केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण

विभाग, जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River
Development and Ganga Rejuvenation,
Ministry of Jal Shakti
Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

PARTS OF ANGUL DISTRICT, ODISHA

दक्षिण पूर्वी क्षेत्र, भुवनेश्वर

South Eastern Region, Bhubaneswar

Government of India

Ministry of Water Resources, River Development & Ganga Rejuvenation

CENTRAL GROUND WATER BOARD

REPORT ON AQUIFER MANAGEMENT PLAN IN PARTS OF ANGUL DISTRICT ODISHA

SOUTH EASTERN REGION, BHUBANESWAR

JULY 2016

PART-I
AQUIFER MANAGEMENT PLAN IN PARTS OF ANGUL DISTRICT, ODISHA

CONTENTS

PART-I

AQUIFER MANAGEMENT PLAN IN PARTS OF ANGUL DISTRICT, ODISHA

1 INTRODUCTION

1.1 Objective

Central Ground water Board has taken up National Aquifer Mapping (NAQUIM) programme during the XIIth five year plan to carry out integration of micro level hydrogeological, geophysical, hydrochemical data and information on geology, geomorphology, soil, hydrometeorology, hydrology, landuse, cropping pattern etc on a GIS platform to formulate district, block or aquifer-wise Ground Water Management Plan. The formulation of sustainable ground water management plan would help in achieving the demand for drinking, irrigation and industrial need for water with minimal stress on the aquifer.

The activities under NAQUIM are aimed at identifying the aquifer geometry, aquifer characteristics their yield potential along with the quality of water occurring at various depths, aquifer wise assessment of ground water resources and development. Aquifer mapping itself is an improved form of groundwater management – recharge, conservation, harvesting and protocols of managing groundwater.

With these aims, Aquifer Mapping study was carried out in five blocks of Angul district in Odisha namely, Angul, Banarpal, Chhendipada, Kaniha and Talcher, which includes Talcher Coal Fields and one of the important industrial clusters in Odisha.

1.2 Scope of the study

Aquifer mapping is a multidisciplinary exercise wherein a combination of geological, geophysical, hydrological, hydrogeological, meteorological and hydro-chemical information is integrated to characterize the spatial and temporal variation of quantity and quality of the aquifer system. The selected blocks of Angul district were included under NAQUIM, because it forms a part of Gondwana sedimentary terrain with cluster of coal based industries. The main issues and challenges are the effect on ground water by waste water from towns and effluents generated from the diverse industries which has already impacted the surface water quality. Apart from that, from the ground water point of view, other problems exist in the area such as limited aquifer thickness of unconfined aquifer, poor yield from deeper aquifers, Failure of borewells due to collapsible formation, fluoride in ground water etc.

To resolve such issues, NAQUIM study was carried out with the following broad objectives: To define the aquifer geometry with precise lateral and vertical demarcation down to the depth of 200 mbgl. To define Ground water regime behaviour in time and space. To study the hydraulic characteristics of both shallow and deeper aquifer. To study the hydrochemistry of aquifer systems. To prepare Aquifer Maps indicating dispositions of aquifers along with their characterization. To formulate the Aquifer Management Plans for sustainable development and management of ground water resources.

1.3 Approach and methodology

Approach and Working Methodology: Multi-disciplinary approach involving geological, geophysical, hydrological, hydrogeological and hydro-geochemical survey would be carried out in topo-sheet scale (1:50000) to meet the aim and objectives listed above. GIS would be used to prepare the maps.

Compilation of Existing data and identification of Data gaps: Preliminary work will consist of the collection and review of all existing data which relate to the area. This usually included the results of any previous hydrogeological studies. Also, Exploration data which have been carried out by CGWB and State agencies and by local administrations shall be collected and compiled to identify the data gaps in the study area. After the Data Compilation all the data were Integrated and Analysed.

Hydrogeological Investigations: review of background information will lead the study teams to the further studies in the field, where they will employ various techniques to determine the three-dimensional extent and aquifer characteristics of the significant water-bearing formations. Key Observation wells representing the different aquifers will be established and monitoring will be carried out. Village wise well inventory and data collection is to be carried out to strengthen the data base. Exploratory wells and Observation wells will be constructed, Litholog samples of aquifer materials and ground waters samples will be collected. Aquifer Performance tests will be carried out to determine the aquifer parameters. The analysis of the data will be carried out for construct maps.

Geo -hydro chemical Investigations: Water Samples will be collected, analyzed and interpreted to bring out ground water quality scenario of the study area.

Geophysical Investigations: Geophysical studies would be carried to assist the hydrogeological survey in aquifer mapping/geometry.

Generation of relevant thematic layers using GIS:

- Drainage
- Soil
- Land use and land cover
- Geomorphology
- Geology
- Hydrogeological map
- Aquifer disposition
- Ground Water Quality

Development of aquifer wise management plan: Collaborative studies that combine geologic, hydrogeological, hydrological, geochemical and geophysical information are to be integrated. Determining aquifer potential for effective, development and management are cantered on for long-term sustainable development of aquifers.

1.4 Study area

During XII five year plan, the National Aquifer Mapping Programme (NAQUIM) were taken up for detailed hydrogeological investigation, data-gap analysis and Aquifer Mapping in five blocks of Angul district namely Angul, Banarpal, Chhendipada, Kaniha and Talcher covering an area of 3088.4 sq. km., during the period 2012-2015. The index map of the study area is presented in **Fig. 1.1a** while an administrative map is presented as **Fig. 1.1b.**

1.5 Data Adequacy and Data Gap Analysis:

The available data of the Exploratory wells drilled by Central Ground Water Board, Southeastern Region, Bhubaneswar, Geophysical Survey carried out in the area, Ground water monitoring stations and ground water quality stations monitored by Central Ground Water Board were compiled and analysed for adequacy of the same for the aquifer mapping studies. The data adequacy and data gap analysis was carried out for each of the quadrant of falling in the study area mainly in respect of following primary and essential data requirements:

Exploratory Wells

Geophysical Surveys

Ground Water Monitoring and

Ground Water Quality

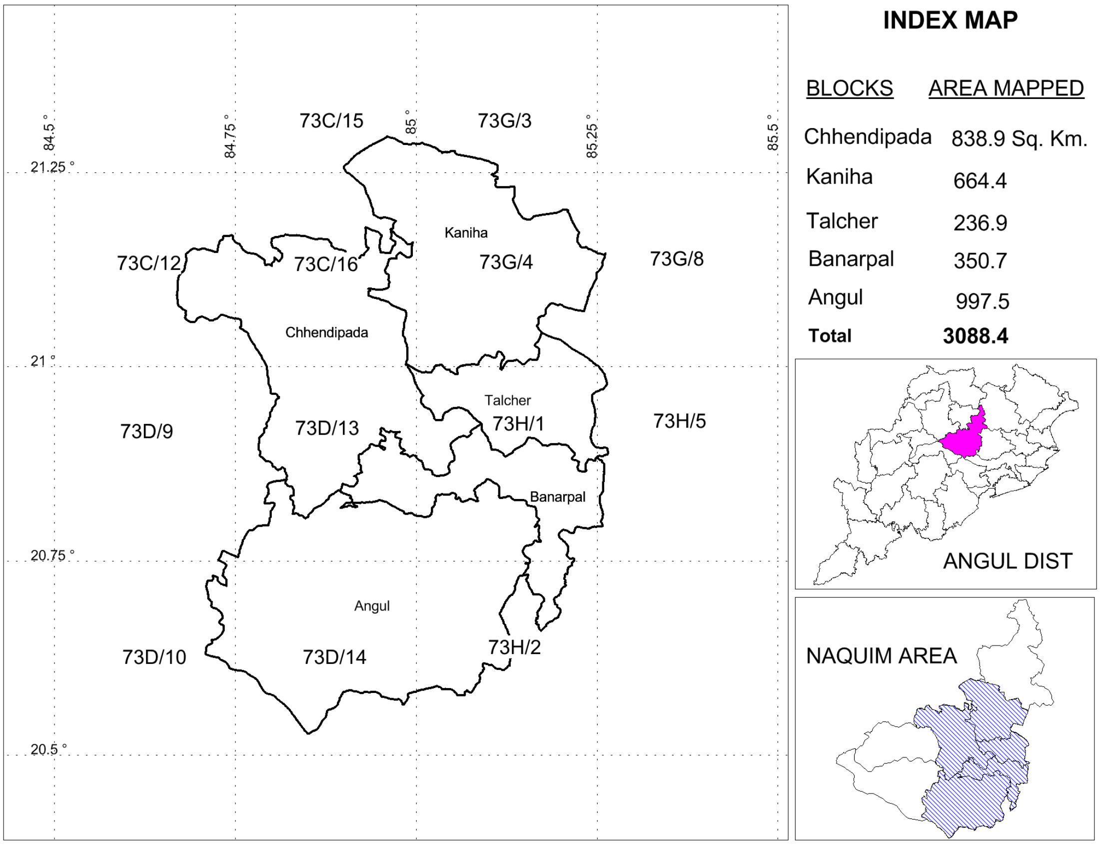


Fig. 1.1a: Index map of study area under NAQUIM in Angul District

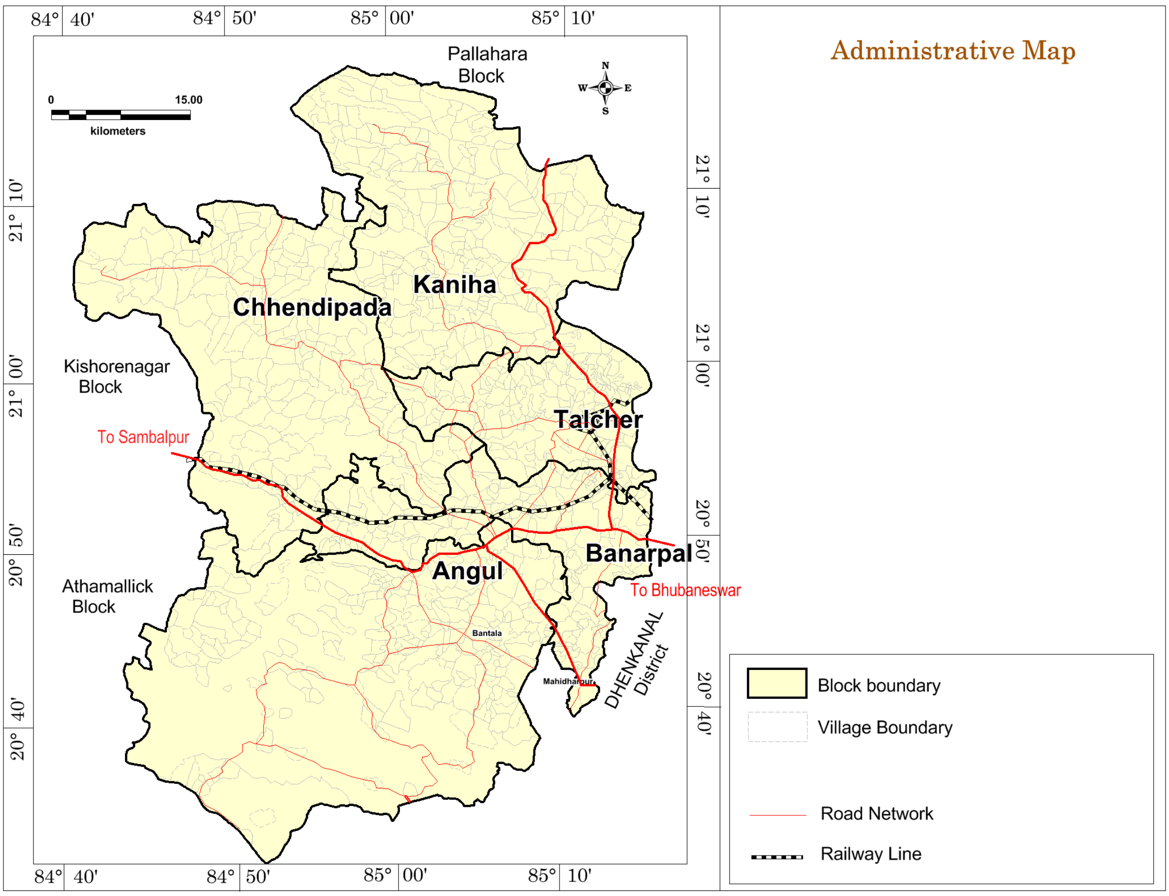


Fig. 1.1b: Administrative map of Study area in parts of Angul District

After taking into consideration, the available data of Ground Water Exploration, Geophysical survey, Ground Water Monitoring and Ground Water Quality, the data adequacy and datagap analysis was carried out.

As the study area is part of hardrock area where ground water occurs in phreatic condition in weathered portion generally up to 30 meters depth and in semi-confined condition between 30 to 200 depths. Only two Aquifer system in hardrock areas i.e. Aquifer-I which extends up to weathered Zone followed by Aquifer-II which normally extends in the fractured portion of hardrock generally between 30 to 200 meter depth. Generally, water-bearing fractures also not uniform, the depth of water bearing fractures varies from one exploratory well to another.

1.5.1 Exploratory Wells

The information in respect of un-confined/Phreatic aquifer has been generated from the dug wells present in the area. Data from CGWB Exploratory wells (EW), OW and Piezometers are necessary for establishing aquifer geometry and determining aquifer parameters.

The existing exploratory wells drilled in the area under Ground Water Exploration programme of CGWB is presented in F**ig. 1.2**. The data gap analysis indicates that, 31 additional exploratory wells are required in the area.

1.5.2 Ground Water Geophysical Surveys

Ground water geophysical survey data (VES) is required for filling gaps while establishing aquifer geometry. So far no geophysical survey has been carried out in the aquifer mapping area of Angul district. The data gap analysis indicates that, 109 VES have to be carried out in the area.

1.5.3 Ground Water Monitoring

For ground water regime monitoring, open/dugwells were considered for phreatic aquifer and piezometers for monitoring deeper aquifers.The frequency of monitoring is four times annually (May, Aug., Nov. & Jan.) for three years in continuation to generate the long term data of the area.The locations of existing ground water monitoring stations are given in F**ig. 1.3**. The data gap analysis indicates that the 266 additional ground water monitoring stations are required in the area.

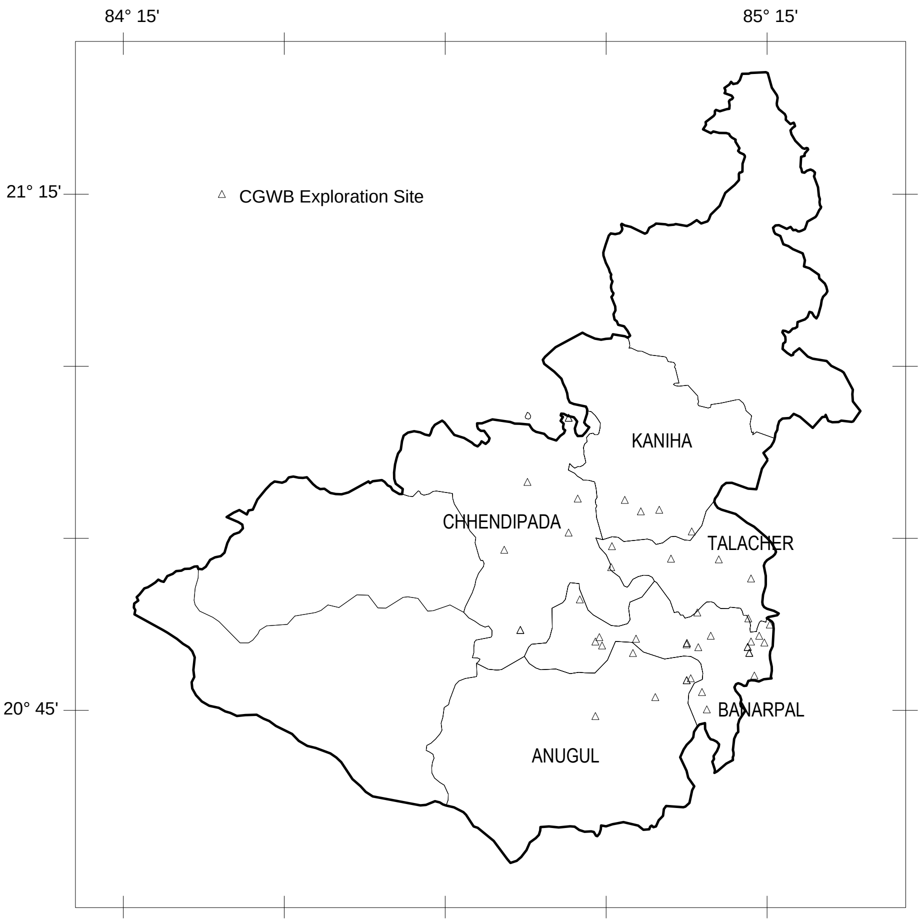


Fig. 1.2: Location of existing Exploratory wells in the aquifer mapping area, Angul District

1.5.4 Ground Water Quality

For the assessment of ground water quality, water sample from open/dugwells has to be collected for phreatic aquifer and for fracture zone aquifer water sample may be collected from EW/OW constructed for exploration. The locations of existing groundwater quality stations are given in **Fig. 1.4**. The data gap analysis indicates that the 419 additional ground water sampling stations are required in the area.

1.6 Data Gap Identification and Data Generation

The summarised details of required, existing and datagap of Exploratory Wells, Ground Water Monitoring Stations and Ground Water Quality Stations is given below and discussed in detail.

EXPLORATORY DATA			GEOPHYSICAL DATA			GW MONITORING DATA			GW QUALITY DATA		
Req.	Exist.	Gap	Req	Exist.	Gap	Req.	Exist.	Gap	Req.	Exist.	Gap
67	36	31	109	0	109	309	43	266	451	32	419

After the data gap completed, further field works were carried out for generation of additional data and minimisation of the data gaps.

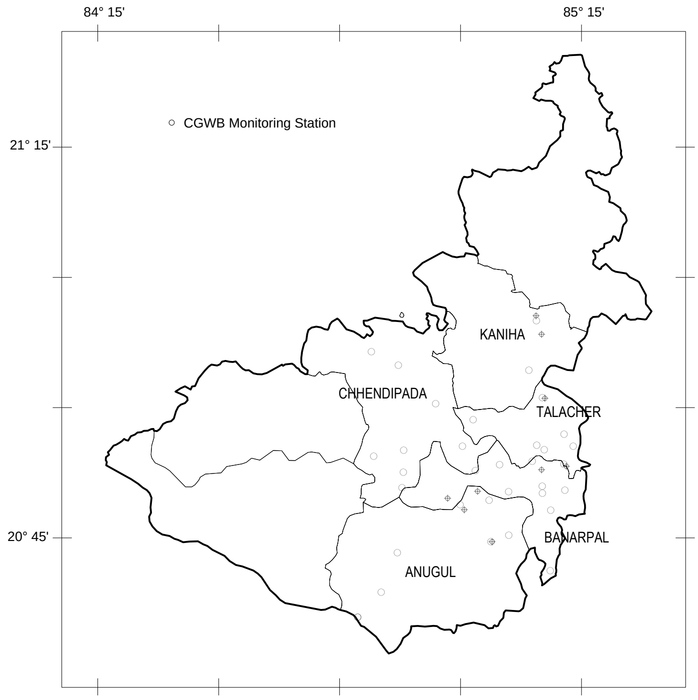


Fig. 1.3: Location of existing GW monitoring stations in the aquifer mapping area, Angul District

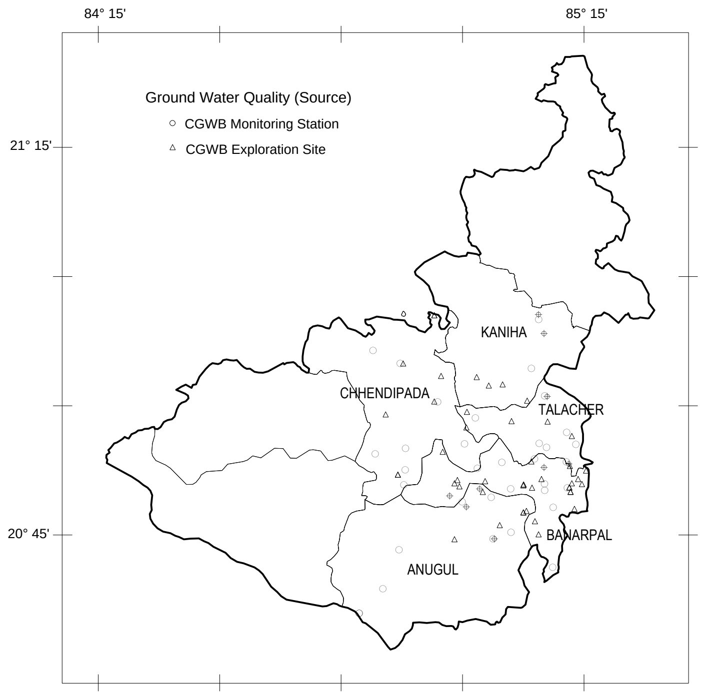


Fig. 1.4: Location of existing Quality sampling stations, Angul District

2 RAINFALL AND CLIMATE

The area experiences the sub-tropical to tropical temperate monsoon climate and characterised by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. December is the coldest month with mean daily maximum temperature at 26.9^{0}C and the mean daily minimum temperature at 13.4^{0}C. Both day and night temperature increases rapidly from March and by May the mean daily maximum temperature reaches to 42^{0}C, while the mean minimum temperature is 26.8^{0}C. As per the IMD observation in the district, the air is generally dry except during the monsoon period. In the summer months, the relative humidity is low in the range of 30%. During monsoon, the humidity goes up to 82% or more. Wind velocity in general is low to moderate with some increase in summer and monsoon season. Winds are mostly blown from southwest and northeast direction during monsoon period. In the cold season winds are mainly from west or north. In the summer months, the wind flows from variable directions. The mean annual wind speed is 6.8 km. /hr. The mean monthly potential evapotranspiration value range from 40 mm in December to 326 mm in May.

The South-west monsoon is the principal source of rainfall in the area. The normal rainfall of the district is 1401.9 mm. The rainfall pattern is erratic and drought is a common feature of the district. The long term analysis of rainfall data recorded at block headquarters for the period 1995-2014 has been carried out and the salient features of rainfall analysis are presented in **Table 2.1.**

Table 2.1: Long-term rainfall analyses Angul district

Sl No	Station	Years	No of Years	Avg. Annual Rainfall (mm)	Coefficient of Variation (%)	Droughts (No of yrs / % of Tot. Yrs)	Rainfall Received (No of yrs/ % of Tot. Yrs)		Rainfall Trend mm/yr
							Normal	Excess	
1	Angul	1995-2014	20	1241.8	14	1/5	19/95	0/0	4.39
2	Banarpal	1995-2014	20	1142.3	25	3/15	14/70	3/15	20.4
3	Chhendipada	1995-2014	20	1126.3	22	2/10	15/75	3/15	3.5
4	Kaniha	1995-2014	20	1197.4	31	4/20	14/70	2/10	-0.95
5	Talcher	1995-2014	20	1059.6	31	5/25	11/55	4/20	34.73

Perusal of **Table 2.1** shows that

1. The coefficient of variation in rainfall is minimum 14% in Angul block and maximum 31% in Kaniha and Talcher blocks.
2. Normal rainfall has been received in 55% to 95 % of the years.
3. The rainfall trend indicates that the southern blocks viz. Angul, Banarpal and Talcher have increasing rainfall over the year in comparison to the rest blocks.

3 PHYSIOGRAPHIC SETUP

3.1 Physiography

Physiographically the district can be divided into three regions :

(i) Northern Mountainous Region

(ii) Central Undulating Plain

(iii) Southern & South-western Mountainous Region.

The variation in land elevations above MSL is shown in **Fig. 3.1**.

