Criteria Decision Analysis (MCDA) techniques such as Analytic Hierarchy Process (AHP) and Catastrophe theory were used for delineating groundwater potential zones. Thematic layers of factors influencing groundwater were generated and weight was assigned according to AHP and catastrophe theory. The AHP-based groundwater potential map revealed four zones with varying areal coverage: (a) 'very good' (19% of the study area), (b) 'good' (49%), (c) 'moderate' (28%), and (d) 'poor' (4%). On the other hand, the Catastrophe-based map indicated spatial variation of groundwater potential as: (a) 'very good' (14% of the area), (b) 'good' (63%), (c) 'moderate' (19%), and (d) 'poor' (5%). Thus finding of both process showed good potential for groundwater, the accuracy of AHP (82 %) method is superior than catastrophe (74%) method.

Sivakumar *et al.* (2018) compared standard techniques and methodologies to demarcate the groundwater potential zone by using remote sensing and geographic information system. The study shows that there were two methods to delineate one was an conventional method (Sensitivity analysis method) and other was advanced method (Remote sensing and GIS). The study observed that each method has its own advantages and disadvantages in the process. Conventional method was more time consuming and requires more data. While satellite data gave accurate result and less time consuming as its takes into consideration the factors influencing groundwater potential zone.

Andualem *et al.* (2019) carried out research on assessment of groundwater potential using GIS and RS at upper Blue Nile basin in Ethiopia. Different thematic maps of study area were prepared and integrated. The weightage was overlaid to each thematic map based on characteristics of groundwater contribution. The landscape has been evaluated as having an area of 833.49 km^2 and 469.12 km^2 with an excellent and very good groundwater potential, respectively. The result indicated that very good and excellent groundwater potential zones were very much located in downstream side of the study area because of the flat slope and very porous lithology which leads to higher infiltration rate and also clay soil that hold large quantity of water. The groundwater prospect maps were validated with the existing wells.

Celik *et al.* (2019) carried out a case study on evaluation of groundwater potential by GIS-based multicriteria decision making as a spatial prediction tool in Tigris River, Turkey. The AHP analysis required 8 hydrological and hydrogeological criteria were considered as influencing factors such as geomorphology, drainage density, slope, lineament density, geology, land use, rainfall and soil properties. The weights were given to each factor by the AHP method. The study shows groundwater potential zones were evaluated as very poor (19%), poor (17%), moderate (34%), good (17%), very good (13%).

Doke (2019) conducted study on delineation of the groundwater potential using remote sensing and GIS in Ulhas basin, Maharashtra. Entire basin was delineated into three potential zones viz. High, moderate and low. The study shows that about 21%, 50% and 29% areas are falling under high, moderate, and low groundwater potential zones. After validating the groundwater potential maps with existing groundwater reports of CGWB of Thane district, it was observed that groundwater potential is higher in the central coastal part of Ulhas basin which has very good lineament density and density and has agricultural land.

Hanisha *et al.* (2019) studied assessment of groundwater potential zonation by using geospatial techniques. The study was carried out at Amravati in state of Andhra pradesh. Groundwater potential zones were delineated by integrating different thematic maps and assigning weight to it. The potential zones were classified into 3 zones viz. Good, moderate, poor. 26.4 sq.km of area came under good zone, 187.3 sq.km under moderate zone and 8.0 sq.km under poor zone. Most of study area indicate the moderate potential zone. The study concluded that there is necessity of water management and more vegetation should be planned in the city.

Roy *et al.* (2019) delineated the groundwater prospect zones using GIS and remote sensing techniques. The case study was carried out in Sonepur district, Odisha, which falls under an extreme climatic region. LANDSAT 8 OLI and ASTER Level-1T were used in conjunction with Cartosat1 imagery to study in detail about study area and it's physical attributes and to prepare the groundwater prospect map using a weighted overlay method. The study shows that the region with hills shows high elevation and steep slope, low-to-moderate lineament density, relatively low rainfall and dense vegetation and it falls under the poor groundwater zone. An area having fractured rocky surfaces, alluvial patches and water bodies comes under good to very good and very good to excellent potential zones.

Siddhiraju *et al.* (2019) studied the identification of groundwater potential zones in Mandavi River basin using remote sensing, GIS and MIF techniques. The study shows that groundwater potential zones were delineated by considering different influencing factor like geology, geomorphology, LULC, density, slope, etc. Groundwater potential zones were classified into 4 zones. It was observed that only one third of area has good groundwater potential. Very good potential zones has areal extent of 319 sq. km (22%), good potential zone occupied area 103 sq. km (7%), poor potential zone occupied area 510 sq. km (35%), very poor potential zone occupied area 510 sq. km (35%).

Kumar *et al.* (2020) carried out study on identification of groundwater potential zones using RS, GIS and AHP Techniques in the part of Deccan volcanic province Maharashtra. Thematic maps like geology, geomorphology, soil maps, LULC are generated. The weightage, ranking were assigned to each thematic maps by analytic hierarchy process (AHP). The groundwater potential map were produced by overlaying the maps. This resulted into 5 different groundwater potential zones such as very poor (11.77%), poor (21.73%), moderate (30.13%), good (25.34%), and very good (11.02%). The results of study were validated by well yield data and fluctuation in groundwater corresponding the rainfall. The study concluded that the yield values changes from 5.94 to 14.88 l/s in the good to very good potential zones and 0.38 to 1.37 l/s within the poor to very poor potential zones.

Navane and Sahoo (2020) studied identification of groundwater recharge sites based on RS, GIS and multi-criteria decision tool. The study was carried out in Latur district of Maharashtra. The study shows that 8 thematic layers were integrated and based on MCDM, potential zones and recharge sites were delineated. The study area was delineated into 5 groundwater potential zones, namely ‘poor’, ‘moderate’, ‘good’, ‘very good’, and ‘excellent’, which cover 1.61%, 71.99%, 22.77%, 3.54% and 0.09% of the study area respectively. The majority of the study area (more than 73%) is dominated by ‘poor’ to ‘moderate’ groundwater potential zones.

2.2. Identification of Artificial Recharge Sites

Bhattacharya (2010) studied artificial ground water recharge with a special reference to India. The study shows that due to over exploitation of groundwater in coastal region, there is need for artificial recharge of groundwater by augmenting the natural infiltration of rainfall or surface-water into underground formations by methods such as water spreading, recharge through pits, wells, etc. The choice of a specific method is governed by local topographical, geological and soil condition.

Chowdhury *et al.* (2010) studied the delineation of groundwater recharge zones and identification of artificial recharge sites in Medinipur district in West Bengal. The Study recommended mainly check dams (permanent or semi-permanent types) at the identified sites for artificial recharge in the study area. These structures are small-scale structures that should be built across lower order streams (2^{nd} and 3^{rd} order) so as to reinforce infiltration into the aquifers. It is expected that the check dam would prevent the water flowing right down to join the higher order streams and instead permit the water to spread out the lower order streams and recharge the underlying aquifer. Other recharge structures, such as percolation ponds/tanks and on-farm reservoirs, can also be built wherever feasible in the demarcated favorable zones, especially in the moderate slopes, in order to slow down the runoff and enhance infiltration.

Saraf and Choudhari (2010) studied integrated use of GIS and remote sensing for groundwater exploration and identification of artificial recharge sites. The study shows that GIS facilitates superimposition of geological and lineament maps over FCC and leads to a better understanding of the factors affecting artificial recharge. The study indicated that all the reservoirs were constructed over weathered and fractured basalt which enhance the infiltration rate. Recharge ponds and check dams provide a good measure of artificial recharge in hard rock terrains by collecting surface run-off and increasing the surface area of infiltration.

Brema and Arulraj (2012) made a study on the identification of sites suitable for artificial recharging and groundwater flow modeling in the region of Noyyal river basin, Tamil nadu. The study found that out of a total of 21 blocks, 7 blocks (with a basin area of

659.26 km2) have greater groundwater recharge potential. Most of the suitable zones were well within the farming zone, therefore, it becomes essential to consider recharging in these locations. Owing to farming activities the groundwater level has declined considerably in the blocks such as Thondamuthur, Sulur, Avinashi and Palladam.

Subbarayan (2012) identified artificial recharge sites in a hard rock terrain using geospatial techniques. The study indicated that almost all alluvial plains and valley fills associated with high density of lineaments and lineament intersections have been classified as relatively high groundwater prospective zone. The low groundwater potential zone matches with steeply mountainous areas underlain by granite with low lineament density. Furthermore, it shows that in hard rock areas, the groundwater potential is high with high lineament density and low drainage density. Similarly, for the artificial recharge zone, the alluvial flood plain region having mild slope shows suitable.

Sina (2013) studied identification of suitable sites for aquifer recharge in Moura region of southern Portugal. The study shows that managed artificial recharge method is main solution for increasing groundwater recharge. The study observed that due to impermeable layers, insufficient groundwater storage space, and insufficient water resources the northern, western, and eastern Moura region was unsuitable for recharge. The central region of the Moura was also unsuitable as the groundwater and hydraulic potential could not be increased in the whole aquifer. The southern margin was observed to be most suitable for groundwater recharge as it had adequate groundwater storage space and an available water supply.

Deeksha (2015) studied identification of appropriate location for artificial groundwater recharging using geospatial technique in Bilaspur district. The study shows that different thematic maps including drainage, geology, lineament, soil and slope maps were considered to identify the location of groundwater recharges structures. By overlaying of these maps, potential zones were delineated which with the help of drainage order gives specific location for artificial recharge structure. Overall total of 179 numbers of Check Dam (CD) and 147 numbers of Percolation Tank sites were identified in the study areas.

Gogate and Rawal (2015) made a study on identification of potential stormwater recharge zones in dense urban context in Pune city. The study shows that GIS and remote sensing techniques is used to select artificial recharge sites in urban areas. Since most of the study area is residential, availability of rainwater from the roof-top is very high. This rainwater can be managed at source by using Low Impact Development (LID) techniques that promote recharge.

Ramireddy *et al.* (2015) identified groundwater recharge zones and artificial recharge structures for part of Tamilnadu by geospatial approach. The study suggested sites for artificial recharge by buffering out different thematic maps and add up in GIS environment. The study indicated that the areas having plain slope and low drainage density are the best suitable areas for artificial recharge through flooding and furrowing. For the percolation ponds, the area must have shallow slopes and the micro drainage catchments.

Senayake *et al.* (2015) delineated groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. Influential thematic layers such as rainfall, lineament, slope, drainage, land use/land cover, lithology, geomorphology and soil characteristics were integrated by using a weighted linear combination method to delineate groundwater potential zones. The study revealed a significant amount of artificial recharging capacity in study area. Around 49% of study area was found to have a high to moderate capability in artificial recharging.

Raviraj *et al.* (2017) studied identification of potential groundwater recharge zones using remote sensing and geographical information system in Amaravathy Basin. The study shows that high prospective zones are correspond to gentle slope, soils with sandy clay loam texture, low runoff potential, high infiltration and high rainfall and low recharge zones are corresponded to structural hills, steep slopes, soils with clay texture, high runoff potential, low infiltration and low rainfall. Check dams, boulder dams, percolation tanks, recharge pits are some artificial groundwater recharging structures which were suggested in appropriate locations of basin.

Tiwari *et al.* (2017) carried out a case study on the identification of artificial groundwater recharging zone using a GIS-based fuzzy logic in a region of the Damodar Valley. The study shows that 7 different factors such as water depth, slope, drainage, soil, infiltration, lithology, and land use were considered very useful to define suitable locations for artificial recharge. Thematic layers for these factors were prepared, classified, weighted, and integrated by employing fuzzy logic. The study concluded that about 29% area was very suitable and 31% of the area was suitable for recharging purposes in the west Bokaro coalfield.

Chandramohan *et al.* (2018) identified artificial recharges structures using remote sensing and GIS for arid and semi-arid areas. In the study land use and land cover maps, slope, lineament density, drainage, drainage density, and micro-drainage catchment area maps are used to identify the suitable sites for implementing artificial recharge structures. The total area is evaluated as moderate artificial zones (71.37 %), excellent artificial recharge zones (0.04%) and good artificial recharge zones (13.29%).

Karthick and Lakshuman (2018) studied identification of groundwater recharge sites and suitable recharge structures for Thuraiyar taluka using geospatial technology. The research suggested percolation tank, check dams, nala bund, recharge wells, de silting of tanks and recharge pits according to the condition of concern terrain. Area suggested for construction of check dams on area having 1^{st} to 4^{th} order streams along the hill foot zones and 0-5 % slope. Percolation tank are suggested for area having 1^{st} to 3^{rd} order streams located in plain area and weathered zone. Nala bund and recharge pits are suggested in plain area having 1^{st} to 4^{th} order streams.

Senthilkumar *et al.* (2019) studied identification of groundwater recharge zones using remote sensing and GIS techniques in Amaravati aquifer system, Tamil Nadu. Geospatial technology was applied in Amaravati aquifer system covering an area 12,285 km^2 for identification of artificial recharge structures by interpreting eight thematic layers. Resultant map shows 4 categories (very high, high, moderate and poor regions) for locating artificial recharge structures. About 45% of the study area has very high and high regions for locating artificial recharge structures and 40% falls in the moderate zone category. The study proposed to construct 166 masonry check dam, 155 nala bunds, 575 recharge shafts (within tanks), and 716 percolation ponds (repair, renovation and restoration). This shall create an additional groundwater resource of 198 million m^3 annually.

Arya *et al.* (2020) delineated groundwater potential zones and recommended different artificial recharge structures for augmentation of groundwater. Groundwater potential zone mapping was carried out for the Vattamalaikarai River basin in South India. The study suggested 3 check dam sites across the 3rd and 4th order streams. The study also identified 4 suitable sites for the construction of percolation ponds and 10 locations for the construction of recharge pits. The study recommended 4 injection well sites to augment groundwater in the black cotton soil regions.

Poddar *et al.* (2020) carried out study on artificial ground water recharge planning by using geospatial techniques in Hamirpur Himachal Pradesh. In the study to identify exact location of recharge site where structures should be built, overlaying drainage density and lineament density thematic maps are obtained. The study suggested Check dam structure for high (18%) recharge potential site, Boulder Bunds for moderate (73%) potential site and Percolation Tanks for poor (9%) recharge potential site.

