Hydro-Geological Investigations In and around JSPL Plant Area, District, Angul, Orissa

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CHAPTER 1.0 INTRODUCTION

1.1 Background

The state of Orissa is endowed with vast natural resources including several strategic minerals. This has led to intensive industrial development. The Angul district which has been carved out from earlier Dhenkanal district is one such area in which various industries are located. The proposed steel plant of Jindal Group of Industries with a capacity of six MTPA is under construction close to Angul town. The town as well as the project area represents an uneven terrain surrounded from all sides by the hills. These hills are sources of several small and medium rivulets and streams. Water being one of the vital inputs for any developmental activities, is of major concern to authorities. The estimated water requirement of the plant area has been worked to the tune of 328800 m^3/day inclusive of domestic requirements. As the requirement is huge and to ascertain the assured water supply, it has been planned to meet the requirement by surface water to be brought from river Brahmani through a 24.5 km pipeline to be laid down upstream of Sambalpur barrage. The necessary approval in this regard has already been received from the State Department. Since the laying of pipeline will take time, it has been proposed to draw 5000 m^3/day ground water during the construction period with an understanding that as soon as the pipeline is ready the entire water requirement shall be met from river water. This study has been taken with the broad objective to suggest feasibility of ground water development to meet the water requirement during construction period as well as to explore the possibilities of harvesting rain water in and around the project area so as to supplement the water requirements in future as well as to maintain an ecological balance in the area.

1.2 Objective

Study aims at suggesting the most viable and scientifically managed plan for development of ground water and utilization of surface water on a watershed management approach. In order to provide sustainability, number of artificial recharge structures has also been proposed.

1.3 Scope of work

To achieve the desired goal detailed hydrogeological and hydrological investigation has been carried out. Various tools such as remote sensing , GIS and advanced analytical techniques has been used at various levels for run off computations, identify suitable areas for ground water development, rain water harvesting and artificial recharge structures.

1.4 Location & Extent of Proposed Project

The project site is located in the Angul district of Orissa. The plant area fall in Survey of India topo-sheet 73 0/13 & 73 H/1 between Longitude 84°55' to 85°0' 45" E, Latitude 20° 51' 40" to 20° 54' N . Angul town which is also the district head quarter is located about 8 km south-east of plant. The plant is spread over an area of about 5675 acres. The plant area is situated on the NH-42 connecting to Sambalpur and also connected through metalled road with Chendipada. The Angul Sambalpur railway line touches the southern limit of the plant. The nearest airport is Bhubaneswar which is about 150 km north from the plant. The administrative map of the Angul district showing the project area is given in Fig. 1.1 and the satellite map with location of the plant area is shown in Fig.1.2. The detailed study has been undertaken in an area extending in a radius of five kms from the plant site. The map of the study area with project location is given in Fig. 1.3.

CHAPTER 2.0 GEO-MORPHOLOGICAL SET UP

2.1 Physiography and Drainage

The Angul district is represented by hills and table land, the entire district of Angul can be divided into three distinct Physiographic regions namely Northern Mountainous Region, Southern and South Western Mountainous Region and Central undulating plains. The Physiographic map of Angul district is given in Fig. 2.1. The northern part of the district is characterized by dense forest of Pallahara subdivision and WNW-ESE trending hills immediately north of the Talchir coal, the area is drained by river Brahmani. The southern hilly region forms the watershed between river Brahmani and Mahanadi River. The central part of the district in which the project area is located is characterized by Undulating plain. The valley portion exposes granites and its variants with hillocks of Khondalites, the remaining including the study area is characterized by considerably flat country. The study area inclusive of core zone represents hilly and rolling topography in the entire western sector. Part of eastern sector represents rolling and south-easterly sloping plain. The highest elevation is over 520 m above mean sea level is observed in south-western sector in Pathargarh reserve forest and Kalapat reserve forest. The average land elevation in the eastern sector is around 150 m above mean sea level. The regional land slope is easterly and south-easterly with local variations. The land slope is steeper over western part of the study area as compared to eastern parts. The existing physiographic set up and prevalence of drainage system in the area provides ample opportunity for rain water harvesting as well water conservation so as to augment the natural recharge to ground water reservoir in the area which will provide long term sustainability. However, this requires a holistic planning at watershed level.

The major part of the Angul district lies between two major river systems of Orissa State i.e. River Brahmani flows in the north east and river Mahanadi which forms the south-south western boundary of the district. The altitude and physiographic set of the area divides the entire district into two distinct catchments, the streams joining the river Mahanadi flows in south-west direction whereas the streams joining the river Brahmani from the central plains flows in north – east direction.

The study area forms a part of Brahmani river basin and Singhara Jhor forms the main watershed in the north while Nigra & Mateliya Nala forms the principle watershed in the south. The Kurdabhali Nala of intermittent nature flows in the north eastern corner of the proposed plant area, major part of the micro watershed of this nala fall in the project area and it is proposed to divert the flow along the plant boundary. In general the major streams show a right angle pattern while joining with the river Brahmani, the meanders indicating differential weathering phenomenon. The drainage pattern is mostly dendritic and occasionally parallel in hills. These rivers have been harnessed to meet the focal water need for irrigation by constructing bunds and medium dams. The Darjanga reservoir is main surface water source in the area which is located 3 km east of Angul town. The reservoir has been created by bunding Nigra nala close to Bengarhia village. The drainage map of the study area is given in the Fig. 2.2.

2.2 Soil and Land Use

As per the agro-climatic classification, the district fall under the broader category of tropical wet and dry climate and locally it has been put under Arid Central Table Land. The agro-climatic map of India is provided in Fig. 2.2. As per the map almost entire Orissa state fall under one climatic category. There are mainly three types of soil found in the district viz. Alfisols, Ultisols and Vertisols. Alfisols which includes red sandy soils, red loamy soils and mixed red and black soils, the red sandy/loamy soils covers major part of the district including the study area. The soil map of the study area is given in Fig. 2.4. Soil plays very important role in over all availability of surface water as well as recharge to ground water.

The red soils are light textured, usually devoid of lime kankar and free of carbonates. Sandy clay is common and these soils are suitable for cultivation of paddy and other crops. Ultisols are also found in the western extremity of the study area which consists of red and yellow soils and are rich in clay content. Nearly 45 % of the district area is occupied by reserve forest. Paddy is major crop of Kharif season, during Rabi season mainly vegetable and oil seeds are grown.

CHAPTER 3.0 CLIMATE AND RAINFALL

The study area experiences tropical monsoon climate with mild winter and hot summer. There are three distinct season, good rainfall has been observed in the area through south-west monsoon between May to September every year. The Climatological data including the monthly temperature, humidity and rainfall for the period of last eight years from Angul I.M.D station has been analyzed to arrive at the annual normal rainfall of the area and is presented in following table. The average annual rainfall of the Angul area has been observed as 1266.7 mm, of which major amount is received during the four months extending from June to September. The Isohyetal map of the Angul district is shown in Fig. 3.1.

Table 3.1: Climatological Data of IMD Station, Angul

Month	Mean Temperature (˚C)		Relative Humidity (%)		Rainfall (mm)
	Max	Min	Morning	Evening	
January	28.85	15.61	80	58	17.0
February	32.41 .	18.19	75	49	16.8
March	37.34	18.63	67	40	21.3
April	39.31	20.00	67	44	40.4
May	40.21	21.46	67	48	93.6
June	35.18	21.23	75	67	212.1
July	31.78	20.57	81	77	258.2
August	31.86	20.81	83	81	317.3
September	32.99	20.47	81	77	165.7
October	32.64	18.21	82	73	93.7
November	31.17	14.59	77	64	23.3
December	28.63	12.69	79	59	7.3
Average	33.53	18.54	76	61	1266.7

3.1 Temperature & Humidity

The temperature of the area plays a very important role in assessing the over all availability of surface water in an area as it controls the evaporation from the open surface as ell as evapo-transpiration from the vegetated area. The temperature variation over the area is not large and it varies between 28.63°C to 40.21°C during the day time and the night time the mean temperature varies between 12.69°C to 21.46°C. The months of December and January are the· coldest months while May is warmest month. The month of March is the beginning of summer and November marks the beginning of winter season. The air is generally dry except during the monsoon period. The humidity over the area remains more or less uniform over the year varying between 67% to 83% in the morning hours and between 40% to 81 % during evening hours.

Wind velocity is also one of the important parameter which controls the loss of water from the ground surface. Wind velocity is in general low to moderate with some increase in speed during summer and monsoon months also the entire district is affected by frequent storms and depressions in the monsoon season. The mean annual wind speed is 6.8 km/hr and mostly blows from southwest to northeast during monsoon period. The mean monthly potential evapo-transpiration value ranges from 40mm in December to 326 mm in May.

CHAPTER 4.0 SURFACE WATER HYDROLOGY

Surface water plays pivotal role in the area and being utilized for various purposes. The major part of the total water requirement for domestic, irrigation and industries of the district as well as the study area are met from surface water sources. The district is also dotted with numerous small water bodies which cater to the domestic water needs. As envisaged in the project plan, the total water demand of the project to the tune of 328800 m^3/day inclusive of domestic requirements has to be met from river Brahmani through a 24.5 km pipeline to be laid down upstream of Sambalpur barrage. The work for laying the pipe line has already been initiated. However, in view of the time taken for full operationalization of pipe line, it has been planned that during the construction period, ground water will be used to the tune of 5000 m^3/day by way of constructing required number of tube wells or bore wells.

Further, to ensure the sustainability of water sources one of the objectives of present study is to explore the possibility of using surface water within and around the project area by way of harvesting/ ponding rain water in and around the streams within or out side the project area. This will not only provide water security and long term sustainability but also enhance the ground water recharge in the area. As the study area has good drainage network, watershed management oriented approach does offer a holistic solution to achieve the desired objective. The idea is to retain rain water in the limits of any given watershed area itself, through construction of suitable water harvesting structures. Watershed defines the natural boundary for flow of water and drains out from a single point before getting transferred in to watershed.

To assess the availability of water resources in the watershed huge number of parameters is required and it is imperative to study all the parameters which are affecting the flow of water within the watershed. In the present study, in order to assess the surface water availability and surface runoff being generated, the entire study area has been divided into number of watersheds using the drainage network (Fig. 2.2) on 1:50,000 scale. The surface water divides have been demarcated to draw the boundaries of watersheds. The watershed map along with the drainage and location of project boundary is given in Fig. 4.1. As seen from the map, broadly there are three watersheds which contribute water in the study area and finally joins river Brahmani further downstream. Nigra Nala is the main stream passing adjacent to the southern boundary of the project area. As per the available information it carries water almost through out the year. The watershed of Nigra Nala which is a third order stream occupies southwestern part of the project area. Within the watershed of Nigra nala, there are two second order streams passing through the project area. The main area of interest lies in the watershed of Kurdabhali Nala which lies in the northern part of the project and covers major part of the project area. As the major part of the watershed lies within the project boundary, it offers good prospect of water harvesting. Basically the main course of Kurdabhali nala forms a third order stream and expected to carry moderate to good amount of discharge during the rainy season. Further, as per the project development plan, the entire catchment of Kurdabhali would be occupied under different development activities, it has been proposed to divert the Kurdabhali Nala from the project area by changing its course along the north and north eastern boundary of the project so as to maintain the flow and ecological balance of the area. Other small streams present in the south western part of the project area and joining the Nigra nala can also be suitably harvested so as to use the water for various purposes during the construction period as well as after that. As the major part of the project area is part of Kurdabhali nala watershed it is proposed to further divide the area in to micro watershed for further planning.

In order to plan water conservation / harvesting structures the basic need is to have a volumetric assessment of run-off as well as the peak flow from the catchment. This will also help in overall water resources planning and design of any hydraulic structure in the area. The watershed of Kurdabhali Nala which occupies major part of the project area has been considered for detailed study.

An attempt has been made to further demarcate the micro watersheds in the Kurdabhali watershed considering the lowest order of drainage network. In total eleven micro watersheds have been demarcated and designated from A to K as shown in Fig. 4.2, the probable locations of water harvesting / ponding structures are also indicated in the figure, however the details regarding the structures will be discussed in subsequent chapters. The micro-watershed designated as 'K' lies outside the project area and hence it has not been considered for working out the surface water availability and volume of run off.

4.1 Surface Water Availability:

In developing countries like India, one of the common problem which emerges in hydrologic analysis is non availability of systematic river discharge data. In such cases the only option left out is to revert to various regional relationships of estimation of peak flow and seasonal runoff. Annual runoff from the catchment is one of the important information/ data needed for realistic assessment and optimal utilization of available water resources. This has further necessitated formulation of regional rainfall and run-off relationships with additional parameters of climate and catchment characteristics. There are various empirical formulas / relationships, developed by hydrologists suiting to different catchments in India, some of the famous relationships are Inglis formula and Khosla's formula which are simple and have wide applicability.

The area of study is basically an un-gauged catchment and hence there is no other option to resort to some standard and established formula which is valid in majority of river catchments. After a reasonable evaluation of various methods, in the present study Khosla's formula has been used to estimate the monthly run-off from different micro watersheds. The Khosla's relationship can be expressed as below:

$R_m = (P_m – L_m)$,

$L_m = 0.48$ Tm for $T_m > 4.5\ ^oC$

Annual Run –off = $\sum R_m$

Where,

R_m = Monthly runoff in cm. and $R_m > 0$

P_m = Monthly rainfall in cm.

L_m = Monthly water Losses in cm.

T_m = Mean monthly temperature of the catchment in ^{o} c

Khosla's formula is indirectly based on the water balance concept and the mean monthly temperature is used to reflect the losses due to evapo-transpiration. The formula has been used on a number of un-gauged catchments in India and is found to give fairly good results for the annual yield for use in preliminary studies. In order to estimate the volume of runoff, the area of watershed has been worked out using GIS methods. In the above formula, the parameter L_m refers to monthly losses, which is in turn is computed by multiplying the constant value by mean monthly temperature. Here, the constant value takes into account the water losses from the catchment due to infiltration, percolation etc. which is dependent upon the soil and other characteristics of the watershed. The temperature takes in to account the evaporation and evapo-transpiration losses. The monthly runoff computed for different watersheds is provided in the Table 4.1 below.

Table 4.1: Runoff generated in each micro watershed during monsoon

Micro-Watershed	Area in sq. km	Runoff in June (in TCM)	Runoff in July (in TCM)	Runoff in August (in TCM)	Runoff in September (in TCM)	Total Monsoon Runoff (in TCM)
A	4.4	337.55	583.26	839.92	164.54	1925.28
B	3.8	29.15	50.37	72.54	14.21	166.27
C	1.97	151.13	261.14	376.06	73.67	862.00
D	1.53	117.38	202.82	292.06	57.22	669.47
E	2.55	195.63	338.03	486.77	95.36	1115.79
F	1.61	123.51	213.42	307.34	60.21	704.48
G	2.32	177.98	307.54	442.87	86.76	1015.15
H	1.82	139.62	241.26	347.42	68.06	796.37
I	3.36	257.77	445.40	641.40	125.65	1470.22
J	2.91	223.24	385.75	555.50	108.82	1273.31
Total		1752.96	3029.00	4361.88	854.50	9998.34

From the table it can be observed that only during four months i.e. June to September the run off will be generated. The maximum run off of about 4362 Thousand Cubic Meter (TCM) will be generated during the month of August followed by 3029 TCM in the month of July and so on in the area. The watershed wise volume of run off water is given in table 4.1. Perusal of the table indicates that a total of about 9998 TCM or 9.99 MCM (Say 10 Million Cubic Meter (MCM) of water is generated as run off from the entire watershed in the four monsoon months. Watershed 'A' is the largest micro watershed with an area of about 4.4 sq.km and lies in the upstream and offers good opportunity to harvest water at the outlet. In total an area of about 26.27 sq.km is covered by these ten micro watersheds. In order to harvest the runoff one water harvesting structure has been proposed in each micro watershed. The details of the structure and its design are discussed in the Chapter 8 of this report.