3.1.1 Northern Mountainous Region

The regions contains WNW – ESE trending hills immediately north of the Talcher coal field and NW-SE trending hills towards the boundary of Keonjhar district which locally change to E-W direction and form the Malayagiri hill, in the south of Pallahara. Malayagiri hill contains one of the loftiest peaks (1,187 m.a.m.s.l in Orissa. The hills and ridges are separated by broad valleys and low hilly areas. The heights above sea level of this region vary from about 76 meters on the bank of Brahmani river to 1,187 meters on Malayagiri peak. The high hills of this region are composed of Quartzites while the lesser hills are made of Quartz-Mica schists, Granites and other rocks. The broad valleys are mostly underlain by gneissic rocks.

3.1.2 Central Undulating Plain

The Central part of the district is characterized by undulating plain. This region is covered by Talcher subdivision and northern parts of Angul and Athmalik subdivisions. The Brahmani valley portion of this region exposes mainly Granites and its variants and Gneisses with occasional hillocks of Khondalites, while the remaining part from west of Murhi and north of Angul up to the western end of the district is characterized by considerably flat country underlain by sedimentary rocks of Gondwana Group having large deposit of coal (Talcher Coalfields). The general slope of the country is from WNW-ESE.

3.1.3 Southern and South Western Mountainous Region

The Southern and South Western parts comprise of hill ranges trending WNW-ESE and is covered by the sub-divisions of Athmalik and Angul. The elevations vary from 60 to 971 meters above sea level. Banamadali peak in Angul Sub-division is 790 meter in height. In Athamallik Sub-division the main peaks are Panchadhara and Hingamandal hills. The southern & south western hilly regions form the watershed between Brahmani and Mahanadi river.

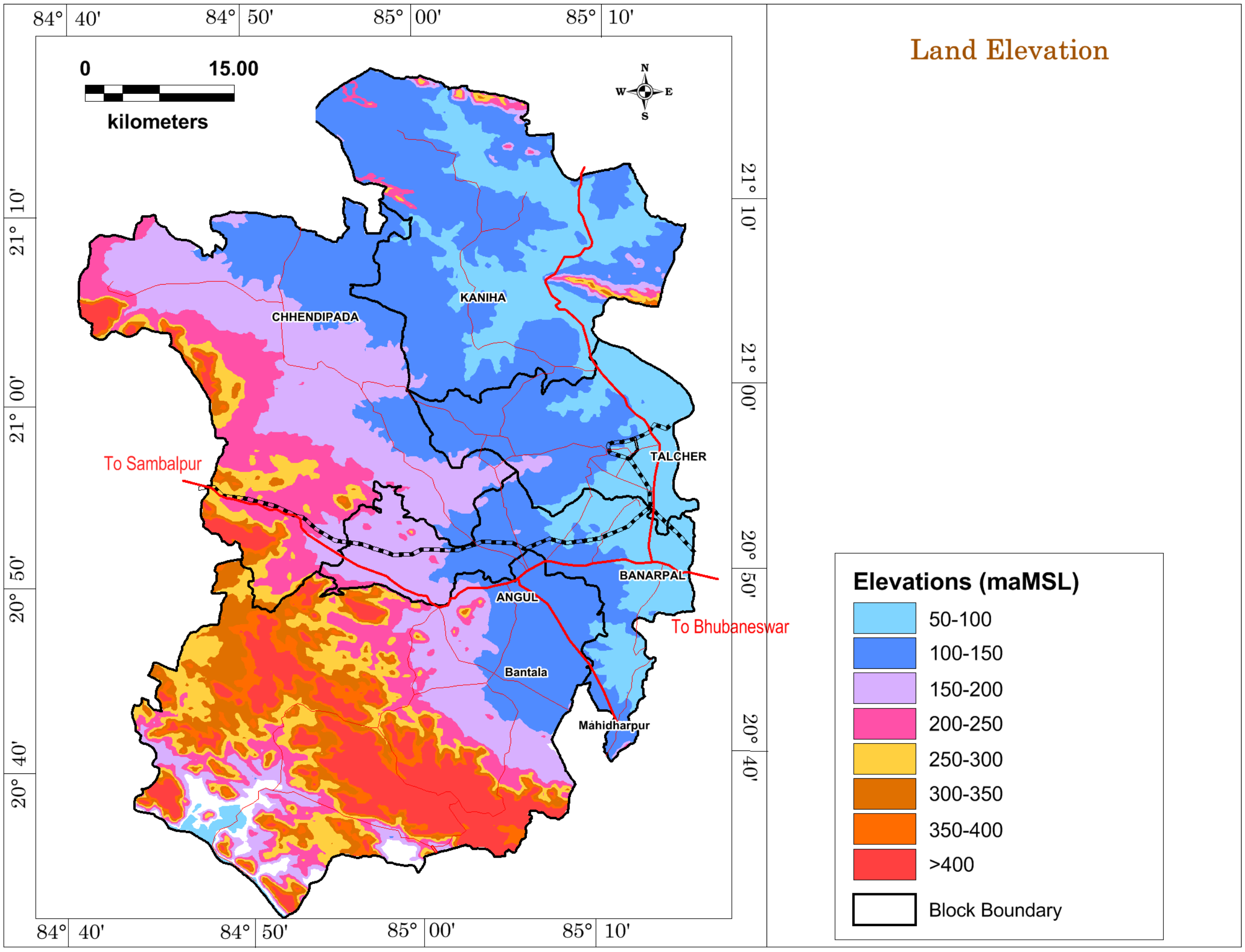


Fig. 3.1: Land Elevations in the NAQUIM area, Angul district

3.2 Geomorphology

The analysis of geomorphological data and thematic map collected from MRSAC, Nagpur. reveals that the hilly terrains in northern and south-south western portions were separated by central undulating plains which comprises of predominantly pediments and shallow buried pediments. The geomorphology of the area is shown in **Fig. 3.2.**

3.3 Land Use and Cropping pattern

Agriculture occupies a vital place in the economy of Angul district. The total cultivable area of this district is 2,16,403 ha constituting 32.7 percent of the total geographical area of the district. However, the total forest area (legal boundary) is higher than the state average. Within district, the forest area is maximum in the Pallahara block followed by Kaniha and Athamallik blocks. The landuse pattern of the blocks under the study area is shown in **Table 3.1** and the thematic map on land use is shown in **Fig. 3.3**.

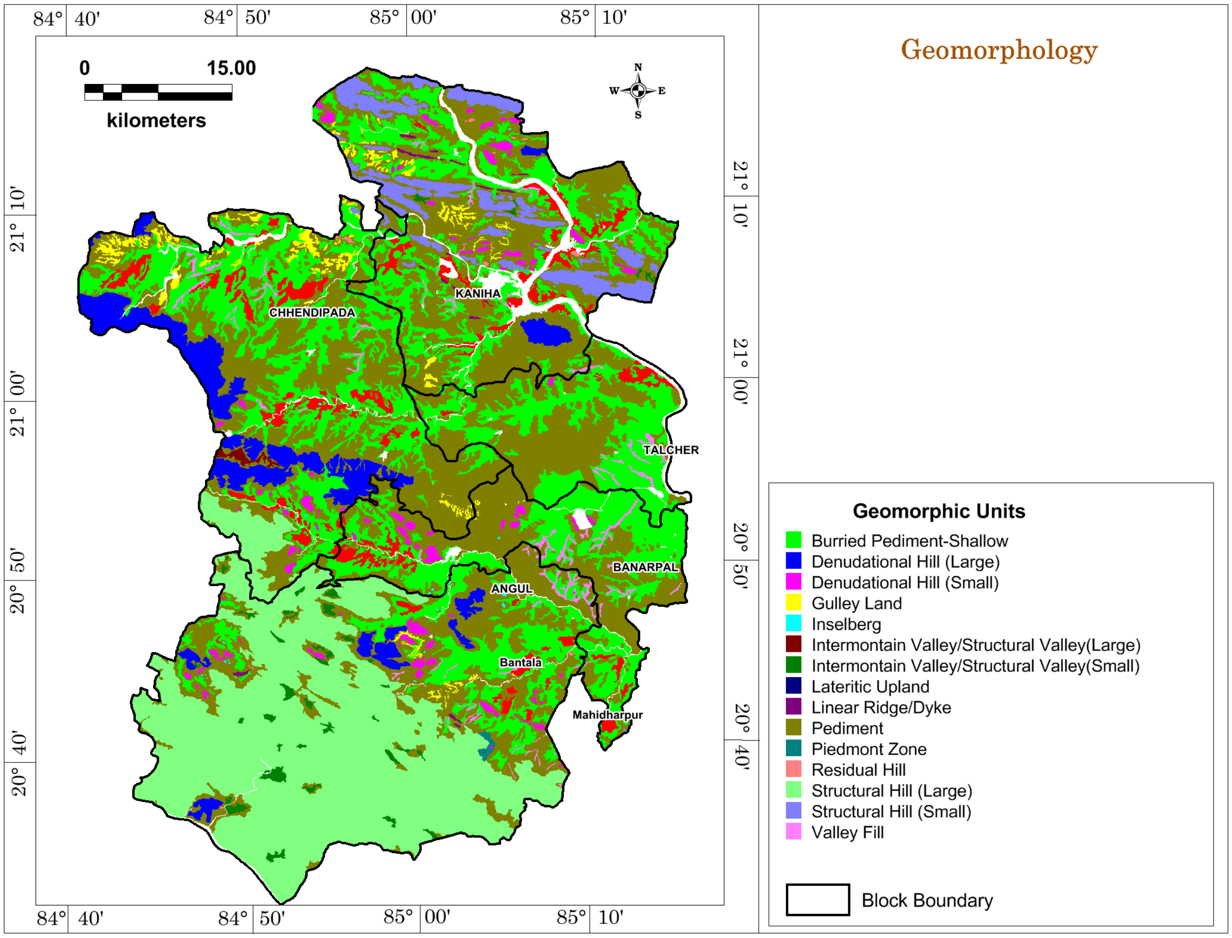


Fig. 3.2: Geomorphology of the NAQUIM area, Angul district

Table 3.1: Land use pattern of different blocks of district Angul during 2007

(Area in hectares)

Particulars	Blocks					Total
	Angul	Banarpal	Chhendipada	Kaniha	Talcher	
Forests	9779	954	8955	16540	4635	**40863**
Misc. tree crops & Groves not included in net area sown	537	364	2359	954	376	**4590**
Barren & Uncultivable land	727	90	205	2369	577	**3968**
Land put to non-agricultural use	3432	5005	5307	7151	3486	**24381**

Culturable waste	2755	940	3607	2003	1083	**10388**
Permanent pastures and other grazing land	2547	2451	2470	1271	551	**9290**
Current Fallows	6209	4076	8103	24735	2615	**23476**
Other Fallows	5048	4719	6380	2969	1724	**20840**
Net area sown	17063	14853	22541	18964	6766	**80187**
Total Irrigated Land	2810.32	4160.01	3229.29	767.49	1097.87	**12064.98**

Source: Angul District Plan, TSI-ERA/DISTRICT ADMINISTRATION/ANUGUL 2011-12

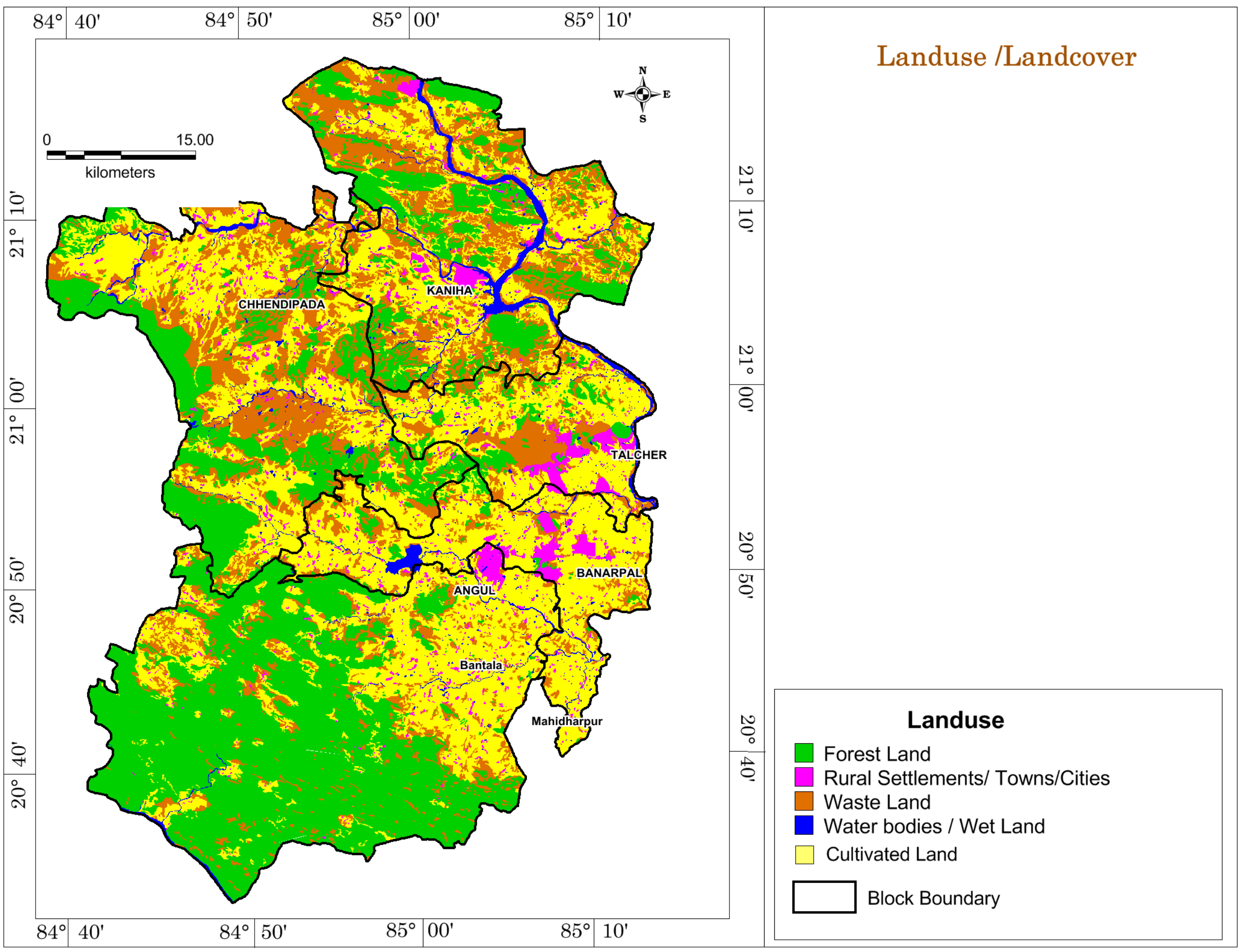


Fig. 3.3: Landuse in the NAQUIM area, Angul district.

Most of the cultivated area of the district is covered with double crops like kulthi (kolath), bengalgram (harad), coriander, field pea; and vegetables are taken after harvest of ground nut and early kharif paddy. The **kharif** crops include paddy, maize, ragi, small millets, arhar, biri, mung, ground nut, til, castor, cotton, turmeric, ginger and vegetables like brinjal, tomato, and early cauliflower. On the other hand, **rabi** crops include paddy, wheat, maize, field pea, mung, biri, mustard, sunflower, safflower, niger, potato, onion, garlic, coriander, vegetables, tobacco, sugar cane etc.

The crop rotation practice followed by the farmers in the district are:

In Upland region: Kulthi and vegetables are taken after harvest of short duration paddy, gram, coriander and groundnut crop.

In Mid land region: Wheat, onion, garlic, mung, biri, vegetables and groundnut are taken after harvesting of kharif season paddy.

In Low land region: Paddy and pulses are taken after harvest of rabi season paddy crop. In assured irrigation farmlands, three crops like paddy-vegetable-pulses, paddy-potato-til and paddy-pulses-groundnut are taken.

Table 3.2 reveals that the average cropping intensity in the district is around 175 percent. The highest cropping intensity is found in Banarpal block followed by Chhendipada block, whereas, in Talcher block the cropping intensity is almost half as compared to other blocks. This is mainly due to the inadequate irrigation facilities in the block.

Table 3.2: Area Irrigated by different sources in Ha.

Block	Area Irrigated by Canal	Area Irrigated by River	Area Irrigated by Dugwell	Area Irrigated by Tubewell	Area Irrigated by Tank	Area Irrigated by Other Sources	Total Area irrigated	Total Area Unirrigated
Angul	1837.74	50.61	0	0	622.61	299.36	2810.32	27085.02
Banarpal	3777.38	198.78	0	0	113.85	70	4160.01	20387.7
Chhendipada	2522.55	100.3	210	16	110.61	269.83	3229.29	30913.57
Kaniha	438.58	245.07	24.12	0	59.72	0	767.49	15480.58
Talcher	471.99	96.14	0	0	359.62	170.12	1097.87	9203.62
TOTAL	**9048.24**	**690.9**	**234.12**	**16**	**1266.41**	**809.31**	**12064.98**	**103070.49**

Source: Angul District Plan, *TSI-ERA/DISTRICT ADMINISTRATION/ANUGUL 2011-12*

3.4 Soil

It has been observed that the major part of the area is occupied by Alfisols which includes red sandy soil, red loamy soil and mixed red and black soils. It is porous and friable, tight textured, usually devoid of lime kankars and is also free of carbonates. It is usually suitable for cultivation of paddy and a large variety of other crops. The thematic map on the soil distribution in the study area is shown in **Fig. 3.4.**

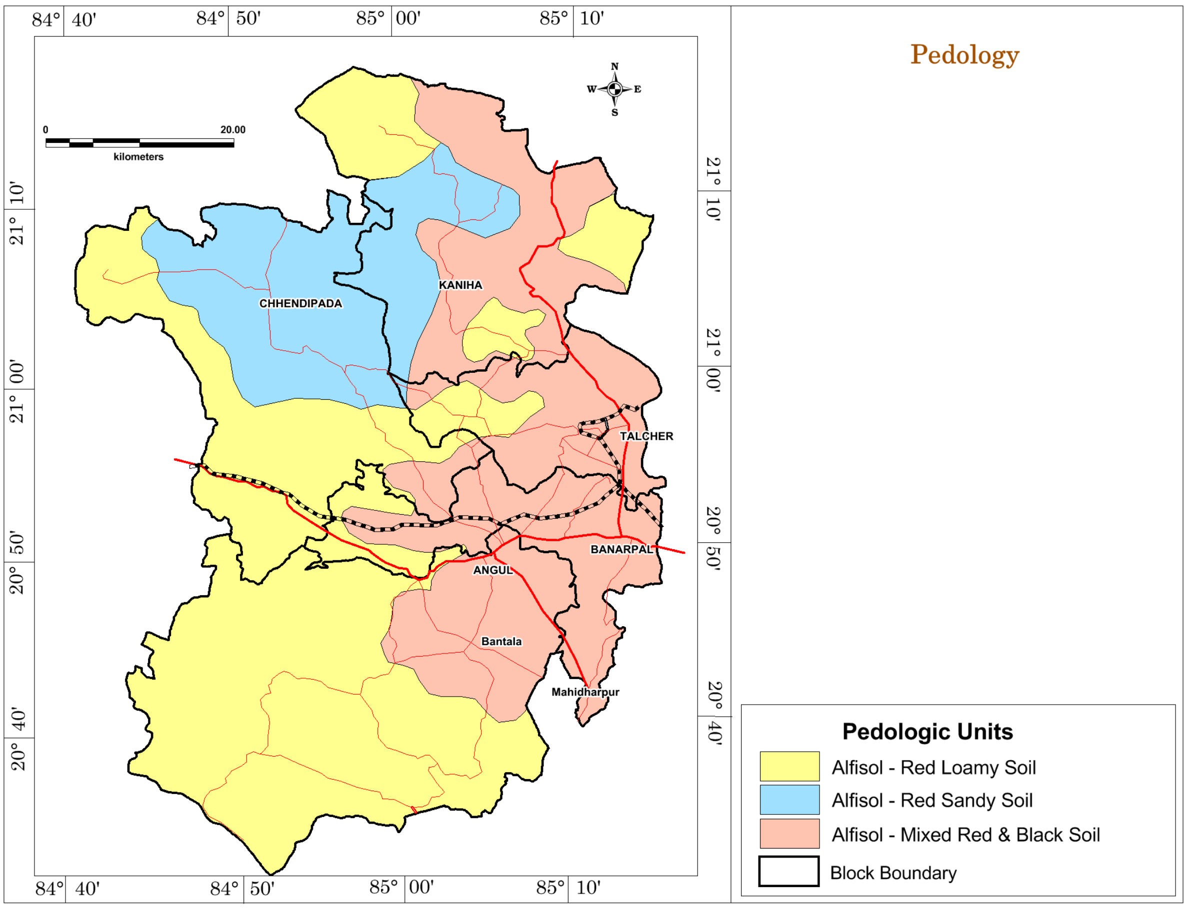


Fig. 3.4: Soil in the NAQUIM area, Angul district.

3.5 Hydrology and Drainage:

3.5.1 Hydrology

The agriculture in the district is primarily rain fed because of inadequate irrigation facility. Area irrigated through all sources is only 31% during kharif season and 21% during rabi season as per the available data. The district has 216403 Ha of cultivable land. The total irrigation potential is 49907Ha the source wise details of which are given in **Table 3.3**.

Table 3.3: Source wise irrigation potential in Angul district.

Sl. No.	Source	No. of Projects	Ayacut in Ha
1	Major/Medium	02	9138
2	Minor (Flow)	52	15602
3	Minor (Lift)	345	6160
4	Dugwell	13730	5636
5	WHS	201	2944
6	Others		10427
	Total	14330	49907

Source: angul.nic.in

There are 2 medium irrigation projects in the study area. The Derjung Medium Irrigation Project is constructed on Ningara and Matalia river in Angul block having total catchment area of 399 sq. km. with CCA of 7392 Ha. The Aunli Medium Irrigation Project is constructed on Aunli river in Chhendipada block**.** Its catchment area is 150 sq. km. and is having CCA of 1746 Ha during Kharif and 300 Ha in Rabi.

The block-wise details of Minor Irrigation Projects in the study area are presented as **Table 3.4.** There are 5 large dams in the study area under MIP, namely, Kansabansa MIP, Kukurpeta MIP, Raijharan MIP, Durgapur MIP and Jhinitipal MIP all of which comes in the Chhendipada block.

Table 3.4: Block wise MIPs in study area in Angul district.

Sl. No.	Block	No of Projects	Ayacut Area (Ha)
1	Angul	25	2493
2	Banarpal	9	1243
3	Chhendipada	21	6709
4	Kaniha	19	2806
5	Talcher	6	525
	Total	80	13776

Source: Dept. of Water Resources, Minor Irrigation Projects, Odisha 2014

3.5.2 Drainage

Brahmani and Mahanadi are the two major rivers of the district. Both these rivers have numerous perennial and non-perennial tributaries. Most part of the district lies within the Brahmani basin while the Mahanadi basin spreads over Athmalik subdivision and southern part of Angul sub-division.

The Brahmani river which is the second longest river in Orissa flows through Talcher subdivision. The major portion of the district is drained by Brahmani river and its tributaries. The Brahmani flows in a general SE direction, broadly parallel to the general strike trends of the prevalent rock formations, but locally guided by major joints and faults. The major tributaries of Brahmani are Tikra Jhor, Singhara Jhor, Samakoi, Nandira Jhor, Gambhira, Nigra, Bade Jhor etc. These major streams show a general right angle pattern while joining with the river Brahmani.

The Mahanadi flows along the south-west boundary of the district, parallel to the strike of Khondalites and is guided by a major shear zone. The major tributaries of this river are Karandi Jhor, Ghosar Jhor, Sindol Jhor, Chanagorhi and Malia Jhor etc., all flow from the northern side of the river originating in Athmalik and Angul subdivisions. The river Mahanadi though flows in a general SE direction, but occasionally flows due south or east at places. The drainage map of study area is shown in **Fig.3.5**.