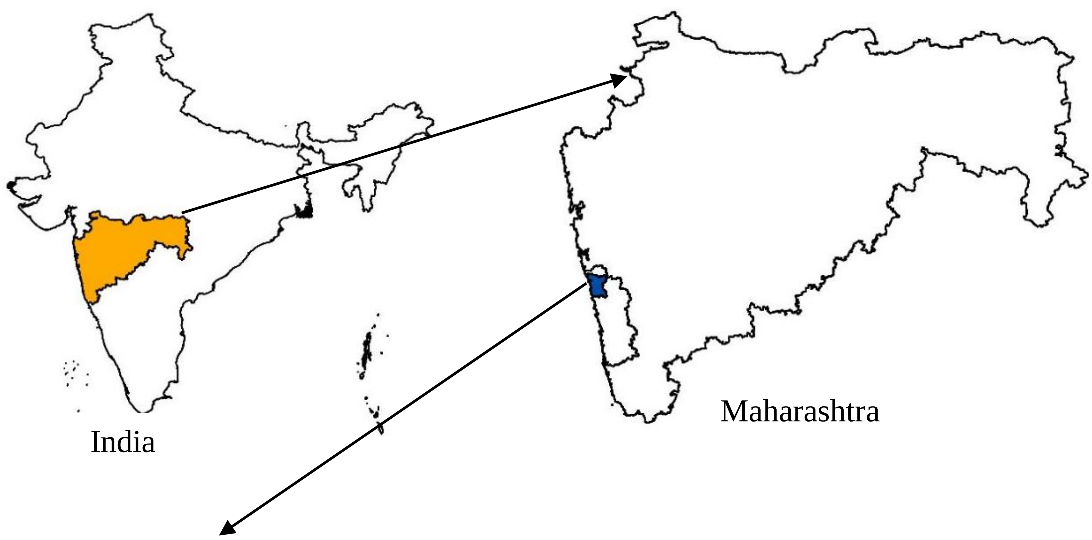
Thiyagarajan *et al.* (2020) studied effect of artificial recharge structures in improving groundwater level in hard rock region of Tamilnadu. The study evaluated effectiveness of different recharge structures such as check dam, borewell and percolation pond. With the natural recharge, increase in depth of groundwater is 1.5 m whereas in the areas having artificial recharge structures the increase in depth of groundwater is 4.7 m. The rate of recharge of a check dam and recharge shaft in percolation pond were estimated as 0.27 m^3/m^2 of ponding area/month and 0.54 m^3/m^2 of ponding area/month, respectively. The recharge shaft in percolation pond was found to be more effective and useful in recharging the groundwater.

III MATERIALS AND METHODS

This chapter deals with the description of study area, data collected, procedure adopted for delineation of groundwater potential zone and site selection for artificial recharge using geospatial technologies in Asond watershed of Dapoli tehsil in Ratnagiri district.

3.1 Study Area

Asond watershed is situated in Dapoli tehsil of Ratnagiri district, Maharashtra. The latitude 17º41' N and longitude 73º16'E are geocoordinates of Asond watershed which covered area 510.76 ha. Average annual rainfall of Wakavali is 2860 mm. Asond watershed was selected for present study as it is part of Central Experiment Station (CES) Wakavali.



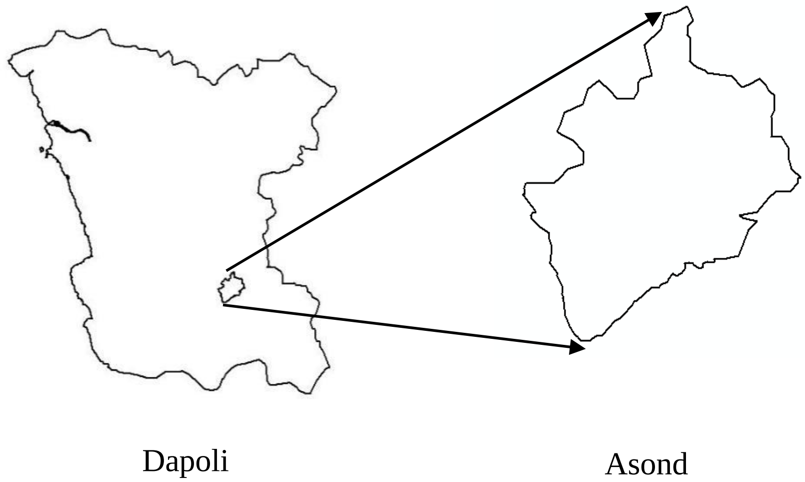


Fig 3.1: Location of Study area

3.2 Data Collection:

1. Watershed boundary map was procured from Gram-panchyat office of Asond village. Ground Control Points (GCP) were collected for georeferencing by using GPS locator.
2. SRTM DEM image data was collected from Bhuvan geoportal https://bhuvan.nrsc.gov.in .
3. LANDSAT-8 satellite image was downloaded from Earth explorer U.S. geological survey portal (https://earthexplorer.usgs.gov/).
4. Geomorphology and Lithology Data was procured from Bhukosh –geological survey of India portal (https://bhukosh.gsi.gov.in/Bhukosh/Public)

3.3 Georeferencing of Village map

Georeferencing is the process of assigning real world coordinates to each pixel of the raster. These coordinates are obtained by conducting survey with the help of GPS device for few easily identifiable features in map. The geo-coordinates of control points of the scanned village map were collected. Georeferencing tab was used to create connect raster with known positions in the map and made fit with chosen geographic coordinate system. In this case, WGS1984 coordinate system was selected.

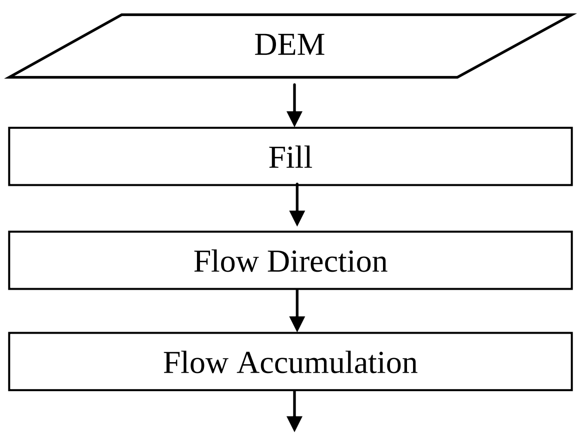
Table 3.1 Location of control points.

Sr. No.	Location (Plot No.)	Latitude (decimal degree)	Longitude (decimal degree)
1	ZP School-1	17.6852	73.2773
2	ZP School-2	17.6845	73.2772
3	Gram Panchayat Office	17.6838	73.2776
4	Rovalnath Temple (191)	17.6820	73.2716
5	Sacred Grove (582)	17.6851	73.2823
6	Sacred Grove (984)	17.6636	73.2715

After georeferencing, boundary of map is created by converting raster into polygon feature.

3.4 Watershed Delineation

Watershed is an area of land that drains runoff through all the streams to a common outlet or any point along a stream channel into large stream, river, lake or pond. It is an ideal unit for management of natural resources. Watershed delineation is the process of identifying the drainage area of an outlet. Digital Elevation model (DEM) was used for delineation of watershed. Arc-GIS 10.5 software was used for delineation of watershed.



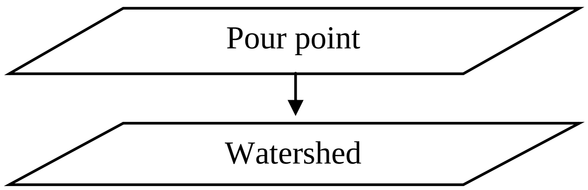


Fig. 3.2: Flow chart for watershed delineation of Asond Watershed

3.5 Geomorphological characteristics

Morphological analysis of watershed indicates geometry of watershed systematically and help to understand watershed characteristics responsible for specific hydrologic behavior. Geometry of drainage basin and its stream channel system requires measurement of following aspects (Singh, 2003).

- Linear aspects of drainage network
- Areal aspects of drainage basin
- Relief aspect of channel network

3.5.1 Linear Aspects of Drainage Network

The linear aspects of morphometric analysis of drainage basin includes stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio and length of overland flow.

3.5.1.1 Stream Order

The order of the stream is based on the connection of tributaries. In the present study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system. According to Strahler (1957), the smallest drainage lines are designated as first order. Two first order channels join with each other then a channel segment of second order is formed, where two second order stream join then a segment of third order is formed and so on. (Bansod *et al.*, 2018)

3.5.1.2 Stream number

The number of stream channel in its order is known as stream number.

3.5.1.3 Stream Length

Stream length is the length of all the streams having order u^{th}. It indicates the contributing area of the basin of that order. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. (Bansod *et al.*, 2018)

3.5.1.4 Mean Stream Length ($\bar{L}_u$)

The mean stream length defined as the summation of the total length of all streams to the number of stream (R. Suresh, 2012).

$$\bar{L}_u = \frac{\sum_{i=1}^{N} Lu}{Nu} \qquad \text{... (3.1)}$$

Where, $\bar{L}_u$ = mean length of channel of order 'u',

Nu= total no. of stream segment of order 'u'.

3.5.1.5 Stream Length Ratio (R_L)

It is the ratio of mean length of stream (Lu) of particular order to the mean stream length of next lower order (Lu-1) (Horton, 1945)

$$R_L = \frac{\bar{L}u}{\bar{L}u-1} \qquad \text{… (3.2)}$$

Where, $\bar{L}_u$ = Average length of stream of order u

$\bar{L}_{u-1}$ = Average length of stream of order u-1

3.5.1.6 Bifurcation Ratio (R_b)

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Horton, 1945)

$$R_b = \frac{Nu}{Nu+1} \qquad \text{… (3.3)}$$

Where, Rb = Bifurcation ratio

Nu = No of streams of order u

Nu+1= No of streams of order u+1

3.5.1.7 Length of overland flow

It is defined as the length of flow of water over the ground, before it becomes concentrated in defined stream channels (Horton, 1945). It is half the reciprocal of drainage density (Dd).

$$L_g = \frac{1}{2Dd} \qquad \text{… (3.4)}$$

Where, L_g = Length of overland flow

Dd = Drainage density

3.5.2 Areal Aspects of Drainage Networks

The areal aspects of morphometric characteristics of drainage basin includes form factor, circulatory ratio, elongation ratio, drainage density and constant of channel maintenance (Bansod *et al.*, 2018).

3.5.2.1 Form Factor (F_f)

It determines about the shape of the basin. Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1945)

$$F_f = \frac{Au}{Lb^2} \qquad \ldots (3.5)$$

Where, A = Area of basin

L_b = Length of basin

3.5.2.2. Circulatory Ratio (R_c)

Circulatory ratio (Rc) is estimated as the ratio of the basin area (A_u) to the area of a circle (Ac) having circumference equal to the perimeter of the basin (Miller, 1953). The value of "C" generally changes from 0 (a line) to 1 (circle). The higher the value of "C" more the circular shape of the basin and vice versa.

$$R_C = \frac{Au}{Ac} \qquad \ldots (3.6)$$

Where, Ac = Area of circle having equal perimeter as the perimeter of basin

A_u = Area of basin

3.5.2.3 Elongation Ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). High Re values indicate that the areas are having high infiltration capacity and low runoff. Values nearing 1.0 are typical of regions of low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

$$R_e = \frac{Dc}{Lbm} = \frac{2 \times \sqrt{(A/\Pi)}}{Lb} \qquad \ldots (3.7)$$

Where, D_C = Diameter of circle with the same area as the basin

L_{bm} = Maximum basin length

3.5.2.4 Drainage Density (D_d)

It is the ratio of total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945).

$$D_d = \frac{\sum_{i=1}^{K}\sum_{i=1}^{N} Lu}{Au} \qquad \ldots (3.8)$$

Where, D_d = Drainage density

K = Principal order = highest order stream

L_u=Length of stream segments

A_u=basin area, km^2

N=total no. of streams

3.5.2.5 Constant of channel maintenance (C)

It is the ratio between the area of the drainage basin and total length of all the channels, expressed as square meter per meter. It is also equal to reciprocal of drainage density (Dd).

$$C = \frac{1}{Dd} \qquad \ldots (3.9)$$

Where, D_d = Drainage density

3.5.3 Relief aspects of channel network

The relief aspects of morphological characteristics of drainage basin includes relief, relief ratio, relative relief, ruggedness number and length of overland flow (Bansod *et al.*, 2018).

3.5.3.1 Maximum relief (H)

It is the maximum vertical difference between highest and lowest point in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

3.5.3.2 Relief ratio (R_n)

It is the ratio of relief (H) to the horizontal distance (L) on which relief was measured (Schumm, 1956).

$$R_n = \frac{H}{Lh} \qquad \ldots (3.10)$$

Where, H = Maximum relief

L_h = Maximum Length

3.5.3.3 Relative relief (R_{hp})

It is the ratio of maximum watershed relief to the perimeter of watershed (Melton, 1957).

$$R_{hp} = \frac{H}{P} \times 100 \quad \ldots (3.11)$$

Where, H = basin relief

P = perimeter of basin

3.5.3.4 Ruggedness number (RN)

Ruggedness number (RN) is a product of relief (H) and drainage density (D) in the same unit (Strahler 1957). The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less dissection.

$$RN = H \times Dd \quad \ldots (3.12)$$

Where, Dd = Drainage density

H= Basin relief

3.6 Preparation of Thematic Maps

In order to delineate groundwater potential zones and artificial recharge sites, different thematic maps are required using Arc- GIS 10.5 software. Cartosat DEM and Landsat 8 satellite data are used to generate thematic maps such as Stream order map, Slope map, Land use land cover map, Drainage density map, Lithology and Geomorphology map.

3.6.1 Slope Map

Slope map is the topographic map showing changes in elevation on a highly detailed level. Slope map of study area was generated by using Cartosat- DEM clip with boundary of watershed having 30m resolution downloaded from Bhuvan portal. For generating slope map in ArcGIS, the slope tool from spatial analyst tool is used. The slope can be determined in percentage and degrees as per requirement. Fig 3.3 shows the procedure for preparation of slope map.