As all the streams present in this watershed are of lower order it is suggested that the water harvesting structures should be designed to harness only 25% of the flow occurring during the any one month of monsoon having maximum runoff, so as to keep minimum flow in the downstream as well as to maintain the ecological balance of the area. In these micro watersheds, runoff of August moth is taken for calculating 25% of the runoff to be harnessed. The design of the harvesting structures will be designed for 33% of the runoff to be harnessed in a month of maximum runoff.

Keeping this in view it is proposed to construct earthen ponds of smaller capacities totaling to about 360 TCM across the streams which can act as temporary water storage, which can be utilized safely in the following months of rain. The details of the water to be harvested by each structure are given in table 4.2. The structures may be located in the different micro watersheds depending upon the place of requirement as well as availability. However the tentative location of these structures is provided in Fig. 4.2.

Table 4.2: Details for water to be harvested and runoff for which structures have been designed

Watershed	Area In sq.km	Total Monsoon Runoff (in TCM)	25% of August runoff (in TCM)	Structure to be designed for 33% of col. 4 (in TCM)
1	2	3	4	5
A	4.40	1925.28	209.98	69.29
B	3.80	166.27	18.13	5.98
C	1.97	862.00	94.01	31.02
D	1.53	669.47	73.02	24.10
E	2.55	1115.79	121.69	40.16

Watershed	Area In sq.km	Total Monsoon Runoff (in TCM)	25% of August runoff (in TCM)	Structure to be designed for 33% of col. 4 (in TCM)
F	1.61	704.48	76.83	25.36
G	2.32	1015.15	110.72	36.54
H	1.82	796.37	86.86	28.66
I	3.36	1470.22	160.35	52.92
J	2.91	1273.31	138.87	45.83
Total		9998.34	1090.47	359.86

In addition, it is also proposed to harness the streams flowing in the south western part of the project area outside the Kurdabhali micro-watershed. These minor streams are finally joining the Nigra nala. The stretch of the steam flowing within the project area can be suitably harvested by constructing Gully plugs or other structures and can be utilized accordingly.

CHAPTER 5.0 GEOLOGY AND HYDROGEOLOGY

5.1 Geology:

The district of Angul represents diverse geological sequence, from rocks of Eastern Ghats of Pre-Cambrian age, Iron-ore super group, Gondwana Super group, Laterites to alluvial deposits of Quaternary age. The Gondwana rocks are exposed in the central part of the district covering parts of Talchir, Kaniha, Chendipada and Kishorenagar blocks. The plant area occupies the southern portion of Talchir coalfield and is located north-west of Angul town.

Major portion of study area is occupied by Precambrian basement rocks except in extreme north eastern corner where Talchirs are present. The geological map of the study area is given in Fig. 5.1. The generalized Stratigraphic sequence of the formations present over the study area is given in table 5.1 below:

Table 5.1: Stratigraphic Units/Sequence of Study Area, Orissa

Age	Formation	Thickness (m)	Lithology
Quaternary	Recent	Around 3-15	Alluvial fills, sand, silt deposits and clay of older alluvium, older and younger flood plain deposits, channel fills etc.,
Cenozoic	Laterite	Around 3-5	Laterites, laterised detrital pebble bed.
Upper Permian to Triassic	Undifferentiated Kamthi Formation	Up to 250	Fine to medium grained light grey to reddish sandstone and shale at the base and pale greenish sand stones with rare shale and pink clay bands, ferruginous coarse grained to pebbly sandstone at top.
Upper Permian	Barren Measures Formation		Greenish grey to buff colored pebbly, coarse sandstone with variable proportions of fresh K-feldspar
Lower Permian	Barakar Formation	Upto 500	Medium to coarse grained grayish feldspathic sandstone, grey to dark grey shale and coal seams
Lower Permian	Karharbari	Upto 300	Pale brownish yellow colored massive medium

	Formation		to coarse grained sandstone containing clasts of Talchir shale and coal seams
Upper Carboniferous to Lower Permian	Talchir Formation	Up-to 325	Diamictite, sandstone, needle shale, turbidite, rhythmite and varves
.... Unconformity..................			
Precambrian		—	Granites, gneisses and associated supra-crustals

Metamorphic

The Pre-Cambrian basement rock, which covers nearly entire plant area and forms the basement for the Gondwana formations. These basement rocks mainly comprise granites, mica schist, phyllite and amphibolites. These formations are seen exposed forming low ridges along the southern boundary of Talchir coal belt. The strike of the formations varies but generally it is almost east-west to NE-SW direction. The quartz reef are exposed within metamorphics along the northern boundary of coal belt.

Talchir formation

The base of the Gondwana sediments is marked by a pile of glacial and peri-glacial deposits. These rocks are well exposed along the southern boundary of the basin, though outcrops do occur in other areas as well. The Talchir series is about 170 m thick and consists of Boulder bed, sandstones, and greenish needle shales. The coal bearing Karharbari and Barakar formations overlie Talchirs and consist of very thick sandstone and shale sequence of rocks. These Gondwanas are overlain by recent alluvium and or valley fill material at places mostly along the river courses. No estimate of the thickness of the Talchir formation is available. However, in a borehole, drilled near Nisa by GSI, 110 meters of Talchir comprising fine to medium grained sandstone inter bedded with shale underlain by 60 meters thick sandy shale bed was encountered.

Karaharbari formation

The Talchir formation conformably overlain by the Karharbari formation, which is exposed as a narrow strip both along the southern and northern margins of the basin. Karharbari formation has a distinct lithological and palynological entity in this coalfield. The sandstones are characteristically pale brownish yellow in color, massive, medium, to coarse grained and contains clasts of Talchir shale, all held together loosely by a clay matrix bearing a slightly greenish tint. Besides, thin shale bands and some superior quality coal seams are developed. Sub-surface data indicates that the formation attains thickness around 270 meters in the west Nandira sector in the southern part of the coalfield.

Barakar formation

The Barakar formation, which overlies the Karharbari, is characterized by a thick and conspicuous conglomerate horizon at its base. The conglomerate members form low ridges in the southern and northern parts of the coalfield. In the southern part, the ridges are persistent for considerable distances in the area between Deulbera collieries in the east to Nisa in the west. In the north, this member forms isolated ridges. The basal conglomerate unit is overlain by a thick sequence (more than 500 meters) of medium to coarse grained grayish feldspathic sandstone, grey to dark grey shale, carbonaceous shale, thick coal seams mostly inter bedded with shale.

The Barren Measure Formation conformably overlies the Barakar formation and the contact between the two is gradational. Lithologically the two formations are very similar near the contact and identification and fixation of boundary between them pose problem. As the name indicates, the Barren Measures are devoid of any economical coal seams but a few thin coal and carbonaceous shale zones are present within it. The Barren Measures comprises fine' to very fine-grained sandstone, gray shale often with siderite ferruginous sandstone, siltstone and occasionally thin coal and carbonaceous shale.

The lower Member of Kamthi is around 200 m thick, dominantly green to light greenish gray in colour, medium to fine grained sandstone with numbers of green, gray and brown shale. The upper member, which is over 375 meters thick, conformably overlies the lower and is represented by dominantly brown very coarse-grained sandstone with numbers of pebbly horizons generally less than a' meter thick. Pebbles are mostly rounded and sub-rounded, embedded in a coarse sand matrix and are made of mostly quartz and quartzite. Occasionally granites, gneisses, shale and sandstone pebbles are found. Thin red shale beds are also noticed.

Quaternary

The alluvial sediments belonging to Quaternary period are fluvial deposits and have limited thickness~/These formations forms colluvial deposits at the foot hills of Precambrian" hillocks. These are heterogeneous and poorly sorted comprising pebbles, sand and clays. The alluvial deposit along the present day drainage forms younger alluvium and mostly comprises silts, clays and fire sands.

The rocks of Eastern Ghat super Group have undergone polytectonic deformation. The oldest fold-axis trends NE-SW direction and have given rise to isoclinals folds at places. The Gondwana rocks occupy faulted troughs with beds dipping at low angle. A number of NW-SE trending faults are observed within Gondwana Super group of rocks.

5.2 Hydrogeology

Major part of the district as well as the study area is underlain by hard crystalline rocks and principally these rocks are devoid of primary porosity. The secondary porosity is dependent upon degree of weathering and fracturing. The semi-consolidated Gondwana sandstones form moderately good aquifers when it is weathered and fractured. Diverse hydrogeological conditions have been observed over the area due to variations in rock types, geology and structures. The hydrogeological map of the study area is given in Fig. 5.2. The large parts of the study area specifically the central and southern portions are covered by Pre-Cambrian granites and gneisses overlain by thin alluvial cover. The Pre-Cambrian formations do not have any primary porosity as discussed above. The ground water occurs with in the secondary porosity of such formation in unconfined to semi confined state. The groundwater occurrence and distribution in space and time is highly controlled by geomorphology of the study area. In general dug wells are the most common ground water abstraction structure in the area tapping the weathered zone, the depth of dug wells are restricted up to 10 mbgl. The bore wells drilled up to 200 m depth have limited yield varying from 2 to 5 liters per second (lps) depending upon the fractures encountered. Hence, the well sites need to be selected carefully so as to get reasonable yield.

Northern part of study area and north western part of the project area is occupied by compact coarse grained sandstones belonging to Talchir stage. Further north Karharbari sandstones are exposed north of Nisa village. The presence of secondary porosity and the intensity of fracturing has got a great bearing on occurrence and movement of groundwater in these rocks. The groundwater in this formation occurs in semi confined to confined state. The wells constructed up to a depth of 200 m in the Talchirs may yield up to 5 lps, however generally the yield varies from 2-3 lps. The ground water exploration carried out by Central Ground Water Board in the area indicates that the well constructed at Tubey located in the south eastern corner of the study area up to a depth of 154 m is mainly occupied by granite gneiss. In the entire drilling, 8-10 small fractures have been encountered, however the ultimate yield of the well was < 1 lps. However, the well constructed at Jharparha up to a depth of 179 m located in the western part of the study area in the same formation has yielded to the tune of 8 lps, water bearing fractures have been encountered at depths of 20 and 98 m , the transmissivity value works out to be 64 m^2/day.

5.3 Ground Water Regime Scenario

The depth to water level in the study area varies widely from less than 4 m bgl to as high as 11 m bgl in different areas. The geomorphological set up as well as undulating topography of the area is mainly responsible for such variations in depth to water level spatially. The water table elevation in the area generally follows the topography and the general ground water flow is towards East to North East directed towards river Brahmanai. The map showing the depth to water level zones during pre-monsoon period is given in Fig. 5.3. The perusal of the map indicates that major part of the study area fall within the 6-8 mbgl zone, however, a sizable portion in the central part including the project area is represented by a comparatively deeper water level and fall in the depth range of 8 to 10 mbgl. Isolated pockets of sallow and deep water levels are also seen the study mostly following the topographic depressions and hills.

Contrary to the general spatial variations, major portion of the project area occupying the central and southern part is represented by depth to water level in the range of 8 to 10 mbgl and the northern potion lies in the depth to water level range of 6-8 mbgl , an isolated pocket of depth to water level in the zone of 4-6 mbgl has also been observed.

The seasonal fluctuation in depth to water level in the area is between 2 to 4m. The long water level trend studied in some of the areas for a period of ten years indicates a marginal fall in water level, the highest rate of fall in water level in the area is recorded to be 0.3 m/year near Kualo, at Tubey located in the south eastern corner of the study area the rate of fall is 0.10 m/year, similarly in the north of the project area at Nisa the fall in the range of 0.09 m/year has been observed.

5.4 Ground Water Chemistry

In general, the ground water quality is in the study area as well as in the project area is good and suitable for drinking and other uses. The ground water samples analyzed by various Agencies time to time indicates that the total dissolved Solids (TDS) in the area varies from 500 to 1250 mg/l which is well within the permissible limit of 2000 mg/l, the TDS is indicator of overall quality of ground water. The chloride concentration in the area varies from 60 to 250 mg/l which is indicative of salinity in ground water is also within the permissible limit of 500 mg/l. Similarly, the concentration of various important chemical constituents present in the ground water affecting the human health such as fluoride, nitrate and iron has also been analyzed by different agencies has been found within the permissible limits.

CHAPTER 6.0 GROUND WATER RESOURCES

Availability of ground water resource in an area depends upon several factors including hydrogeological characteristics, intensity and duration of rainfall etc. Rainfall is the major source of recharge in addition to the recharge contribution from other sources like surface irrigation, tanks, ponds and return seepage etc. Assessment of ground water resources is a joint activity of Central and State Agencies based on the recommendations of Ground Water Estimation Committee (GEC-1997) of Govt. of India. As per the National report on “Dynamic Ground Water Resources of India” published by CGWB, the Net Ground Water Availability in the Angul district has been estimated as 86673 HaM (866.73 MCM), the reported ground water draft is to the tune of 11881 HaM. The project areas major part fall in the Banarpal block of Angul district in which the ground water availability has been assessed to the tune of 94 MCM and draft is just 17 MCM, the stage of ground water development in the Banarpal block is hardly 18 % leaving ample scope for further development. However, being a hard rock area it is recommended that the site selection should be based on scientific considerations. Ground water utilization in the area is largely for drinking use, followed by irrigation and Industries. Open wells or dug wells are the main ground water abstraction structures in the area with limited yield tapping weathered part of the existing formation. Bore wells are mainly used for supplementary irrigation, tapping mostly the water bearing fractures at deeper level and pumped as per requirement.

Table 6.1: Ground Water Resources Availability in Banarpal block, Angul

Assessment Unit/ District	Command/ non-command/ Total	Net Annual Ground Water Availability	Existing Gross Ground Water Draft for irrigation	Existing Gross Ground Water draft for domestic and industrial Water Supply	Existing Gross Ground water draft for all uses	Allocation for domestic and industrial requirement supply up to next 25 years	Net Ground Water availability for future irrigation Development	Stage of Ground Water Development
		1	2	3	4	5	6	7
Banarpal	Command	5502	1388	412.8	1800.8	432	3682	32.73
	Non-Command	3851	347	103.2	450.2	108	3396	11.69
	Total	9353	1735	516	2251	540	7078	24.07

CHAPTER 7.0 GROUND WATER DEVELOPMENT AND RECHARGE POSSIBILITIES

7.1 Ground Water Development Prospects

As per the project plan, the ground water development to the tune of 5000 m^3/day would be required for meeting the water demand for initial constructions activities and drinking water, till completion and operationalization of pipe line to be constructed for bringing water from river Brahmani. Keeping this in view an attempt has been made to prioritize the project area into feasible ground water development zones, so that required number of wells may be constructed in these zones as per the demand. As already discussed hydrogeologically the entire area is underlain by hard consolidated granite/granite gneisses of Precambrian age and sandstones of Talchir Super Group. In this type of formations ground water generally occurs in the secondary porosity and hence the degree of weathering and fracturing controls the availability of ground water. Further, the groundwater occurrence and distribution in space and time is highly controlled by geomorphology and topographic set up of the area. The volumetric assessment of ground water resources discussed in the earlier chapter, indicates ample scope of ground development, however the caution is selection of suitable water well sites, which requires detailed understanding of the area and wherever required surface Geophysical techniques may be adopted. Various criteria's considered in the present analysis for the prioritization of areas for ground water development are the prevailing depth to water level and their seasonal fluctuations, recharge characteristics which in turn indicates the infiltration capabilities of underlying soils, hydraulic properties of aquifer material in terms of water holding and transmitting properties, surface manifestations of weak zones reflected in terms of lineaments, structural control of river courses and so on. Geomorphology and topographic set up of the area has lot of bearing in site selection and hence these parameters have been given top priority in zonation of feasible area for ground water development. The map showing different zones identified for ground water development is given in Fig. 7.1. Broadly, four zones have been identified as feasible areas, two of which lies within the project boundary, whereas two areas are outside but adjacent to the project boundary. The exact location of well site may be decided after ground verification and if required resistivity sounding may be carried out. It can be observed from the map that mostly the favorable zones for development are located in the areas having high network density as well as signatures of lineaments.