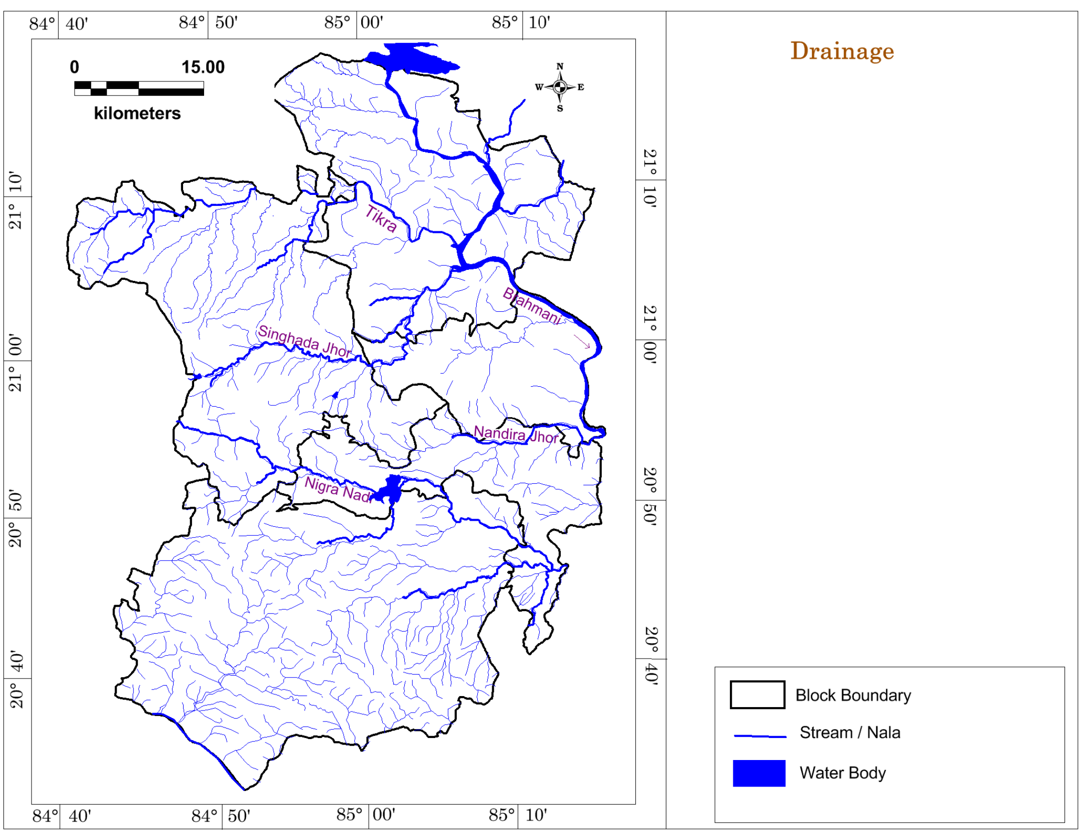


Fig. 3.5: Drainage in NAQUIM area, Angul district

4 HYDROGEOLOGY

4.1 Geology Sequence

The study area exposes rocks of Iron-Ore Super Group, Easternghat Super Group and Gondwana Super group. Besides these laterites and alluvial deposits of Quaternary period also occurs at places. The generalized stratigraphic sequence is given in **Table 4.1** and the geological map of the study area is shown in **Fig. 4.1.**

Table 4.1: **Generalized Stratigraphic sequence in NAQUIM area, Angul district**

Age		**Lithology**
Quaternary		Alluvial and Laterites
Upper Paleozoic to Lower Mesozoic		Sandstones, Shales, Conglomerates, Coal, Boulder Beds (Gondwana Super Group)
Pre-cambrian	Proterozoic	Quartz-feldspar-garnet-sillimanite-graphite schist/gneiss, charnokite, pyroxene granulite and gneiss (Eastern Ghat Super Group)
	Archean	Mica Schists, quartzites (Iron-Ore Super Group)

4.1.1 Pre-Cambrians

The rocks of Iron-Ore super group are exposed to the north of Brahmani River and consist mainly of Quartzites (known as Tikra Quartzites) and Mica schists. Eastern Ghat Supergroup of rocks mainly comprising quartz-feldspar-garnet-sillimanite-graphite schist/gneiss, charnokite, pyroxene granulite and gneiss (augen, garnetiferous, biotite gneiss, migmatised khondalite) occur in central and southern parts covering around 70 % of the study area.

4.1.2 Gondwana Rocks

Gondwana Supergroup consisting of Conglomerate, sandstone, shale and coal occur in north and northeastern parts of the study area. The area of Talcher coal-field is underlain by Pre-cambrian basement rocks on which the lower Gondwana sediments unconformably rest. Gondwana rocks are overlain by recent alluvium and or valley-fill materials at places.

4.1.3 Alluvial Deposits and Laterites

The recent to sub-recent alluvium occur as flood-plain and channel deposits along the tributaries of Brahmani River. It comprises coarse to fine sand, gravel, silt and clay. The average extent of these formations is limited and their maximum thickness is about 25m. Laterites occur as patches capping over the country rocks and attain a limited thickness.

4.1.4 Structural Features

The Iron-Ore Super group of metasediments have undergone three phase of deformations. The axis of the first generation fold trends in E-W direction, the second generation fold in WNW-ESE direction and the youngest one by the N-S trend. The Gondwana rocks occupy faulted troughs with beds dipping at low angles (60 to 100 towards north). A number of NW-SE trending faults are observed within Gondwana supergroup of rocks.

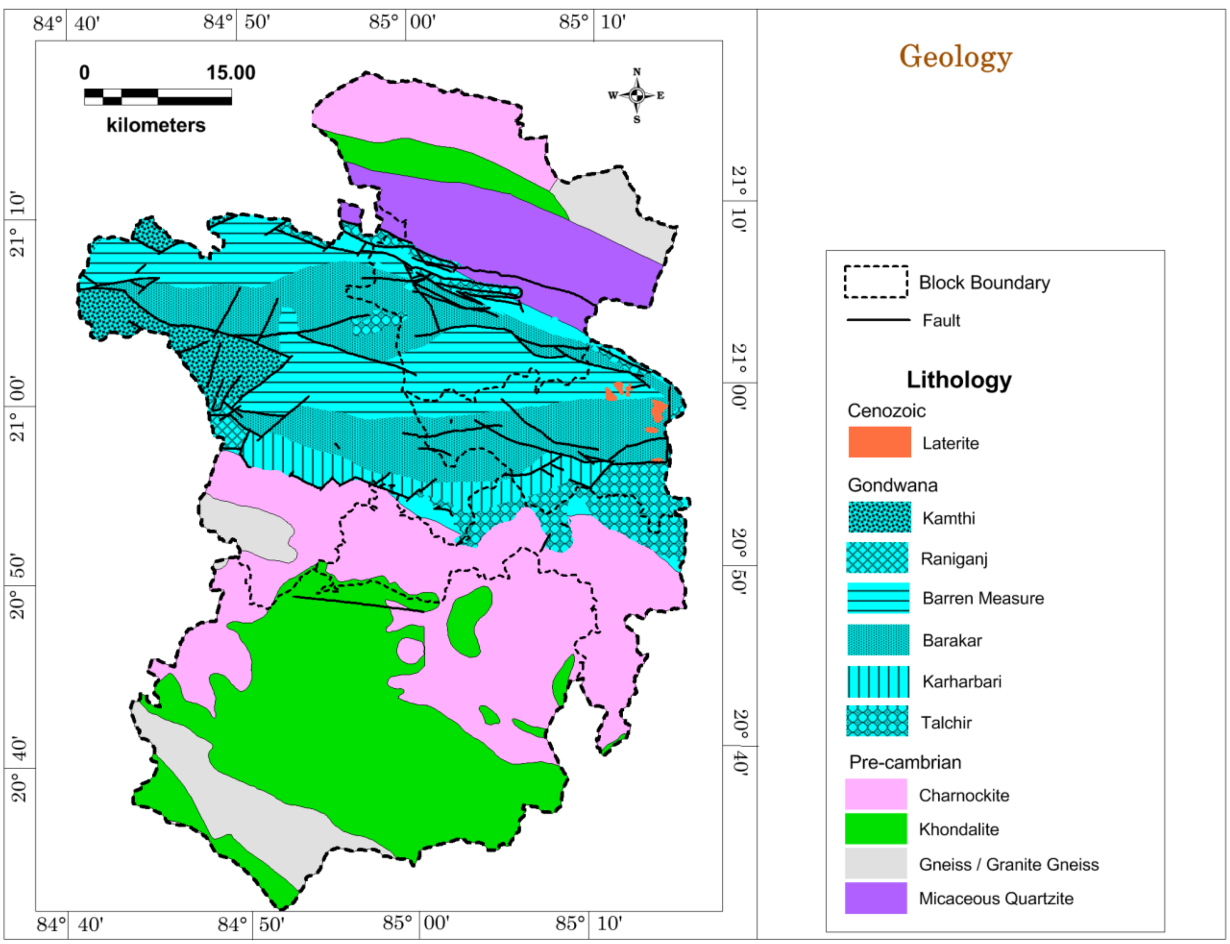


Fig. 4.1: Geological map of the NAQUIM area, Angul, Amravati district

4.2 Hydrogeology

The hydrogeological condition of the study area can be broadly grouped into three units. The hydrogeological map of the area is present in **Fig. 4.2**.

Consolidated Formation

Semi-Consolidated Formation

Unconsolidated Formation

4.2.1 Consolidated Formation

This includes Granite, Granite gneiss, Charnockites, Khondalites, Quartzite, Phyllites, Mica schist etc. These rocks are devoid of primary porosity. The secondary porosity developed in the rocks due to intense weathering and fracturing, which forms repository and passage for movement of ground water. Groundwater occurs under water table condition in the weathered residuum and in semi-confined to confined condition in fractured rocks at deeper depths. The thickness of weathered residuum varies from 5 to 20 m, which form repository of ground water at shallow depth. Groundwater from this zone is developed through dugwells. The result of shallow deposit wells constructed by CGWB in the study area show that weathered and semi-weathered granite gneiss form moderately potential aquifers.

4.2.2 Semi-consolidated Formation

It includes semi-consolidated Gondwana formation comprising mainly of sandstone and shale. The sandstone when weathered and fractured form good aquifer. Groundwater occurs under water table condition in the weathered zone and under semi-confined to confined condition in the fracture zone.

4.2.3 Unconsolidated Formation

Laterite occurs as capping over the older formation and groundwater occurs under water table condition. The aquifer supports moderate yield. The alluvium occurs along the course of major rivers and streams and is having limited occurrence in pocket. The alluvium supports good yield.

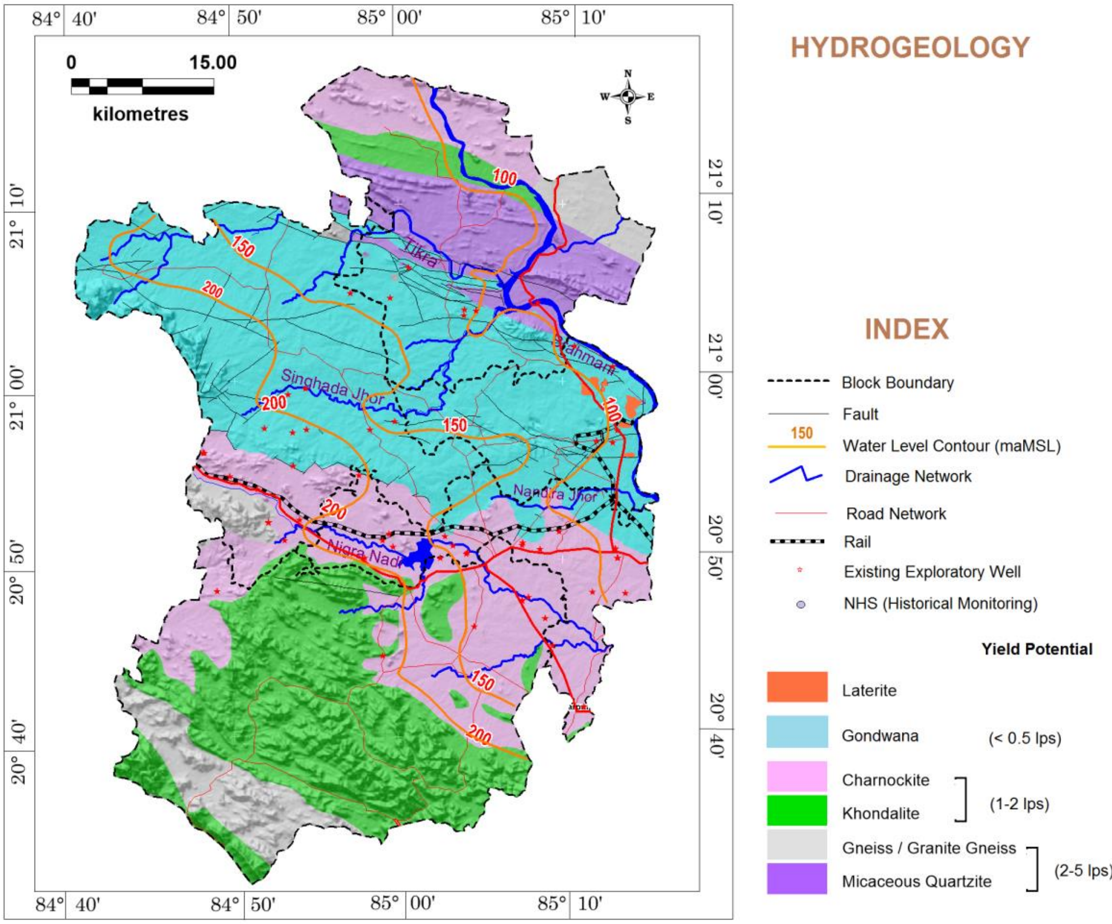


Fig. 4.2: Hydrogeology of NAQUIM area, Angul district

4.2.1 Ground Water Exploration and Ground Water Monitoring for Aquifer Mapping

Ground water exploration data, down to the depth of 200 m bgl in the NAQUIM area, has been taken up for the preparation of Aquifer Map. The data includes the exploration data of datagap analysis and subsequently constructed exploratory wells in the area. The total no of Exploration points including EW, OW and piezometers are 83.

The major objectives of ground water exploration in the study area were

I. To understand aquifer geometry of the area.
II. Estimation of various aquifer parameters required for formulation of the aquifer management plan.
III. Assessment of ground water quality in various aquifers system occurring up to 200 m depth for ensuring its suitability for various uses.

Similarly 225 no. of key observation wells were established in the NAQUIM area for monitoring of ground water regime as well as assessment of ground water quality of the phreatic aquifer (classified as **Aquifer-I** in chapter-6). CGWB has 40 National Hydrograph Network Stations in the five blocks. The data from 40 monitoring stations from State Govt. (GWSI) were included for analysis for aquifer mapping. The exploration and monitoring locations are shown on map is in **Fig. 4.3.**

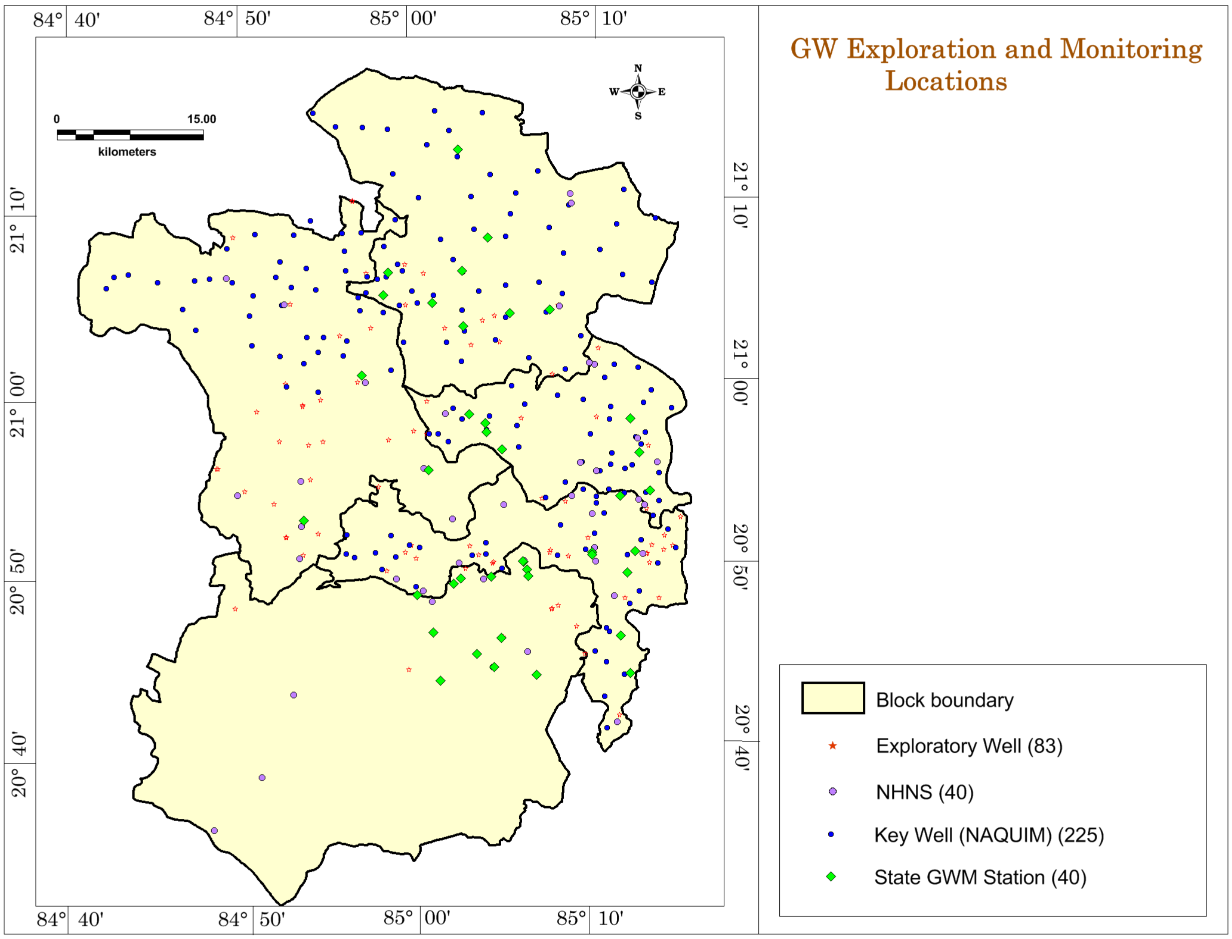


Fig. 4.3: Locations of ground water exploration and monitoring stations in NAQUIM area, Angul District.

4.3 Ground Water Dynamics

4.3.1 Depth to water level (Aquifer-I)

4.3.1.1 Depth to Water Level (pre-monsoon 2015)

The depth to water levels during May 2015 ranges between 1.56 (Kalamchuin) and 11.85 (Gopinathpur) m bgl. Depth to water levels during pre-monsoon shows water levels mostly within

5-8 mbgl and shallow water level of 2-5 mbgl in north eastern part. Deepest water level of more than 8 mbgl is observed in patches mostly in Chhendipada block. The pre-monsoon depth to water level map is given in **Fig. 4.4**.

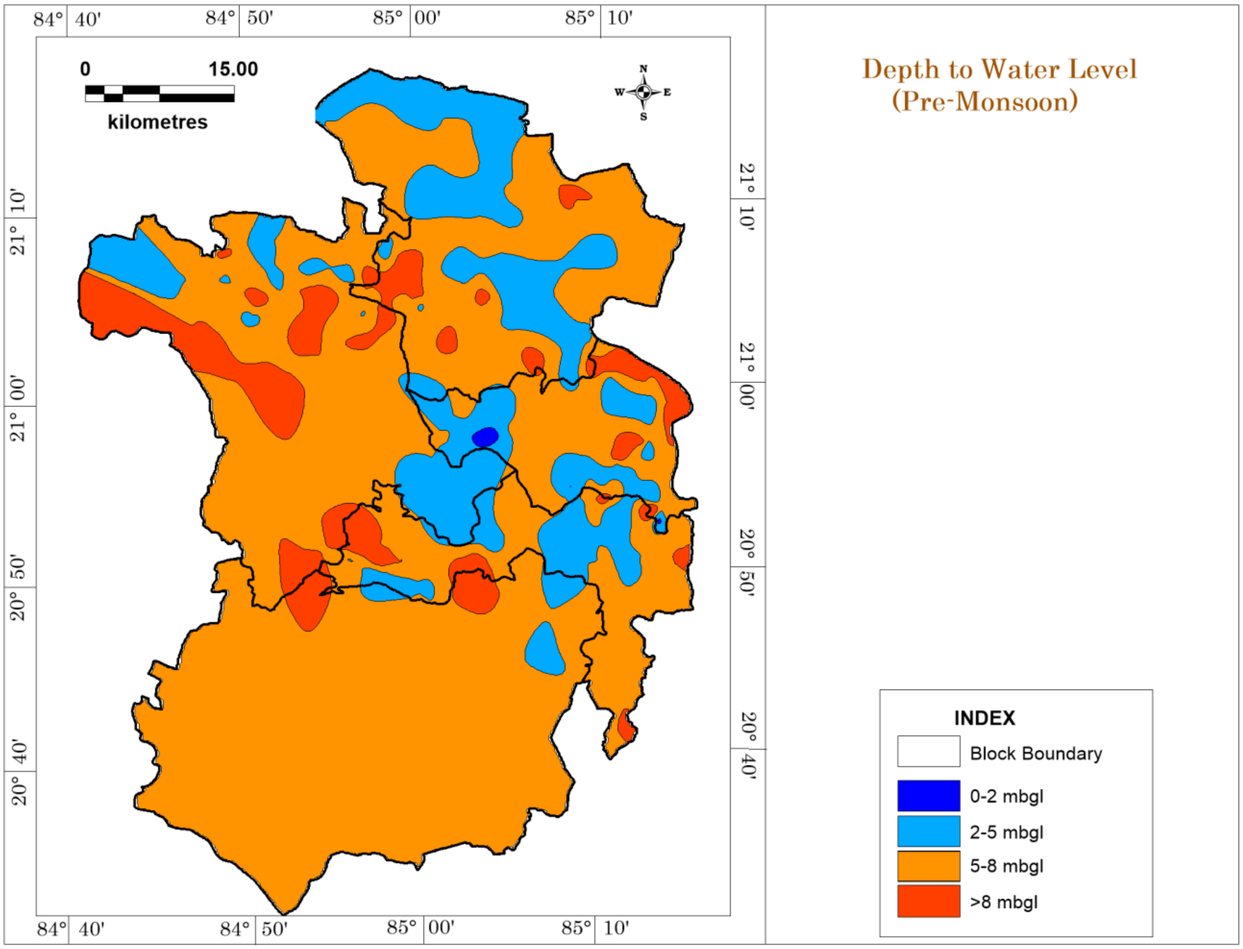


Fig. 4.4: Depth to Water Level (Aquifer-I) (pre-monsoon 2015)

4.3.1.2 Depth to Water Level (Post-monsoon 2015)

The depth to water levels during Nov 2015 ranges between 0.7 (Golagadia) and 9.28 (Talcher) m bgl. Except small isolated patches, depth to water level is mostly within 2-5 mbgl. Deeper water level of more than 7 to 9.28 mbgl was observed at the boundary of Banarpal and Chhendipada blocks near villages Jaruda-Partara-Jaruda-Derjung. The post-monsoon depth to water level map is given in **Fig. 4.5**.