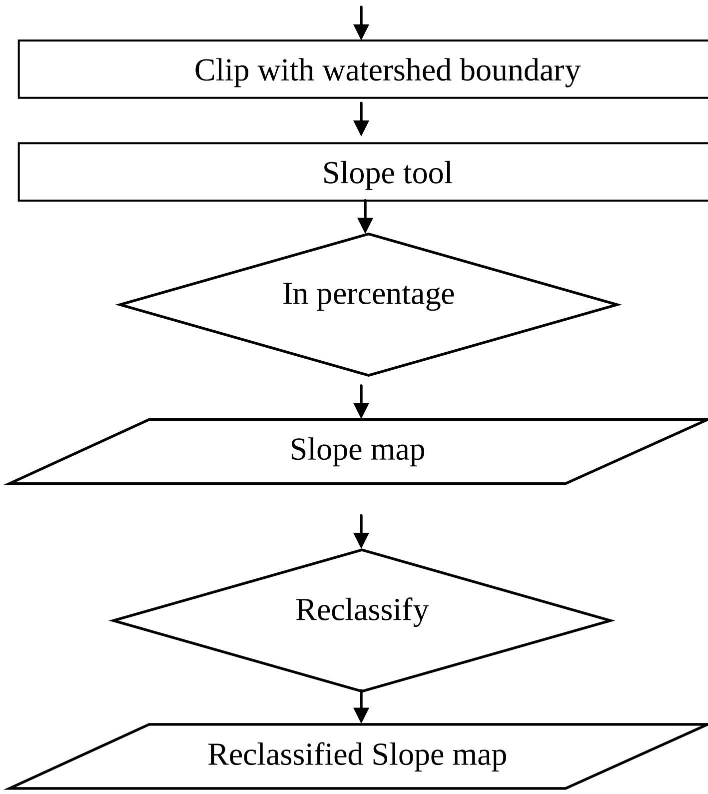
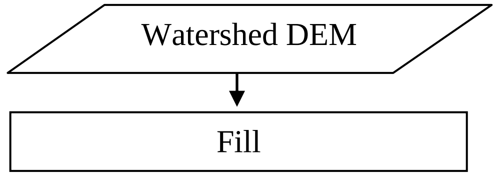


Fig. 3.3: Flow chart for preparation of Slope map

3.6.2 Stream order map

Stream order is used to describe the hierarchy of streams from top to bottom of watershed. It indicates the level of branching in a river system. There are different method to describing stream order but in the study Strahler's method is used. As per Strahler's method, when two streams of same order joins, the resulting stream has next highest order than joining streams. The stream network (order) map was generated using Cartosat- DEM. The hydrology tool of ArcGIS was used to prepare the stream order or stream network map of study area. Flowchart shows the procedure for preparing the stream order map of study area as shown in Fig. 3.4.



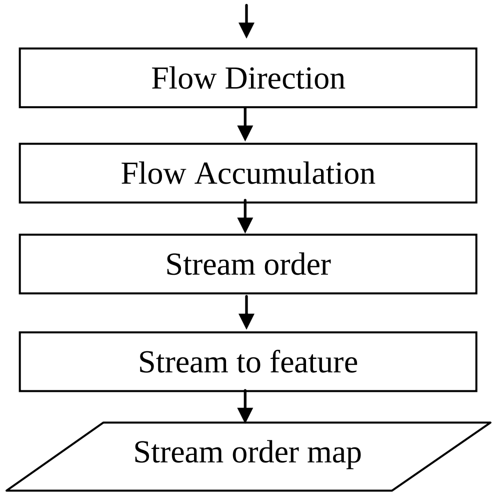


Fig. 3.4: Flow chart for stream order Map

3.6.3 Lithology Map

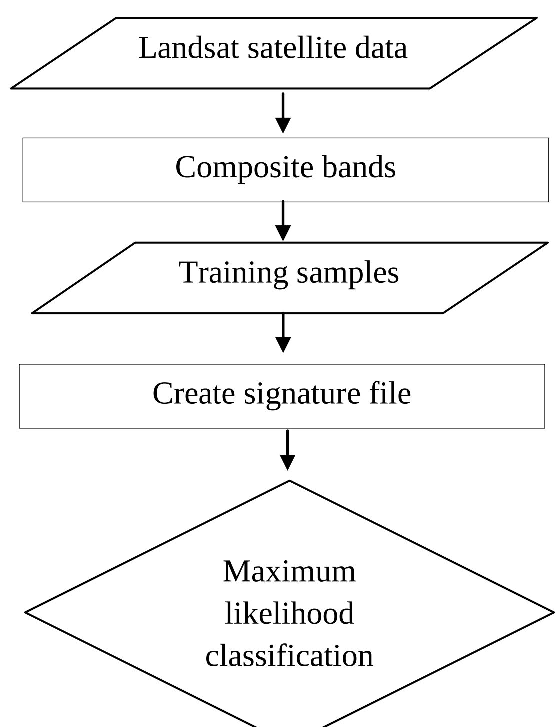
The description of the chemistry, mineral composition and physical properties of rock is known as lithology. Lithology helps in understanding porosity, permeability and water saturation properties of rocks. Lithological data is downloaded from the bhukosh geological Survey of India portal (https://bhukosh.gsi.gov.in/Bhukosh/Public). Lithology represents the type of rock present all over the study area.

3.6.4 Geomorphology Map

Geomorphology is the science which is concerned with study of landforms at surface of earth. Geomorphological maps are the graphical inventories of landscape depicting landforms and surface as well as subsurface material. Geomorphological data is downloaded from the bhukosh geological survey of India portal (https://bhukosh.gsi.gov.in/Bhukosh/Public).

3.6.5 Land Use/Land Cover Map

In the study, LANDSAT 8 satellite image downloaded from Earth explorer USGS portal (https://earthexplorer.usgs.gov/) of watershed pertaining to May 2020 was used to classify different land use/land cover classes. In this process, training sets were collected from known land use/land cover classes for classification of image. Training sample were collected and checked with google earth software for more accuracy. Maximum Likelihood Classification algorithm was followed in ArcGIS. All the polygons of the same LULC are selected and merged in a single class and renamed it. Signature file is created for same process. The flow chart for land use/ land cover is given in Fig. 3.5.



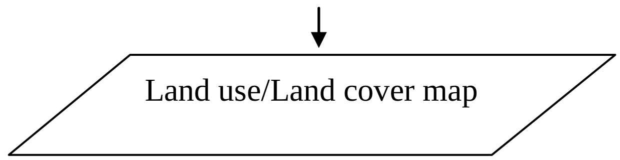
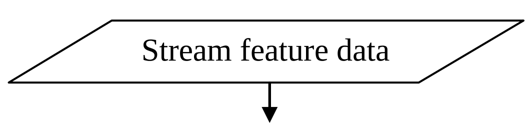


Fig. 3.5: Flow chart for Land use/Land cover Map

3.6.6 Drainage density Map

Drainage density is the indicative of infiltration and permeability of drainage basin, as well as relating to shape of hydrograph. It also measures the texture of the network. Drainage/stream density map was extracted using stream network of watershed by using line density tool. Drainage density map is generated. It is then classify into various classes. The flow chart for Drainage density is given in Fig. 3.6.



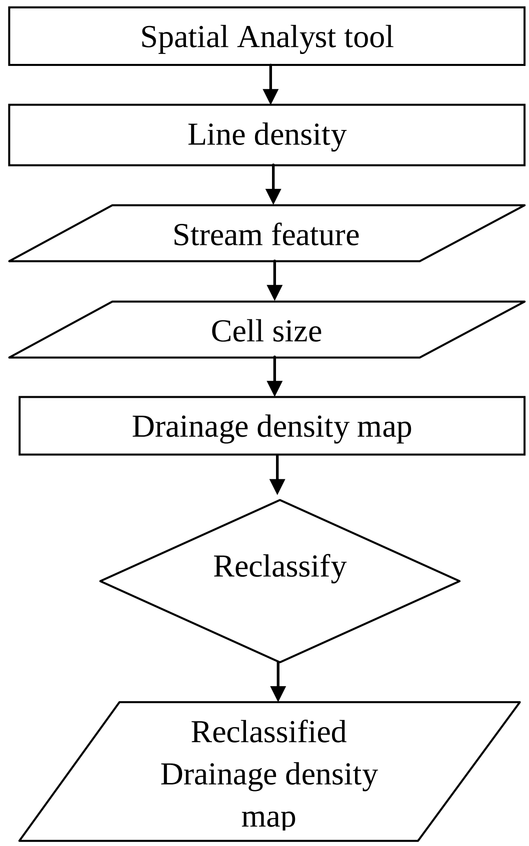


Fig. 3.6: Flow chart for Drainage Density Map

3.7 Integration of thematic maps for Groundwater potential map

All thematic maps were combined in final step in Arc GIS environment. Based on the integration of these thematic maps new thematic map was generated indicating poor, moderate, good, very good and excellent groundwater zone category. The assignment of weights using the analytical hierarchal process (AHP) is developed by Saaty (1980). The highest weights were assigned to the themes of good groundwater potentiality and lowest weights to poor groundwater potentiality. To determine the weight of each thematic layer, the judgment of comparison ratings on the Saaty’s scale was prepared. The weightages are assigned as given in Table 3.2.

Table 3.2: Weights assigned to different layers with ranking for preparation of groundwater potential map

3.8 Delineation of favourable zones for artificial recharge-

For the sustainable groundwater resource management, artificial recharge structures play a vital role in hard rock regions. Therefore, proper planning is needed in the regional and local scale for the conservation of groundwater resources through artificial recharge structures. By considering this aspect, zones favorable for artificial recharge of groundwater were to be demarcated. Ranking were assigned to each class of thematic map and all the thematic maps were integrated using weighted overlay method.

Table 3.3: Weights assigned to different layers with ranking for preparation of artificial recharge zone map (Saaty,1980)

Layer	Weight Assigned (%)	Feature Classes	Rank
Geomorphology	30	Moderately Dissected Plateau	1
		Pediment Pedi plain Complex	3
		Water body/ River	5
Lithology	20	Basalt	5
		Laterite	3
Slope	15	Very Good (0-5 %)	5
		Good (5- 10 %)	4
		Moderate (10 – 15 %)	3
		Poor (15 – 20 %)	2
		Very poor (20-25%)	1
		Very Poor (>25%)	1
Drainage Density	20	0 – 1	5
		1 – 3	4
		3 – 5	3
		5– 8	2
		>8	1
Land Use Land Cover	15	Settlement	1
		Barren Land	2
		Forest Land	3
		Agriculture Land	4

Layer	Weight Assigned (%)	Feature Classes	Rank
Geomorphology	30	Moderately Dissected Plateau	1
		Pediment Pedi plain Complex	2
		Water body/ River	2
Lithology	20	Laterite	1
		Basalt	2
Slope	15	Very Good (0-5 %)	2
		Good (5- 10 %)	1
		Moderate (10 – 15 %)	1
		Poor (15 – 20 %)	1
		Very poor (20-25%)	1
		Very Poor (>25%)	1
Drainage Density	20	0 – 1	2
		1 – 3	2
		3 – 5	1
		5– 8	1
		>8	1
Land Use Land Cover	15	Settlement	1
		Forest Land	1
		Barren Land	2
		Agriculture Land	2

3.9 Selection of suitable sites for artificial recharge

Artificial recharge is the practice of increasing the amount of water that enters an aquifer through human controlled means. Artificial recharge structures aid to augment the surface water into the aquifer layers. The suggestion of suitable artificial recharge structure depends on geologic, hydrologic, hydrogeomorphic and topographic parameters

(Bhowmick et al. 2014). The entire thematic map was overlapped to get the artificial recharge zone map. These zones are then compared with the Land use /Land cover map and ordering of drainage for the further adopting the suitable structures for rain water harvesting/artificial recharge to the aquifer system in the particular structures. Proper land management practices and suitable structures can help to reduce surface runoff and help to improve infiltration. Depending on these parameter suitable structures for artificial recharge can be constructed at suitable sites.

There are various artificial recharge structures located as per criteria. Artificial recharge structures like recharge pond, check dam, percolation tank were suitable for construction in watershed. Integrated Mission for Sustainable Development (IMSD) guidelines are used for locating artificial recharge structures in watershed. The guidelines are listed as below.

3.9.1 Percolation tank

Percolation pond is a small water storage structure constructed across stream to harvest the runoff from the catchment and impound for a longer time thereby recharging ground water storage in zone of influence of pond. Such ponds are very useful in harvesting unutilized balance of the surface flow during the period of availability and conserving it in the underground reservoirs. It should be constructed across the natural stream or watercourse. Suitability criteria for percolation pond is as:

i) The slope should be less than 10 %.

ii) The land use/ land cover may be barren or scrub land.

iii) Percolation tank can be constructed on 2^{nd} to 3^{rd} order streams.

3.9.2 Check Dam

Check dams are small devices constructed of rock, gravel bags, sandbags or other proprietary product placed across a natural or manmade channel or drainage ditch. A properly designed, constructed and maintained check dam will reduce scour and channel erosion by reducing flow velocity and encouraging sediment settlement. In general check dam are usually suggested for lower order streams upto 3^{rd} order streams. The slope of terrain should be between flat to gentle slope in order to retain maximum possible quantity of water. Suitability criteria for check dam is as follows:

i) The slope should be less than 15 %.

ii) Check dam can be constructed at convergence points of 2nd or 3rd order stream.

iii) Check dam can be constructed on 1st to 4th order streams.

3.9.3 Recharge pond

Recharge ponds is the common method to catch the surface runoff and increase the infiltration to recharge groundwater and aid in natural spring recharge in the middle of mountain regions. Recharge ponds are circular or rectangular dugout structures which were constructed a natural depression area on sloping land. Recharge ponds helps in water conservation and harvesting of surplus monsoon runoff to recharge groundwater reservoir which is otherwise going unutilized. Suitability criteria for recharge pond is as follows:

i) The slope should be less than 15 %.

ii) The land use/ land cover may be barren or scrub land.

iii) Recharge pond can be constructed on 1st to 3rd order streams.

IV. RESULTS AND DISCUSSIONS

This chapter deals with the results obtained during research work. The morphological characteristics of watershed are explained in detail in this chapter. Also, different thematic maps generated for delineation of groundwater potential zones were explained in details in following sections.

4.1 Study area

After georeferencing the scanned map of village boundary of Asond village in the form of shapefile is generated. The total area of Asond village was 788.81 ha. Area of land that drains all the rainfall to the single outlet of village was delineated. The total area of watershed calculated was 510.76 ha which was 64.75 % of area of village. Asond watershed was 270 meters above mean sea level.