7.3 Proposed Well Design

Mainly two types of wells are recommended in the project area, the large diameter dug cum bore wells and simple bore wells. The design of each type is given below:

Design for Dug-cum-Bore well

A borehole of 8 inches (203 mm) diameter may be drilled by DTH rig, down to the depth of 150 m bgl. A casing of MS slotted pipe of 7 inches diameter (178 mm) may be lowered in the entire overburden (nearly 10 to 15 m bgl) and further a MS blank casing pipe should be lowered about 5 m in hard rock where it should rests on massive hard rock, as indicated in the design Fig. 7.2 The rest of the bore hole will remain open to its entire depth. Now construction of 4 m diameter dug well should be taken up by excavating the overburden to the depth of 15 m bgl. The dug well should be excavated in such a way that the bore well should come in the side wall of the dug well as shown in the Fig. 7.2 and the bore well casing pipe should not be tampered during excavation. Bore well should come within the dug well walls, may be at any corner of the dug well. The dug well should be horizontally perforated for 1.5 to 2 m with 4-5 inches diameter drills which will act as conduit to provide ease to bring water into the dug well lateritic formation and overburden. Slotted MS pipe of 4 inches may be inserted in theses horizontals through which the ground water of overburden and lateritic soil aquifers may come into the dug well. The dug well can be lined looking into the condition of overburden (if overburden is collapsible), with some perforations in lining to provide inlet for the shallow aquifer water. The MS slotted pipe of bore well within the dug well will act as inlet for dug wells water to the pump. The large diameter dug well will be acting as storage tank for bore well water as well as dug well water both. A suitable submersible pump may be lowered in the bore well at a depth of 30 m approximately. This depth can be finalized after conduction of pumping test and estimation of maximum drawdown in the well. Fig. 7.2 gives a technical design of dug-cum-bore well to be constructed in the project area.

A pump of appropriate Horse Power only, as recommended by the ground water experts after conducting Primary Yield Test and Aquifer Performance Test, should be lowered in the well for sustainable discharge with acceptable drawdown. Before conducting the well test the bore well may be developed by an air compressor followed by an over capacity pump till the water becomes clear and silt free. After that only the bore well may be tested for its yield characteristics and aquifer parameters using a submersible pump.

Design for Bore wells in Hard rock (consolidated formations)

Firstly a borehole of 8 inches (203 mm) diameter may be drilled by DTH rig in overburden down to the depth varying from 15 to 20 m bgl in the proposed drilling locations. Once the well reaches to the hard rock the same may be reamed to 11 inches diameter and a casing of 8 inches (203 mm) is lowered to the drilled hole in such a way that the casing pipe should rest on hard formation. The annular space should be shrouded by gravels. Fig. 7.3 is the well design to be constructed in the hard rock area through DTH rig.

Total depth of bore well is proposed to be 150 m. Therefore, the drilling will further continue with 7 inches (178 mm) diameter in the hard and partly fractured formation to the remaining depth of 80m bgl. The bore hole should be kept naked within the hard formation. Once the well is constructed proper development may be done and pump test may be conducted. A pump of suitable capacity may be installed at a depth nearing 30 m bgl or as suggested by the ground water experts.

A submersible pump of 4 inches diameter of suitable Horse Power, as recommended by the ground water experts after conducting Primary Yield Test and Aquifer Performance Test, should be lowered in the well for sustainable discharge with acceptable drawdown. Before conducting the well test the tube well may be developed by an air compressor followed by an over capacity pump till the water becomes clear and silt free. After that only the tube well may be tested for its yield characteristics and aquifer parameters using a submersible pump.

Well Development

All the bore wells may initially be developed with an Air Compressor followed by an Over Capacity Pump till the water becomes silt free. Pumping test viz well test and aquifer test are proposed to be conducted for evaluation of well characteristics and aquifer characteristics as specified below:-

Well Test

It comprises a Step Draw Down test of 3 to 4 hrs duration (3 to 4 hrs steps of 1 hr each.) The bore well is pumped at 3 to 4 constant discharge rates in ascending order and lowering of water levels in the well i.e. drawdown is recorded at different time interval. The recorded data is analyzed for evaluation of specific capacity and well efficiency at different discharge rates.

Aquifer Test

It comprises an aquifer performance Test of say 3 to 4 hrs pumping duration (short duration test suffices the need in case of production wells).The bore well is pumped at constant discharge for 3 hrs to 4 hrs and drawdown is recorded at different time intervals. The pumping is stopped after 3 to 4 hrs and recovery of water levels in the bore well is recorded with time. Time drawdown and time recovery data is analyzed for evaluation of aquifer characteristics viz. Transmissivity and Hydraulic Conductivity. During the above test water sample are collected for chemical quality determination.

7.4 Feasibility of Artificial Recharge

The sustainability of ground water resources is one of the major concerns in hard rock terrains and hence it is recommended that with the ground water withdrawal, there should be a comprehensive plan for recharge to ground water as well. This will not only provide long term sustainability of ground water resources but also improve the overall quality of ground water quality as well as soil moisture conditions which have far reaching consequences in maintaining the ecological balance of the area.

While prioritizing the areas suitable for artificial recharge to ground water, in addition to the parameters considered for development, the intake capabilities of underlying aquifer as well as the ground water flow direction has also been taken into account. The four areas have been identified for undertaking artificial recharge activities through suitable structures as given in Fig. 7.4 are located in different parts of the project area, strictly speaking three areas lies within the project boundary and one area is adjacent to boundary. The broad objective is to ensure that the volume recharged should contribute mainly in enhancing the total water availability of the project area.

CHAPTER 8 MANAGEMENT STRATEGIES

Efficient management of water resources in an area is the key of long term sustainability. The JSPL plant is spread over a large area of about 5700 acre with undulating topography. A tentative estimate of availability of surface and ground water in the area provides an opportunity for conjunctive management of water resources. Keeping this in view it is recommended to adopt two pronged management strategy in the project area.

First is to utilize the available runoff within the project area through water harvesting i.e. by constructing suitable storage structures and second is to develop ground water in the feasible areas with suitable augmentation measures including roof top rain water harvesting for artificial recharge to ground water. Both the strategies are discussed in detail in following paragraphs.

8.1 Water Harvesting

Drinking water supply in urban areas is mostly from surface sources like natural or impounded reservoirs and from ground water sources. As the population density and usage levels are comparatively high in urban areas, agencies construct, operate and maintain huge surface water dams and reservoirs for meeting their water demands. These sources are planned and constructed to take care of the water requirements of the population. In earlier days, open wells and ponds that belonged to the community were the source of drinking water supply. With the advent of bore well technology and progress made in rural electrification, the scenario of rural water supply has considerably changed. The traditional methods and practices have given way to hand pumps and power pump schemes. Indiscriminate exploitation of ground water and the decline in ground water levels have rendered many bore wells dry either seasonally or through out the year. To overcome such a situation and to ensure the long-term sustainability of our precious ground water resources, identification and promotion of simple, reliable and environmental friendly technologies are necessary. Reviving the traditional practices of rainwater harvesting along scientific lines can go a long way in preventing a serious water crisis in the major part of our country in the years to come.

8.1.1 Concept of Water Harvesting

The concept of rainwater harvesting involves 'tapping the rainwater where it falls'. A major portion of rainwater that falls on the earth's surface runs off into streams and rivers and finally into the sea. An average of 8-12 percent of the total rainfall recharge only is considered to recharge the aquifers. The technique of rainwater harvesting involves collecting the rain from localized catchment surfaces such as roofs, plain / sloping surfaces etc., either for direct use or to augment the ground water resources depending on local conditions. Construction of small barriers across small streams to check and store the running water also can be considered as water harvesting.

8.1.2 Water Harvesting in Micro Watershed of Kurdabhali Nala

Water harvesting is a technique to store the surplus rain water from the natural channels, roof top or any other catchment using suitably designed structures and utilizes the same for required purposes for meeting the water demand. The watershed of Kurdabhali nala as indicated in Fig. 4.2 (of Chapter 4) offers good opportunity for rain water harvesting and has been divided in to 11 micro watersheds A to K for suggesting the suitable water harvesting structures. These structures will provide the temporary storage for water to be lifted from and pumped to the desired location fur further utilization. These structures are so designed that they will also facilitate the recharge to ground water to augment the ground water resources in the down stream areas and provide the sustainability to the yields of ground water wells.

The selection of a suitable structure for water harvesting is worked out after a detailed analysis. Considering all the factors relevant for assessment of surface runoff being generated from the micro watersheds, the designs are suggested for harvesting the surplus runoff for using it in construction uses and other purposes. These factors include:

a. Quantum of surface run-off available.

b. Rainfall pattern

c. Land use and vegetation

d. Topography and terrain profile

e. Soil type

f. Hydrological and hydrogeological characteristics

g. Environmental and ecological impacts of water harvesting scheme proposed.

8.1.3 Proposed designs

After demarcating the micro watersheds in the catchment of Kurdabhali nala, drained by first and second order streams, suitable sites were located to harvest the rainwater based on the estimation of runoff for each micro watershed . After identification of the site the design of harvesting structures has been firmed up. In total eleven micro watersheds have been demarcated and designated from A to K as shown in Fig. 4.3, the proposed locations of construction of water harvesting / ponding structures are given in the Fig.8.1. In view of the topography of the area, slope, rain fall pattern and bifurcation ratio of the drainage of first order and second order streams flowing in the micro watershed, it is suggested to construct small check dams of the specified dimensions as given in the table 8.1. It has been worked out that total of around 10 MCM of water is available in the watershed during monsoon period of four months. Out of which around 2.5 MCM water can be easily harnessed by constructing suitable check dams, which is sufficient to meet the entire water requirement (1.825 MCM per annum) of the project during construction phase. As this entire amount of water is available only with in span of four months there is a need to store such a huge amount of water for using it throughout the year. This will require very high capacity tanks may be under ground or over head tanks which is very expensive option. Therefore, it is suggested to constructed small water reservoir near the project works area where water is required and harvested water may be stored in these tanks through lift pumping from check dam pounding sites.

Table 8.1: Proposed designs of check dams for rainwater harvesting from the micro-watersheds of Kurdabhali Nala

Watershed	Area In sq.km	25% of August runoff (in TCM)	Structure to be designed for 33% of col. 4 (in TCM)	Design of the Check dam (Dimensions in m)		
				Length of wing wall	Width of abutment	Height of Key wall
A	4.40	209.98	69.29	2.0	10	2.0
B	3.80	18.13	5.98	1.0	5.0	1.5
C	1.97	94.01	31.02	1.2	8.0	2.0
D	1.53	73.02	24.10	1.2	8.0	2.0
E	2.55	121.69	40.16	1.2	8.0	2.0
F	1.61	76.83	25.36	1.2	8.0	2.0
G	2.32	110.72	36.54	1.2	8.0	2.0
H	1.82	86.86	28.66	1.2	8.0	2.0
I	3.36	160.35	52.92	1.6	8.5	2.0
J	2.91	138.87	45.83	1.2	8.0	2.0
Total		1090.47	359.86			

The above explained plan and concept of water harvesting can be justified at MOEF with the help of publication of Central Ground Water Board on "Planning of Artificial Recharge Schemes". The abstract of the above publication is quoted here below:

Published by CGWB in para 5.1.5.1 'Climatic Conditions'

In regions experiencing high (1000 to 2000 mm/year) to very high (>2000 mm/year) rainfall, such as the Konkan and Malabar coasts, North-eastern States, parts of lesser Himalayas in Uttar Pradesh and Himachal Pradesh, eastern part of Madhya Pradesh and parts of Bihar and Bengal, a major part of the water received during the rainy season goes as surface runoff. Only 5 to 10 percent of the total precipitation may infiltrate into the ground and reach the water table, which may be sufficient for adequate recharge. In areas of very high rainfall, the phenomenon of rejected recharge may also occur.

Most of such areas may not require artificial recharge of ground water and the best option is to store as much of the surplus water available as possible in large surface reservoirs, to be released to downstream areas during non-monsoon periods for direct use or to be used as source water for artificial recharge in suitable areas. The second and third order streams in such regions may have flow throughout the winter and the major rivers are normally perennial. The water in these streams and rivers, diverted, lifted or drawn through induced recharge may also be used as source water for artificial recharge.

In areas having moderate rainfall (750 – 1000 mm/year) such as eastern parts of Punjab and Maharashtra, eastern and central parts of Madhya Pradesh, parts of Godavari delta, eastern coast and Karnataka, adequate ground water resources are generally available only during the rainy season. A major component of the precipitation goes as surface runoff in these areas too and recharge may be 10 to 15 percent of annual precipitation. Ground water recharge is normally not sufficient to saturate the water table aquifers in deficit rainfall years. The second and third order streams normally do not have any flow during a major part of winter and only major streams may have some flow during summer.

The non-availability of surplus runoff beyond the rainy season may impose a severe constraint on artificial recharge to ground water in these areas. Diversion of water released from surface water reservoirs in the upper reaches of the catchments, water transferred from surplus basins or lifted from rivers wherever available may be required for sustaining irrigation water supplies. Hence, conserving as much of surface runoff as possible through watershed treatment measures, inducing additional recharge during and after rainy season and conserving ground water outflow through subsurface dykes may be suitable for such areas.

In semi-arid regions with low to moderate rainfall in the range of 400 to 700 mm/year, the annual precipitation may not even suffice to meet the existing water demand, and droughts may occur with regular frequency due to variations in rainfall. Western part of Punjab and

Haryana, eastern Rajasthan and parts of Gujarat, Saurashtra, central Maharashtra and Telengana and Rayalseema regions of Andhra Pradesh fall under this category. The evapotranspiration losses in these areas are quite high and even though 15 to 20 percent of water gets infiltrated into the ground, the total ground water recharge will be limited because of the low rainfall. The stream flow in these regions is mostly restricted to the rainy season.

The replenishment of aquifers during rainy season generally is not enough to cater to the irrigation requirements during Rabi season in such areas, though it may be adequate for drinking water use through winter. Shortage of drinking water supplies is common during summer, which may be acute in years of deficit rainfall. Though recharge augmentation is warranted, due to lack of availability of source water, the only option available is to conserve as much of the surplus surface runoff during the short rainy season. Rainwater harvesting and runoff conservation measures for augmenting the ground water resources are appropriate in such situations.

In areas falling in arid zone, such as western Rajasthan desert, parts of Kutch region of Gujarat and Ladakh region of Jammu and Kashmir, the annual precipitation is less than 400 mm, the number of rainy days between 20 and 30 or even less and the coefficient of variation of rainfall is normally between 30 and 70 percent. The major component of outflow is evaporation and drainage is poorly developed in these areas.

Infiltration of water may rarely exceed field capacity of soils and ground water recharge may be very small or negligible. Such areas may be left out of consideration for artificial recharge in spite of need unless trans-basin water is available. Rainwater harvesting may be contemplated in such regions for augmenting drinking water supplies. In case imported water is available, spreading or injection methods (for confined aquifers) may be considered depending on surface conditions (sandy/rocky), topographic set-up and salinity profiles of soils and the zone of aeration.

8.1.4 Check Dams/Nalah Bunds:

These structures are constructed across gullies, *nalah*s or streams to check the flow of surface water in the stream channel and to retain water for longer durations and create a temporary pond across the nalah. As compared to gully plugs, which are normally constructed across 1^{st} order streams, *nalah* bunds and check dams are constructed across second or higher order streams and in areas having gentler slopes. These may be temporary structures such as brush wood dams, loose / dry stone masonry check dams, Gabion check dams and woven wire dams constructed with locally available material or permanent structures constructed using stones, brick and cement. Competent civil and agro-engineering techniques are to be used in the design, layout and construction of permanent check dams to ensure proper storage and adequate outflow of surplus water to avoid scours on the downstream side for long-term stability of the dam.