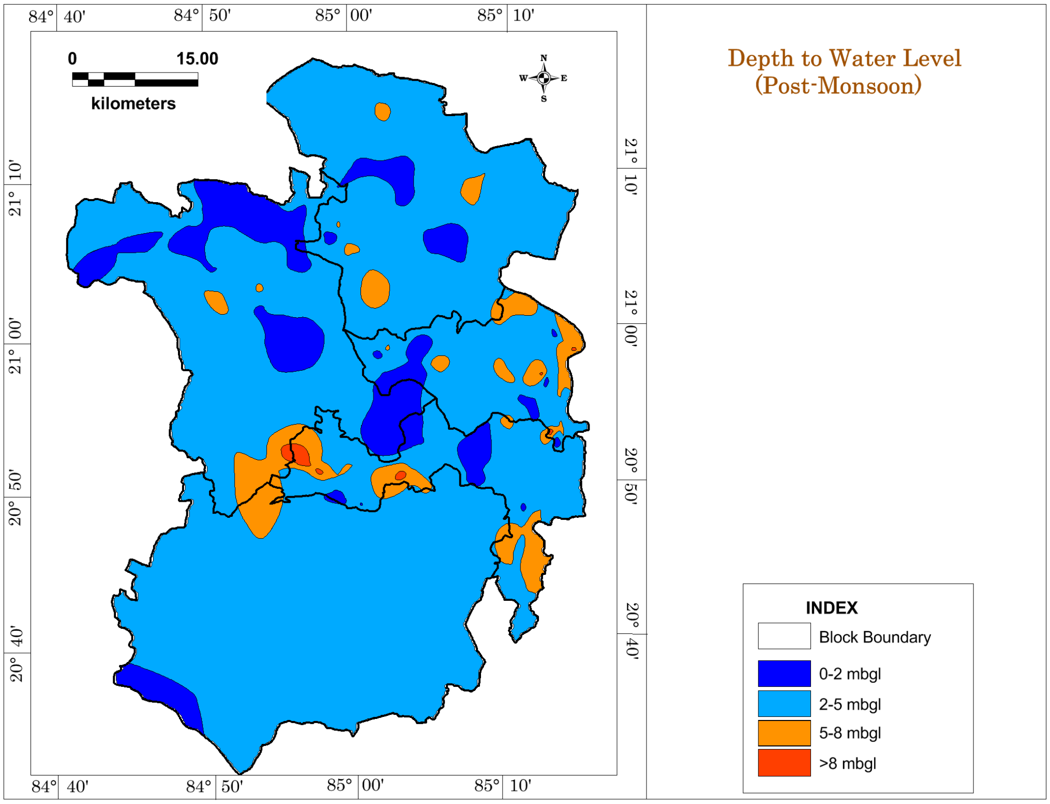


Fig. 4.5: Depth to Water Level (Aquifer-I) (Post-monsoon 2015)

4.3.2 Water Level Fluctuation (Aquifer-I)

The water level measured during pre and post monsoon period was used to calculate the fluctuation. The seasonal fluctuation (May 15-Nov 15) in water level was obtained from difference in water level during pre and post monsoon water level. In the area, number of wells and their percentage falling in each fluctuation range is presented in **Table 4.2**.

Table 4.2: Seasonal fluctuation (May-15 vs. Nov-15) in water level with percentage

No. of key wells	Seasonal fluctuation in water level m with %				
	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10
213	86 (40.38%)	78 (36.62 %)	40 (18.78%)	8 (3.76%)	1 (0.46 %)

It is observed that minimum water level fluctuation was measured at Viru and Banarpal Village (0.25m) while maximum water level fluctuation was measured at Kakudia (8.35m). The water level fluctuations are grouped under three categories and are discussed under.

0-2 m and 2-4 m - Less water level fluctuation

4-6 m - Moderate water level fluctuation

>6 m - High water level fluctuation

Area with less water level fluctuation, about 77% wells were showing the water level fluctuation less than 4m. The area with less water level fluctuation is observed in all blocks except northern part of Chhendipada block.

Area with moderate water level fluctuation, about 19% wells were showing the moderate water level fluctuation between 4 and 6 m. The central and northern part of Chhendipada block and the maximum fluctuation (> 6m) was observed in only 4% (9 wells). These are Bada Changudia in western part of Kaniha block and Podapada, Gopinathpur, San Changudia, Gambharipal, Dahibar, Kanloi and Kakudia in northern part of Chhendipada block. The higher water level fluctuation is indicative of being recharge area. The seasonal fluctuation of water level of Aquifer-I is shown in **Fig. 4.6**.

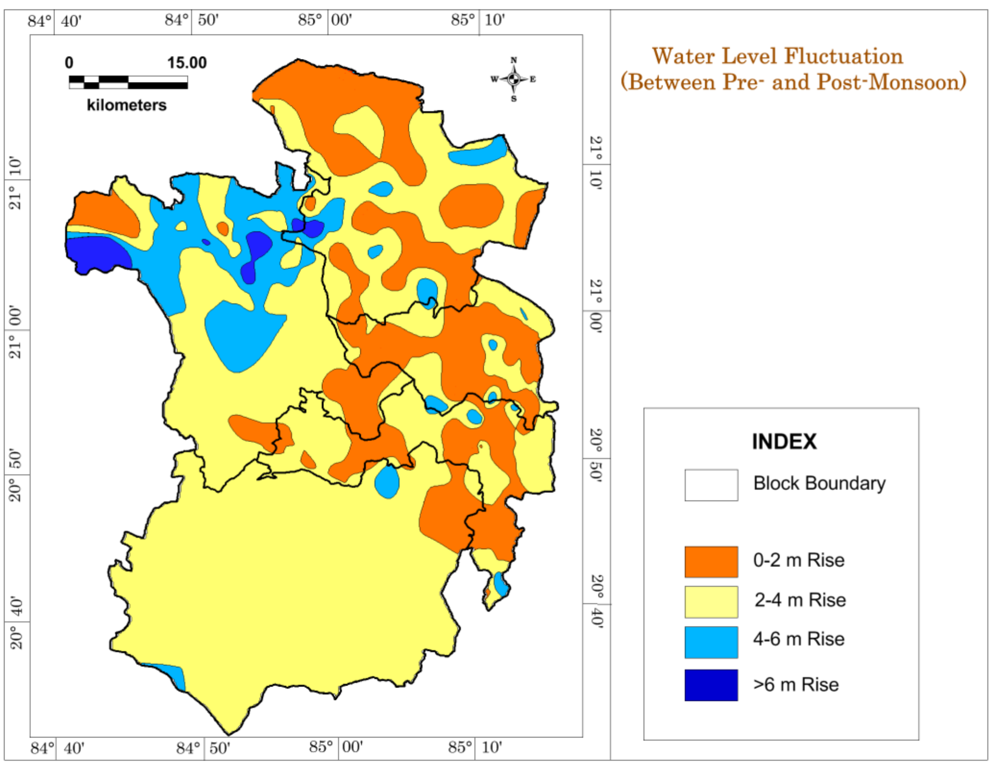


Fig. 4.6: Seasonal Fluctuation in Water Level (Aquifer-I) (Pre vs. Post-monsoon 2015)

4.3.3 Depth to Water Level Trend (2006-15 Aquifer-I)

The long-term trend of water levels for pre-monsoon and post-monsoon periods for the last ten years (2006-15) have been computed. The long term water level data of 36 National

Hydrograph Network Stations (NHNS) CGWB has been utilised. The maps depicting the special variation in long-term water level trend is presented as (**Fig. 4.7 and 4.8**). In the study area, rise in pre-monsoon water levels trend has been recorded at 23 stations and it ranges between 0.034 m/year (Kulnara1) to 0.570 m/year (Kukurang) while falling trend was observed in 12 stations varying from -0.011 m/year (Nisa) to -0.355 (Balanda).

In pre-monsoon, falling water level trend has been observed in the areas surrounding Talchir coalfields and central and southern part of Banarpal block. The rest of the area is showing rise in water level trend.

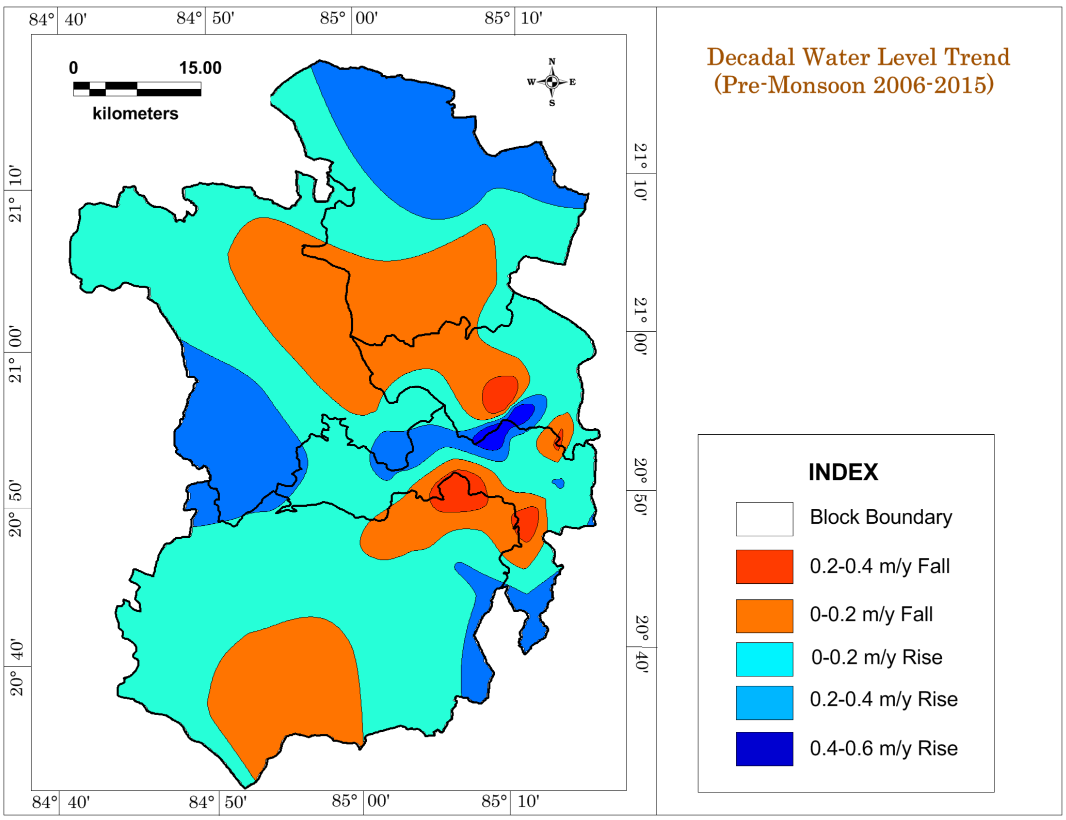


Fig. 4.7: Pre -monsoon decadal water level trend (2006-15)

In the study area, post monsoon rise in water levels trend has been recorded at 13 stations and it ranges between 0.004 m/year (Kuio) to 0.354 m/year (Bhogaberini) while falling trend was observed in 22 stations varying from -0.008 m/year (Kosala1) to -0.502 (Talcher1). In post-monsoon the falling water level trend has been observed in central part from Kaniha to Angul block however rising trend has been observed in southern part of Chhendipada block and eastern parts of Angul and Banarpal block.

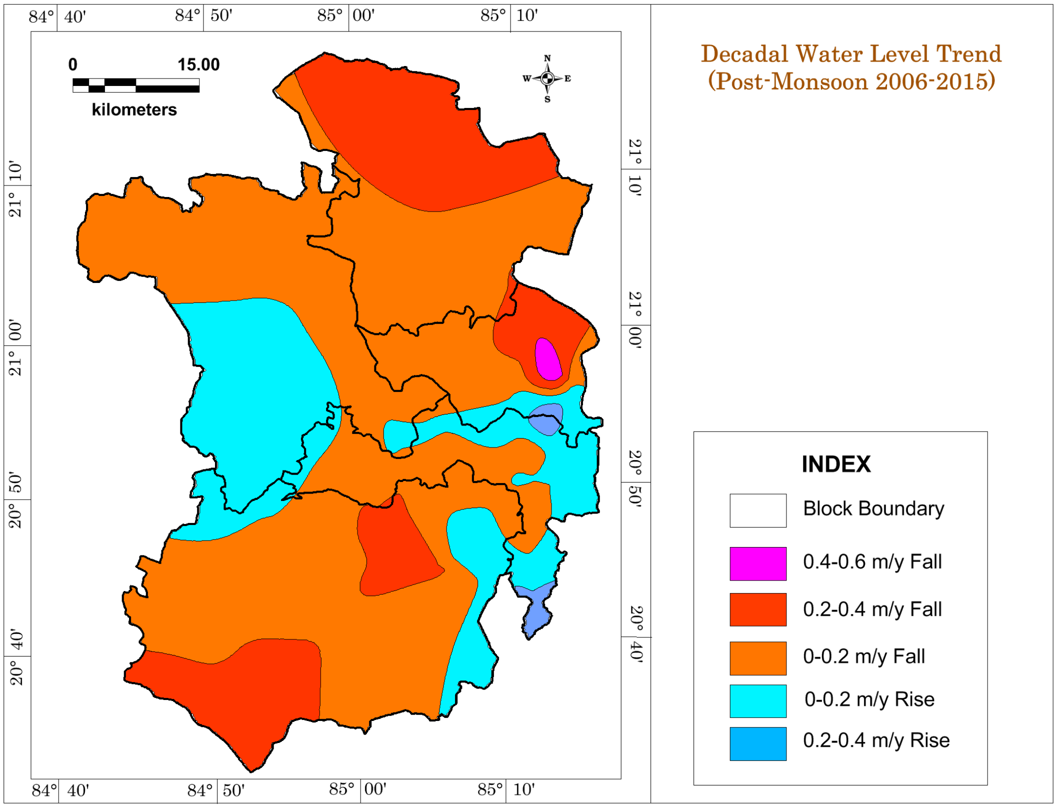


Fig. 4.8:Post-monsoon decadal water level trend (2006-15)

4.3.4 Hydrograph Analysis

The hydrographs of 12 ground water monitoring stations from the five blocks under NAQUIM in Angul district, were analysed for the period from 2006 to 2015. The variation in short term and long-term water level trends may be due to variation in natural recharge due to rainfall and withdrawal of groundwater for various agricultural activity, domestic requirement and mining & industrial needs. The analysis of hydrographs show that the annual rising limbs in hydrographs indicate the natural recharge of groundwater regime due to monsoon rainfall, as the monsoon rainfall is the only source of water (**Fig. 4.9a** through **4.9l**). However, the groundwater draft continuously increases as indicated by the recessionary limb. The groundwater resources are not replenished / recharged fully and the groundwater levels are under continuous stress and depleting. It has also been observed that there were few years when the recharge exceeded draft for a particular period or year but in the next successive year, the draft again exceeded recharge.