4.2 Geomorphological characteristics

Basic physical geomorphological characteristics of watershed such as drainage network, shape, size, etc. were derived from digital elevation model (DEM). The drainage pattern is dendritic in nature and it is influenced by general topography of area. Dendritic drainage pattern is mostly found in area having homogeneous rock.

4.2.1 Linear aspects

4.2.1.1 Stream number

Total 26 number of streams were identified in the watershed. Out of 26 streams, Ist order streams are 13, IInd order streams are eight and five streams are of IIIrd order. More 1st order streams indicate that there was heavy runoff load to the down streams.

4.2.1.2 Stream order

The order of the stream is based on the connection of tributaries. In Study area, Stream network were identified to be up to IIIrd order. Higher the stream order, higher is the watershed area. Fig 4.2 Shows stream order map of study area.

4.2.1.3 Stream length

The total length of all the streams was calculated with help of GIS. It was found to be 10.13 km. Total length of Ist order stream length was found to be 4.06 km. IInd order stream length was 4.73 km and IIIrd order stream length was 1.34 km. Similar results were also observed by Bansod *et al.*,2018.

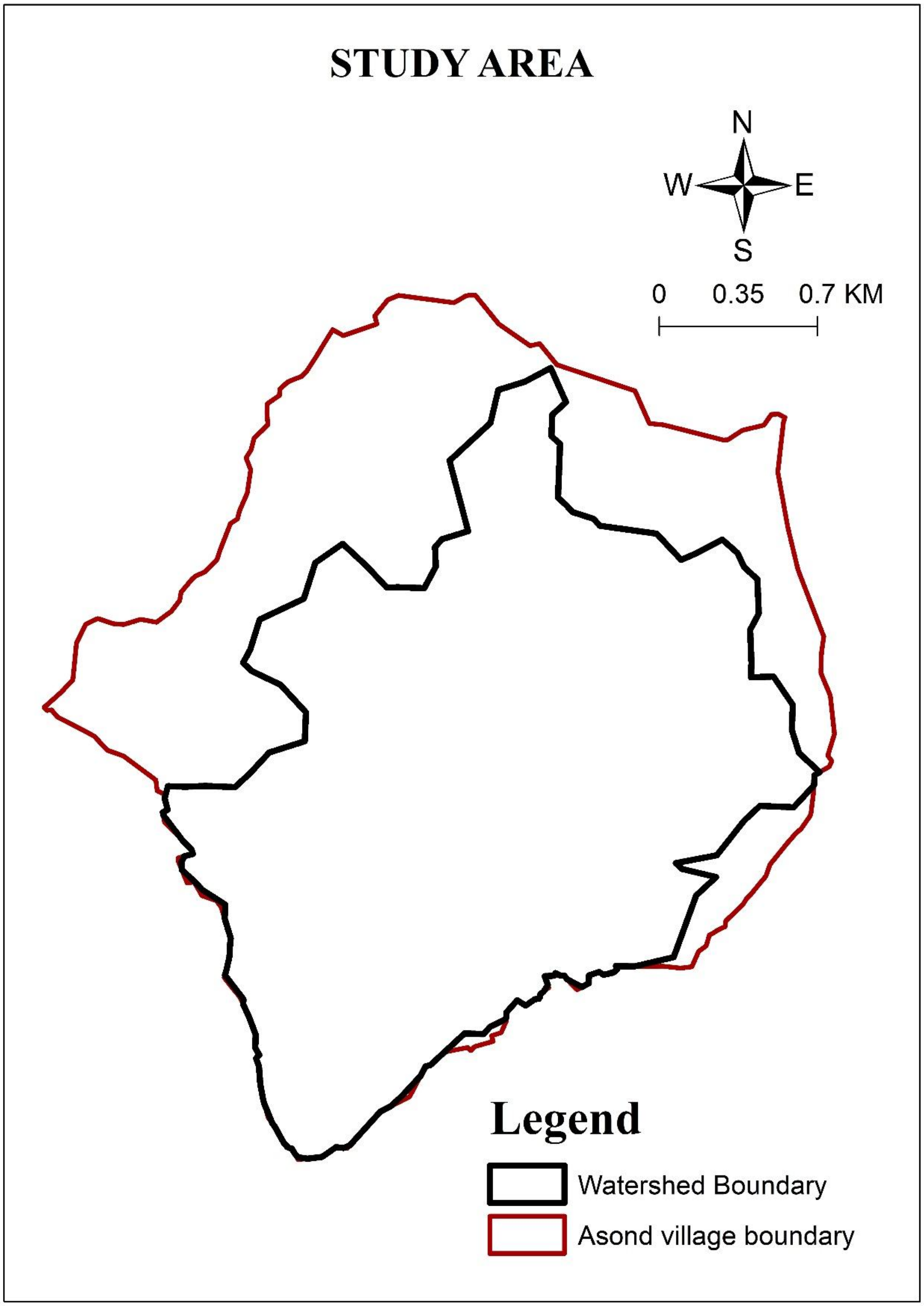

STUDY AREA
N
W
E
S
0 0.35 0.7 KM
Legend
Watershed Boundary
Asond village boundary

Fig 4.1: Location Map of study area

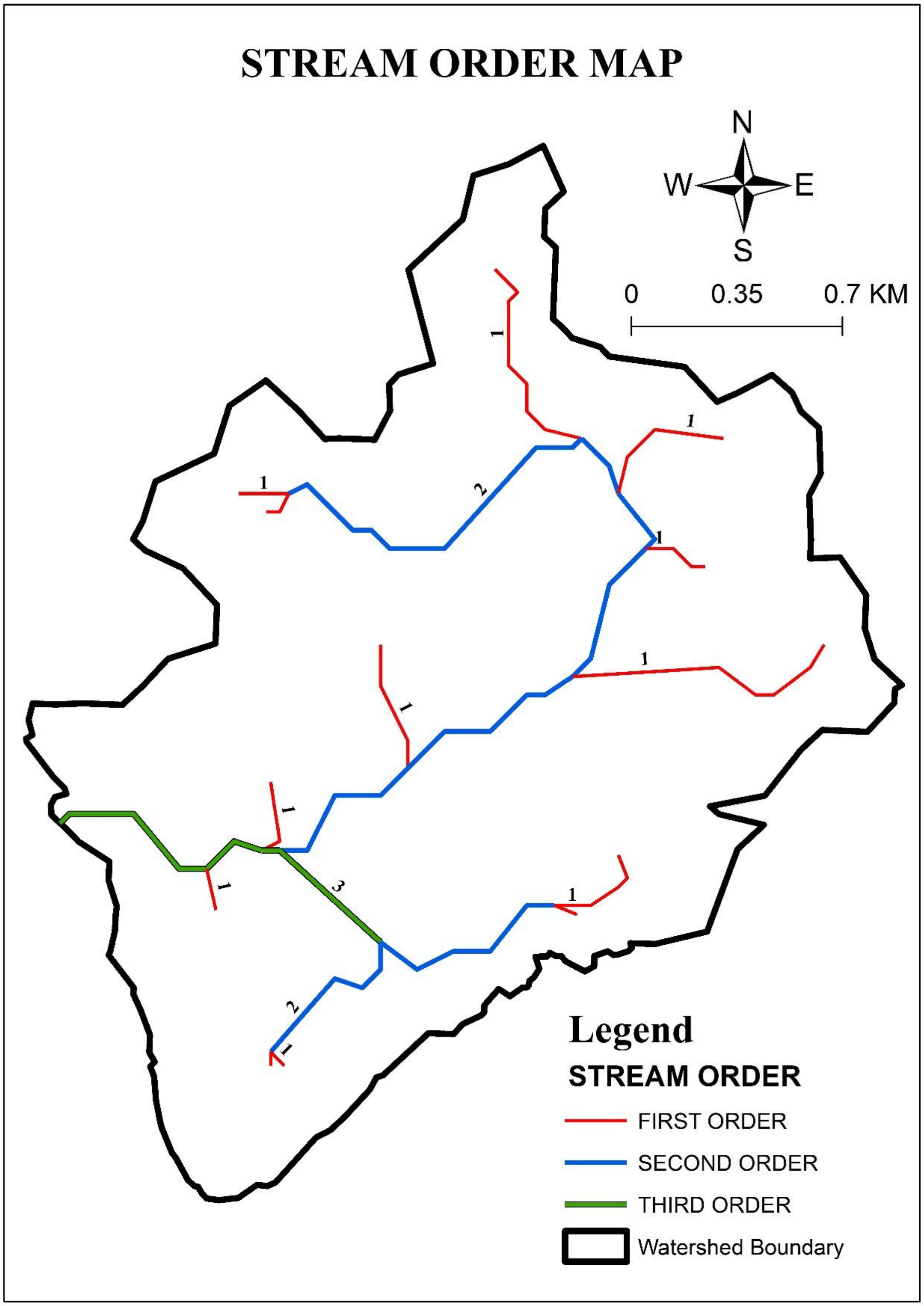

STREAM ORDER MAP
N
W
E
S
0
0.35
0.7 KM
1
1
1
2
1
1
1
1
1
1
1
3
2
1
Legend
STREAM ORDER
FIRST ORDER
SECOND ORDER
THIRD ORDER
Watershed Boundary

Fig 4.2: Stream order Map of study area

4.2.1.4 Mean stream length ($\bar{L}_u$)

The mean stream length is found to be 0.312 km, 0.591 km and 0.268 km for Ist, IInd and IIIrd order streams, respectively. It is observed that length of IInd order stream is more than length of trunk order stream. The size of watershed area which contributes to drainage network can be revealed by mean stream length. Size of watershed was relatively small.

4.2.1.5 Stream length ratio (R_L)

The stream length ratio is estimated to be 1.16 and 0.28 for II/I, III/II orders respectively. Variations in stream length ratio exists between successive streams orders.

This variation are attributed mainly due to difference in slope and topographic conditions within the watershed.

4.2.1.6 Bifurcation ratio (R_b)

Bifurcation ratio is estimated 1.62 and 1.60 for I/II, II/III orders respectively. The average bifurcation ratio is calculated as 1.61. The high value of Rb means watershed has low permeability. It also indicated that drainage pattern has strong structural control.

4.2.1.7 Length of overland flow

The length of overland flow was calculated as 0.25 km. In the study, length of overland flow was more it means watershed has less structural disturbance.

4.2.2 Areal Aspects

4.2.2.1 Form factor (Ff)

For a perfectly circular watershed the value of form factor should be 0.754. Smaller the value, less circular or more elongated the watershed. High peak flows with short duration are common for the watershed with high form factors. Elongated watershed with low form factor indicates that flow for longer duration. In the present study, the form factor was 0.63 indicating sudden peak discharge at the outlet. Similar results were also observed and strongly supported by Adhikary *et al*.,2018.

4.2.2.2 Circulatory ratio (R_c)

Circulatory ratio is generally influenced by the stream length and frequency, geology, relief, land use and land cover and climatic condition of the basin. In this study, circulatory ratio is calculated as 0.44 which indicates elongated and highly permeable homogenous geologic materials.

4.2.2.3 Elongation ratio (R_e)

The elongation ratio of watershed is calculated as 0.89. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). It is observed that the watershed is oval shaped. Similar results were also observed by Bansod *et al.*,2018.

4.2.2.4 Drainage density (D_d)

The drainage density of the watershed is calculated as 1.98 km/km^2. A low drainage density indicates permeable subsurface strata. It is a characteristic feature of coarse drainage which generally shows values less than 5.0. A low value of the drainage density indicates a relatively low density of streams and thus a slow stream response. Similar results were also observed by Bansod *et al.*,2018.

4.2.2.5 Constant of channel maintenance (C)

Value of Constant of channel maintenance(C) for the basin is 0.50 km which is reciprocal of drainage density. Higher is the average slope of the channel lower is the length of overland flow.

4.2.3 Relief Aspect

4.2.3.1 Maximum relief (H)

The maximum relief for the watershed is 105 m.

4.2.3.2 Relief ratio (R_n)

The relief ratio for watershed is 0.037. It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region. In the present study, relative relief was found to be low which represent the undulating surface with lower degree of slope. Similar results were also observed by Adhikary *et al.*,2018.

4.2.3.3 Relative relief (R_{hp})

Relative relief can be used as an index of the relative velocity of vertical tectonic movements. The relative relief of the watershed was 0.913.

4.2.3.4 Ruggedness number (RN)

The Ruggedness number for the basin is 0.208 km. This value represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase. In the present study, value of ruggedness number is low i.e. it is less susceptible to soil erosion. Similar results were also observed by Bansod *et al.*,2018.

Table 4.1 Geomorphological characteristics of Asond watershed

A) Linear Aspects of Drainage Network			
Stream order	Number of streams	Total stream length (km)	Mean stream Length(km)

1	13	4.06	0.312
2	8	4.73	0.591
3	5	1.34	0.268
Bifurcation ratio			
1st order /2nd order	2nd order/3rd order	Bifurcation ratio	
1.63	1.6	1.61	
Stream length ratio	0.28		
B)Areal Aspects Of Drainage Network			
Form Factor	0.64		
Circulatory ratio	0.45		
Elongation ratio	0.90		
Drainage density	1.98 km/sq.km		
Constant of Channel maintenance	0.50 km		
C) Relief aspects of drainage Network			
Relief	105 m		
Relief Ratio	0.037		
Relative Relief	0.913		
Ruggedness Number	0.208 km		
Length of overland flow	0.25 km		

4.3 Thematic maps

Five different influencing factors such as lithology, geomorphology, drainage density, slope and land use/land cover are inspected to demarcate different groundwater prospect zones of the Asond watershed.

4.3.1 Slope Map

The slope plays important role in delineation of groundwater potential zone map. Slope map of watershed was derived from DEM of resolution of 30 m. The slope is directly proportional to the surface runoff. As the slope of area increases, velocity of flow also increases and thereby recharge will be less. The study area is divided into six classes. The area 118.89 ha having 0-5% slope fall into ‘Excellent to very good’ category because of nearly flat terrain and relatively high infiltration rate. The 133.82 ha areas with 5-10% slope was considered as ‘Very good to good’ for groundwater storage due to slightly undulating topography with some runoff. The areas having a slope of 10-15% which covers 103.21 ha area was considered as ‘good to moderate’. Fig. 4.3 shows slope map in percentage. The areas having slope of 15-20% which covers 82.45 ha area cause relatively high runoff and low infiltration, and hence are categorized as ‘Moderate to moderately poor’. The areas having slope 20-25% (46.30 ha) and >25% (26.08 ha) were considered as ‘very poor’ due to steep slopes and high runoff. Similar results were also observed and strongly supported by Bhange et al. (2016). Table 4.2 Shows the slope map category.