The sites selected for check dam should have sufficient thickness of impermeable soils or compact material to prevent recharge of stored water within a span of time. This will facilitate pumping of higher amount of water which otherwise may seep in to ground and recharge the ground water. If such dams are constructed for artificial recharge to ground water then the site is located on pervious and weathered and fractured rock formations so as to facilitate the recharge to ground water. However, here we are looking for water storage and using it directly to the construction site. The water stored in these structures is mostly confined to the stream course and the height is normally about 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. The width of abutment given in table 8.1 is tentative and the same can be fine tuned as per nala width at the check dam site. In order to avoid scouring from excess runoff, water cushions are provided on the downstream side. To harness maximum runoff in the stream, a series of such check dams can be constructed to have intermittent ponding of water. Such ponding of water also helps in recharge to ground water on a regional scale. The design particulars of a cement *check dam* shown in Fig.8.1.

The above sites selected are tentative and can be suitably modified slightly up stream or down stream keeping in view of feasibility of construction of the check dam. The following parameters should be kept in mind while selecting sites for check dams:

- The total catchment area of the stream should normally be not less than 40. Local situations can, however, be a guiding factor in this regard.
- The rainfall in the catchment should be to the tune of 1000 to 1500 mm/ annum.
- The stream bed should be 3 to 15 m wide and at least 1m deep.
- The soil downstream of the bund should not be prone to water logging and should have a pH value between 6.5 and 8.
- The area downstream of the Check Dam / bund should have ground water abstraction structures.
- The Check dams / *Nalah* bunds should preferably be located in areas where contour or graded bunding of lands have been carried out.
- The rock strata exposed in the ponded area should be adequately impermeable for storing large amount of water and permeable to cause ground water recharge as the case may be.

Check dams / *Nalah* bunds are normally 5 to 15 m long, 1 to 3 m wide and 2 to 3 m high, generally constructed in a trapezoidal form. Designs of all the three type of check dams as suggested in table 8.1 are given in Fig. 8.2 to 8.13 Detailed studies are to be made in the watershed prior to construction of the check dam to assess the current erosion condition, land use and water balance. The community in the watershed should also be involved in the planning and selection of the type and location of the structure.

For construction of the check dam, a trench, about 0.6 m wide in hard rock and l.2 m wide in soft impervious rock is dug for the foundation of core wall. A core brick cement wall, 0.6 m wide and raised at least 2.5m above the *nalah* bed is erected and the remaining portion of trench back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and stone pitching is done on the upstream face. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

8.2 Artificial Recharge to Ground Water

The term artificial recharge has different connotations for various practitioners. The process of recharge itself is not artificial. The same physical laws govern it whether it occurs under natural or artificial conditions. What is artificial is the availability of water supply at this particular location and that particular time. In the broadest sense one can define as artificial recharge "any procedure which introduces water in a pervious stratum.

Artificial recharge provides sustainability to ground water by restoring supplies to aquifers depleted due to excessive draft and to enhance recharge to the aquifers lacking adequate natural recharge both in space and time. To achieve the objective, detailed multidisciplinary scientific aspects are taken into consideration. Selection of cost effective and efficient recharge techniques at suitable locations is the main thrust along with the emphasis on optimum utilisation of available hydrological resources in the area.

Artificial recharge systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources. Other objectives of artificial recharge are to store water, to improve the quality of the water through soil-aquifer treatment or geo-purification, to use aquifers as water conveyance systems, and to make groundwater out of surface water where groundwater is traditionally preferred over surface water for drinking. Artificial recharge is expected to become increasingly necessary in the future as growing populations require more water, and as more storage of water is needed to save water in times of water surplus for use in times of water shortage.

Artificial recharge efforts are basically augmentation of the natural movement of surface water into ground water reservoir through suitable civil construction technique or other similar methods. Availability of source water is one of the important requirements for recharge schemes. It is assessed in terms of non-committed surplus monsoon run-off, which is going unutilized as per the water resource development pattern. The other basic requirement is the availability of sub-surface storage space in different hydrogeological situations of the country. The topography and the soil condition of the area links the above two factors. Topography governs the extent of run-off and its retention where as the soil condition determines the extent of percolation. The artificial recharge technique inter relate and integrate the source water to ground water reservoir which in turn dependent on the hydrogeoloical situation of the area.

Identification of the area suitable for Artificial Recharge

Artificial recharge projects are site specific. The replication of the techniques from similar areas is to be based on the local hydrogeoloical and hydrological environs. The first step in planning the project is to demarcate the area of recharge. The scheme can be implemented systematically in case a hydrologic unit like watershed is taken for implementation. However, localized schemes are also can be taken to augment the ground water reservoir. Schemes are normally taken in the following areas.

- Areas where ground water levels are declining over a period of time.
- Areas where substantial amount of aquifer has already been desaturated.
- Areas where availability of ground water is in adequate in lean months and there is availability of surface water for recharge during rainy season.
- Areas where salinity ingress is taking place.
- Areas where there is quality problem in ground water

8.3 Artificial Recharge in JSPL Project area:

The project area is characterized by varied topography of undulating plains, flat topography and at places high elevation mounds or hillocks. It is recommended to construct suitable artificial recharge structures in the potential recharge areas for increasing the sustainability of the bore well for optimum yields. Artificial recharge to ground water will help in arresting the declining water levels and enhance the yields of the bore wells in the project area. Some of the suitable recharge structures and their design aspect is elucidated in the following paragraphs.

The most suitable recharge practice in the hillocks or highly sloping areas is construction of contour bunding or trenches. This will increase the time of contact of surface runoff with the ground surface and facilitate the recharge possibilities. Besides this recharge structures such as trenches with bore wells, percolation tanks and

8.3.1 Contour Bunding :

Contour bunding, which is a watershed management practice aimed at building up soil moisture storage involve construction of small embankments or bunds across the slope of the land. They derive their names from the construction of bunds along contours of equal land elevation. This technique is generally adopted in low to moderate rainfall areas where gently sloping agricultural lands with very long slope lengths are available and the soils are permeable. They are not recommended for soils with poor internal drainage e.g. clayey soils. Schematic of a typical system of contour bunds is shown in Fig.8.14.

Contour bunding involves construction of narrow-based trapezoidal embankments (bunds) along contours to impound water behind them, which infiltrates into the soil and ultimately augment ground water recharge. Field activities required prior to contour bunding include leveling of land by removing local ridges and depressions, preparation of map of the area through level surveying and fixing of bench marks. Elevation contours, preferably of 0.3 m interval are then drawn, leaving out areas not requiring bunding such as habitations, drainage etc. The alignment of bunds should then be marked on the map.

The important design aspects of contour bunds are i) spacing, ii) cross section and iii) deviation freedom to go higher or lower than the contour bund elevation for better alignment on undulating land.

Spacing of Bunds: Spacing of contour bund is commonly expressed in terms of vertical interval (V.I), which is defined as the difference in elevation between two similar points on two consecutive bunds. The main criterion for spacing of bunds is to intercept the water before it attains the erosive velocity. Spacing depends on slope, soil, rainfall, cropping pattern and conservation practices.

Spacing of contour bunds is normally calculated using the formula

Vertical Interval (V.I) = 0.305 (XS+Y), where

X is the rainfall factor,

S is the land slope (%) and

Y is the factor based on soil infiltration during the erosive period of rains

The rainfall factor 'X' is taken as 0.80 for scanty rainfall regions with annual rainfall below 625 mm, as 0.60 for moderate rainfall regions with annual rainfall in the range of 625 to 875 mm and as 0.40 for areas receiving annual rainfall in excess of 875 mm. The factor 'Y' is taken as 1.0 for soils having poor infiltration with low crop cover during erosive rains and as 2.0 for soils of medium to good infiltration and good crop cover during erosive rains. When only one of these factors is favourable, the value of Y is taken as 1.50. Vertical spacing can be increased by 10 percent or 15 cm to provide better location, alignment or to avoid obstacles.

The horizontal interval between two bunds is calculated using the formula

Horizontal Interval (H.I) = V.I x 100/Slope

Cross Section of Contour Bunds: A trapezoidal cross section is usually adopted for the bund. The design of the cross section involves determination of height, top width, side slopes and bottom width of the bund. The height of the bund depends on the slope of the land, spacing of the bunds and the rainfall excess expected in 24-hour period for 10-year frequency in the area. Once the height is determined, other dimensions can be worked out depending on the nature of the soil. Height of the bund can be determined by the following methods

Arbitrary Design:

a) The depth of impounding is designed as 30 cm. 30 cm is provided as depth flow over the crust of the outlet weir and 20 cm is provided as free board. The overall height of the bund in this case will be 80 cm. With top width of 0.50 m and base width of 2 m, the side slope will be 1:1 and the cross section, 1 sq m.

b) The height of bund to impound runoff from 24 hour rain storm for a given frequency can be calculated by the formula

$$H = \frac{\sqrt{Re \times V.I}}{50}$$, where

H is the depth of impounding behind the bund (m),

Re is the 24 hour rainfall excess (cm) and

VI is the vertical interval (m)

To the height so computed, 20 percent extra height or a minimum of 15cm is added for free board and another 15 to 20 percent extra height is added to compensate for the settlement due to consolidation.

Top width of the bund is normally kept as 0.3 to 0.6 m to facilitate planting of grasses. Side slopes of the bund are dependent on the angle of repose of the soil in the area and commonly range from 1:1 for clayey soils to 2:1 for sandy soils. Base width of the bund depends on the hydraulic gradient of the water in the bund material due to the impounding water. A general value of hydraulic gradient adopted is 4:1. The base should be sufficiently wide so that the seepage line should not appear above the toe on the downstream side of the bund.

Size of the bund is expressed in terms of its cross-sectional area. The cross sectional area of bunds depends on the soil type and rainfall and may vary from 0.50 to 1.0 sq m in different regions. Recommended contour bund specifications for different soil depths are shown in Table: 8.2 below:

Table 8.2 Recommended Contour Bund Specifications for Different Soil Depths

Soil Type	Soil Depth (m)	Top Width (m)	Bottom Width (m)	Height (m)	Side Slope	Area of Cross section (sq m)
Very Shallow Soils	< 7.5	0.45	1.95	0.75	1:1	0.09
Shallow Soils	7.50 to 23 .0	0.45	2.55	0.83	1.25:1	1.21
Medium Soils	23.0 to 45.0	0.53	3.00	0.83	1.50:1	1.48
Deep soils	45.0 to 80.0	0.60	4.20	0.90	2:1	2.22

The length of bunds per hectare of land is denoted by the Bunding Intensity, which can be computed as

$$\text{Bunding Intensity} = \frac{100\ S}{V.I}$$, where

S is the land slope (%) and

V.I is the vertical interval (m)

The earthwork for contour bunding includes the main contour bund and side and lateral bunds. The area of cross-section of side and lateral bunds is taken equal to the main contour bund. The product of cross sectional area of the bund and the bunding intensity gives the quantity of earthwork required for bunding / hectare of land.

Deviation Freedom: Strict adherence to contours while constructing bunds is a necessary prerequisite for ensuring maximum conservation of moisture and soil. However, to avoid excessive curvature of bunds, which makes agricultural operations difficult, the following deviations are permitted

a) a maximum of 15 cm while cutting across a narrow ridge,
b) a maximum of 30 cm while crossing a gully or depression and
c) a maximum of 1.5 m while crossing a sharp, narrow depression not exceeding 5 m in width.

8.3.2 Contour Trenches

Contour trenches are rainwater harvesting structures, which can be constructed on hill slopes as well as on degraded and barren waste lands in both high- and low- rainfall areas. Cross section of a typical contour trench is shown in Fig.8.15.

The trenches break the slope at intervals and reduce the velocity of surface runoff. The water retained in the trench will help in conserving the soil moisture and ground water recharge. The size of the contour trench depends on the soil depth and normally 1000 to 2500 sq. cm cross sections are adopted. The size and number of trenches are worked out on the basis of the rainfall proposed to be retained in the trenches. The trenches may be continuous or interrupted and should be constructed along the contours. Continuous trenches are used for moisture conservation in low rainfall area whereas intermittent trenches are preferred in high rainfall area.

The horizontal and vertical intervals between the trenches depend on rainfall, slope and soil depth. In steeply sloping areas, the horizontal distance between the two trenches will be less compared to gently sloping areas. In areas where soil cover is thin, depth of trenching is restricted and more trenches at closer intervals need to be constructed. In general, the horizontal interval may vary from 10 m in steep slopes to about 25 m in gentle slopes.

8.4 Artificial recharge to ground water in JSPL Township

8.4.1 Roof Top Rain Water Harvesting

Roof top rain water harvesting can also be adopted to meet domestic water requirements. The roof top rain water can be stored in specifically constructed surface or sub-surface tanks. In these areas dependence on ground water has increased many folds and the natural recharge to ground water has decreased, due to urbanization, construction of buildings and paved area. In urban areas water falling on roof tops can be collected and diverted to the open wells/ tubewells/ borewells by providing a filter bed.

Roof top rainwater harvesting, which involves the collection of rainwater from the roof of the buildings and its storage in surface tanks or recharge to sub-surface aquifer, can play an important role in conservation of water.

Ideal Conditions for Rain Water Harvesting and Artificial Recharge to Ground Water

Artificial Recharge techniques are adopted where:

- Adequate space for surface storage is not available especially for urban areas.
- Water level is deep enough (> 8m) and adequate subsurface storage space is available.
- Permeable strata are available at shallow / moderate depth.
- Where adequate quantity of surface water is available for recharge to ground water.
- Ground water quality is bad and our aim is to improve it.
- Where there is possibility of intrusion of saline water especially in coastal areas.
- Where the evaporation rate is very high from surface water bodies.
- In other areas, rainwater harvesting techniques may be adopted.

Design Considerations

The important aspects to be looked into for designing a rain water harvesting system to augment ground water resources are: -

- Hydrogeology of the area including nature and extent of aquifer, soil cover, topography, depth to water level and chemical quality of ground water.
- The availability of source water, one of the prime requisite for ground water recharge, basically assessed in terms of non-committed surplus monsoon runoff.
- Area contributing run off like area available, land use pattern, industrial residential, green belt, paved areas, roof top area, etc.
- Hydrometerological characters like rain fall duration, general pattern and intensity of rainfall.

Potential Areas

- Where ground water levels are declining on regular basis.
- Where substantial amount of aquifer has been de-saturated.
- Where availability of ground water is inadequate in lean months.
- Where due to rapid urbanisation, infiltration of rain water into subsoil has decreased drastically and recharging of ground water has diminished.

8.4.2 Computation of Rainfall Runoff & Approach for Artificial Recharge to Ground Water

It is proposed to implement rain water harvesting structures by diverting the runoff that is generated from the roof tops, paved areas and green belt for surface storage and recharging into the ground water system. Implementation of recharge mechanism shall ensure the balance between the discharge vis-à-vis recharge relationships of the aquifer system and improve in the ground water quality. The normal annual rainfall for the said area has been taken as 1287 mm. as per the data of IMD. Based on the site plan and the land use pattern of the plot area, the computation of runoff for each unit has been worked out and the details are tabulated below.

Table 8.3: Runoff Available for Recharge to Ground Water

Sl. No.	Land use type	Area (m^2)	Co-efficient of runoff	Rainfall (m)	Quantity of Rainwater (m^3)
1.	Roof area	5,05,850	0.80	1.3	5,26,084
2.	Paved area	2,83,280	0.60	1.3	2,20,958
3.	Green belt & other open areas	4,84,972	0.15	1.3	94,570
	Total	12,74,102			8,41,612

From the above computation, it is evident that a total quantum of 8,41,612 cu.m. (8416 lakh litres) of rain water can be fruitfully harvested annually by constructing suitable recharge structures. In order to design the recharge structures, hourly runoff of 40 mm/hr has been taken into account and the details are tabulated below.