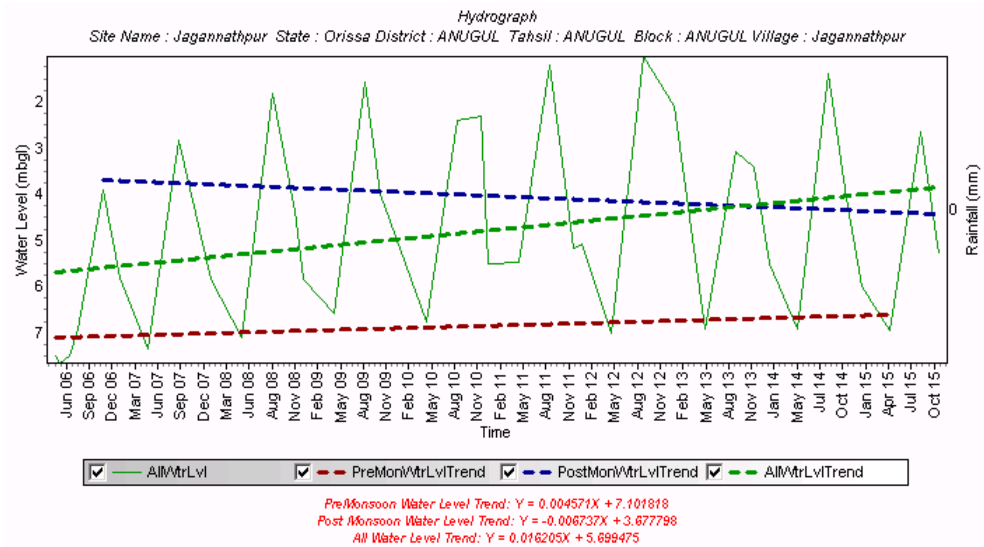


Fig. 4.9a: Hydrograph (2006-15), Jagannathpur, Angul block, Angul district

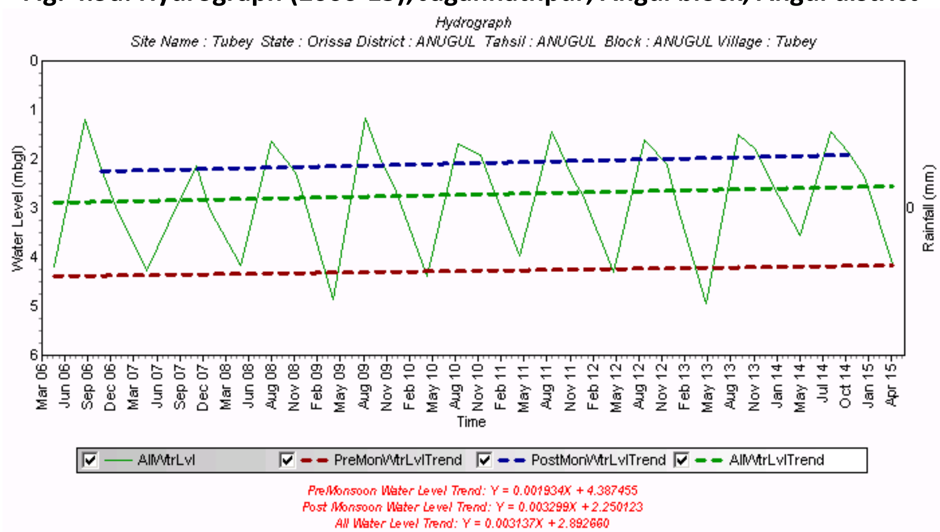


Fig. 4.9b: Hydrograph (2006-15), Tubey, Angul block, Angul district

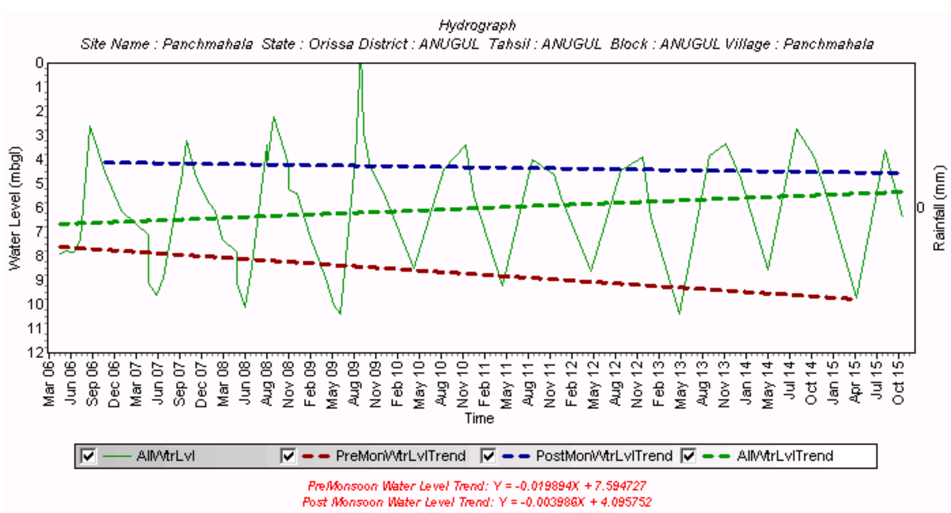


Fig. 4.9c: Hydrograph (2006-15), Panchmahala, Angul block, Angul district

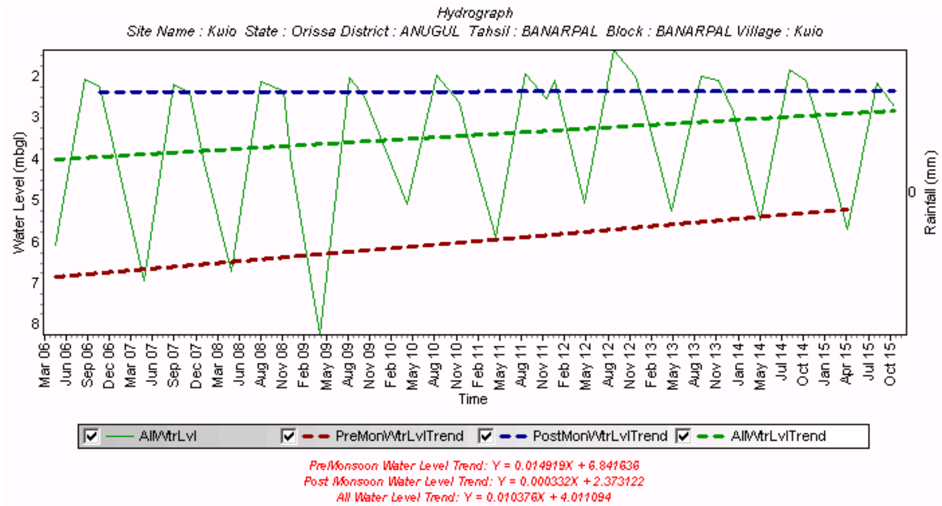


Fig. 4.9d: Hydrograph (2006-15), Kuio, Banarpal block, Angul district

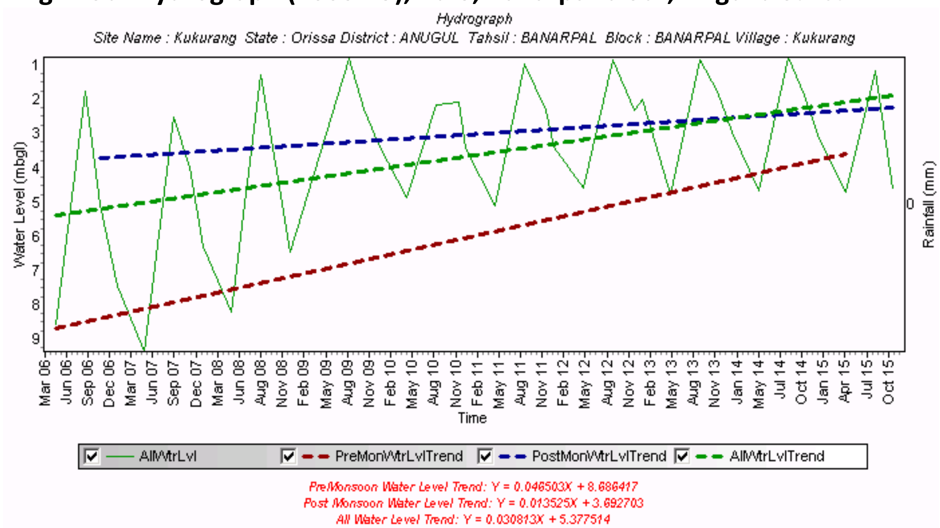


Fig. 4.9e: Hydrograph (2006-15), Kukurang, Banarpal block, Angul district

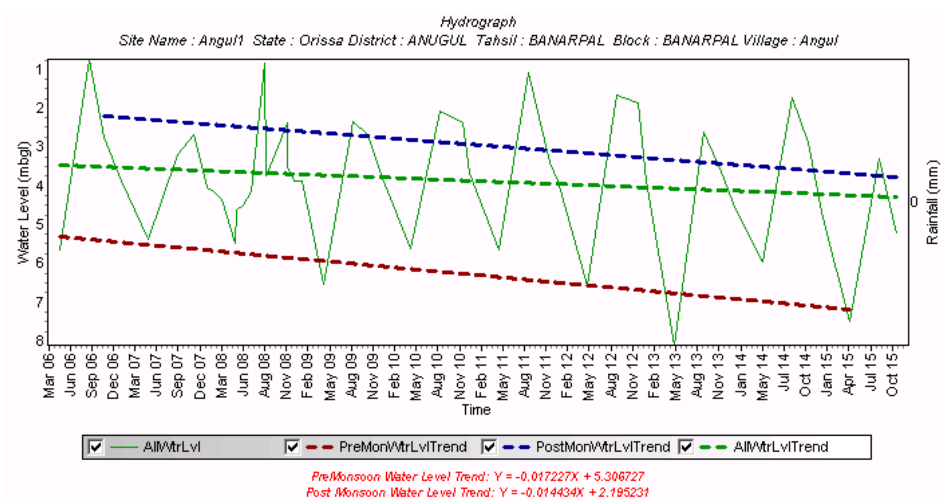


Fig. 4.9f: Hydrograph (2006-15), Angul1, Banarpal block, Angul district

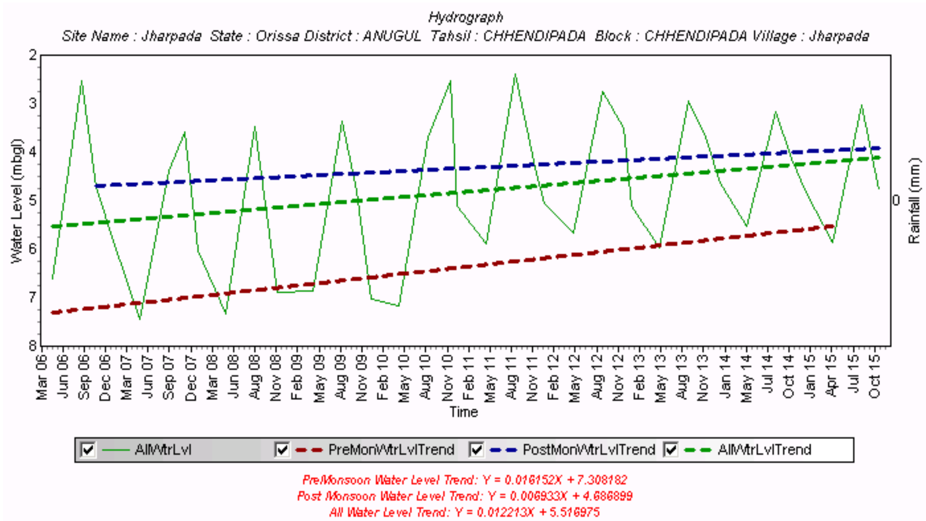


Fig. 4.9g: Hydrograph (2006-15), Jharpada, Chhendipada block, Angul district

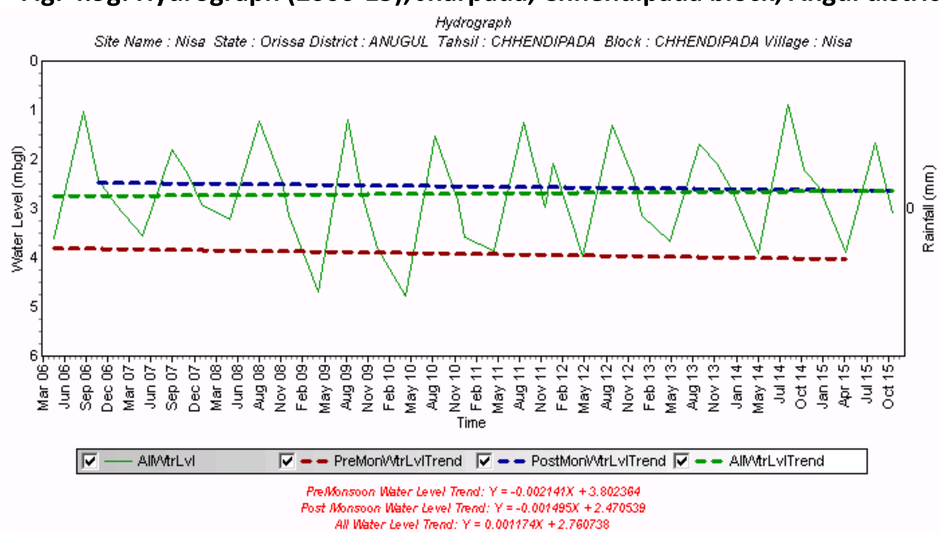


Fig. 4.9h: Hydrograph (2006-15), Nisa, Chhendipada block, Angul district

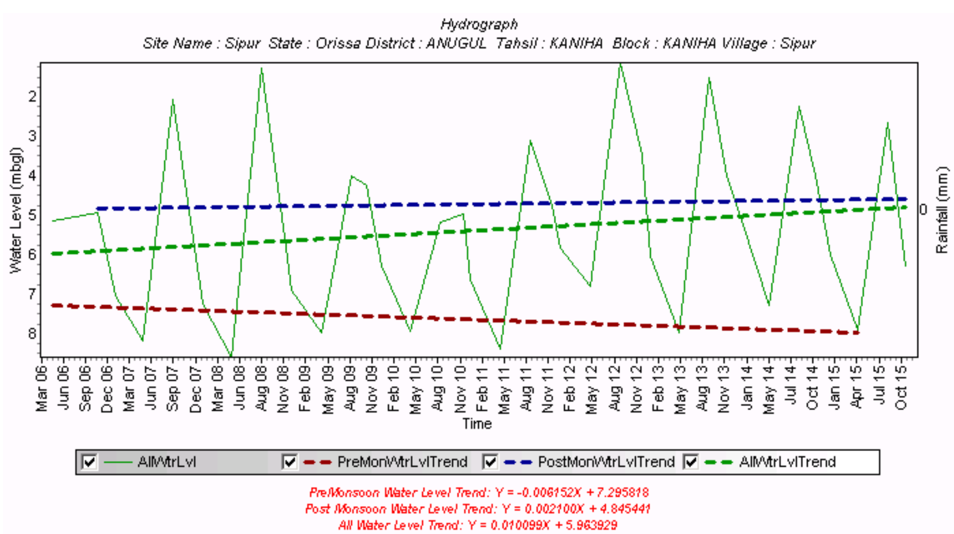


Fig. 4.9i: Hydrograph (2006-15), Sipur, Kaniha block, Angul district

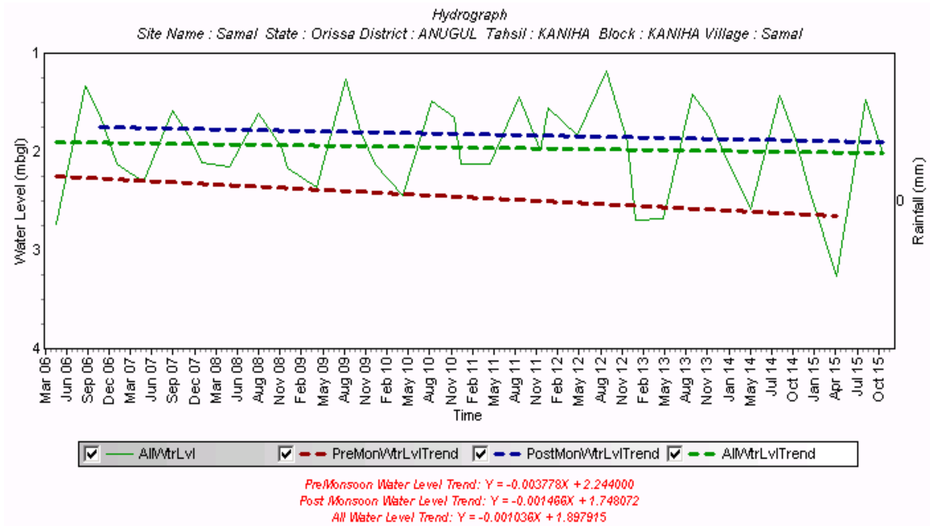


Fig. 4.9j: Hydrograph (2006-15), Samal, Kaniha block, Angul district

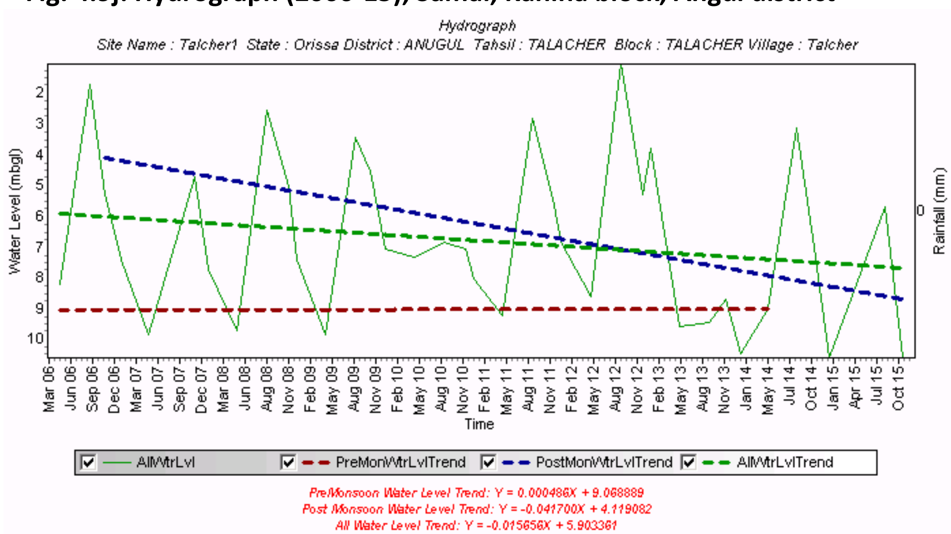


Fig. 4.9k: Hydrograph (2006-15), Talcher1, Talcher block, Angul district

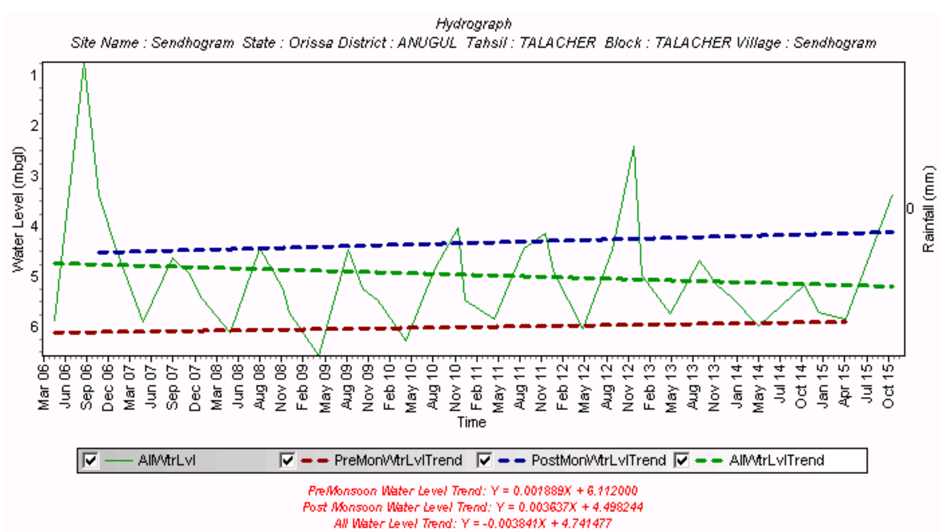


Fig. 4.9l: Hydrograph (2006-15), Sendhogram, Talcher block, Angul district

4.3.5 Ground Water Flow

In a groundwater regime, equipotential lines, the line joining points of equal head on the potentiometric surface, were drawn based on the area of variation of the head of an aquifer. Based on the Water table elevation, ground water flow directions are demarcated (F**ig. 4.10**). It has been observed that the ground water flow directions follow the major drainage channels and topography of the area. This indicates the topographic control for the ground water movement.

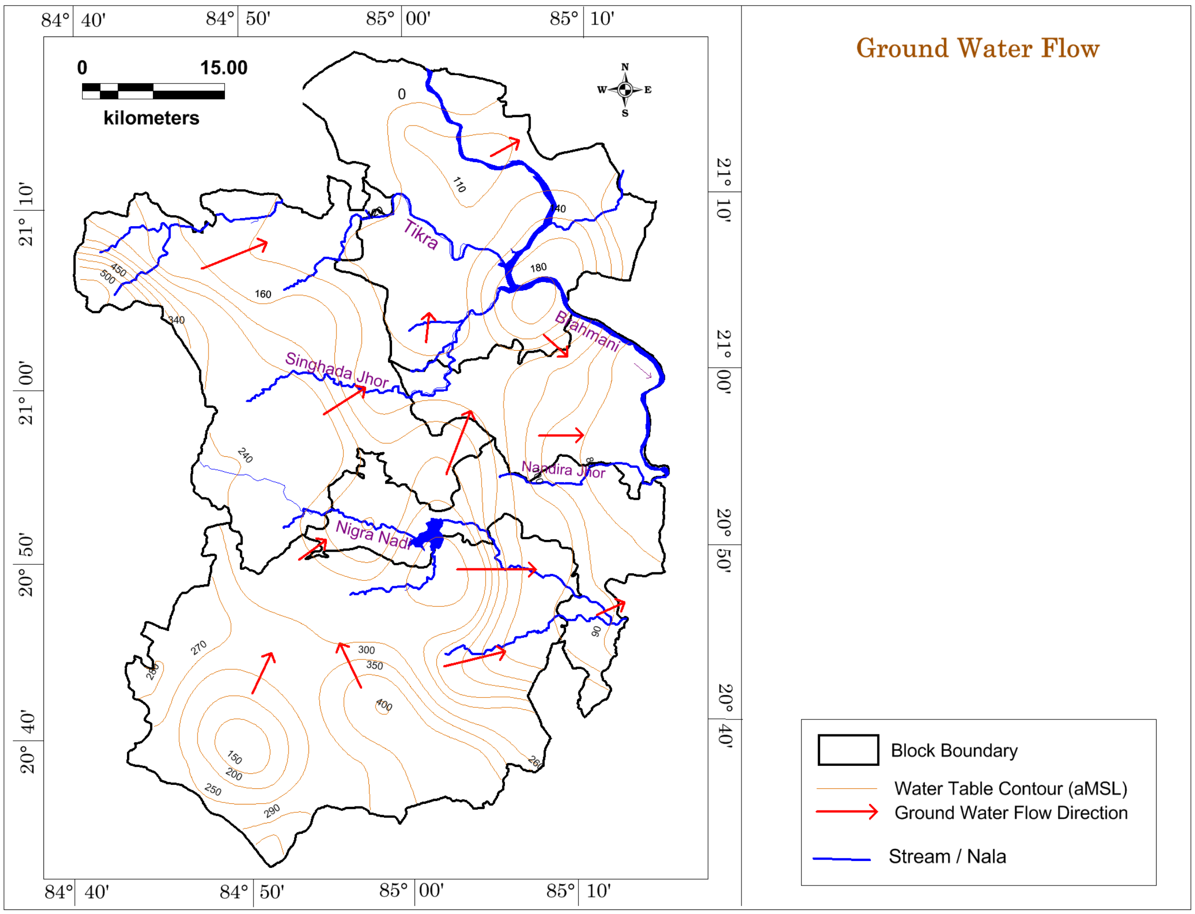


Fig. 4.10: Ground water flow in the NAQUIM area, Angul district

5 Ground Water Quality

The suitability of ground water for drinking/irrigation/industrial purposes is determined keeping in view the effects of various chemical constituents present in water on the growth of human being, animals, various plants and also on industrial requirement. Though many ions are very essential for the growth of plants and human body but when present in excess, have an adverse effect on health and growth. The chemical quality of ground water in the district is monitored annually on a routine basis by CGWB through its national Hydrograph Network Stations. Quality of ground water from deeper aquifers was assessed during the Exploration activities like drilling and pumping tests. Apart from these, a number of special studies have been carried out by CGWB in the area on ground water quality and its pollution aspect. During the NAQUIM programme, about 169 water samples collected during pre-monsoon period and were analysed for chemical quality. The ground water samples were analysed for major chemical constituents and the results are shown in ***Annexure-III***. Taking the results of chemical analysis during NAQUIM field work and the available historical chemical data, he aquifer wise ranges of different chemical constituents present in ground water, are determined and given in **Table 5.1.**

Table 5.1: Aquifer wise ranges of chemical constituents in NAQUIM area, Angul district.

Parameter	Unit	Shallow (Aquifer-I)			Deep (Aquifer-II)	
		Minimum	Maximum	Avg	Minimum	Maximum
pH	-	7.36	8.69	8.11	7.38	8.44
EC	mS/cm	180	**4007**	921	330	1073
TDS	mg/L	87	1951	449	200	547
TH	mg/L	40	**1355**	**314**	160	**395**
TA	mg/L	50	**660**	193		
Ca	mg/L	6	**340**	61	14	76
Mg	mg/L	0.11	**197**	39	7	74
Na	mg/L	1	370	43	12	120
K	mg/L	0.09	121	5	0.1	31
CO_3	mg/L	0	66	1	0	72
HCO_3	mg/L	61	781	232	189	451
NO3	mg/L	0.6	**105**		<1	9
Cl	mg/L	7	**1127**	134	14	138
SO_4	mg/L	0.21	272	43	<1	53
F	mg/L	0.06	**3.80**	0.56	0.1	**1.85**
Cu	ppm	0	0.03	0.01		
Fe	mg/L	0	**0.75**	0.15		
Mn	ppm	0	0.25	0.05		

Pb	ppm	0	**0.03**	**0.02**		
Zn	ppm	0	0.28	0.04		
As	ppb	0	1.46	0.19		
SAR	-	0	12.7	1.3		

Based on the chemical analysis of water samples from different sources, it was observed that, almost all chemical parameters lie within permissible limit for drinking and irrigation purpose except few samples of some isolated pockets. Higher EC (µS/cm) has been found at Bhogaberini (4900), Salagadia(4007) Karnapur(2680) Derjang (2365), Tentulei (2210), Chhelia (2150), Ekagharia (2058), Bantala (2050) and Badabahal (2000). The iso-conductivity map of Aquifer I and II has been prepared and presented as **Fig. 5.1**. From the diagram it’s found that higher EC value is in the area between Angul, Talcher and Banarpal.

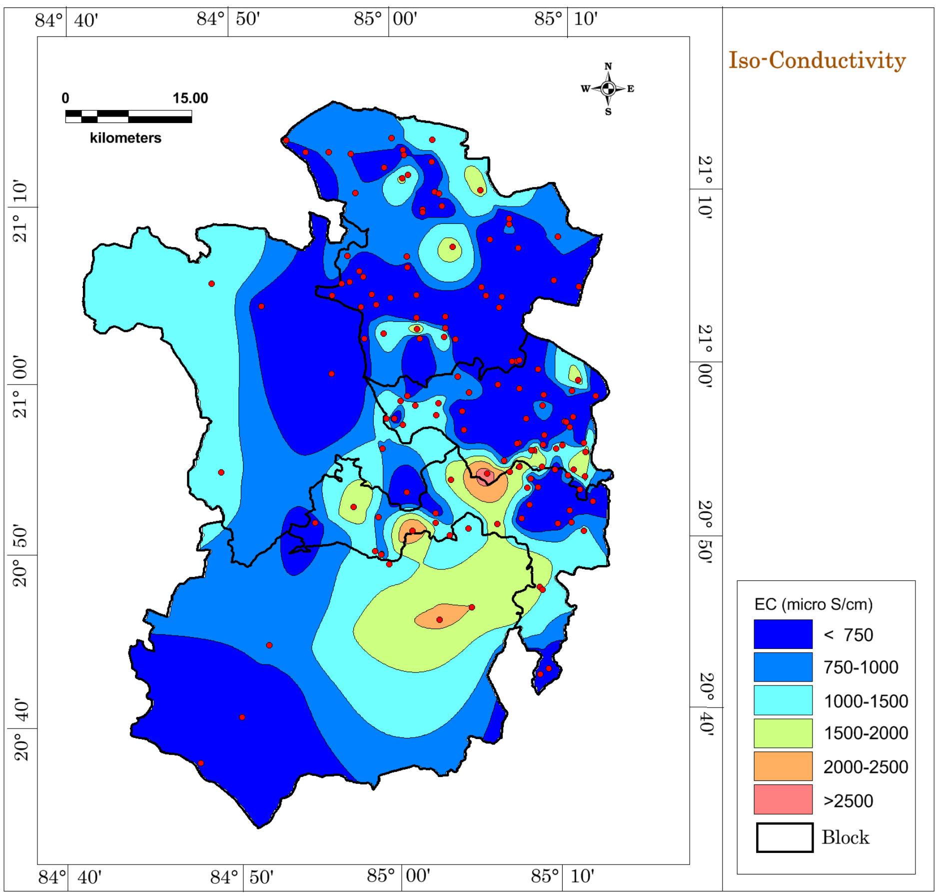


Fig. 5.1: Iso-conductivity Map of NAQUIM area, Angul district

The SAR value of the samples of Aquifer-I ranges from 0 to 12.7. The suitability of the ground water for the purpose of irrigation analysed in the US-Salinity diagram as shown in **Fig. 5.2**. the predominant USSL classes of the water samples fall within C2S1 and C3S1 classes. The water samples represent mixed facies of water, the predominant type being the Na-Ca-Mg-HCO_3-Cl-SO_4 type as shown in the Piper diagram in **Fig. 5.3**. This indicates a transitional or mixing environment between the younger water and resident water.

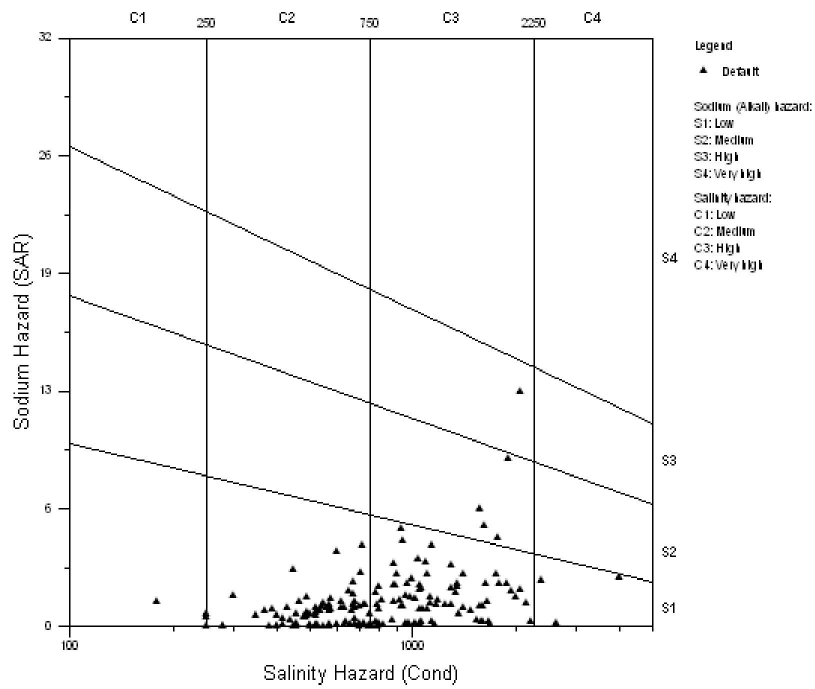


Fig. 5.2: US-Salinity diagram, Aquifer-I in the NAQUIM area, Angul district.