Table 4.2 Slope map category

Sr. No.	Class	Slope category	Area (ha)	Area percent
1	0-5%	Excellent	118.89	23.27
2	5-10%	Very Good	133.82	26.20
3	10-15%	Good	103.21	20.20
4	15-20%	Moderate	82.45	16.14
5	20-25%	Moderately poor	46.30	9.06
6	>25%	Very poor	26.08	5.13

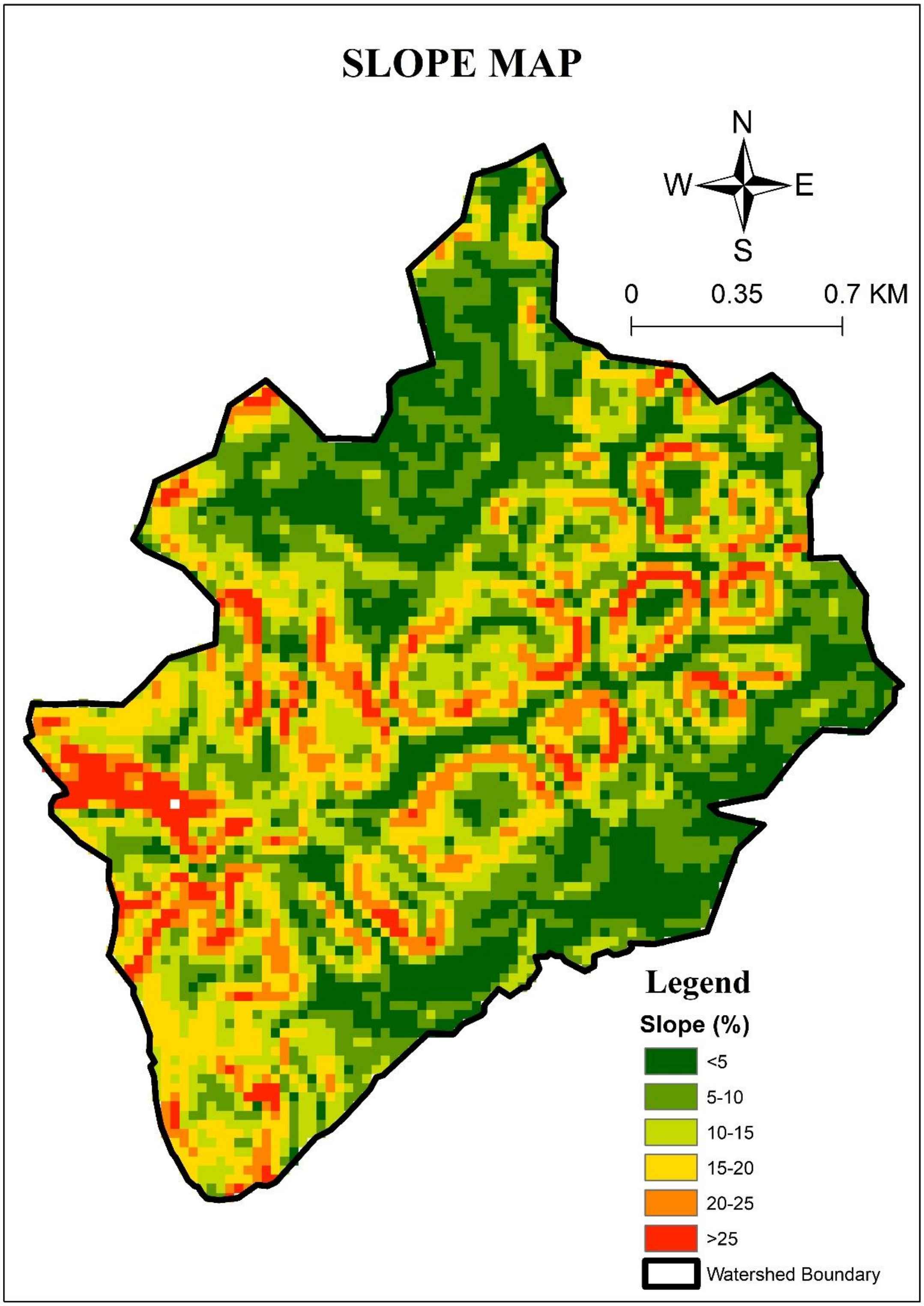


Fig 4.3: Slope Map of study are

4.3.2 Drainage Density Map

The drainage density depends indirectly on the groundwater prospect due to its correlation with surface runoff and permeability. The area that comes under a high drainage density is unsuitable for groundwater occurrence. An area with moderate drainage density indicates medium groundwater potential, and the low drainage density area indicates high groundwater prospect. The study area has been grouped into five classes. The classes of drainage density have been assigned to 'Excellent to very good' (0-1 km/km^2), 'Very good to Good'(1- 3 km/km^2), 'Good to Moderate' (3-5 km/km^2), 'Moderate to Moderately poor' (5 - 8 km/km^2) and 'Moderate Poor to poor' (> 8 km/km^2), respectively. Similar results were also observed and strongly supported by Bhange *et al*. (2016). Table 4.3 shows drainage density map of study area. The drainage density map is shown in Fig. 4.4.

Table 4.3: Drainage Density Category

Sr. No.	Drainage density (km/km^2)	Category	Area (ha)	Area percent
1	0-1	Excellent	338.03	66.18
2	1-3	Very good	25.45	4.98
3	3-5	Good	37.81	7.40
4	5-8	Moderate	83.19	16.28
5	>8	Poor	26.28	5.16

4.3.3 Land use land cover map

Land use plays a significant role in the development of groundwater resources. It controls many hydrogeological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff, etc. Surface cover provides roughness to the surface, reduce discharge thereby increases the infiltration. Supervised classification of study area shows that major portion of land use is agriculture covering area 208.26 ha., forest land covering area 137.05 ha., settlement covering area 153.86 ha and barren land covering area 11.59 ha. In the agriculture and forest areas, infiltration would be more and runoff would be less whereas in settlement rate of infiltration may decrease. Agriculture areas are considered very good groundwater potential whereas settlement is considered poor potential. Similar results were also observed and strongly supported by Bhange *et al.* (2016) and Waikar *et al.* (2014). Land use land cover classification is given in Table 4.4.

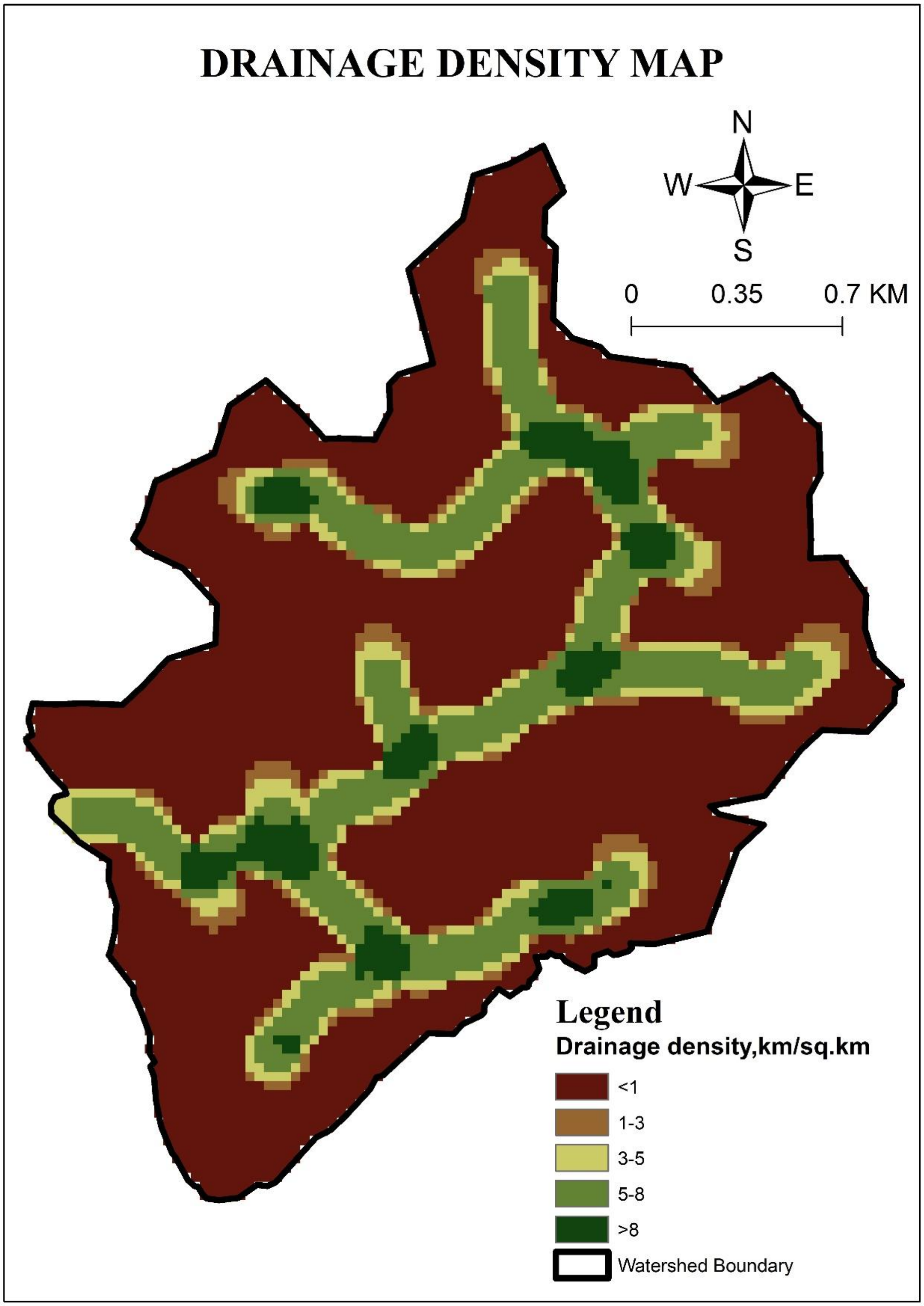


Fig 4.4: Drainage Density map of study area

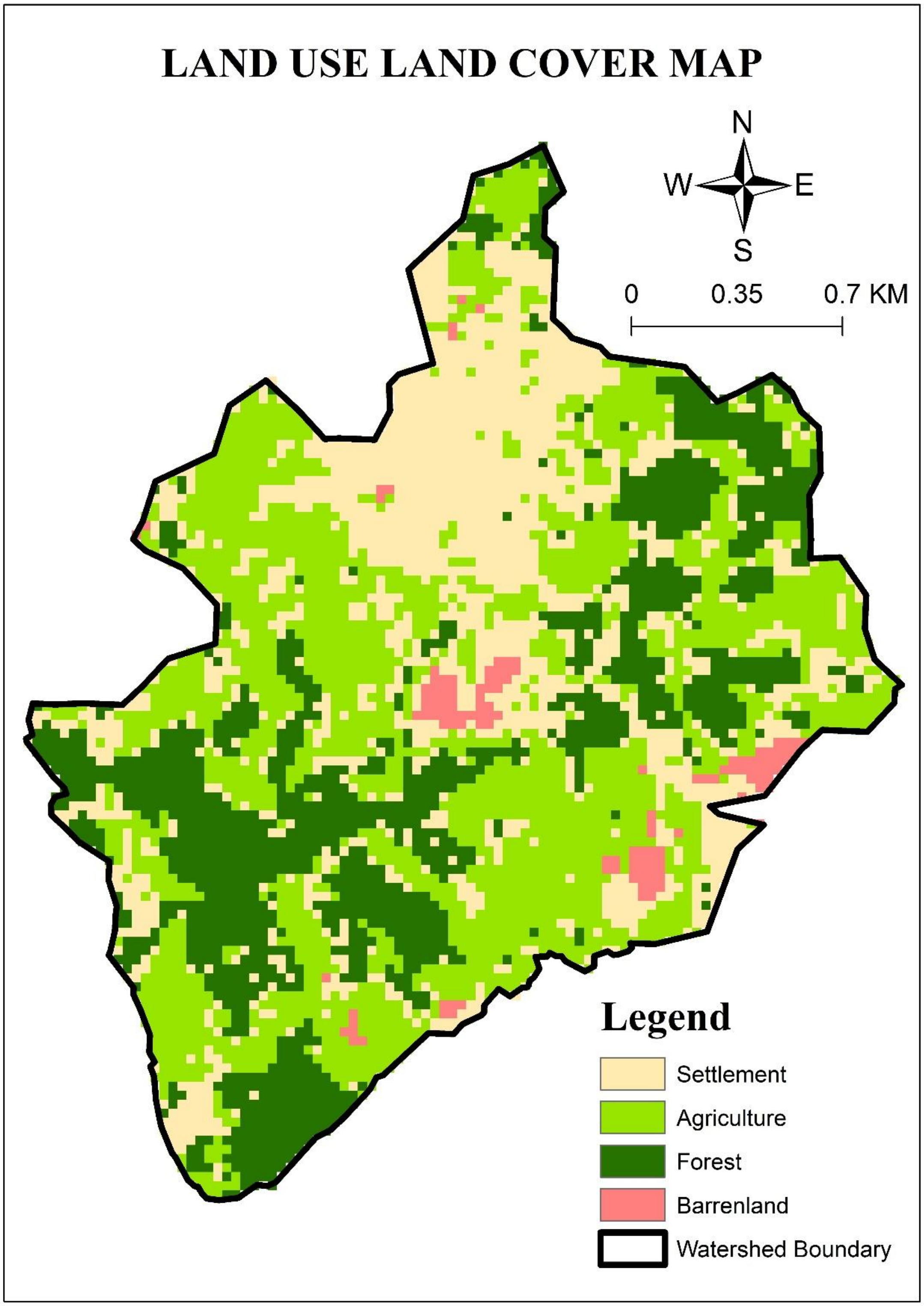


Fig 4.5: Land use/ land cover map of study area

Table 4.4: Land use land cover classification

Sr. No.	Land Use	Area (ha)	Area percent
1	Settlement	153.86	30.12
2	Agriculture	208.26	40.77
3	Forest	137.05	26.84
4	Barren land	11.59	2.27

4.3.4 Geomorphology map

Geomorphology, along with information on soil, water and vegetation has become one of the essential inputs in planning for various developmental activities. Geomorphology of an area depends upon the structural evolution of geological formation. Geomorphology reflects various land form and structural features. Many of the features are favourable for the occurrence of groundwater and classified in terms of groundwater potentiality. The geomorphic units of the watershed are divided into moderately dissected lower plateau (Structural origin), low, pediment-pediplain complex (Denudational origin), waterbodies**.** Plateaus are flat topped residual mountains seen in plains. Nature of plateau is such that it accelerates more run off so it falls under the category of poor groundwater potential zone. Pediment as the term suggests, feature usually formed at the foot of mountain. Pediments occur as gently undulating plains with moderate slope. The agriculture land in study area is constituted by pediment-pediplain complex i.e. 21.21%. Pediment-pediplain complex are considered as moderate potential for groundwater. The geomorphology of Asond watershed is given in Table 4.5.