Table 8.4: Hourly Computation of Runoff – (40 mm/hr)

Sl. No.	Land use type	Area (m^2)	Co-efficient of runoff	Intensity of Rainfall (m)	Quantity of hourly runoff (m^3)	Structure
1.	Roof area	5,05,850	0.80	0.040	16,187	Indicated on site plan
2.	Paved area	2,83,280	0.60	0.040	6,800	
3.	Green belt & other open areas	4,84,972	0.15	0.040	2,910	Recharge shafts
	Total	12,74,102			25,897	

The locations of these sites are marked on the site plan as per the layout of storm water drains. Necessary precautions shall be taken to avoid any contaminated water entering into the recharge structures. All precaution like settling chambers needs to be provided, wherever there is any apprehension about silt & contamination. The recharge structures would be so designed that these are operational only during the monsoon seasons.

For the plot areas having green belt necessary slopes may be given so that the rainfall runoff is channelised and diverted to the proposed recharge structure, if feasible. Settling chambers may be located at suitable locations before the recharge structures so as to avoid any excess siltation to the recharge trenches. Provision of Geo-textile mesh/ Johnson cloth on the top of the filter media is preferable to avoid frequent clogging of the filter media. Special care needs to be taken for identifying the exact locations of the recharge structures so that the ground water augmentation is optimal.

The area under recharge project has hydrogeological conditions having alluvial aquifer systems, exact depth of recharge well and its slot positions would be ascertained based initial wells and subsequently tested for its intake rate. Proper type of rig deployment and construction of recharge structures warrants for strict supervision of ground water experts while implementation. It would be imperative that the recharge wells are tested and it is suggested that slug test may be conducted at selected recharge wells so as to ascertain the dissipation rate of the rainfall runoff to the aquifer systems. Such an approach shall ascertain the proper recharge mechanism at the study area.

Implementation of recharge mechanism in the study area would create a balance between the recharge vis-à-vis discharge relationships of the aquifer system. It shall also maintain the ground water quality which may deteriorate due to prolonged pumping and the recharge of fresh rainfall runoff shall compensate it. The designs of the proposed recharge structures to be implemented at the project site are indicated below. The overflow from these recharge structures may be suitably diverted to the two ponds earmarked for recharge.

Based on the above calculation we can go for three options:

Option –I:

We can construct 15 (fifteen) recharge structures of 144 cum each which will account for 2160 cum of recharge holding capacity and will recharge approximately approx 450 cum of water with 3 bores each which comes to 2610 cum and we can go for the same storage size of 2000 Cum and 40000 Cum as proposed earlier. We need to take higher storage capacity then calculation of (25897-2610)= 23287

Option –II.

We can go for 15 recharge structures of based on blocks which will accommodate 2160 cum of water for rain and extra runoff can be diverted via a Hume pipe to construction facility purpose pond, by that way we need not construct the ponds for Rainwater Harvesting purposes and we will also require less water to be pumped out of river in rainy session.

Option –III.

We can plan an online recharge systems in purpose built storm water drain from the township to the main water pond constructed for production facility.

In the online recharge drain we can provide 15 number of recharge structures of small size and diver the extra runoff left after that to the main production pond.

More of utilisation and less of Holding and recharging can reduce your big cost in construction of recharge structures, construction of ponds and will also reduce the pumping cost in rain session for you for the water to be pumped from river for production facilities.

Additional Points to be Taken into Account

- No contaminated water would be diverted into the storm water drains. Necessary peripheral drains will be constructed to divert the runoff to the recharge structures.
- Before the onset of the monsoon all the catchment area considered for recharge would be cleaned. The recharge structures would be in operation during the monsoon season only so as to avoid any contamination.
- A mesh would be provided on the mouth of the inlet to discard the debris entering into the recharge pit. A sluice/ shutter would be provided to ensure that no water other than rainwater is diverted to the recharge structures.
- Depth and location of the recharge wells may vary slightly as per the prevailing site conditions.
- After the first rain the de-silting pit would be cleaned and subsequently on the onset of next monsoon. A hygienic condition in the township area would be maintained after implementation of artificial recharge structures, as the recharged water would augment the water level in the proposed tube wells.
- Depth of the retaining capacity of the recharge trenches (as per the enclosed designs) is below the proposed inlet pipes. All the dimensions indicated in the designs are the inner dimension.

- The work of rain water harvesting would be undertaken by the specialized agencies so that the objective of rainwater harvesting is implemented in true sprit and due benefits are accrued. The drilling agency engaged in construction of the recharge structures would be a registered one with the Central Ground Water Authority.

CHAPTER 9 CONCLUSION & RECOMMENDATIONS

- Orissa state is exceptionally rich in natural resources including several strategic minerals. Angul is one of the most developing towns; industries are coming up at a faster rate in and around the town of Angul and Talcher.
- The proposed steel plant of Jindal Group of Industries with a capacity of six MTPA is under construction over an area of about 5675 acres situated on the NH-42 connecting to Sambalpur and close to Angul town.
- The study area represents an uneven topography surrounded by the hills which acts as origin of several small and medium streams and offers excellent scope of rain water harvesting.
- The total water requirement of the Project has been estimated as 328800 m^3/day inclusive of domestic requirements. It has been envisaged to meet the requirement from river Brahmani through a 24.5 km pipeline to be laid down upstream of Sambalpur barrage.
- Further, ground water development to the tune of 5000 m^3/day has been proposed to meet the water demand for initial constructions activities and drinking water, till operationalization of pipe line.
- The present study aims at suggesting the most viable and scientifically managed plan for development of ground water and utilization of surface water on a watershed management approach. In order to provide sustainability, number of artificial recharge structures has also been proposed.
- To achieve the desired goal detailed hydrogeological and hydrological investigation has been carried out. Various tools such as remote sensing , GIS and advanced analytical techniques has been used at various levels for run off computations, identify suitable areas for ground water development , rain water harvesting and artificial recharge structures.
- The southern half of the project area is occupied by red loamy soil and the northern half is underlain by red sandy soil. The average annual rainfall of the area has been reported to be about 1267 mm.

- In order to assess the surface water availability and surface runoff being generated, the entire study area has been divided into number of watersheds using the drainage network on 1:50,000 scale.
- The main area of interest lies in the watershed of Kurdhabhali Nala , situated in the northern part , covers major part of the project area and offers good prospect of water harvesting .
- The Kurdhabhali watershed has been further divided into micro watersheds considering the lowest order of drainage network. In total, eleven micro watersheds have been demarcated and designated from A to K. The monthly surface water run off has been computed for each micro watershed.
- A total of about 9998 TCM (Say 10 Million Cubic Meter (MCM)) of water is being generated as run off from the entire watershed in the four monsoon months.
- It is recommended that the water harvesting structures should be designed to harness only 20 to 25% of the flow to the tune of 2 to 2.5 MCM so as to keep minimum flow in the downstream as well as to maintain the ecological balance of the area.
- Major portion of study area is occupied by Precambrian basement rocks consisting of mainly granites and gneisses, except in extreme north eastern corner where Talchirs are present.
- Most common ground water abstraction structure in the area are dug wells, tapping the weathered zone , the depth of dug wells are restricted up to 10 mbgl. The bore wells drilled up to 200m depth have limited yield varying from 2 to 5 liters per second (lps) depending upon the fractures encountered.
- One of the successful well constructed at Jharparha located in the western part of the study area up to a depth of 179 m in granite gneiss has yielded to the tune of 8 lps, water bearing fractures have been encountered at depths of 20 and 98 m , the transmissivity value works out to be 64 M2/day.
- The depth to water level in the study area varies widely from less than 4 mbgl to as high as 11 mbgl in different areas. General ground water flow is towards East to North East and directed towards river Brahmanai.

- Ground water quality in the study area as well as in the project area is good and suitable for drinking and other uses. The total dissolved Solids (TDS) in the area varies from 500 to 1250 mg/l.
- Major part of the project areas fall in the Banarpal block of Angul district in which the annual ground water availability has been assessed to the tune of 94 MCM and draft is just 17 MCM , the stage of ground water development is around 18 % leaving ample scope for further development.
- Based on the hydrogeological and other related criteria's four zones have been identified as feasible areas for ground water development within the project boundary. The exact location of well site may be decided after ground verification and resistivity sounding if required.
- Similarly, in order to provide sustainability to ground water, four areas have been identified and shown in map for undertaking artificial recharge activities through suitable structures.
- In order to harvest rain water from the catchment of Kurdhabhali Nala it is proposed to construct 10 check dams at different locations which will harvest rain water during four months of monsoon, to the tune of 1090 TCM and same can be stored in storage tanks as the requirement may be.
- For maintaining the sustainable yield of the ground water abstraction structures artificial recharge structures are also suggested in the elevated hillocks falling in the project area. This will help in arresting the declining water levels as well as provide sustainable yield of bore wells in the project area.
- Constructing 15 (fifteen) recharge structures of 144 cum each will account for 2160 cum of recharge holding capacity and will recharge approximately approx 450 cum of water with 3 bores each which comes to 2610 cum.
- Recharge structures of based on blocks which will accommodate 2160 cum of water from rain and extra runoff can be diverted via a Hume pipe to construction facility purpose pond, by that way we need not construct the ponds for Rainwater Harvesting.

- Online recharge systems in purpose built storm water drain from the township to the main water pond can be constructed for production facility. This will also associated with 15 number of recharge structures of small size and divert the extra runoff to the main production pond.
- More of utilisation and less of Holding and recharging can reduce your big cost in construction of recharge structures, construction of ponds and will also reduce the pumping cost in rain session for you for the water to be pumped from river for production facilities.

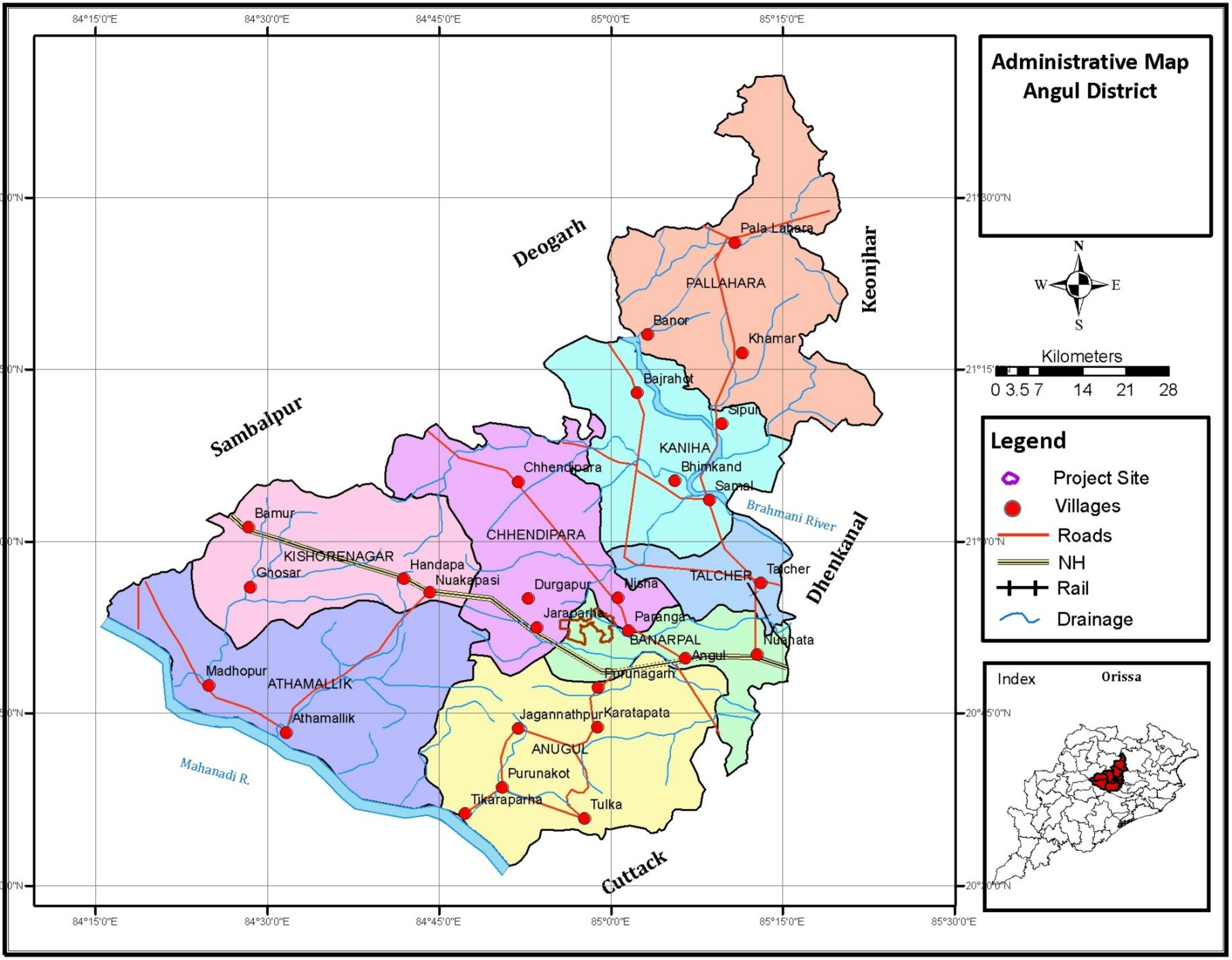

Figure 1.1: Administrative Map of Angul District

Figure 1.2: Satellite image of the study area

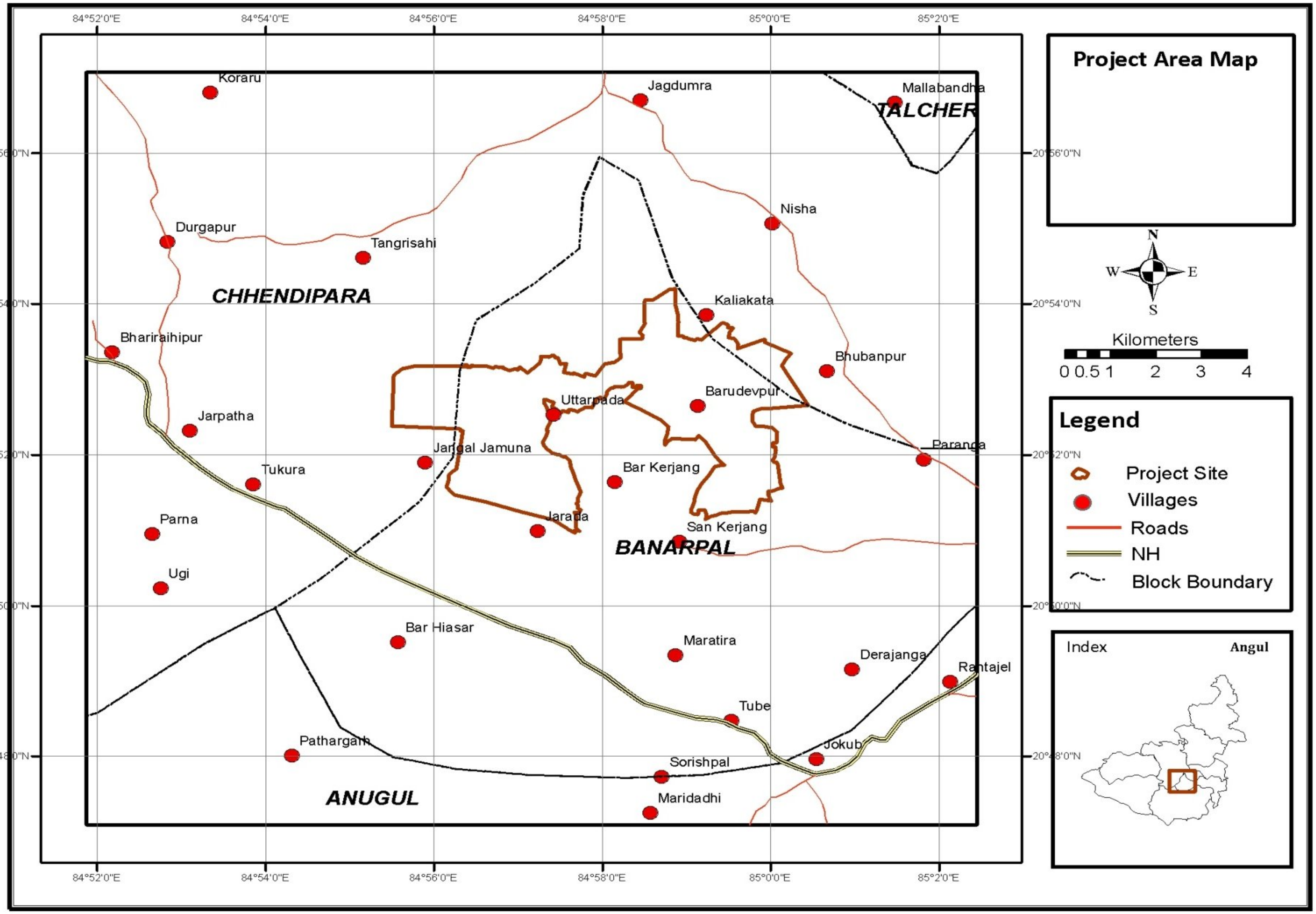

Figure 1.3: Map of the Study Area with project location.