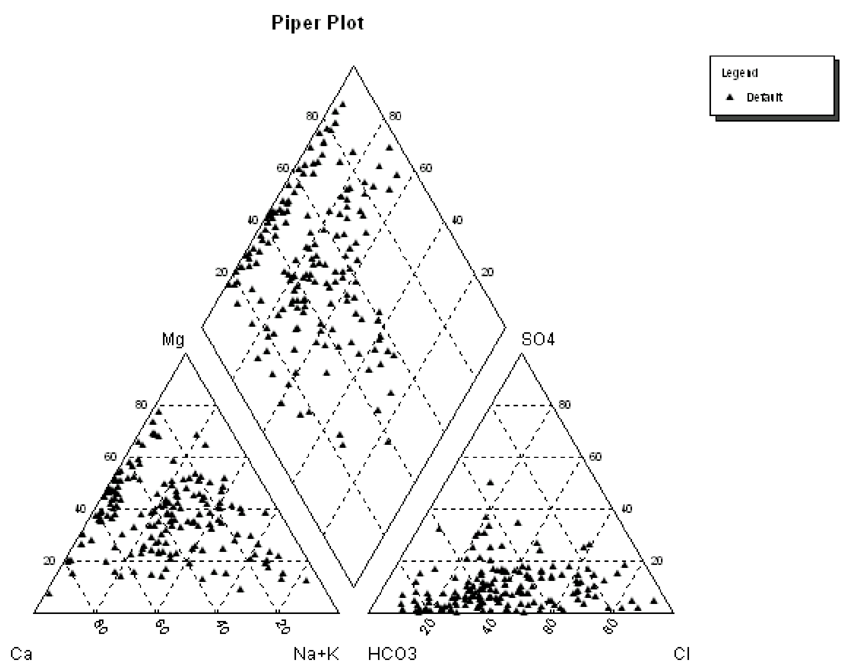


Fig. 5.3: Piper Diagram, samples of Aquifer-I, NAQUIM area, Angul district

Higher fluoride (F >1.5ppm) has been recorded numerous locations. In shallow aquifer at Badabahal (2.32), Bantala(2.23), Gopalprasad (2.21), Kuio (1.2), Sendhogram (1.3 & 3.8), Samal (1.7), Rengali (1.4) and Bhogabereni (1.07), Chhendipada (1.7), Paranga (1.7), Bentapur (1.43), Turanga (1.28), Thakurgarh, Tulasipal and in deeper aquifer at Korada (1.7) and Santrapur (1.85). The occurrence of high F does not show any pattern and can not be linked with the Industries. The waste water from NALCO effluent channel contains high F, whereas the same is low in ground water in that area. Any adverse effect of effluent discharged from ash pond areas like NTPC Kaniha, on the ground water quality has not been noticed yet.

6 AQUIFER MAP AND AQUIFER CHARACTERISTICS

6.1 Aquifer Characteristic

The main rock type of the area are Pre-cambrian consolidated formations like Granite, Granite-Gneiss, Charnockites, Khondalites, Quartzites, Phyllites and Mica Schists and Gondwana semi-consolidated formations like Sandstone and Shale. The Pre-cambrian crystalline formations are hard, compact and does not have primary porosity and hence impermeable. Weathering, jointing and fracturing induces secondary porosity. Ground water occurs under phreatic/ unconfined condition in weathered residuum from which water moves downward through joints, fractures etc. Ground water occurs in semi-confined to confined conditions in such deep fracture zones. The semi-consolidated Gondwana formations in the area have very little or no primary granular porosity. They are of hard and indurated in nature. Fracture and faults play an important role in occurrence and movement of ground water in them. Ground water occurs in top weathered zones as phreatic aquifer and at depth, water occurs in the fractured zones only in these formations lacking primary porosity. The yield of bore wells is generally poor in comparison to the Pre-Cambrian formations.

6.2 Aquifer Group Thickness & Demarcation

Based on extensive analysis of historical data, micro level hydrogeological survey data generated and ground water exploration carried out in the area, the following two types of aquifers can be demarcated and the details are given below:

Aquifer I - Unconfined aquifer, occurs in entire area except rocky outcrops, formed by the weathered mantle atop all crystalline as well as Gondwana formations and discontinuous alluvial tracts along major river channels. This aquifer generally occurs down to maximum depth of 30 m bgl. Based on field observations, isopach map of Aquifer–I is generated and shown in **Fig. 6.1.**

Aquifer II – Semi-confined to confined aquifer. Generally occurs in as fracture zone aquifers in the entire area irrespective of rock types. However the aquifer properties, the yield of bore wells constructed in them depends on the rock type. As per the ground water exploration, carried out by CGWB. Aquifer-II in Granitic rocks have better yield in comparison to Gondwanas, Charnockites and Khondalites. In general, most of the fracture zones are encountered within 0 to 150 mbgl and seldom beyond that. Thus that maximum depth for the Aquifer-II can be safely taken as 200 mbgl. Based on the exploration data, delineation of Aquifer-I and Aquifer-II has been done from the lithological section as shown in **Fig. 6.2a** and **Fig. 6.2b**.

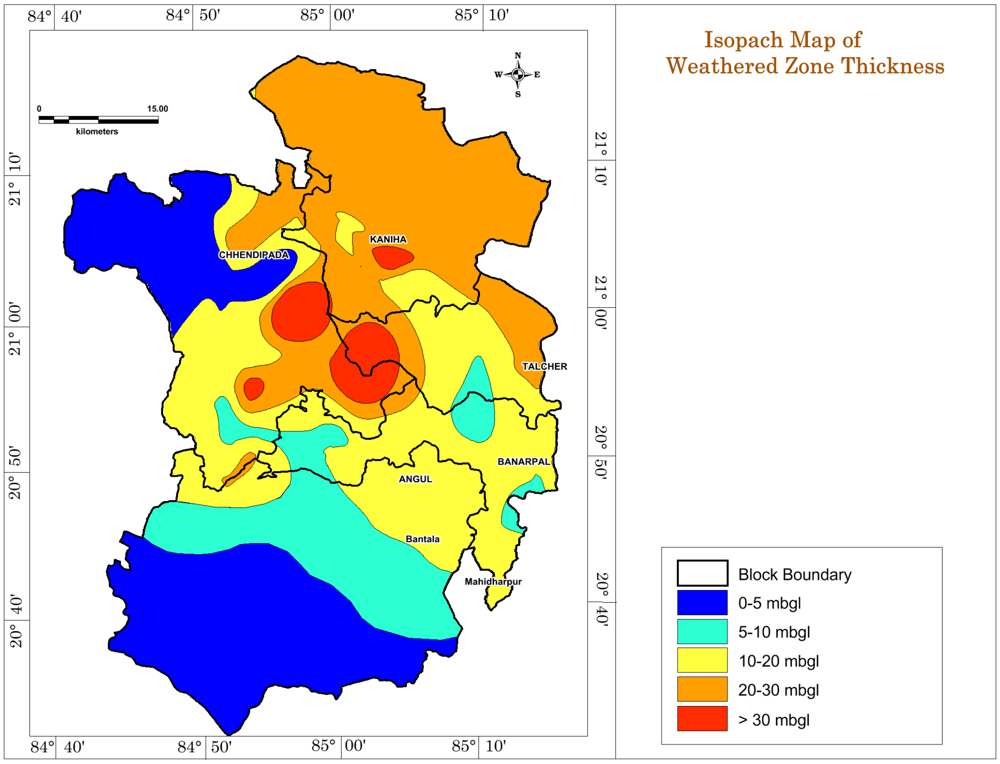


Fig. 6.1: Isopach of Weathered Zone (Aquifer-I) in the NAQUIM area, Angul district.

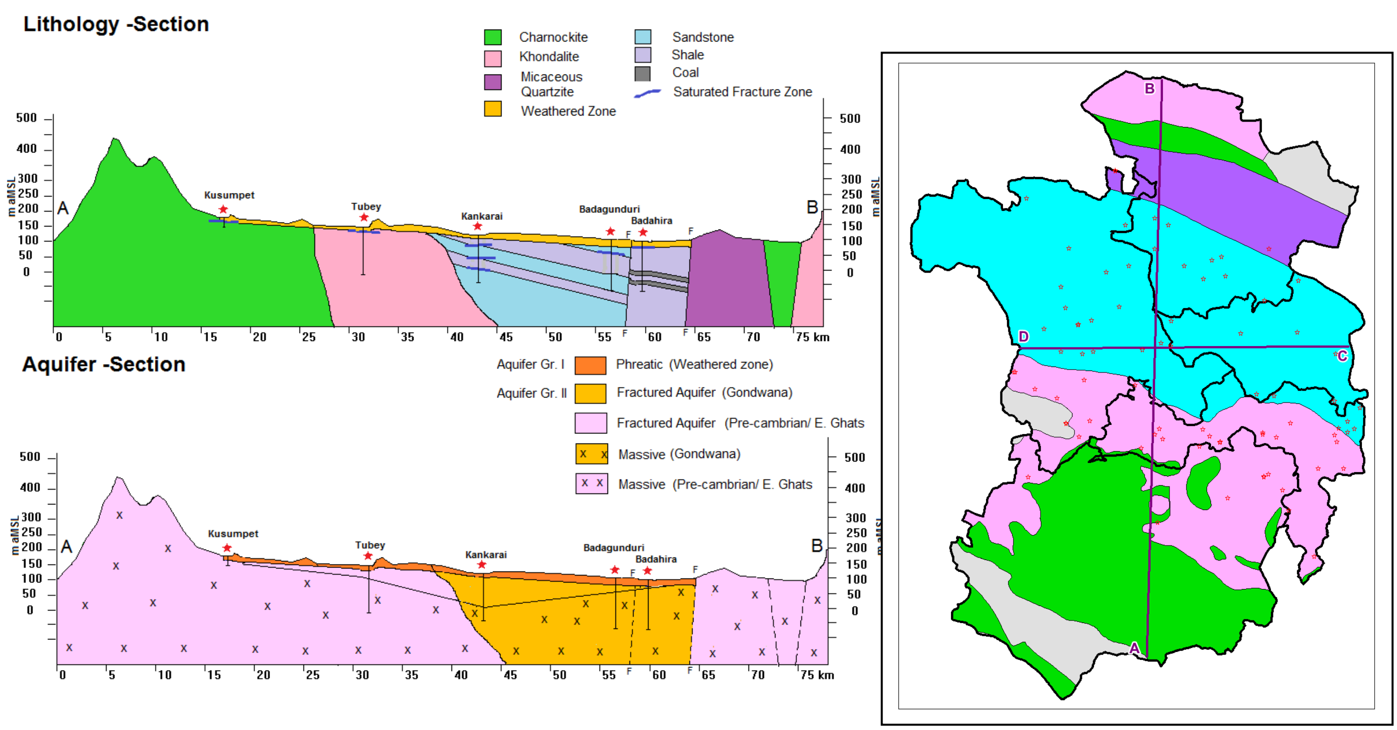


Fig. 6.2a: Delineation of Aquifers I & II from Lithological Section in the NAQUIM area, Angul district.

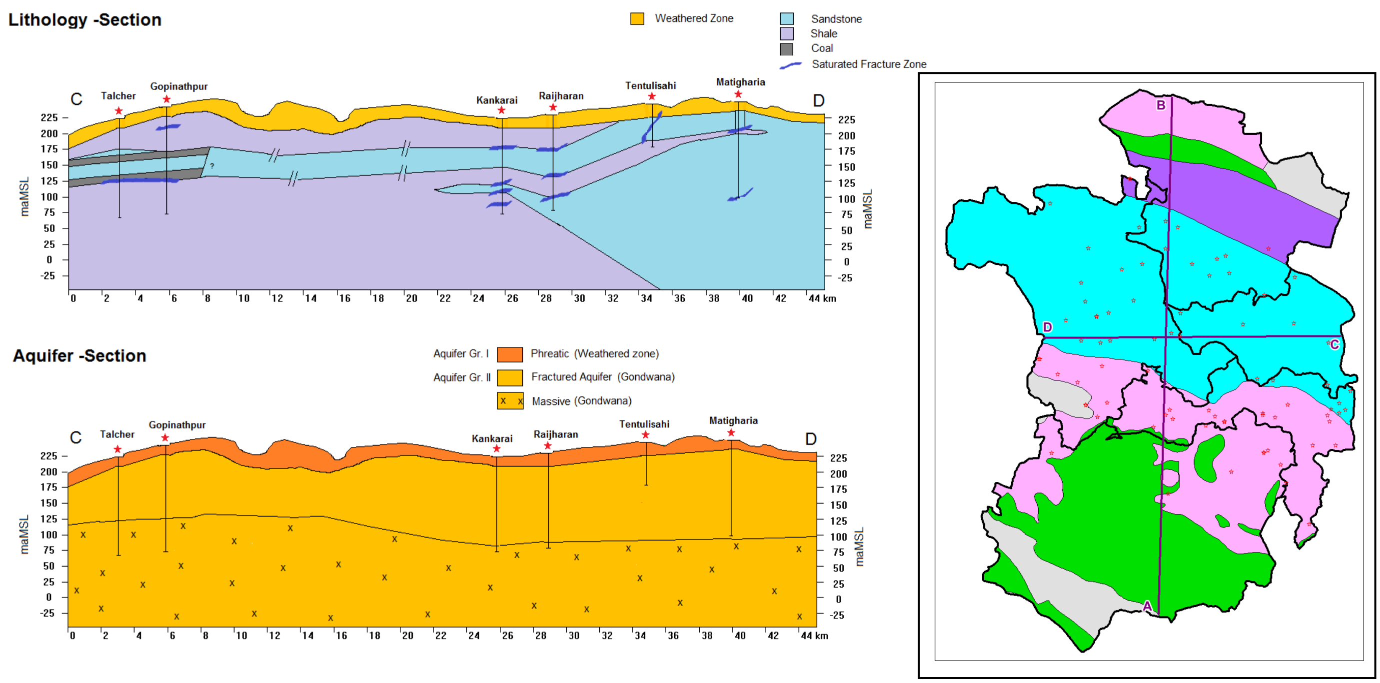


Fig. 6.2b: Delineation of Aquifers I & II from Lithological Section in the NAQUIM area, Angul district.

Based on field survey and ground water exploration, the deeper aquifer i.e. Aquifer-II in Easternghat formations viz. Charnockite and Khondalite and Gondwana formations viz. Sandstone and Shale have comparatively poorer yield prospect than the Granitic aquifers. the aquifer characteristic of NAQUIM area has been computed and is given in **Table 6.1.**

Table 6.1 : Aquifer Characteristic of NAQUIM area, Angul district

Type of Aquifer	Formation	Depth range of the aquifers (mbgl)	Yield (m3/day)	Aquifer parameter (T : m^2/day)	Suitability for drinking/ irrigation
Aquifer-I (phreatic)	Weathered- Granite Gneiss, Charnockite, Khondalite, mica quartzite, Sandstone, shale	0-30	10-50	-	Yes for both (except Fluoride affected villages for drinking)
Aquifer-II (semi-confined to confined)	Fractured-Granite Gneiss Fractured Charnockite, Khondalite, mica quartzite	30-200 30-200	Negl. to 1730 Negl. to 380	0.6-60 -	Yes for both Yes for both
Aquifer-II (semi-confined to confined)	Fractured-Sandstone, Shale	30-200	Negl. to 730	0.84-46	Yes for both

6.3 Aquifer Disposition

The ground water exploration data has been used to generate the 3D disposition of deeper basaltic aquifers. It comprises of all existing litho-units and the zones tapped during the ground water exploration, forming an aquifer. Based on the ground water exploration and micro-level hydrogeological survey data and aquifer delineation method adopted. A schematic 3-D diagram of aquifer disposition has been prepared and shown in **Fig. 6.3** and a lithological Fence diagram has been generated and shown in **Fig. 6.4**. To visualize the Aquifer-I and Aquifer-II, Based on ground water exploration different sub-surface lithological sections have been prepared to know the lithological continuity and extent. The sections are shown in **Fig. 6.5a to 6.5d.**

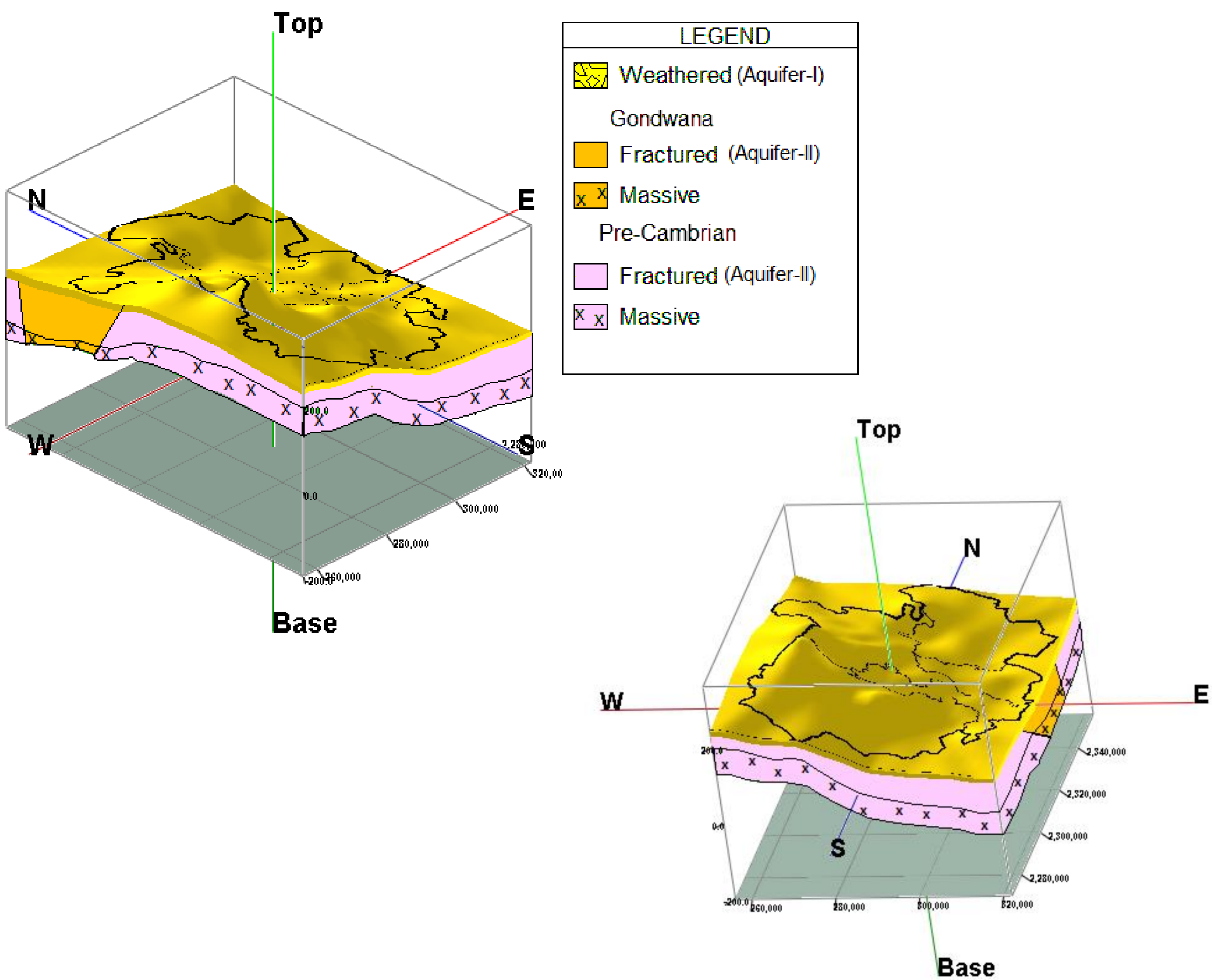


Fig. 6.3: Schematic 3-D Aquifer Disposition in NAQUIM area, Angul district

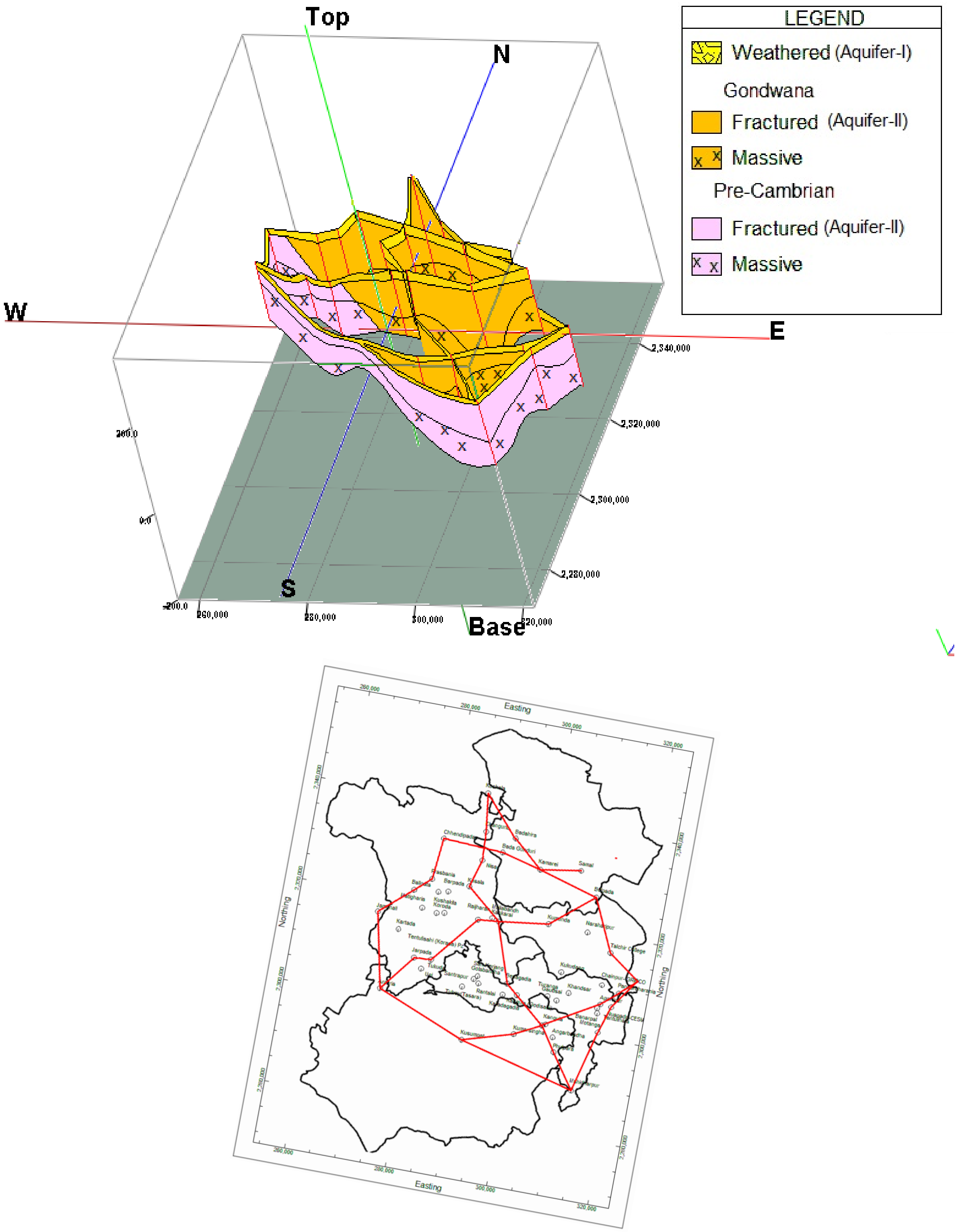
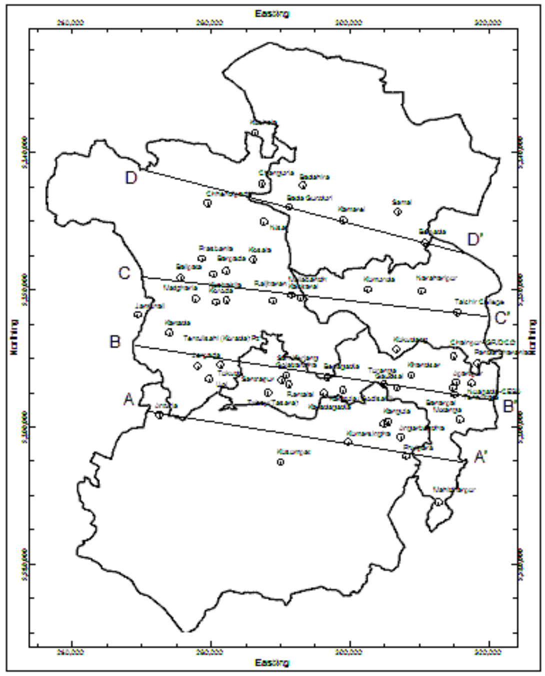
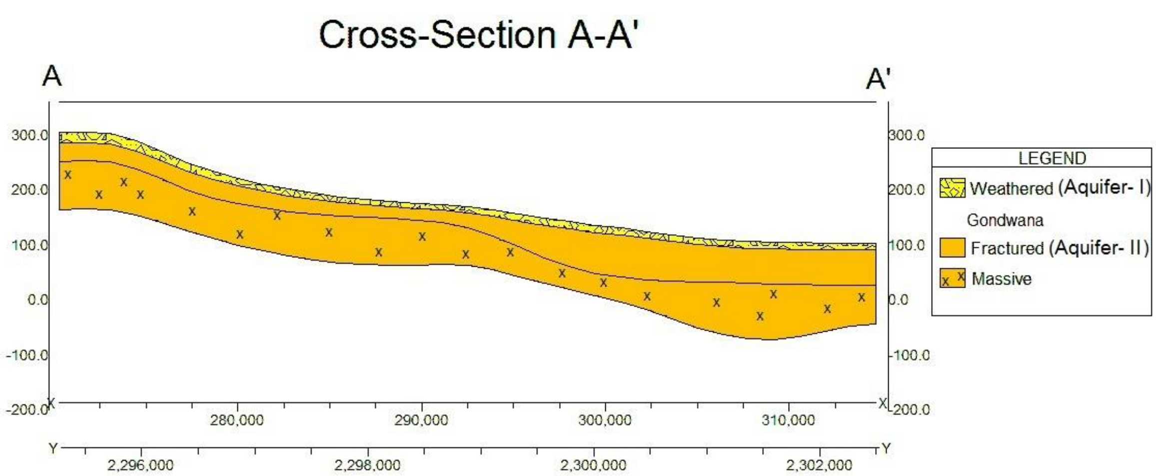