Table 4.5 Geomorphology category of Asond watershed

Sr. No.	Geomorphic units	Area (ha)	Area percent
1	Moderately dissected lower plateau	399.17	78.15
2	Pediment-pediplain complex	108.36	21.21
3	Waterbodies	3.23	0.64

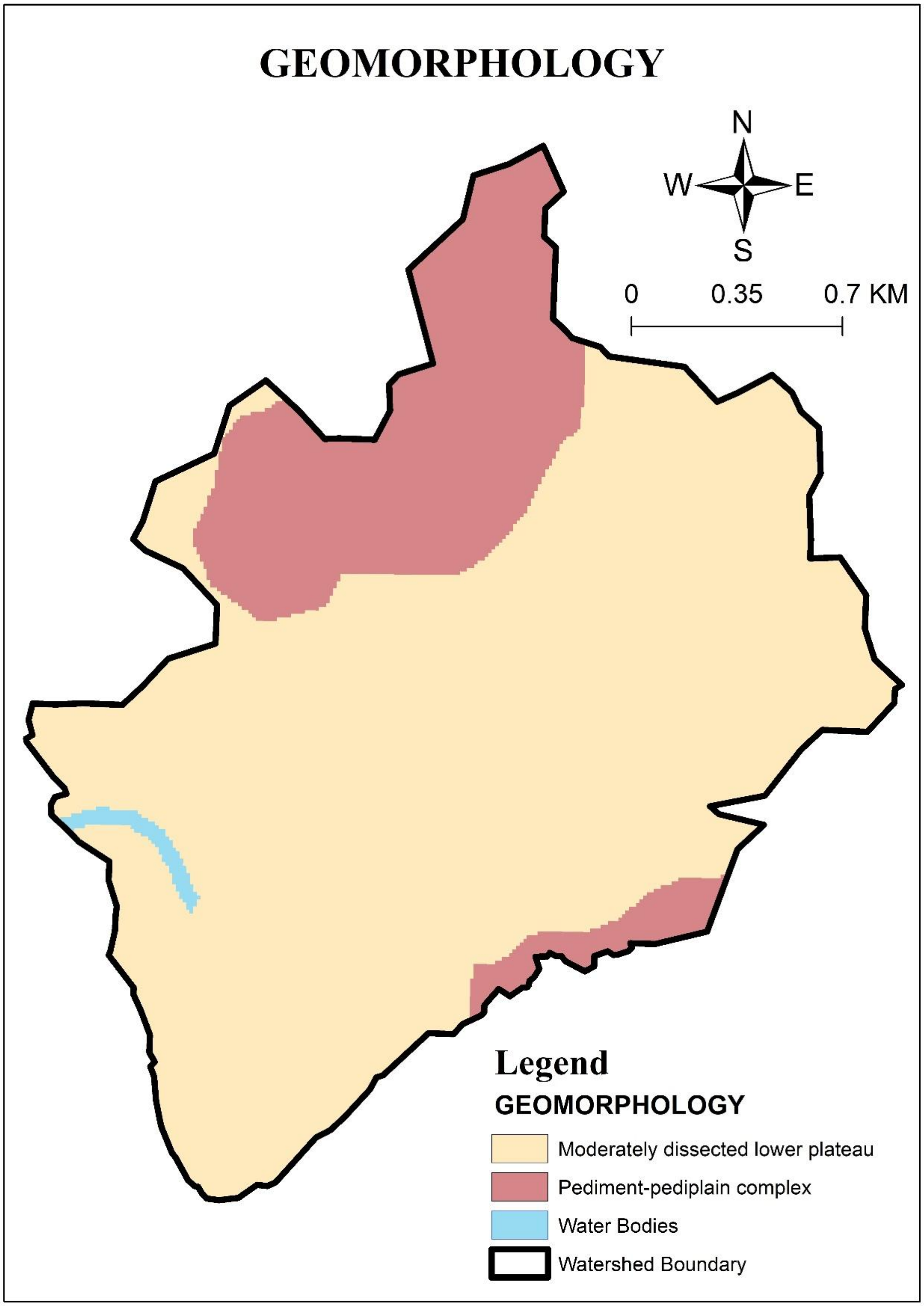


Fig 4.6: Geomorphology Map of study area

4.3.5 Lithology map

It is a very significant characteristic in predicting groundwater potential zones. The Asond watershed fall under two group of geological formation, which is (i) Laterite (ii)

Basalt. Laterite rock formation which is 37% (188.94 ha) of total area has very less water holding ability therefore runoff generated will be more and infiltration will be less. Laterite is considered very poor groundwater potential. Around 63% (321.75 ha) of total area is covered by basalt rock formation which has moderate groundwater potential. The lithology Category is given in Table 4.6

Table 4.6: Lithology category

Sr. No.	Lithologic unit	Area (ha)	Area percent
1	Laterite	188.94	36.99
2	Basalt	321.82	63.01

4.4 Delineation of Groundwater potential zones

The groundwater potential zones were generated by overlaying all the thematic maps in terms of weighted overlay method using spatial analyst tool in ArcGIS 10.2. During the weighted overlay analysis, the ranks have been given for each individual parameter of each thematic map and weight is assigned according to the influence of the different parameters.

All the thematic maps are converted into raster format and superimposed by weighted overlay method in which rank and weight wise thematic maps and integrated with one another through GIS. Geomorphology, Lithology, Drainage density were assigned higher weight, whereas the land use land cover and slope were assigned lower weight. The maximum value is given to the feature with highest groundwater potentiality and the minimum given to the lowest potential feature.

The groundwater potential map of the study area was generated using GIS and categorized into three zones such as ‘Good’, ‘Moderate’, ‘Poor’ groundwater potential.

Good groundwater potential zones are found in Pediment-pediplain formations and in the less slope area. The map shows that a good potential zone occurs in the low drainage density areas and where basalt rock are underlaid. About 15.18% i.e. 77.55 ha area of the study area falls under poor potential zone category; 62.80% i.e. 320.77 ha area falls under moderate category and 22.01% i.e. 112.44 ha area falls under good potential category. The classification of groundwater potential zone in given in Table 4.7.

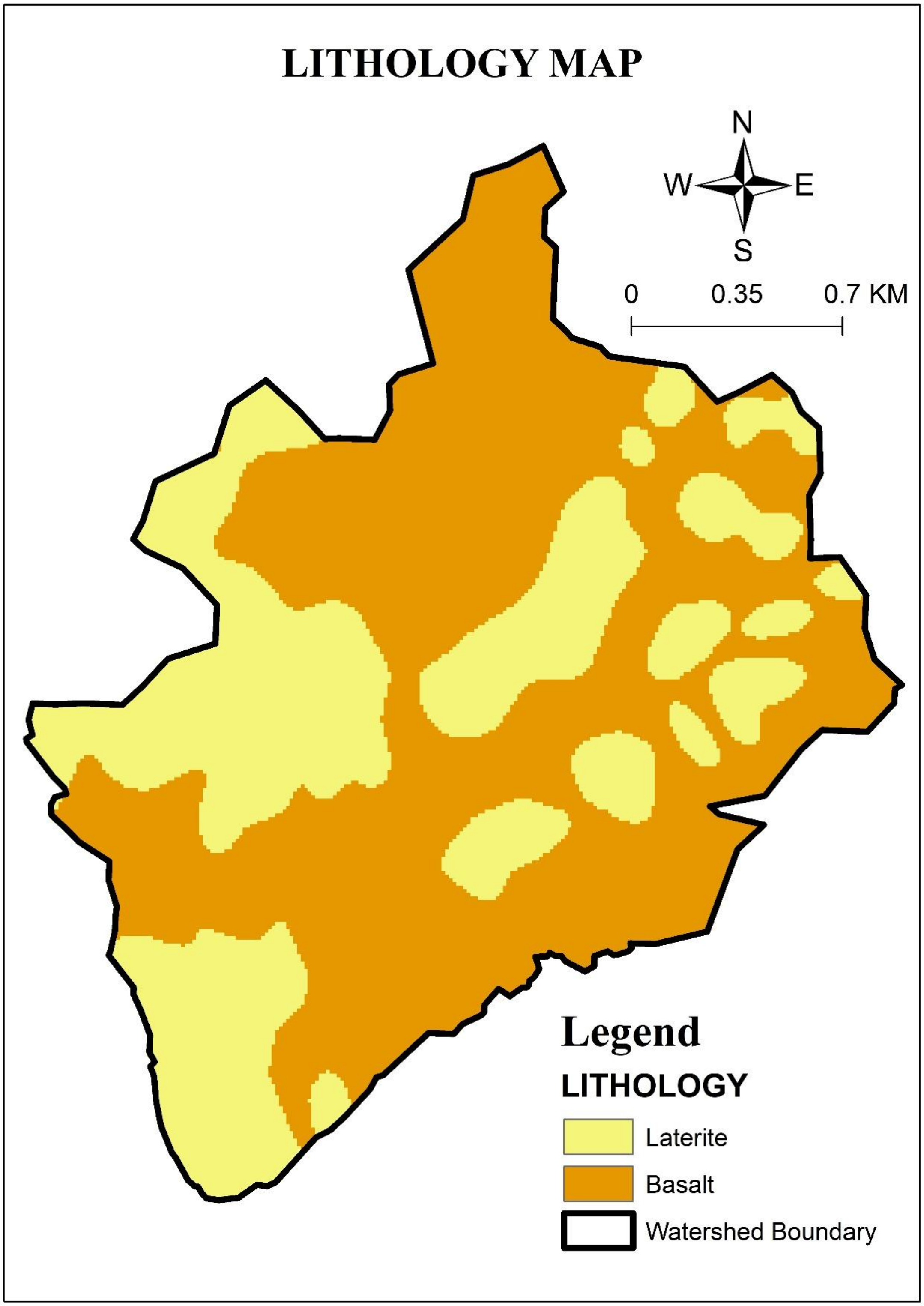


Fig 4.7: Lithology Map of study area

Table 4.7: Classification of groundwater potential zone

Sr. No.	Potential zones	Area (ha)	Area percent
1	Poor	77.55	15.18
2	Moderate	320.77	62.81
3	Good	112.44	22.01

4.5 Validation of groundwater potential zones

Validation of the data is one of the most essential works after designing any model in order to check proficiency of the predicted results. To validate the groundwater recharge zones of Asond watershed, all the major locations of wells (GPS location) are plotted in the groundwater potential maps. It is observed that all the wells are located in the moderate and good groundwater potential zones.

4.6 Delineation of Suitable zones for artificial recharge

In the study area, the infiltration of rainwater varies from place to place and also the changes occur within the same basin due to several terrain factors and rainfall availability. Poor groundwater potential and over exploitation create serious groundwater scarcity during the summer season. Therefore, proper planning is needed in the area and local scale for the conservation of groundwater resources through artificial recharge structures. By considering this aspect, zones favorable for artificial recharge of groundwater were demarcated. Geomorphology, slope, land use land cover, lithology and drainage density were considered for demarcation of suitable zones.

The map was categorized into two zones, ‘Suitable’ and ‘Not suitable’. The category ‘Suitable’ is more favorable for artificial recharge structure construction, and possesses good water-retaining capacity and storability. The suitable artificial recharge zone possesses areas with surface water bodies, flat to gentle slope, basalt rock, less drainage density, agriculture land and pediment-pediplain complex landform. The artificial recharge zone category is given in Table 4.8

Table 4.8: Artificial recharge zone category

Sr. No.	Recharge zone	Area (ha)	Area percent
1	Suitable	260.05	50.91
2	Not suitable	250.71	49.09