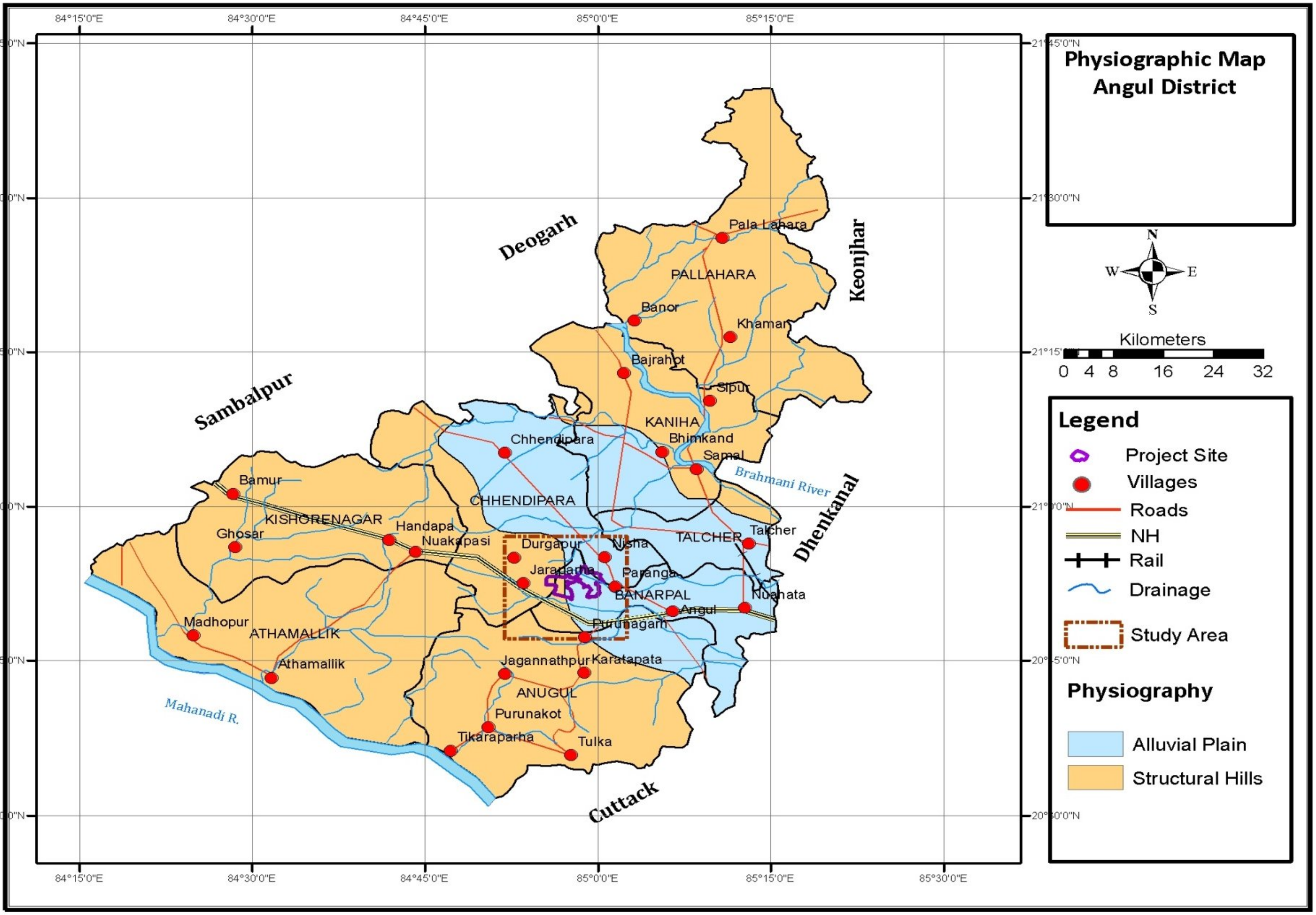

Figure 2.1: Physiographic Map of the Angul District

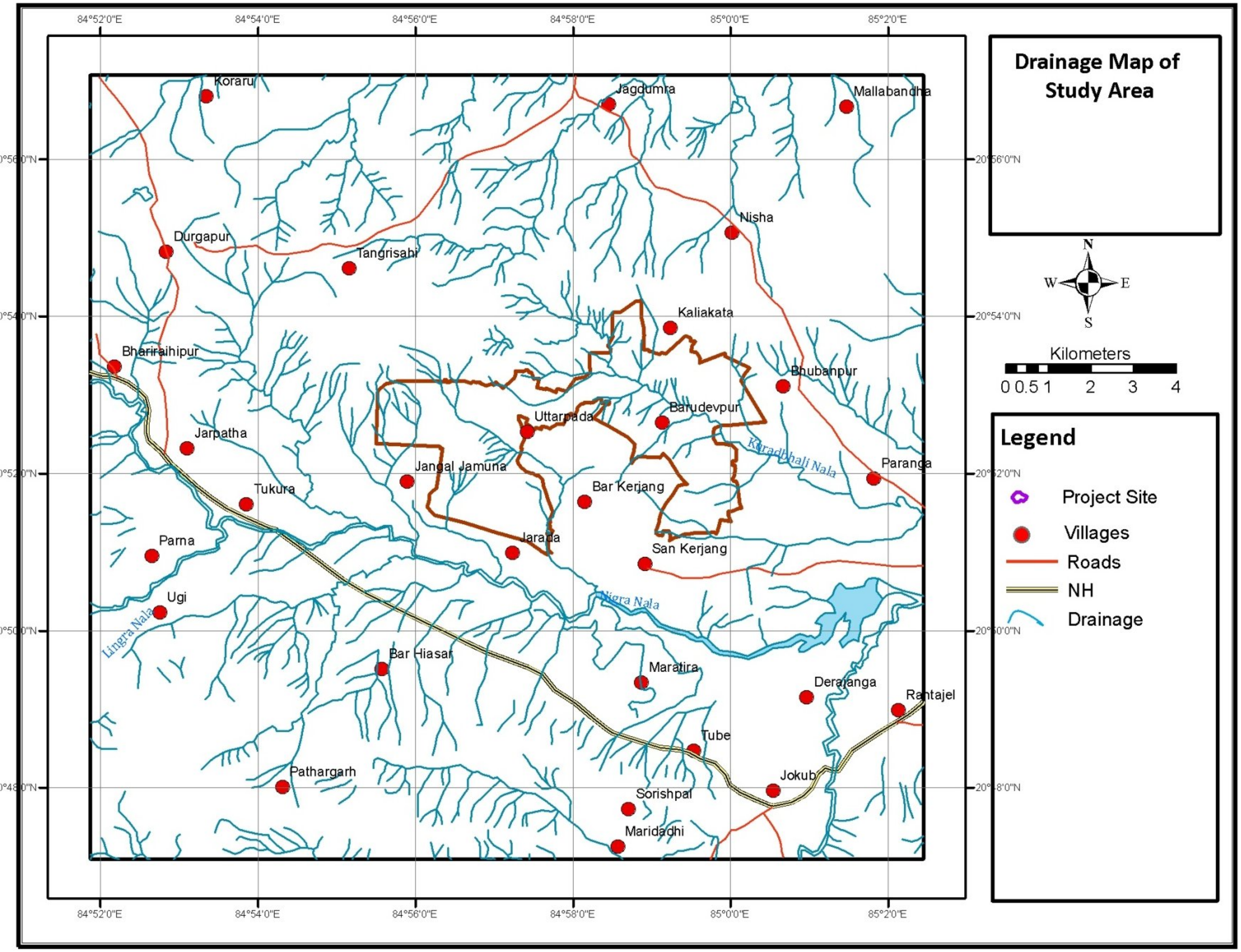

Fig. 2.2 Drainage map of the study area.

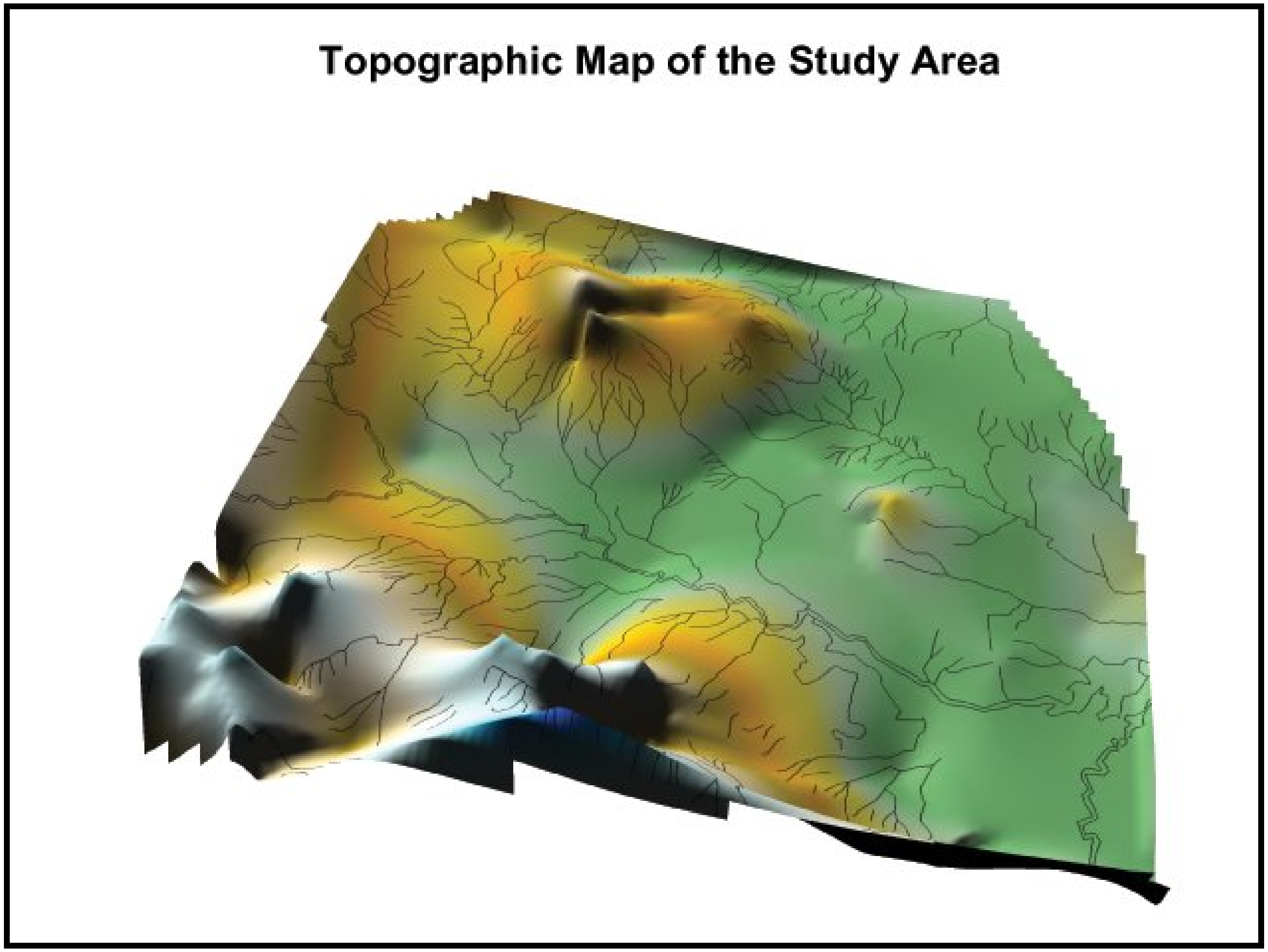

Fig. 2.3: 3-D map showing the Drainage Network of the Area.