Fig. 6.4: 3-D Fence diagram, NAQUIM area, Angul district





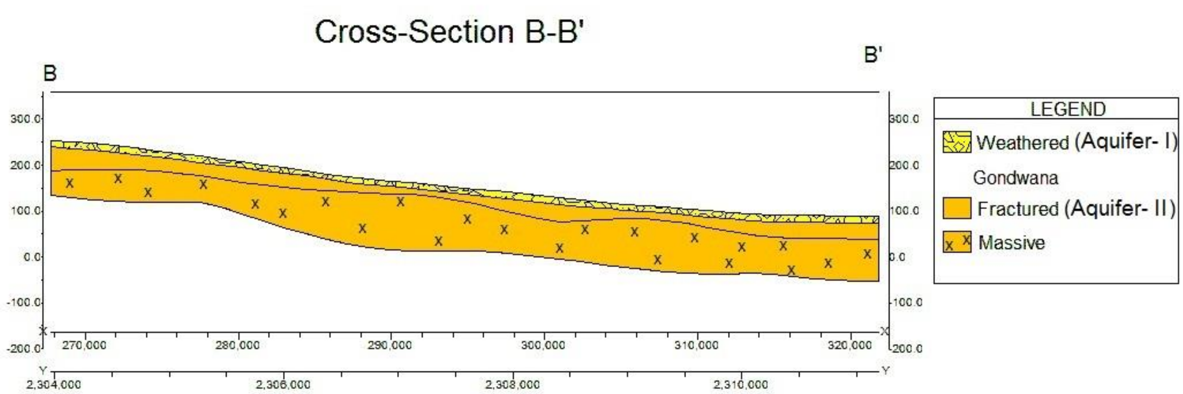


Fig. 6.5a: Lithological section along A-A' & B-B', NAQUIM area, Angul district

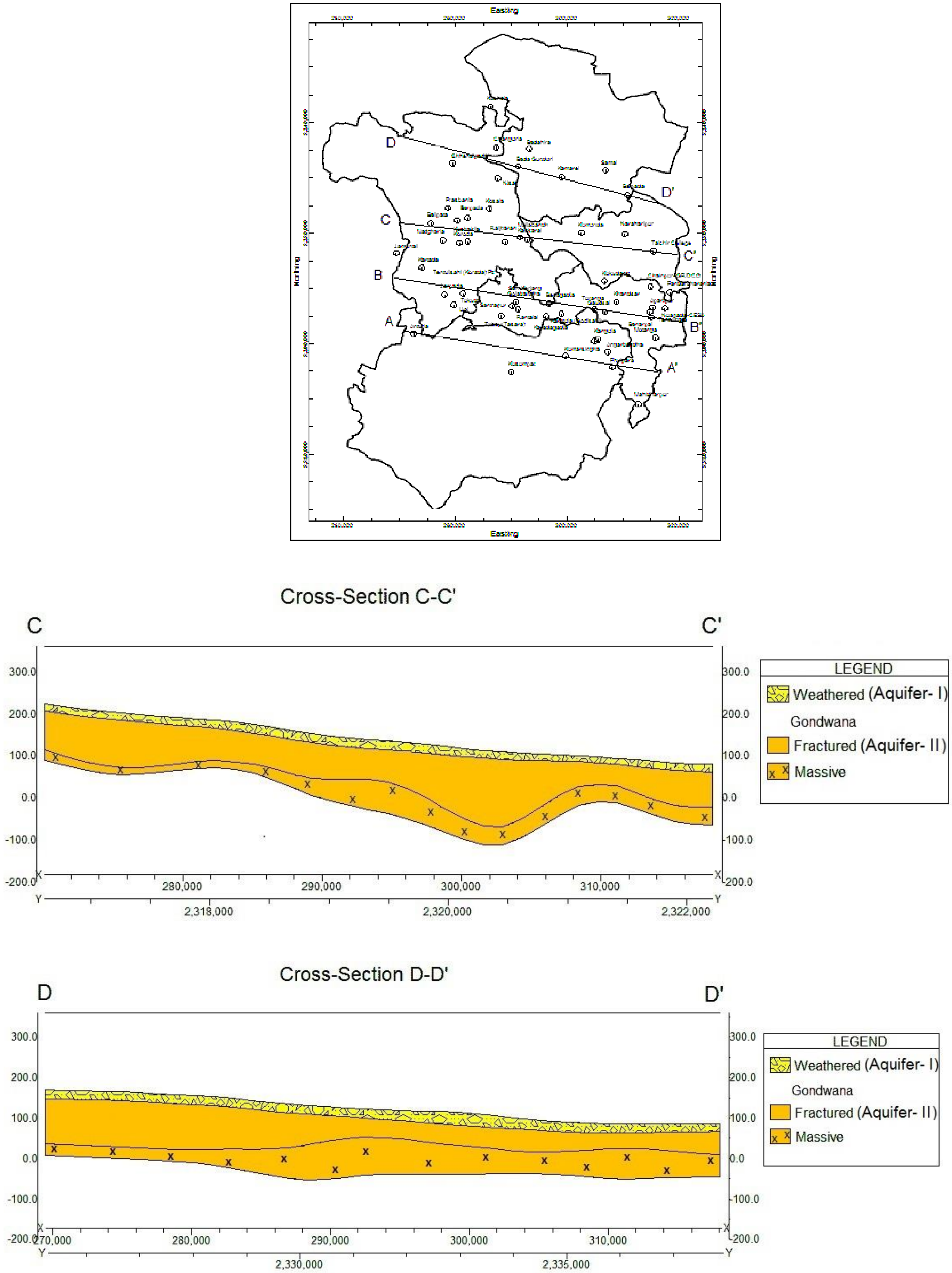
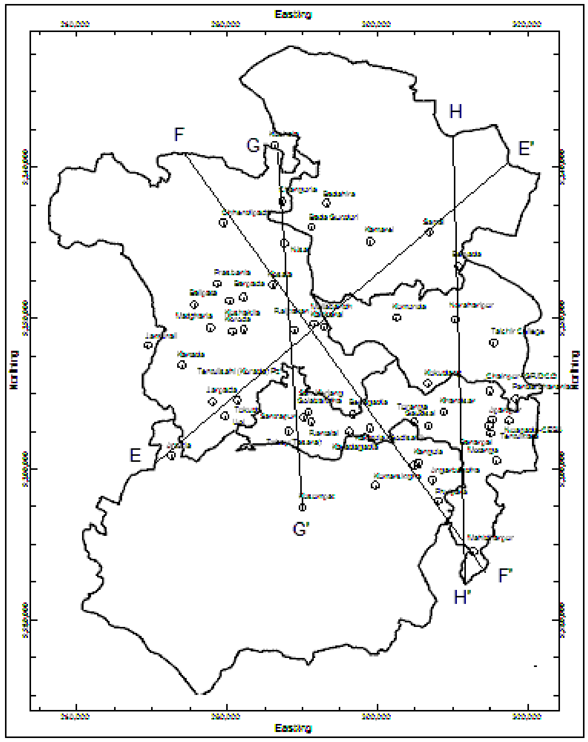
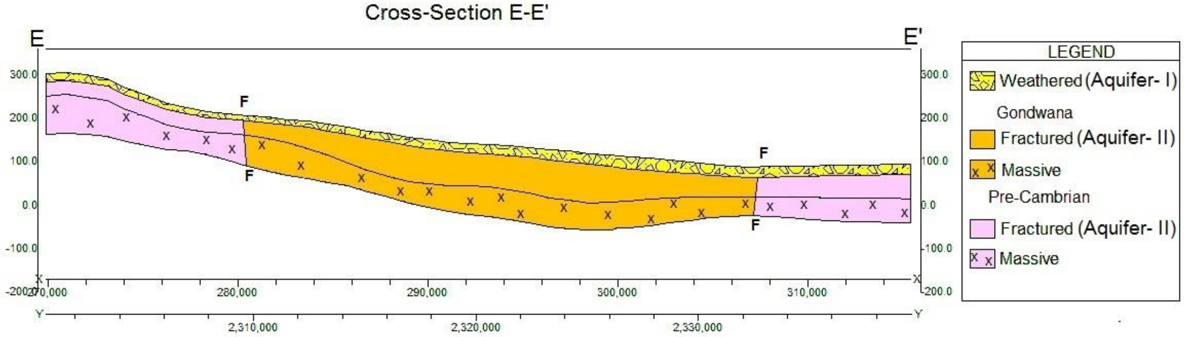


Fig. 6.5b: Lithological section along C-C' & D-D', NAQUIM area, Angul district





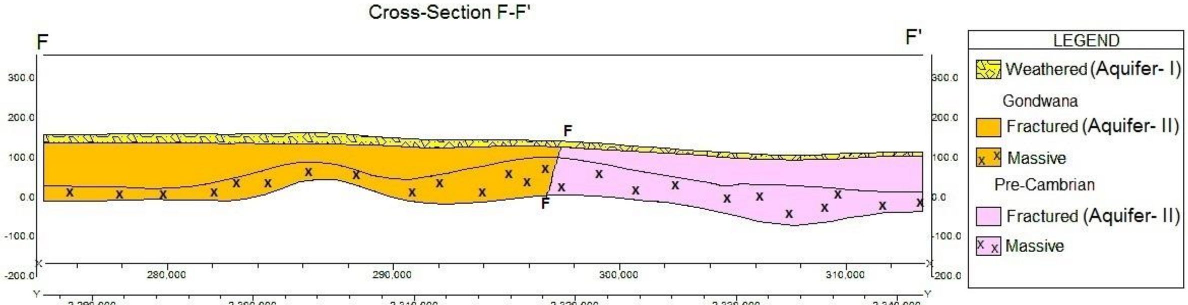


Fig. 6.5c: Lithological section along E-E' & F-F', NAQUIM area, Angul district

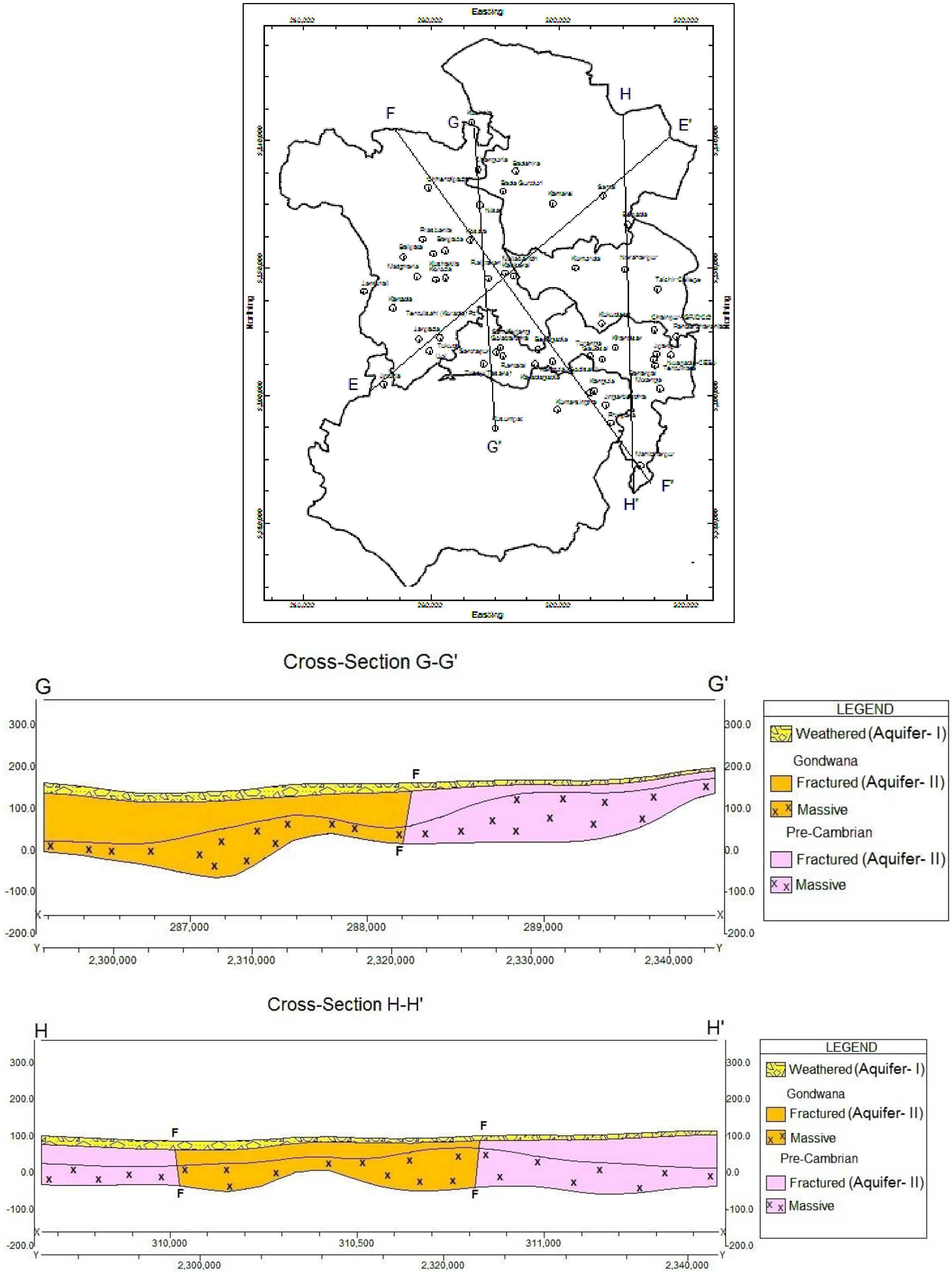


Fig. 6.5d: Lithological section along G-G' and H-H', NAQUIM area, Angul district

6.4 Fracture Analysis (Aquifer-II)

Based on the exploration data, the bottom depth of the Aquifer-II is taken down to 200 mbgl depth because this is the maximum likely depth within which fracture zones are encountered. Most of the fractures are encountered within 0-30 mbgl and then 30-100 mbgl and beyond that, the chances of encountering fracture zones gradually reduces. The occurrence of fracture with respect to depth down to 300 mbgl as explored by CGWB, in different lithology of the NAQUIM area are analysed and the result is summarized in **Table 6.2** and the number and percentage of fractures at different depths is shown in **Table 6.3**.

Table: 6.2: Depth wise occurrence of fracture zones in Aquifer-II, NAQUIM area, Angul district.

Fracture	Depth Range (mbgl) (No of wells)		
	Granite/Gr.Gneiss	Gondwana	Charnockite/Khondalite
1st	6.0-134.0 (39)	3.0-143.5 (32)	13.31-15.5 (1)
2nd	31.0-114.2 (20)	11.5-153.7 (12)	-
3rd	60.0-141.7 (6)	36.7-137.0 (5)	-
4th	80.0-99.6 (2)	105.7-156.0 (3)	-
5th	-	133.1-195.0 (2)	-
6th	-	207.0-214.0 (1)	-
7th	-	231.0-238.0 (1)	-
8th	-	247.0-254.0 (1)	-
9th	-	262.0-268.0 (1)	-
10th	-	282.0-286 (1)	-

Table: 6.3: No and Percentage of fractures in different depths in Aquifer-II, NAQUIM area, Angul district.

Formation	No of fractures encountered in the Depth Range (mbgl)						
	0-30	**30-50**	**50-100**	**100-150**	**150-200**	**200-300**	**Total**
Granite/ Gr. Gneiss	25	8	19	8	-	-	60
Gondwana	15	14	13	16	2	6	66
Charnockite/Khondalite	2	-	-	-	-	-	2
Total	**42**	**22**	**32**	**24**	**2**	**6**	**128**
%ge	**32.8**	**17.2**	**25**	**18.75**	**1.5**	**4.7**	

6.5 Aquifer Parameters and Yield Potentials

The principle of pumping test is that if we pump water from an Exploratory well and measure the discharge and drawdown in both EW and OW, which is at known distance, we can substitute these measurements to calculate different aquifer parameters such as Transmissivity (T) Storativity (S) and yield potentials.

Transmissivity (T): It is defined as rate of flow under a unit hydraulic gradient through a cross-section of unit width over the saturated thickness of aquifer. It is expressed as m^2/day. The T value in the NAQUIM area range between 0.59 m^2/day (Anturia) to 60.05 m^2/day (Ugi) in pre-Cambrian granitic rocks, between 0.84 m^2/day (Jarada) to 46.13 m^2/day (Koshala) in Gondwana sandstone.

Storativity (S): It is the volume of water released from storage per unit surface area of the aquifer per unit decline in the hydraulic head normal to that surface. It is dimensionless property. The S value in the area available for 2 places. They are 0.0000423 (Ugi, granite gneiss) and .00045 (Maliabandh, Sandstone).

Yield potential (Q): The yields of wells are functions of the permeability and transmissivity of aquifer encountered and varies with location, diameter and depth etc. There are three type of ground water structures i.e. dugwells, shallow tubewells and borewells in the area. Their yield characteristics are described below.

Aquifer-I: Dugwells tapping weathered residuum in Granite, Granite gneisses, mica quartzites, phyllites, khondalites, charnockites, sandstone and shale range in their depth 4.3 to 15.75 mbgl. The yield of dugwells range from 10 to 50 m^3/day. Shallow tube wells are feasible in very limited areas, especially in the flood plains of the Brahmani and Mahanadi rivers. The depth of these wells may be <30 m, tapping (through slotted pipe) 5-10 m thickness of the aquifer. The effective diameter of these wells can be even 155 mm and the yield may be up to 15.0 lps. Areas in Chhendipada block with Kamthi formation have very good yielding shallow as well as deeper aquifer.

Aquifer-II: The data of exploratory wells in NAQUIM area reveals that, high yielding area is restrict to western part of area mostly in Chhendipada block where most of the successful wells have been drilled, where out of 31 exploratory wells 14 have discharge 3.0 lps or more with maximum at 20.3

lps. Success rate is least in Talcher and Kaniha block followed by Banarpal block. This indicates that Gondwana sandstone are least productive in Talcher and Kaniha block and not in Chhendipada block where it shows good yield because of Kamthi formation which is most prolific among the Gondwana formations. Among the consolidated crystalline formations granitic aquifers have promising yield mainly in Chhendipada block and western part of Banarpal block where as the eastern and southern parts have poor yield.

6.6 Recharge Parameters

During monsoon season, the rainfall recharge is the main recharge parameter, which is estimated as the sum total of the change in storage and gross draft. The change in storage is computed by multiplying groundwater level fluctuation between pre and post monsoon periods with the area of assessment and specific yield. The specific yield value as estimated from dry season balance method or field studies was taken, wherever available. In absence of field values of specific yield values through above methods recommended values as per GEC-1997 norms has been taken. The sp. yield value of 0.03 has been used for ground water estimation in the Angul district.

The monsoon ground water recharge has two components- rainfall recharge and recharge from other sources. The other sources of groundwater recharge during monsoon season include seepage from canals, surface water irrigation, tanks and ponds, ground water irrigation, and water conservation structures. During the non-monsoon season, rainfall recharge is computed by using Rainfall Infiltration Factor (RIF) method. Recharge from other sources is then added to get total non-monsoon recharge. In Angul district, the infiltration factor is taken as 0.08. The details of recharge and discharge parameters are given in **Table 6.4.** The discharge parameters include natural discharge in the form of springs and base flow and discharge for ground water irrigation, domestic and industrial draft.

Table 6.4: Recharge and discharge parameters estimated based on Ground Water Resources Estimation (2011). (In Ham)

Taluka	Command / Non command	Recharge from Rainfall during Monsoon	Recharge from other sources during monsoon	Recharge from Rainfall during Non-Monsoon	Recharge from other sources during non-monsoon	Total Annual GW Recharge	Natural Discharge	Discharge for Irrigation	Discharge for Domestic and Industrial
Angul	Command	128	308	20	305	761	76	422	13
	Non-	4628	223	657	318	5826	291	1078	501
	Total	**4756**	**531**	**677**	**623**	**6587**	**367**	**1500**	**514**
Banarpal	Command	495	1679	0	2218	4392	439	572	97
	Non-	3255	298	0	421	3974	199	1532	437
	Total	**3750**	**1977**	**0**	**2639**	**8366**	**638**	**2104**	**534**
Chhendipada	Command	132	421	0	532	1085	109	391	21
	Non-	4954	282	0	449	5685	284	1864	697
	Total	**5086**	**703**	**0**	**981**	**6770**	**393**	**2255**	**718**
Kaniha	Command	0	0	0	0	0	0	0.00	0.00
	Non-	5493	314	0	544	6351	318	2423	338
	Total	**5493**	**314**	**0**	**544**	**6351**	**318**	**2423**	**338**
Talcher	Command	0	0	0	0	0	0	0.00	0.00
	Non-	2607	183	0	276	3066	153	923	593
	Total	**2607**	**183**	**0**	**276**	**3066**	**153**	**923**	**593**
NAQUIM Area 5 Blocks	**TOTAL**	**21692**	**3708**	**677**	**5063**	**31140**	**1869**	**9205**	**2697**

7 Ground Water Resources

Central Ground Water Board and Ground Water Survey and Investigation (GWSI) have jointly estimated the ground water resources based on GEC-97 methodology as on 2011. The ground water resource can be aquifer wise divided into Dynamic and Static resource. The dynamic resource is the part of resource within the water level fluctuation zone which is also the annual replenishable resource. The resource below the water level fluctuation zone is termed as the In-storage (Static) resource. As per the resource estimated during 2011, the stage of ground water development is maximum in Talcher block (52.05%) and minimum in Angul block (32.37%) which indicates that sufficient scope exists for further ground water development. The ground water resources for Aquifer-I as estimated in year 2011, are given in **Table 7.1** and **7.2 and 7.3.**

Table 7.1: Dynamic ground water resources of Aquifer-I, NAQUIM area, Angul district (2011)

Sl No	Block	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for Irrigation	Existing Gross Ground Water Draft for domestic & Industrial Supply	Existing Gross Ground Water Draft for all uses	Provision for domestic & industrial requirement supply for next 25 years	Net Ground Water Availability for future irrigation development	Stage of Ground Water Development
		(Ham)	(Ham)	(Ham)	(Ham)	(Ham)	(Ham)	(%)
1	Angul	6220.00	1499.68	514.00	2013.68	675.00	4045.32	32.37
2	Banarpal	7728.00	2104.46	534.00	2638.46	728.00	4895.54	34.14
3	Chhendipada	6377.00	2255.34	718.00	2973.34	718.00	3403.66	46.63
4	Kaniha	6033.00	2422.98	338.00	2760.98	424.00	3186.02	45.76
5	Talcher	2913.00	923.10	593.00	1516.10	840.00	1149.90	52.05
	Total	**29271.00**	**9205.56**	**2697.00**	**11902.56**	**3385.00**	**16680.44**	**40.66**

Table 7.2: In-Storage ground water resources of Aquifer-I, NAQUIM area, Angul district (2011)

Sl No	Block	Assessment Area	Bottom Depth of Aquifer	Average Pre-monsoon Water Level	Total Saturated Thickness (2-3)	Average Specific Yield	In Storage Ground Water Resources [(1)*(4)*(5)]
		(Ha) (1)	(mbgl) (2)	(mbgl) (3)	(m) (4)	(5)	(Ham) (6)
1	Angul	49456	23.2	6.55	16.65	0.015	12252

2	Banarpal	33765	21.9	7.64	14.26	0.015	7222
3	Chhendipada	61012	20.6	5.83	14.77	0.015	13517
4	Kaniha	45523	21.7	7.01	14.69	0.015	10131
5	Talcher	28866	20.6	8.2	12.4	0.015	5369
	Total	**218622**					**48491**

Table 7.3: Total ground water resources of Aquifer-I, NAQUIM area, Angul district (2011)

Sl No	Block	Dynamic Resource	In Storage Resource	Total Ground Water Resource
		(Ham) (1)	(Ham) (2)	(Ham) (3)
1	Angul	6220	12252	18472
2	Banarpal	7728	7222	14950
3	Chhendipada	6377	13517	19894
4	Kaniha	6033	10131	16164
5	Talcher	2913	5369	8282
	Total	**29271**	**48491**	**77762**

The ground water resource in Aquifer- II (Fractured Aquifer) is entirely in-storage. The estimation of Aquifer-II resource is shown in **Table 7.4**.