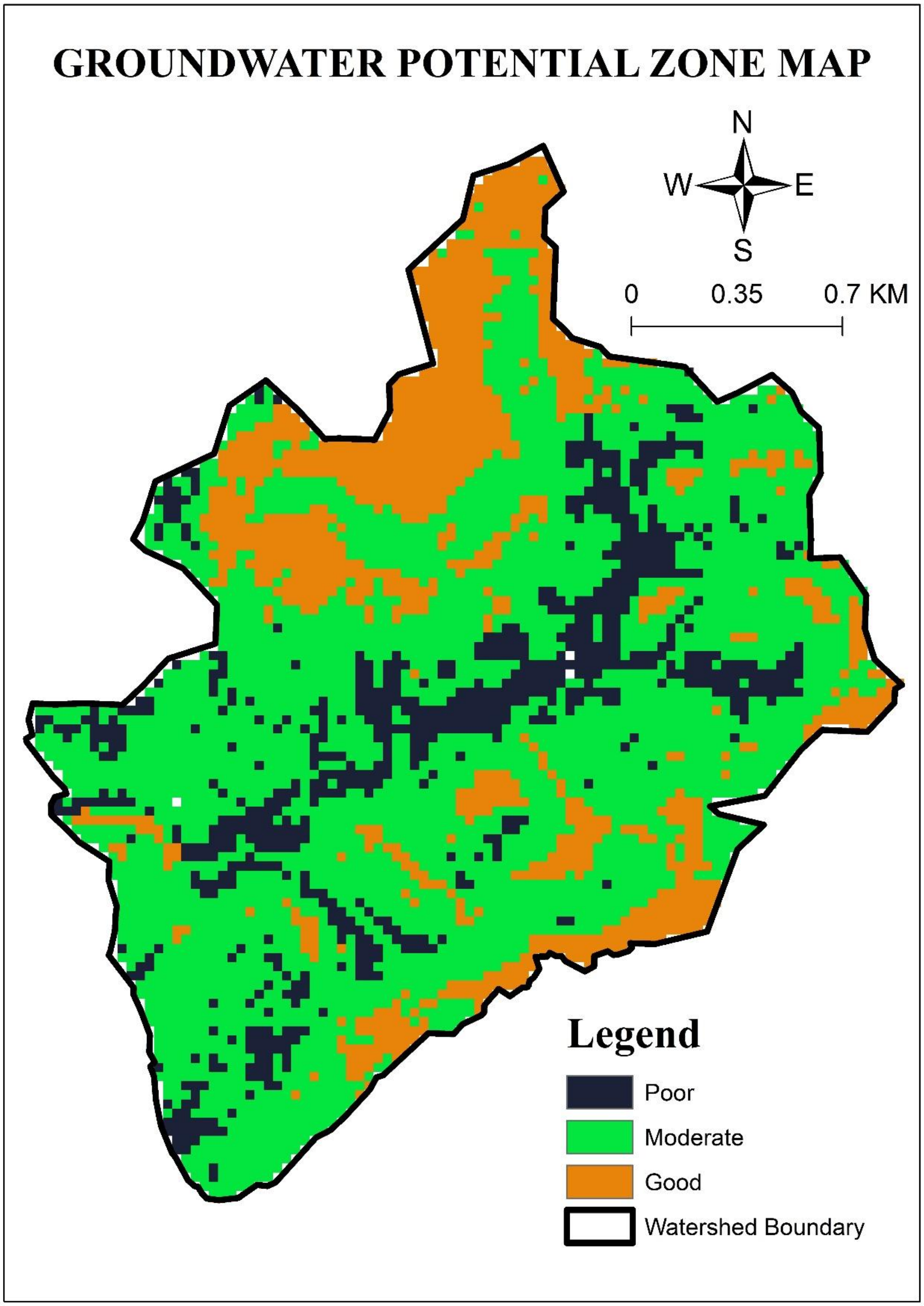


Fig 4.8: Groundwater potential zone map of study area

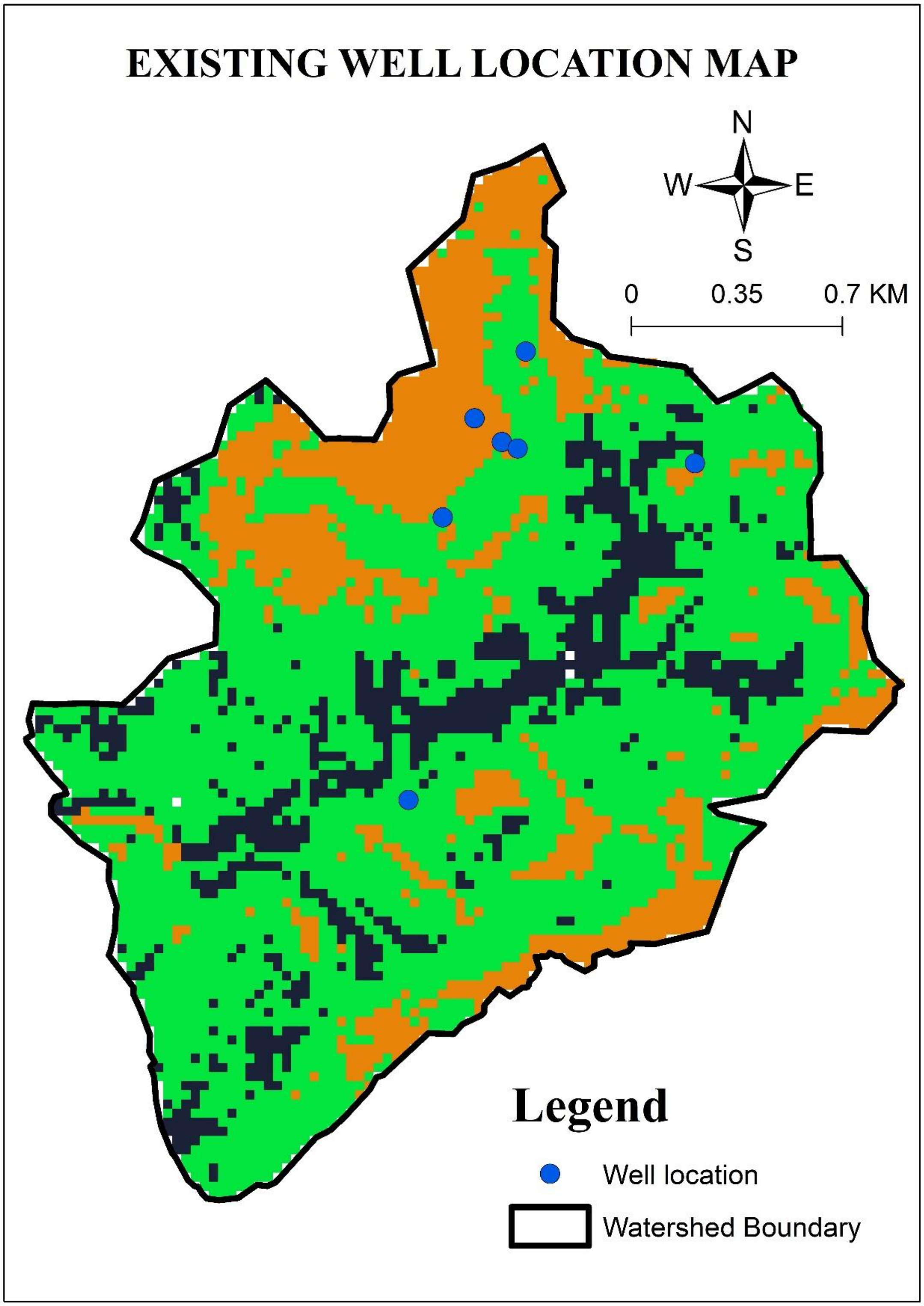

EXISTING WELL LOCATION MAP
N
W
E
S
0
0.35
0.7 KM
Legend
Well location
Watershed Boundary

Fig 4.9: Validation of groundwater potential zone

4.7 Artificial recharge structures

Artificial recharge structures helps to infiltrate the surface water into the aquifer layers. The suggestion of suitable artificial recharge structure depends on geologic, hydrologic, hydrogeomorphic and topographic parameters (Bhowmick *et al.* 2014). In hard rock areas, the rainfall runoff can be stored in the aquifers for future extraction through infiltration of water artificially. Therefore, site selection for artificial recharging highly considers the porosity, permeability and hydrogeologic parameters of the aquifers present in the area. The best artificial recharging site has the specific property of absorbing a huge quantum of water and does not transmit quickly (CGWB 2000).

Based on the artificial recharge potential zone map, the favorable artificial recharge sites were selected in the watershed. Three types of recharge structures, namely percolation tanks, check dams and recharge ponds were suggested to augment the groundwater. Suitable sites for the construction of these artificial recharge structures were also identified.

4.7.1 Recharge pond

A recharge pond is a huge dug out type recharge structure in the earth, usually square/rectangular in dimension, which collects rainwater and stores it for future use. It has only one inlet to control inflow and an outlet channel for discharging surplus water. Recharge ponds are suggested at northern part of study area near settlement where wells are more in number. These recharge ponds helps to increase the water level in wells. There are two recharge ponds suggested in study area.

4.7.2 Percolation tank

Percolation ponds are normally large tanks of manmade or natural area surrounded by a bank, which stores the rainwater, runoff and infiltrates into the deeper aquifers. These structures are suggested in the low potential zones with medium to high water table fluctuations (Bhowmick *et al.*, 2014). Three favorable sites were identified for the construction of percolation ponds to facilitate more recharge**.**

4.7.3 Check dam

Check dams are generally constructed across the downstream side of higher-order streams. These structures help to avoid scouring from excess runoff by enabling the percolation of water into the subsurface aquifers Check dams were recommended at two locations across the second and third-order streams in the runoff zones accompanied by low to moderate slope.

Table 4.9 Number of suggested artificial recharge structures

Sr. No.	Recharge Structures	Total number
1	Recharge pond	2
2	Percolation tank	3
3	Check dam	2
Total		7