Figure 2.3: Agro climatic map of India

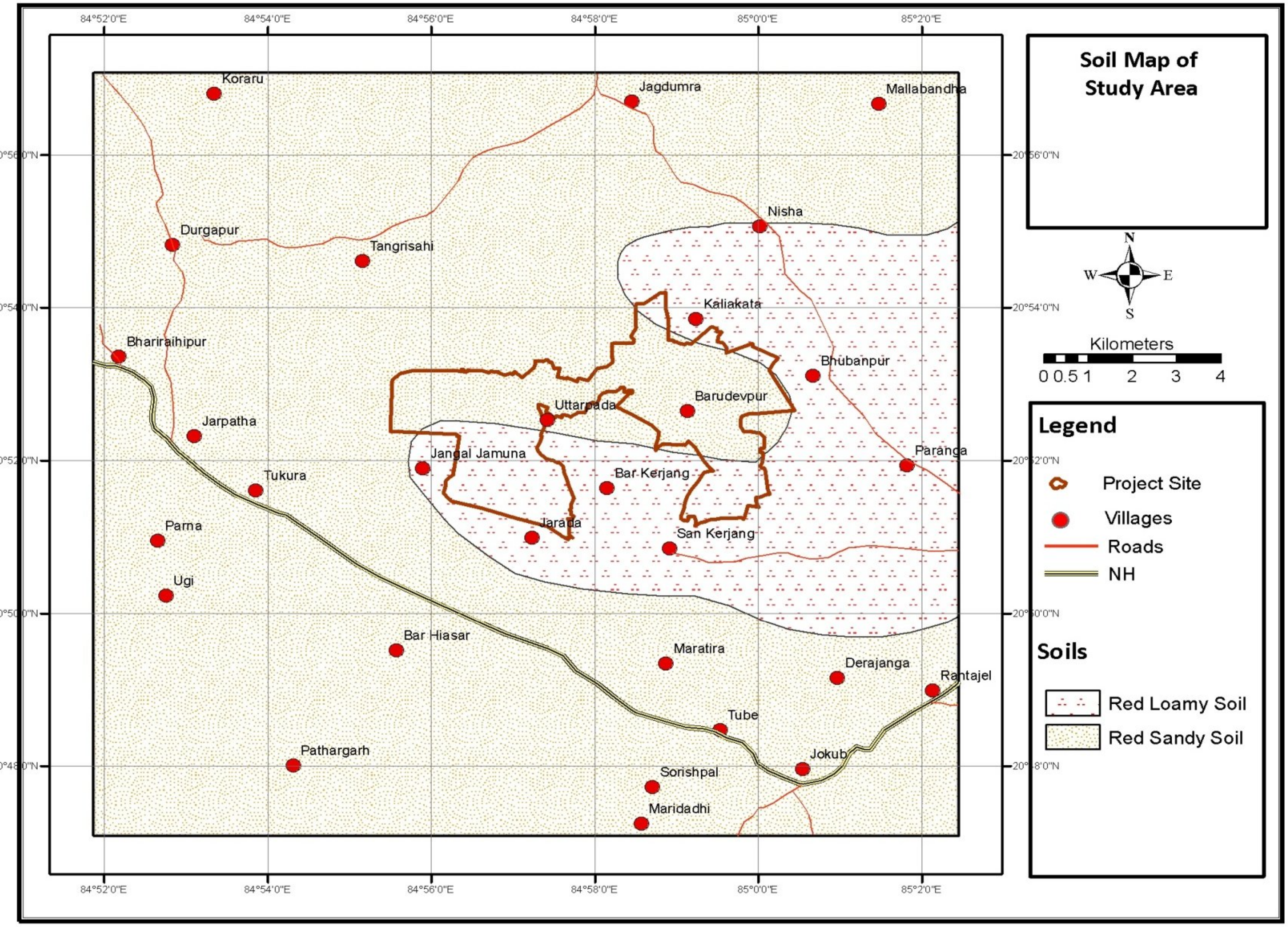

Figure 2.4: Soil Map of the Study Area

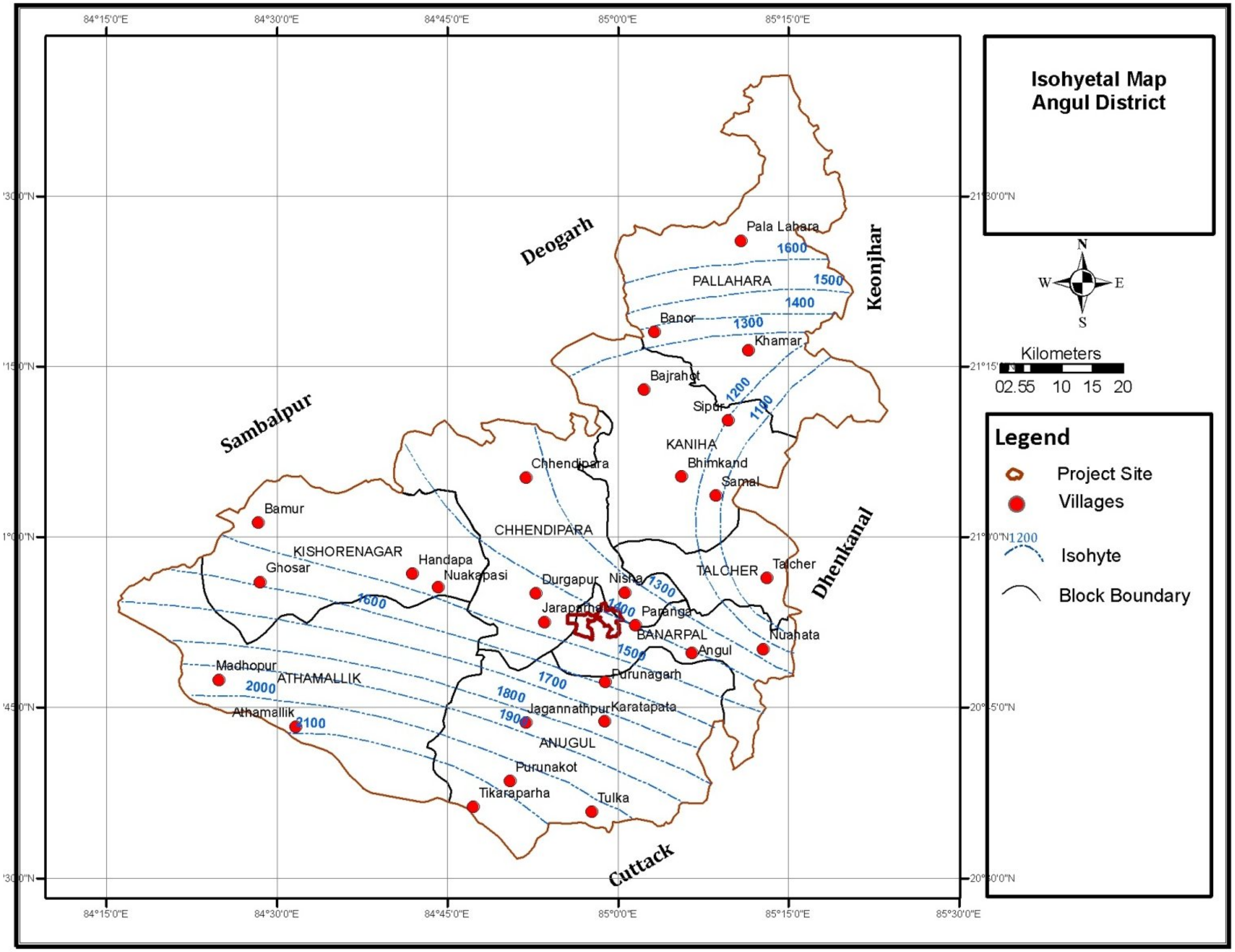

Figure 3.1: Isohyetal Map of Angul District

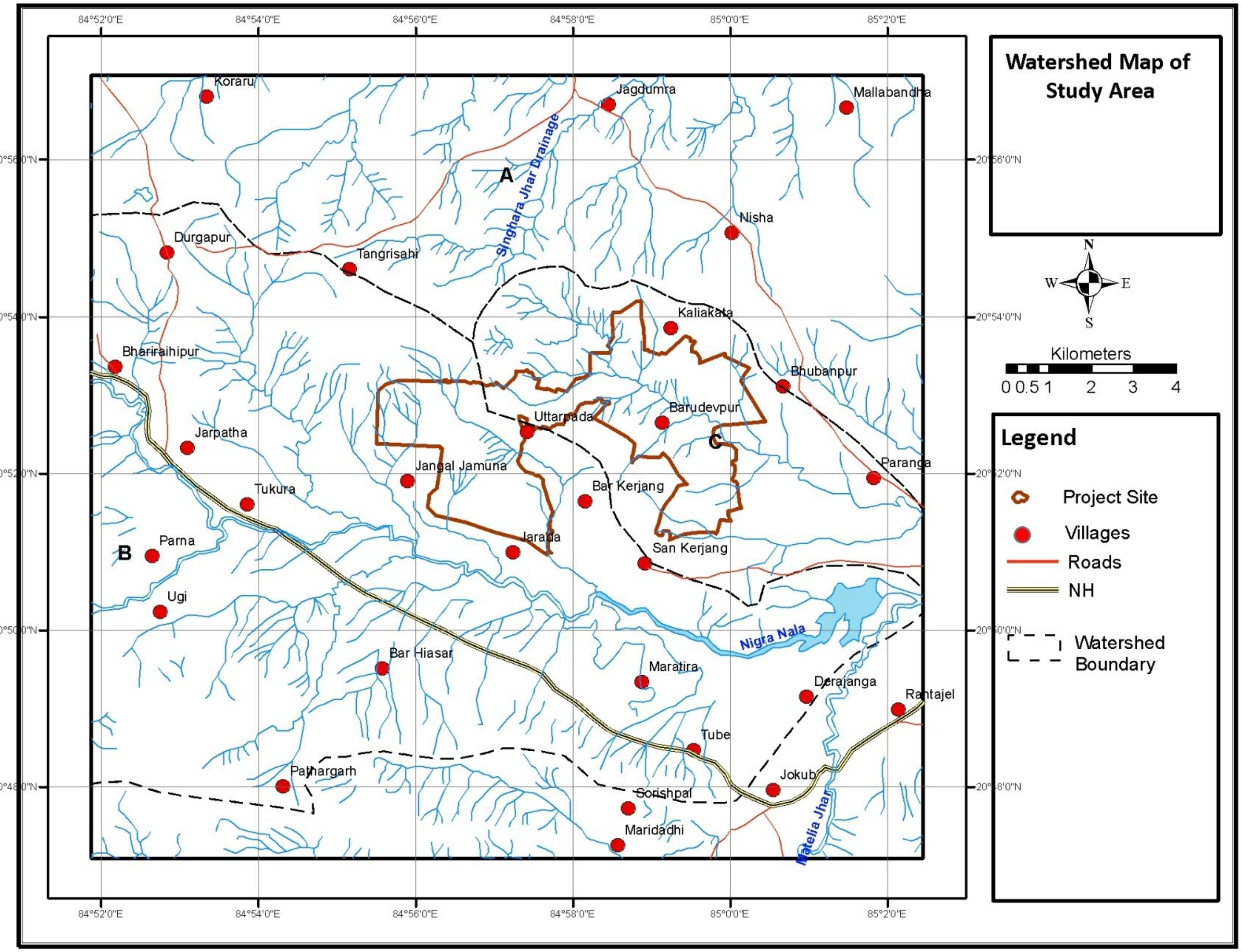

Figure 4.1: Watershed map of the Study area.

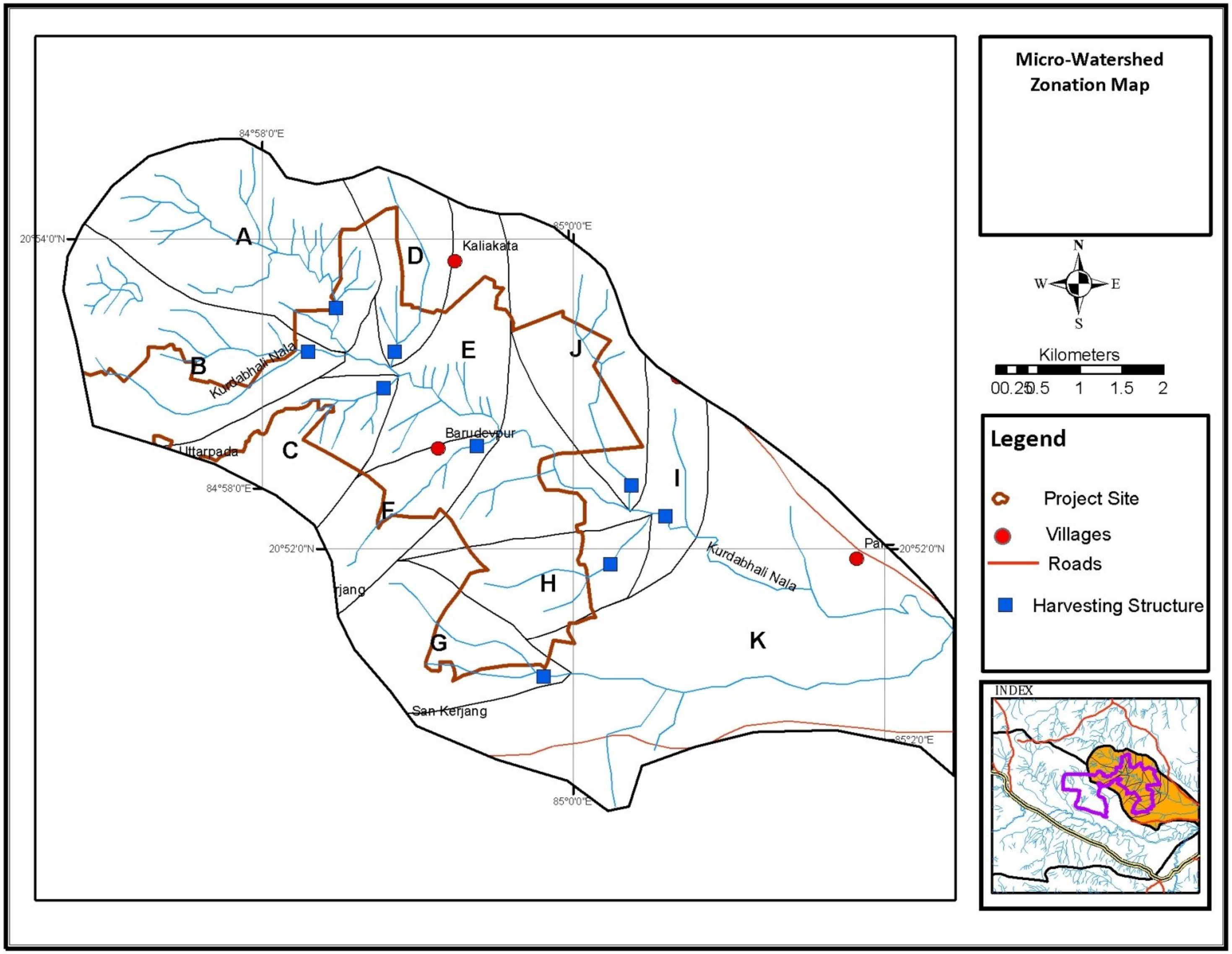

Figure 4.2: Micro-watersheds and location of probable sites for water Harvesting/ Ponding.