Table 7.4: In-Storage ground water resources of Aquifer-II, NAQUIM area, Angul district (2011)

Sl No	Block	Assessment Area	Top Depth of Aquifer	Bottom Depth of Aquifer	Total Saturated Thickness (3-2)	Productive Zone (5% of Total Thickness)	Avg. Sp. Yield	In Storage Ground Water Resources (1)*(5)*(6)
		(Ha) (1)	(mbgl) (2)	(mbgl) (3)	(m) (4)	(m) (5)	(6)	(Ham) (7)
1	Angul	49456	23.2	200	176.8	8.84	0.015	6558
2	Banarpal	33765	21.9	200	178.1	8.9	0.015	4507
3	Chhendipada	61012	20.6	200	179.4	8.97	0.015	8209
4	Kaniha	45523	21.7	200	178.3	8.915	0.015	6088
5	Talcher	28866	20.6	200	179.4	8.97	0.015	3884
	Total	**218622**						**29246**

8 AQUIFER MANAGEMENT PLAN

A through study was carried out based on data gap analysis, data generated in-house, data acquired from State Govt. departments and maps procured from GSI and other sources, an integrated approach was adopted while preparing aquifer management plan of the NAQUIM area of Angul district. Based on this, geomorphology, soil, land use, field data, lithological information and ground water related issues, aquifer management plan is carried out and the detailed taluka wise aquifer management plan is prepared.

8.1 Ground Water Related Issues

8.1.1 Impact of Mine Dewatering

The study area occupies a significant position in the mineral map of India because of its huge deposit of coal. Talcher Coal Field is one important coal field of the country occurs in the study area. The coal mining activities are centered around Talcher and spread over an area of about 1814 km^2. The anticipated coal resource is about 44,30,943 million tones comprising of all grades of coal. There are 4 underground mines namely Nandira, Handidhua, Deulbera and Talcher and opencast mines at Balanda, Jagannath, Ananta, Kalinga, Bharatpur, Lingaraj, Hingula, Bhubaneswari, Chhendipada and Kaniha. A map showing the operational mines is given in **Fig. 8.1**.

Though coal mining is important for Industry, Power and national economy, it has the main demerit as coal mining needs large scale dewatering of ground water and thus greatly affects the ground water regime and the ecology. The impact of mine dewatering is assessed in the Talcher Coal Field area which comes in the NAQUIM area in Angul district. The seasonal quantum of water dewatered from various coal mines are given in **Table 8.1**. The total ground water discharged is about 277.8 Ham during summer and 405.2 Ham during the monsoon season. Thus the annual mine dewatered is around 683 ham. The effect of dewatering is reflected in the lowering of water table and piezometric head and formation of a ground water trough in the coal mining blocks. The effect is more pronounced in the piezometric head because of the fact that the deeper aquifer formed by the Barakars has poor ground water potential. The piezometric head has fallen down to maximum depth of about 34 mbgl at Kandhal near Talcher. However outside the mine boundaries the piezometric head is in the range of 3-7 mbgl. The map showing the depth to water level of Aquifer-I and piezometric heads of Aquifer-II, in the mining blocks are given in **Fig 8.2** and **8.3**.

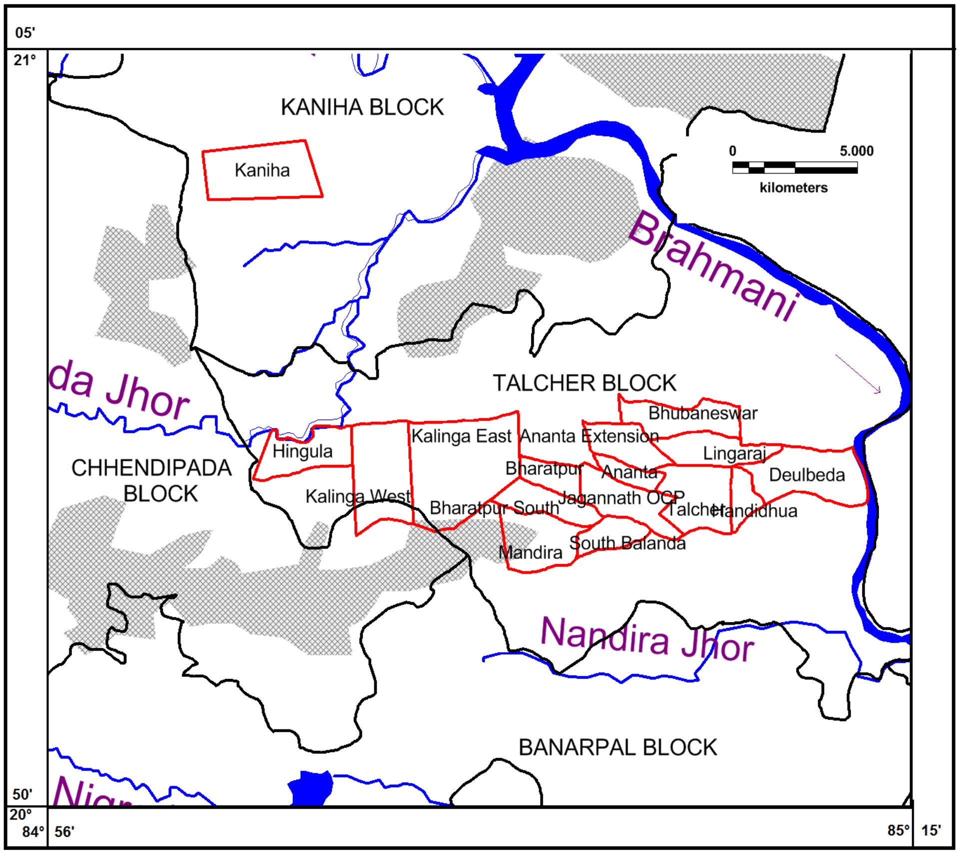


Fig. 8.1: Coal Mines under operation in Talcher Coal Field, NAQUIM area, Angul district

Table 8.1: Ground Water discharge due to coal mine dewatering in Talcher Coal Fields, Angul district.

Sl No	Name of Mines	Total Area (Sq. Km)	Type of Mining	Coal Reserve (MTons)	Mine Water Discharge (Ham)		Total Summer Discharge	Total Monsoon Discharge	Annual Discharge
					Summer	Monsoon	Ham	Ham	Ham
1	Talcher	6.53	UG	58.1	0.0571	0.4006	15.7025	36.054	51.76
2	Dulbera	7.15	UG	28.16	0.059	0.059	16.225	5.31	21.54
3	Handidhua	2.13	UG	5.2	0.1308	0.9806	35.97	88.254	124.22
4	Nandira	5.19	UG	36.7	0.147	0.147	40.425	13.23	53.66
5	Jagannath	4.89	OC	134	0.0572	0.5148	15.73	46.332	62.06
6	South Balanda	2.27	OC	34.6	0.32	1.0869	88	97.821	185.82
7	Ananta	4	OC	258.9	0.0204	0.4412	5.61	39.708	45.32
8	Bharatpur	6.76	OC	133.2	0.109	0.109	29.975	9.81	39.79
9	Kalinga	8.21	OC	347.6	0.1098	0.764	30.195	68.76	98.96
	Total	**47.13**		**1036.**			**277.8325**	**405.279**	**683.11**

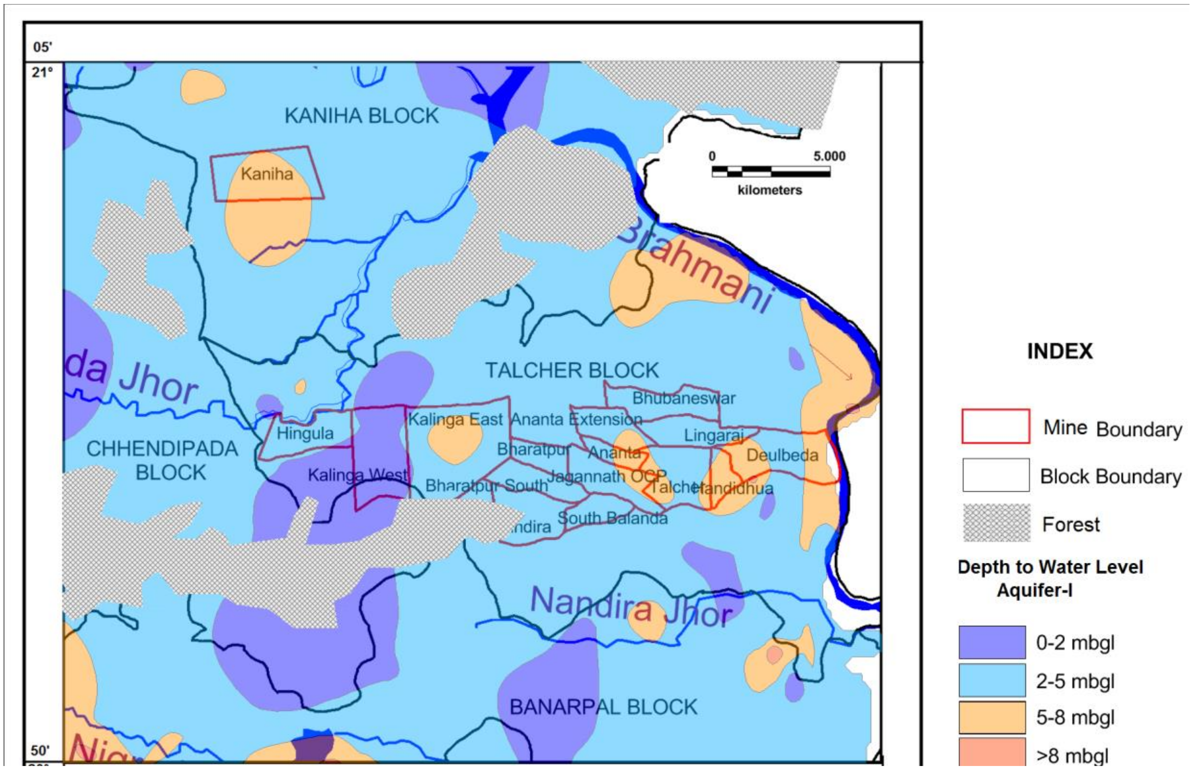


Fig. 8.2: Depth to Water Level (2015) in Aquifer-I in Talcher Coal Field, Angul district

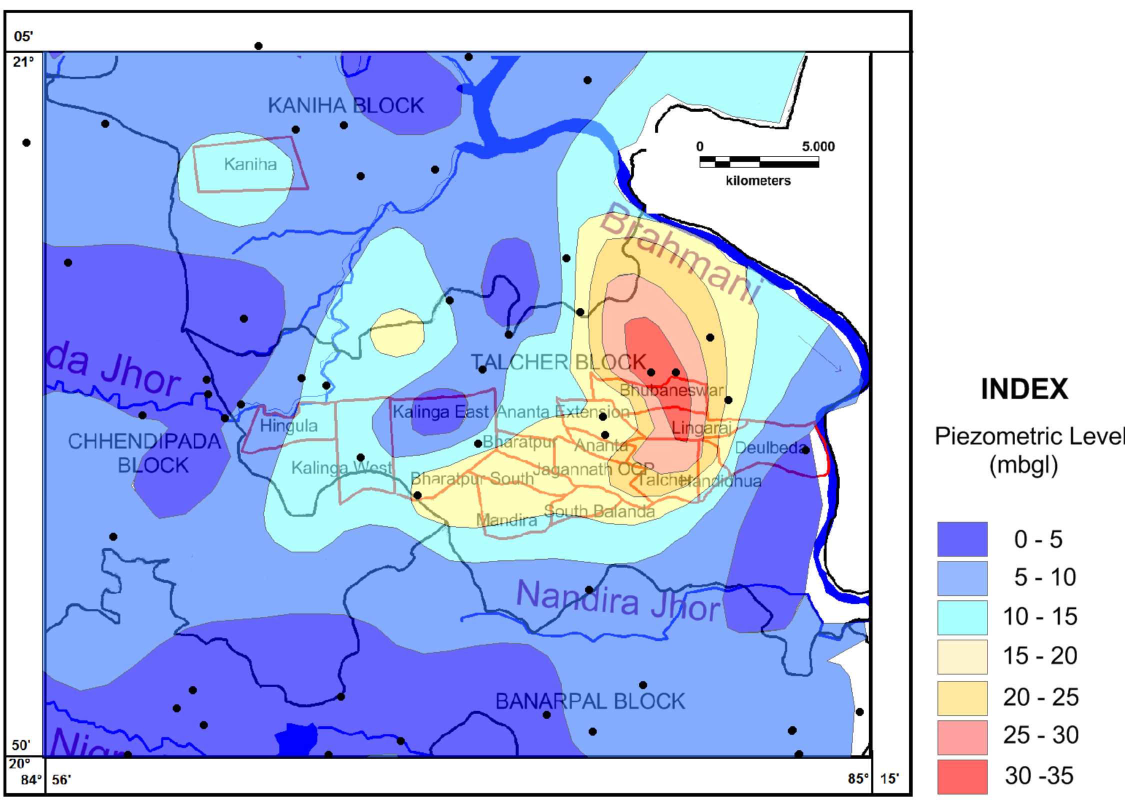


Fig. 8.3: Piezometric Head of Aquifer-II in Talcher Coal Field, Angul district

8.1.2 Fluoride in Ground Water

It has already been found that higher concentration of fluoride has been observed in the ground water in shallow as well as deeper aquifer. The State Pollution Control Board (SPCB), Odisha has already reported excess fluoride in the soil samples from 11 villages surrounding the Nalco smelter plant area in Banarpal block. But as per the findings of studies carried out by CGWB on different occasion, the occurrence of higher fluoride in isolated locations and does not show any pattern. Also any adverse effect of effluent discharged from mining and industries, on the ground water quality has not been noticed yet.

8.2 Management Plan

8.2.1 Management Plan for Mine Dewatering

The discharge of large quantum of ground water by the mine dewatering has created a ground water trough in the Talcher coal mining area. The maximum piezometric head is around 35 mbgl however outside the mining areas the piezometric head is within the range of 3-7 mbgl. From this it's evident that the cone of depression of pumping is low due to poor transmissivity of the aquifers.

As per the information available, about 50% of ground water discharged from the mines is used in domestic and industrial purpose in the Mining area and in the surroundings. The remaining unused ground water which is normally discharged to the nearby drainage channels can be collected and used for recharge purpose. By recharging water through injection wells in the form of garland recharge wells along the periphery of ground water trough, to create a boundary of ground water mound which will check further spreading of the effect of mine dewatering as a result of which the ground water regime beyond the coal mining area will remain unaffected from pumping within the mines. The garland recharge well concept is shown in **Fig. 8.4**.

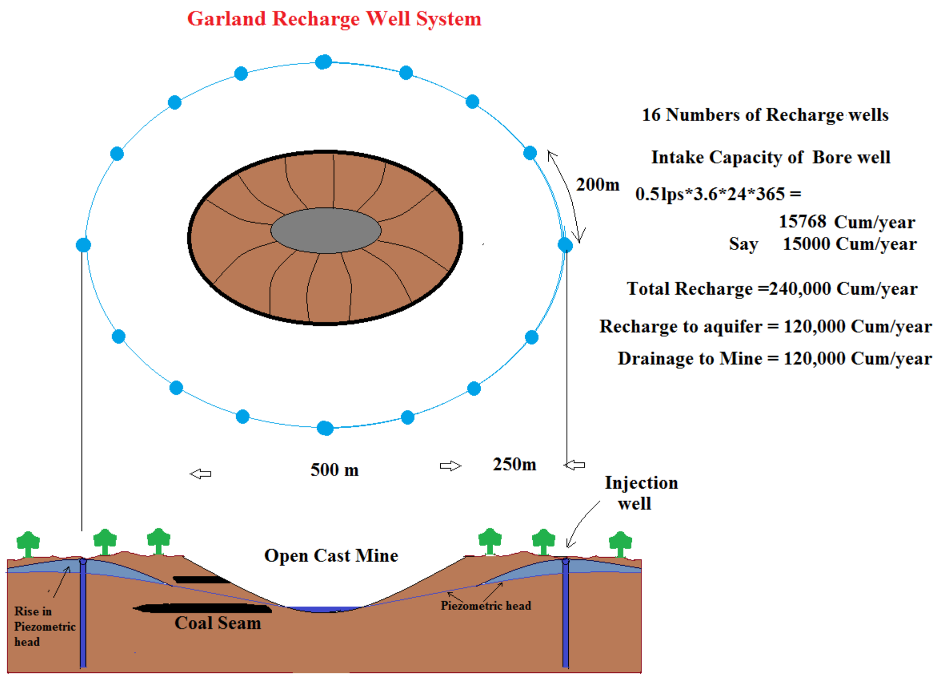


Fig. 8.4: Garland Recharge Well System to check the effect of mine water dewatering.

8.2.2 Management Plan for Fluoride in Ground Water

Fluoride higher than permissible limit of drinking has been found in the NAQUIM area in shallow as well as deeper aquifers. Drinking water sources like dugwells, borewells and hand pumps, once found to be of high F, should be immediately marked unsuitable and informed to the public to prohibit the use of such sources for drinking. The occurrence of fluoride is known to be a local phenomenon and in none of the village, fluoride is found everywhere and in all ground water sources. Hence it's advisable to make suitable arrangement for providing alternate, safe and hygienic source for drinking water in those fluoride affected villages.

8.2.3 Future Ground Water Development Potential

From the ground water resource estimation carried out for the Aquifer-I in 2011, the present ground water development ranges from 32.47 % in Angul Block to maximum 52.05% in Talcher block. This includes ground water usage for all usage domestic, industrial as well as irrigation. However the percentage of area irrigated by ground water is the area is mere 2% of total irrigation area. Taking ground water development safely up to 60% of the resource available, the ground water potential for further development is calculated, which is about 5660 Ham in the NAQUIM area with minimum 231.7 Ham in Talcher block and maximum 1998.34 Ham in Banarpal block. The details of the same are shown in **Table 8.2**.

Table 8.2: Ground Water development potential in NAQUIM area, Angul district.

Block	Total Area irrigated (Ha)	Area irrigated by Ground Water (Ha)	% of Area Irrigated by Ground Water	Net Annual Ground Water Availability (Ham)	Existing Gross Ground Water Draft for all uses (Ham)	60% of Annual Resource Available (Ham)	Further Ground Water development potential (Ham)
Angul	2810.32	0	0	6220	2013.68	3732	1718.32
Banarpal	4160.01	0	0	7728	2638.46	4636.8	1998.34
Chhendipada	3229.29	226	6.9	6377	2973.34	3826.2	852.86
Kaniha	767.49	24.12	3.1	6033	2760.98	3619.8	858.82
Talcher	1097.87	0	0	2913	1516.10	1747.8	231.7
TOTAL	**12064.98**	**240.12**	**1.9**	**29271**	**11902.56**	**17562.6**	**5660.04**

9 Summary and Recommendations

9.1 Summary

National Aquifer Mapping Programme (NAQUIM) were taken up for detailed hydrogeological investigation, data-gap analysis and Aquifer Mapping in five blocks of Angul district namely Angul, Banarpal, Chhendipada, Kaniha and Talcher covering an area of 3088.4 sq. km., during the period 2012-2015. The following are the summarised details.

1. Data gap analysis was carried out in the area and further data acquisition is planned accordingly.
2. The study area exposes rocks of Iron-Ore Super Group, Easternghat Super Group and Gondwana Super Group. Besides these laterites and alluvial deposits of Quaternary Period also occurs at places.
3. Ground Water Occurs in Phreatic condition in weathered portions generally down to a depth of about 30 mbgl.
4. Ground water occurs under semiconfined to confined condition in fractured formation down to maximum depth of about 200 mbgl.
5. The area receives a good rainfall of about 1150 mm/yr.
6. The average pre-monsoon water level in the area is within 6 mbgl.
7. The estimated dynamic ground water resource shows that the stages of development of ground water range from 32.37 to 52.05 %, therefore sufficient scope still exists for further ground water usage.
8. The quality of ground water is potable and good except some isolated cases of excessive fluoride.
9. Huge quantum of ground water are being pumped out from the ground water reservoir due to the coal mine dewatering which is impacting the ground water regime by lowering of water table and piezometric head in and around the coal mining area.

9.2 RECOMMENDATIONS

The highly diversified occurrence and considerable variations in the availability and utilization of groundwater makes its management a challenging task. Scientific development and management strategy for groundwater has become imperative to avert the looming water crisis. In this context, various issues such as, prioritization of areas for development of groundwater resources vis-a-vis its availability, augmentation of groundwater through rainwater harvesting and artificial recharge, pricing and sectoral allocation of resources and participation of the stakeholders must be considered. In view of the above, the present study area a systematic, economically sound and politically feasible framework for groundwater management is required. Considering the local physiographical and hydrogeological set up the following ground water management strategy is suggested.

1 As the current stage of ground water withdrawal is within 50%, utilization of ground water resource for the socio-economic development is feasible. Annually about 6000 Ham of ground water can be withdrawn safely for further usage. The phreatic aquifer in Chhendipada block covering the Kamthi formation have very high and sustainable ground water potential.

2 Drinking water sources like dugwells, borewells and hand pumps, once found to be of high F, they should immediately be marked unsuitable and informed to the public to prohibit the use of such sources for drinking. Moreover it's advisable to make suitable arrangement for providing alternate, safe and hygienic source for drinking water in those fluoride affected villages.

3 The effect of large scale ground water pumping from the coal mining areas can be arrested by using the unused pumped ground water for creating a recharge front around the mining area through the proposed Garland Recharge Well concept.

4 Artificial recharge through construction of Percolation tank and check dams are feasible where source water is available. The check dams should be constructed on 2nd and 3rd order drainages. Further details such as aquifer wise storage potential, source water availability etc. are discussed in Part-II of the report.