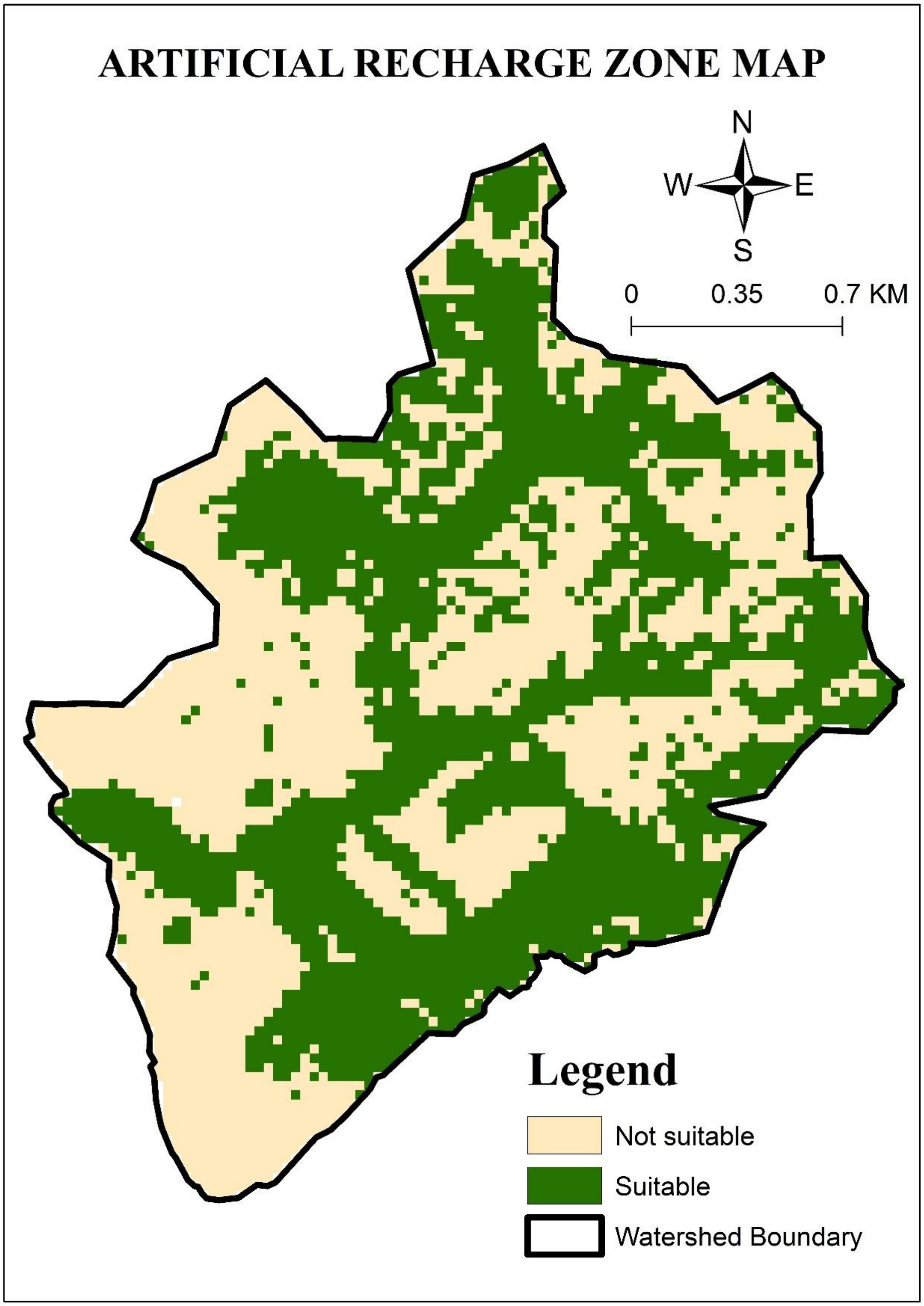


Fig 4.10: Artificial recharge zone

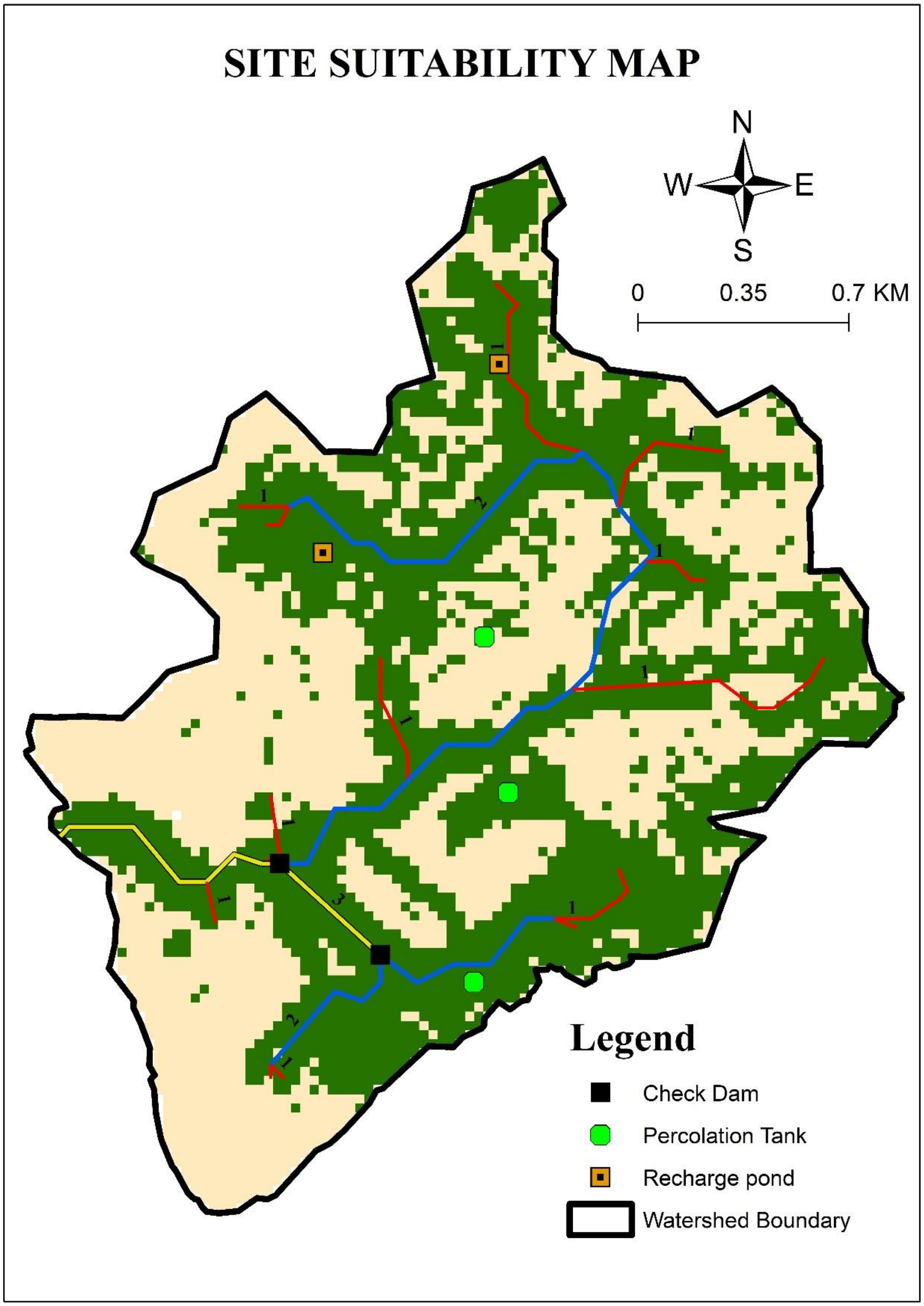
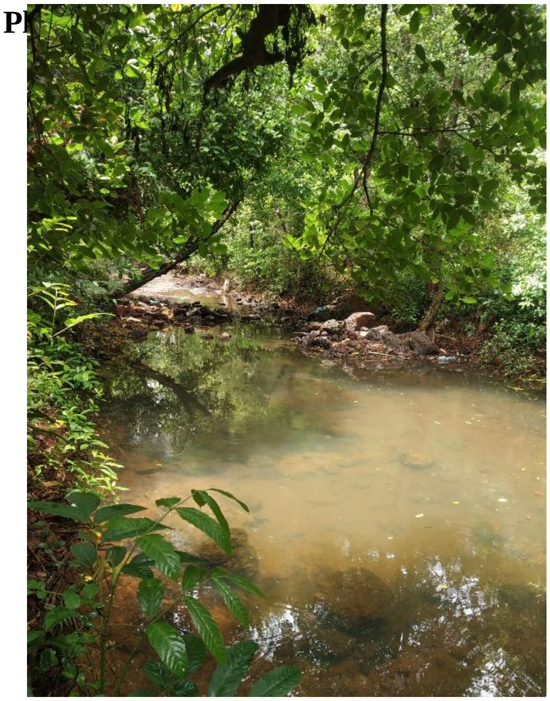


Fig 4.11: Site suitability Map of study area

Plate 4.1: Site suggested for Recharge pond

Plate 4.2: Site suggested for Percolation tank

Pl



4.8 Ground truth

Ground truth refers to the collection of information of location. This information enables calibration of remotely sensed data and helps in interpretation and analysis. In this study, ground truth is carried out by collecting locations on ground with the help of GPS of suitable sites suggested. It was then compared with the geocoordinates given by ArcGIS software. The study found slight change in location suggested when compared.

The change in location for recharge pond and percolation tank was because the land suggested by GIS for construction has uneven topography and was cultivated. Similarly, For check dam the slight change in location was because the embankment is not good for construction where the structure is suggested by GIS.

Table 4.12 Ground truth

Sr. No.	Recharge structures	Location from GIS		Location from ground	
		latitude	Longitude	latitude	Longitude
1	Recharge pond	17^{0} 40' 49.44"	73^{0} 16' 19.2"	17^{0} 40' 48.36"	73^{0} 16' 29.64"
		17^{0} 41' 11.4"	73^{0} 16' 46.56"	17^{0} 41' 12.48"	73^{0} 16' 44.4"
2	Percolation tank	17^{0} 40' 45.48"	73^{0} 16' 34.32"	17^{0} 40' 44.04"	73^{0} 16' 47.28"
		17^{0} 40' 27.12"	73^{0} 16' 44.04"	17^{0} 40' 46.2"	73^{0} 16' 44.4"
		17^{0} 40' 2.28"	73^{0} 16' 44.04"	17^{0} 40' 1.2"	73^{0} 16' 40.8"
3	Check dam	17^{0} 40' 5.88"	73^{0} 16' 31.08"	17^{0} 40' 4.8"	73^{0} 16' 30"
		17^{0} 40' 15.6"	73^{0} 16' 19.92"	17^{0} 40' 12"	73^{0} 16' 12"

V. SUMMARY AND CONCLUSIONS

This chapter summarizes the study carried out for delineation of groundwater potential zone and suitable sites for artificial recharge for Asond watershed.

5.1 Summary

Groundwater is emerging as the critical issue all over the world. Due to overuse of groundwater, water level from deep aquifers that have taken decades to accumulate have been diminishing. The study of groundwater has remained difficult, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters.

Various technique can be used to provide information about potential occurrence of groundwater. Remote sensing has been practiced for about three decades in groundwater exploration. An integrated approach of remote sensing (RS) and GIS technique is very useful in demarcation of various groundwater potential zones. Remote Sensing and GIS are one of the advanced technologies which understands sub-surface water condition with their advantages of spectral, spatial, temporal nature of data and analyse of data.

Asond is small watershed situated in Dapoli tehsil of Ratnagiri district, Maharashtra. The total area of Asond watershed was 510.76 ha. The average annual rainfall of nearby raingauge station Wakavali was 2860 mm. Even though every summer, it faced severe water scarcity due to improper water management. Therefore, there was need to delineate groundwater potential zone and suitable sites for artificial recharge to increase the groundwater level.

For delineation of groundwater potential zones, Data collected were Cartosat-DEM, Landsat 8 satellite image, scanned village boundary map were collected. Scanned village was georeferenced to create the boundary of village. Watershed was delineated by using Digital Elevation Model (DEM). Morphometric analysis of watershed was carried out for understanding the geometry and characteristics of watershed responsible for specific hydrologic behavior. The linear, areal and relief aspects of drainage pattern were calculated.

Five thematic maps such as lithology, geomorphology, drainage density, slope and land use/land cover were generated to demarcate different groundwater potential zones of the Asond watershed. Each thematic map plays a significant role in delineation of groundwater potential zone. All the thematic maps were integrated using weighted overlay method in spatial analyst tool. In weighted overlay analysis, the ranking has been given to each individual parameter of each thematic map and weights were assigned according to the influence characteristics such as geomorphology – 30%, Lithology – 20%, slope – 15%, Land use/land cover-15% and drainage density – 20% to find out the potential zones of study area.

The groundwater potential zone map was delineated and classified into three zones, 'Poor', 'Moderate' and 'Good'. Good groundwater potential zones are found in Pediment-pediplain formations and in the less slope area. The map shows that a good potential zone occurs in the low drainage density areas and where basalt rock is underlaid. 62.80% study area was covered with moderate potential zone i.e., 320.77 ha. This result was validated by conducting field survey by randomly selecting wells in study area using handheld GPS. The coordinates of each well location were obtained by GPS and plotted in the GIS platform and it clearly showed that the dug wells were exactly situated in the good and moderate groundwater potential zones.

For the sustainable groundwater resource management, artificial recharge structures play a vital role in hard rock regions. By considering this aspect, zones favorable for artificial recharge of groundwater were to be demarcated. Ranking was assigned to each class of thematic map and all the thematic maps were integrated using weighted overlay method. Geomorphology, slope, land use land cover, lithology and drainage density were considered for demarcation of suitable zones. The map was categorized into two zones, 'Suitable' and 'Not suitable'. The category 'Suitable' is more favorable for artificial recharge structure construction, and possesses good water-retaining capacity and storability. The suitable artificial recharge zone possesses areas with surface water bodies, flat to gentle slope, basalt rock, less drainage density, agriculture land and pediment-pediplain complex landform.

Based on the artificial recharge potential zone map, the favorable artificial recharge sites were selected in the watershed. Three types of recharge structures, namely percolation tanks, check dams and recharge ponds were suggested to augment the groundwater. Suitable sites for the construction of these artificial recharge structures were also identified. Recharge ponds are suggested at northern part of study area near settlement where wells are more in number. These recharge ponds help to increase the water level in wells. There are two recharge ponds suggested in study area. Three favorable sites were identified for the construction of percolation ponds to facilitate more recharge**.** Check dams were recommended at two locations across the second and third-order streams in the runoff zones accompanied by low to moderate slope.

5.2 Conclusions

1. Total 26 number of streams were identified in the watershed. Out of 26 streams, 13 are Ist order streams, 8 are IInd order streams and 5 are IIIrd order streams. Stream network were identified to be up to IIIrd order. Bifurcation ratio is estimated of 1.62 and 1.60 for I/II, II/III orders respectively. The average bifurcation ratio is calculated as 1.61.

2. The form factor was 0.63 indicating sudden peak discharge at the outlet. Circulatory ratio is calculated as 0.44 which indicates strongly elongated and highly permeable homogenous geologic materials. The elongation ratio of watershed is calculated as 0.90. It is observed that the watershed is Oval. The drainage density of the watershed is calculated as 1.98 km/km^2.

3. The relief ratio for watershed is 0.0370. The relative relief of the watershed was 0.913. The Ruggedness number for the basin is 0.208 km.

4. The groundwater potential zone map was delineated into three zones, ‘Poor’, ‘Moderate’ and ‘Good’. About 15.18% of the study area falls under poor potential zone category; 62.80% area falls under moderate category and 22.01% area falls under good potential category.

5. The Artificial recharge zone map was categorized into two zones, 'Suitable' and 'Not suitable'. 260.05 ha area falls under highly suitable zone and 250.71 ha area falls under not suitable zone.

6. Three types of recharge structures, namely percolation tanks, check dams and recharge ponds were suggested to augment the groundwater. Three percolation tank, two recharge pond and two check dam are suggested at suitable locations.

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VII. APPENDIX

APPENDIX I

7.1 Morphological characteristics of Asond watershed

7.1.1 Linear aspect of drainage network

7.1.1.1 Number of streams of order

Number of streams of 1st order = 13

Number of streams of 2nd order = 8

Number of streams of 3rd order = 5

7.1.1.2 Total stream length

Stream length of 1st order = 4.06 km

Stream length of 2nd order = 4.73 m

Stream length of 3rd order = 1.34 m

7.1.1.3 Mean stream length ($\bar{L}_u$)

$$\text{Mean length of u order stream} = \frac{\text{Total length of u order stream}}{\text{Number of streams of u order}}$$

$$\text{Mean length of 1}^{st}\text{ order stream} = \frac{4.06}{13}$$

$$= 0.312 \text{ km}$$

$$\text{Mean length of 2}^{nd}\text{ order stream} = \frac{4.73}{8}$$

$$= 0.591 \text{ km}$$

Mean length of 3rd order stream = $\frac{1.34}{5}$

= 0.268 km

7.1.1.4 Stream length ratio (R_L)

Stream length ratio = $\frac{\text{Mean length of stream (Lu) of particular order}}{\text{Mean stream length of next lower order (Lu-1)}}$

$$= \frac{\bar{L}\text{u}}{\bar{L}\text{u}-1}$$

Stream length ratio of 1st and 2nd order = $\frac{4.73}{4.06}$

= 1.16

Stream length ratio of 2nd and 3rd order = $\frac{1.34}{4.73}$

= 0.28

7.1.1.5 Bifurcation ratio (R_b)

Bifurcation ratio = $\frac{\text{number of streams of any given order}}{\text{number of streams in next higher order}}$

$$R_b = \frac{Nu}{Nu+1}$$

Bifurcation ratio for 1st and 2nd order = $\frac{13}{8}$

= 1.62

Bifurcation ratio of 2nd and 3rd order = $\frac{8}{5}$

$$= 1.6$$

$$\text{Average bifurcation ratio} = \frac{1.62+1.6}{2}$$

$$\text{Average } R_b = 1.61$$

7.1.1.6 Length of overland flow

$$Lg = \frac{1}{2Dd}$$

$$= \frac{1}{2*1.98}$$

$$L_g = 0.25 \text{ km}$$

7.1.2 Areal aspect of watershed

Area of watershed = 510.76 ha

Perimeter of watershed = 11.98 km

Maximum length of basin = 2.83 km

7.1.2.1 Form factor (Ff)

$$\text{Form factor} = \frac{\text{Basin area}}{\text{Square of basin length}}$$

$$Ff = \frac{Au}{Lb^2}$$

$$= \frac{5107600}{8008900}$$

$$= 0.63$$

7.1.2.2 Circulatory ratio (Rc)

$$R_C = \frac{Au}{Ac}$$

Perimeter = 11.98 km

2*3.14*R= 11.98

R= 1.906 km

$$R_c = \frac{5.1076}{3.142*1.90*1.90}$$

$$= \frac{5.1076}{11.4195}$$

R_c= 0.44

7.1.2.3 Elongation Ratio (Re)

$$R_e = \frac{Dc}{Lbm} = \frac{2 \times \sqrt{(A/\Pi)}}{Lb}$$

3.142 * R^2 = 5.1076

R= 1.274 km

$$\text{Elongation ratio} = \frac{2*1.274}{2.833}$$

R_e= 0.89

7.1.2.4 Drainage Density

$$D_d = \frac{\sum_{i=1}^{K} \sum_{i=1}^{N} Lu}{Au}$$

$$= \frac{10.138}{5.1076}$$

D_d = 1.98 km/km^2

7.1.2.5 Constant of channel maintenance (C)

$$C=\frac{1}{Dd}$$

$$=\frac{1}{1.98}$$

C= 0.50 km

7.1.3 Relief Aspect of watershed

7.1.3.1 Relief (H)

Relief= Elevation difference between Highest point and lowest point

= 165-60

=105 m

H= 0.105 km

7.1.3.2 Relief ratio (R_n)

$$\text{Relief ratio}=\frac{\text{Relief}}{\text{Basin length (Lb)}}$$

$$=\frac{0.105}{2.833}$$

R_n= 0.0370

7.1.3.3 Relative relief (R_{hp})

$$R_{hp}=\frac{H}{P}\times 100$$

$$= \frac{105}{11493} * 100$$

$$R_{hp} = 0.913$$

7.1.3.4 Ruggedness number (RN)

$$RN = H \times Dd$$

$$= 0.105 * 1.98$$

$$RN = 0.208$$