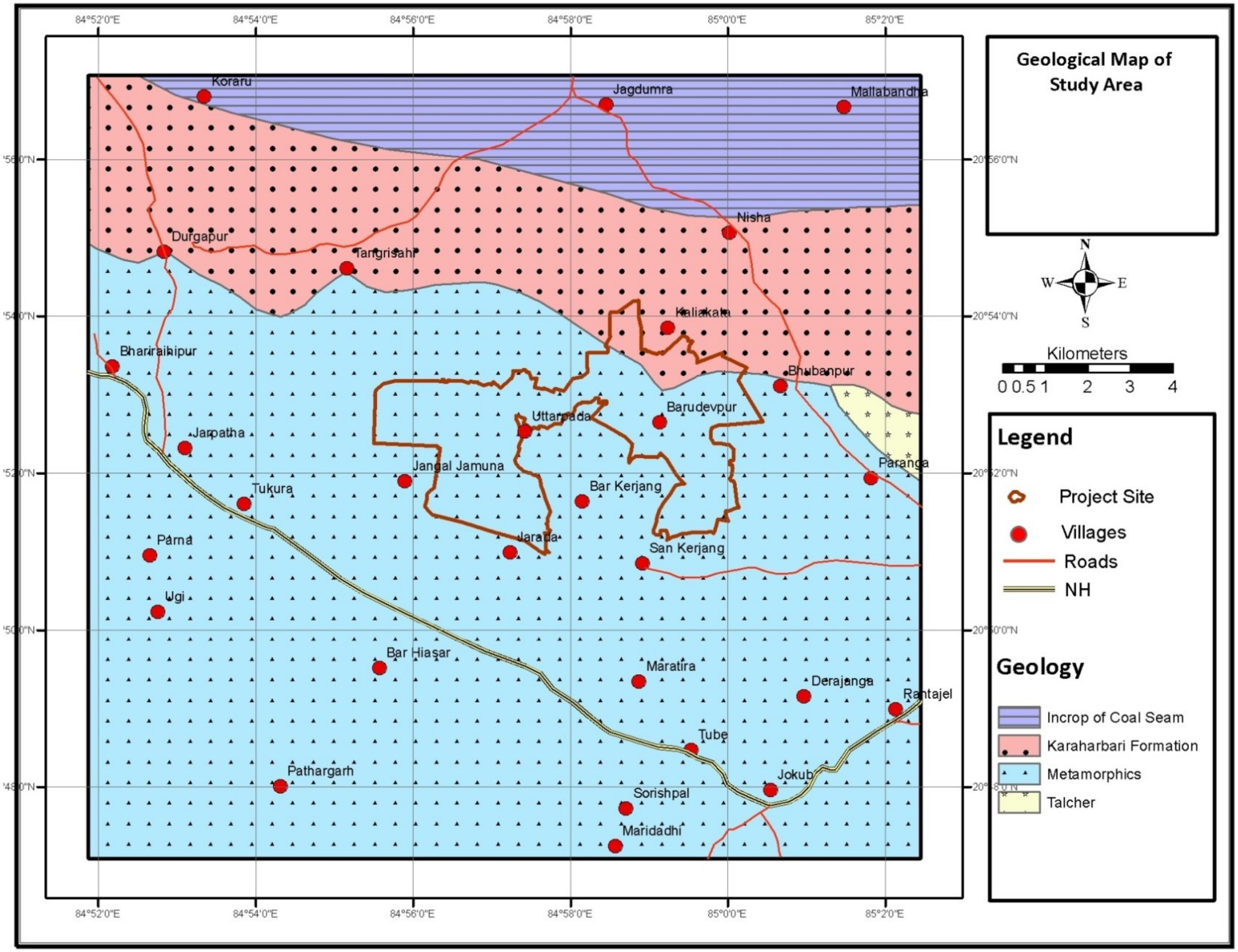

Figure 5.1: Geological map of the study area

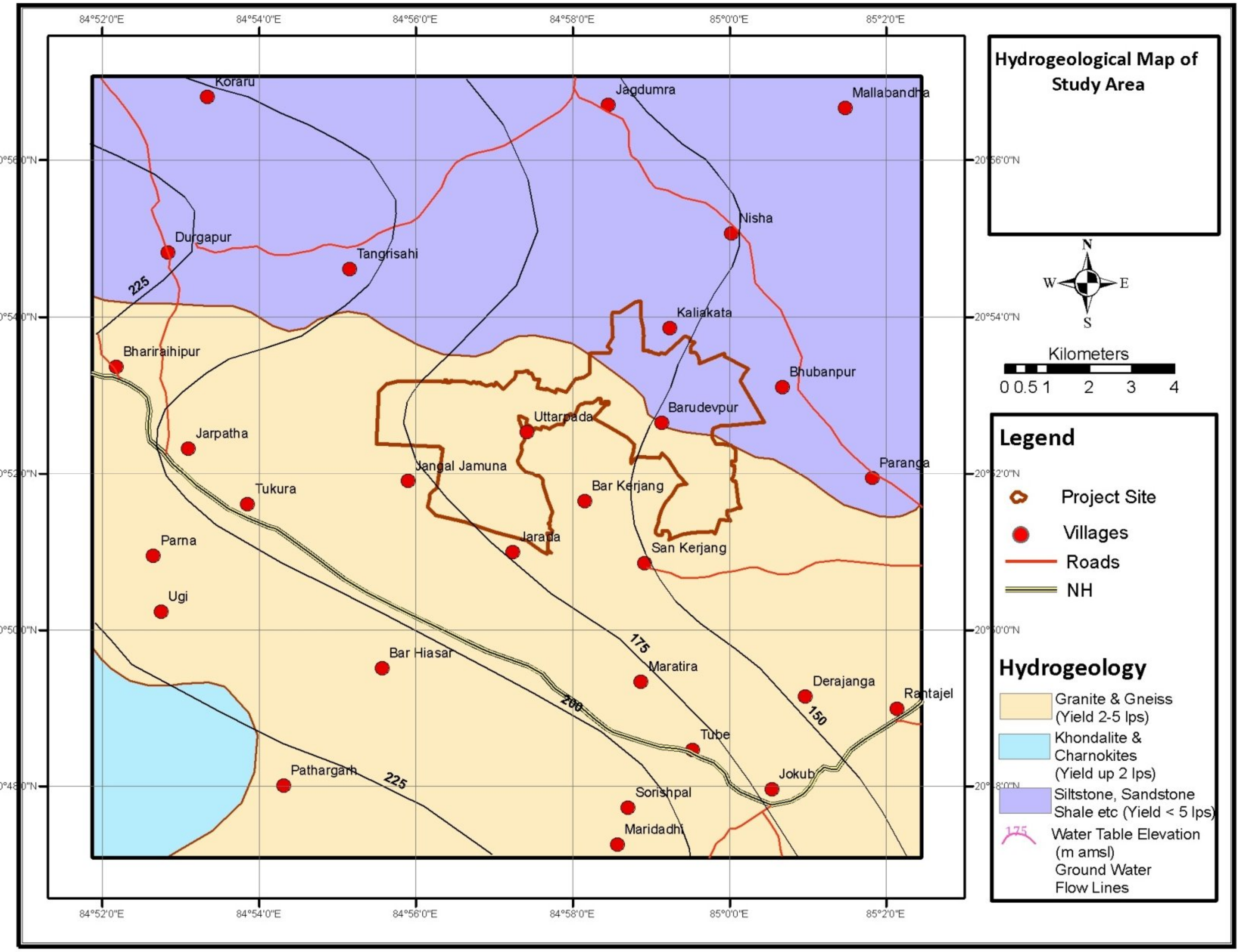

Figure 5.2: Hydrogeological map of the Study Area

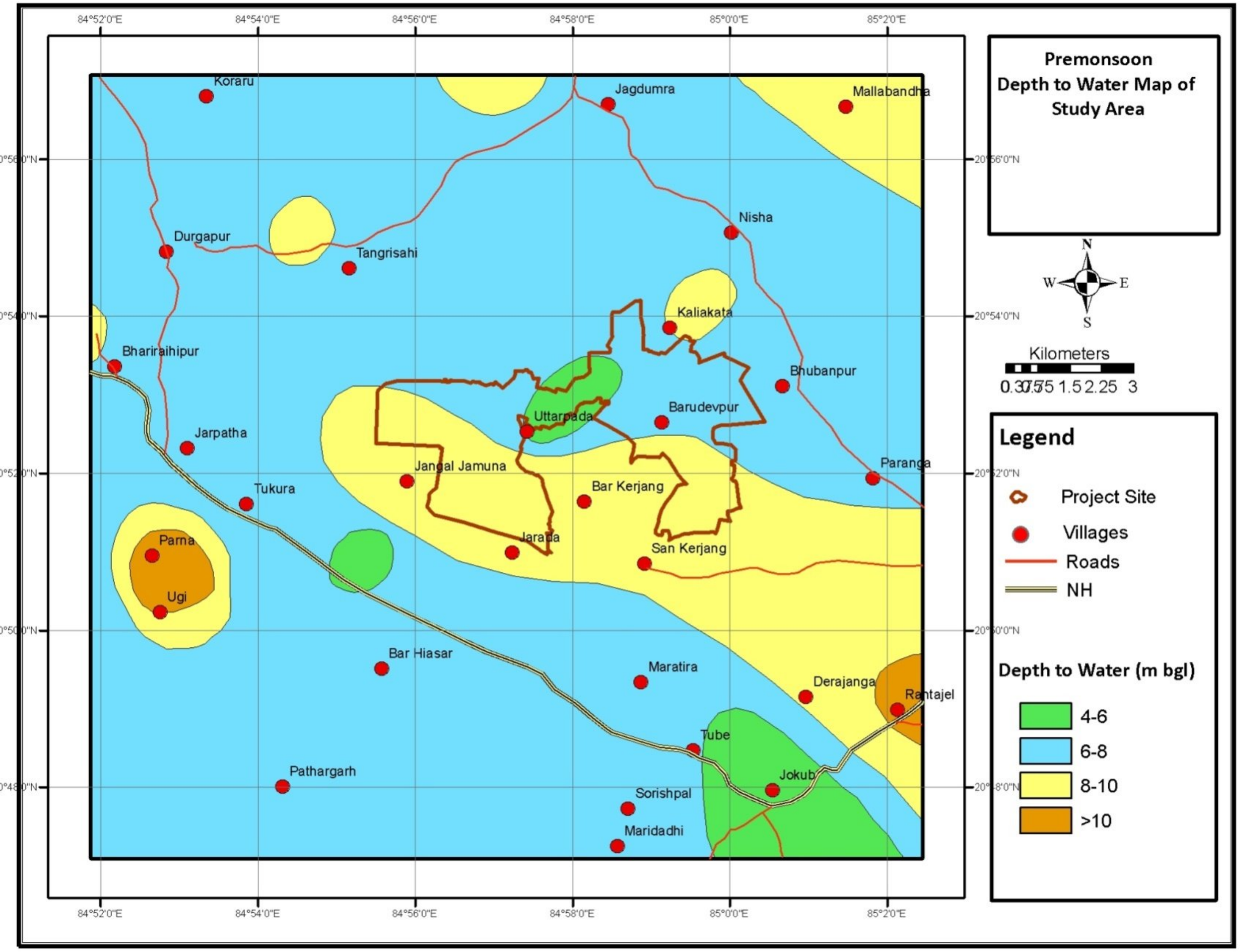

Figure 5.3: Depth to Water Level Map of the Study Area.

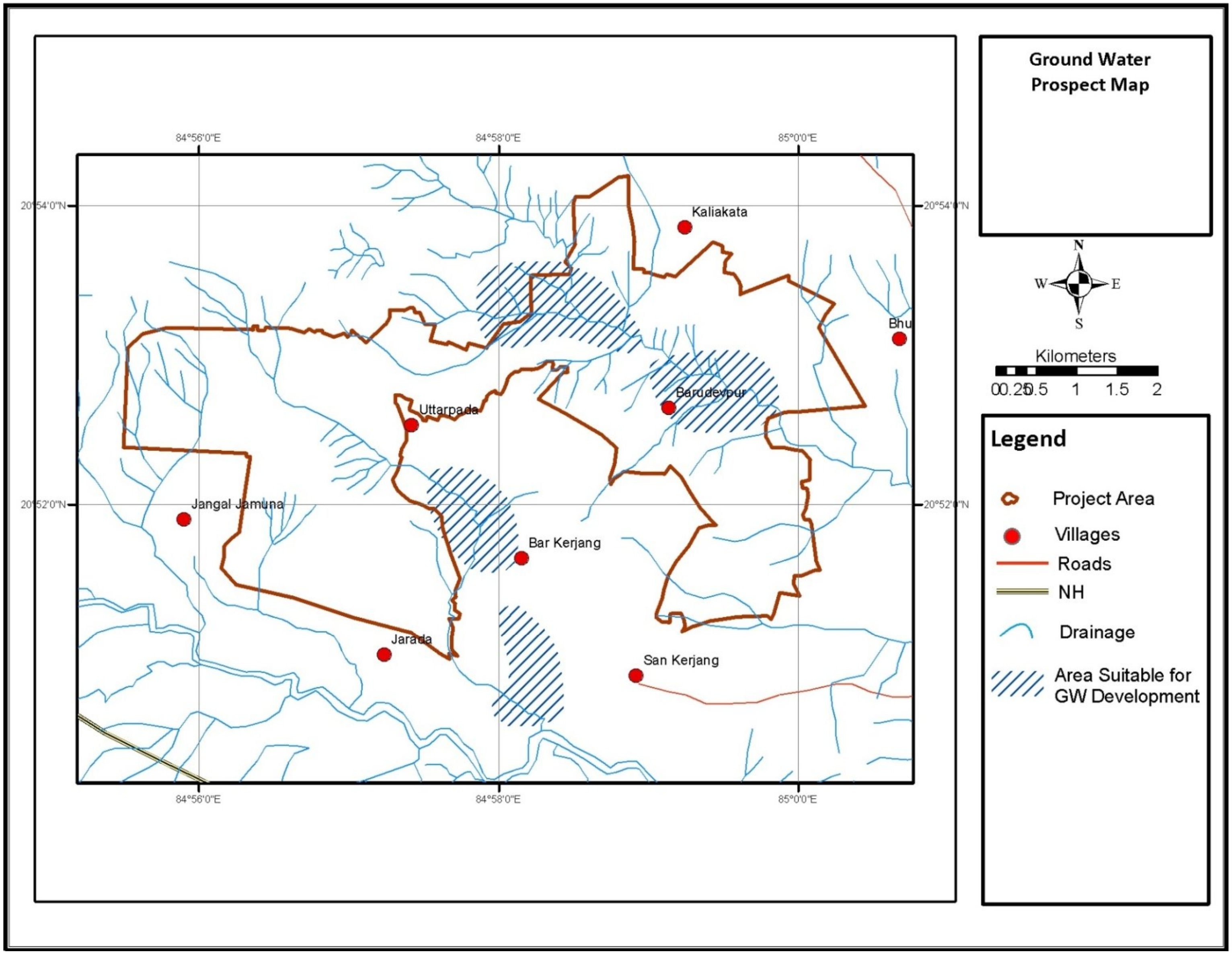

Figure 7.1: Ground Water Prospect map

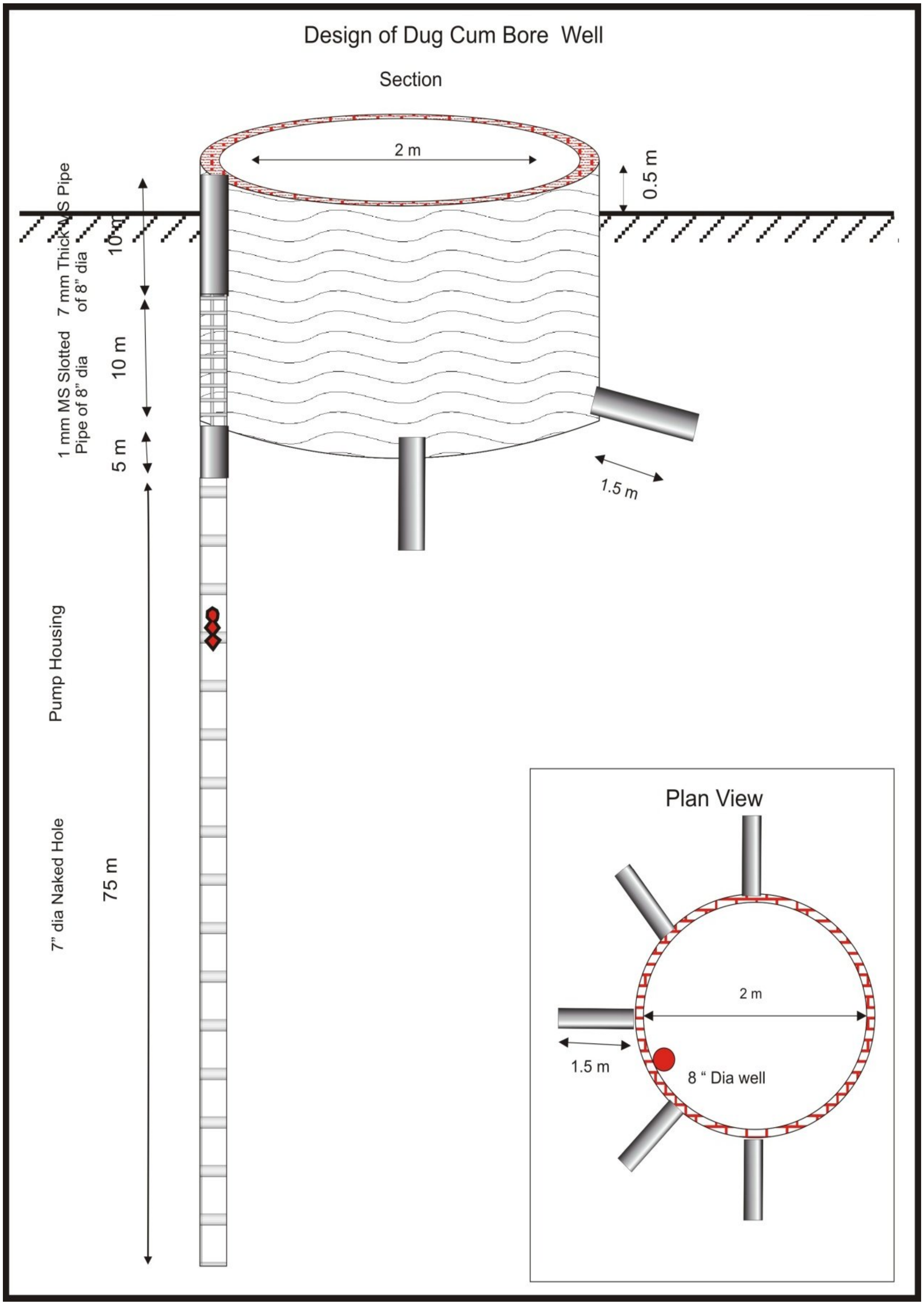

Fig: 7.2 Design of Dug cum Bore well

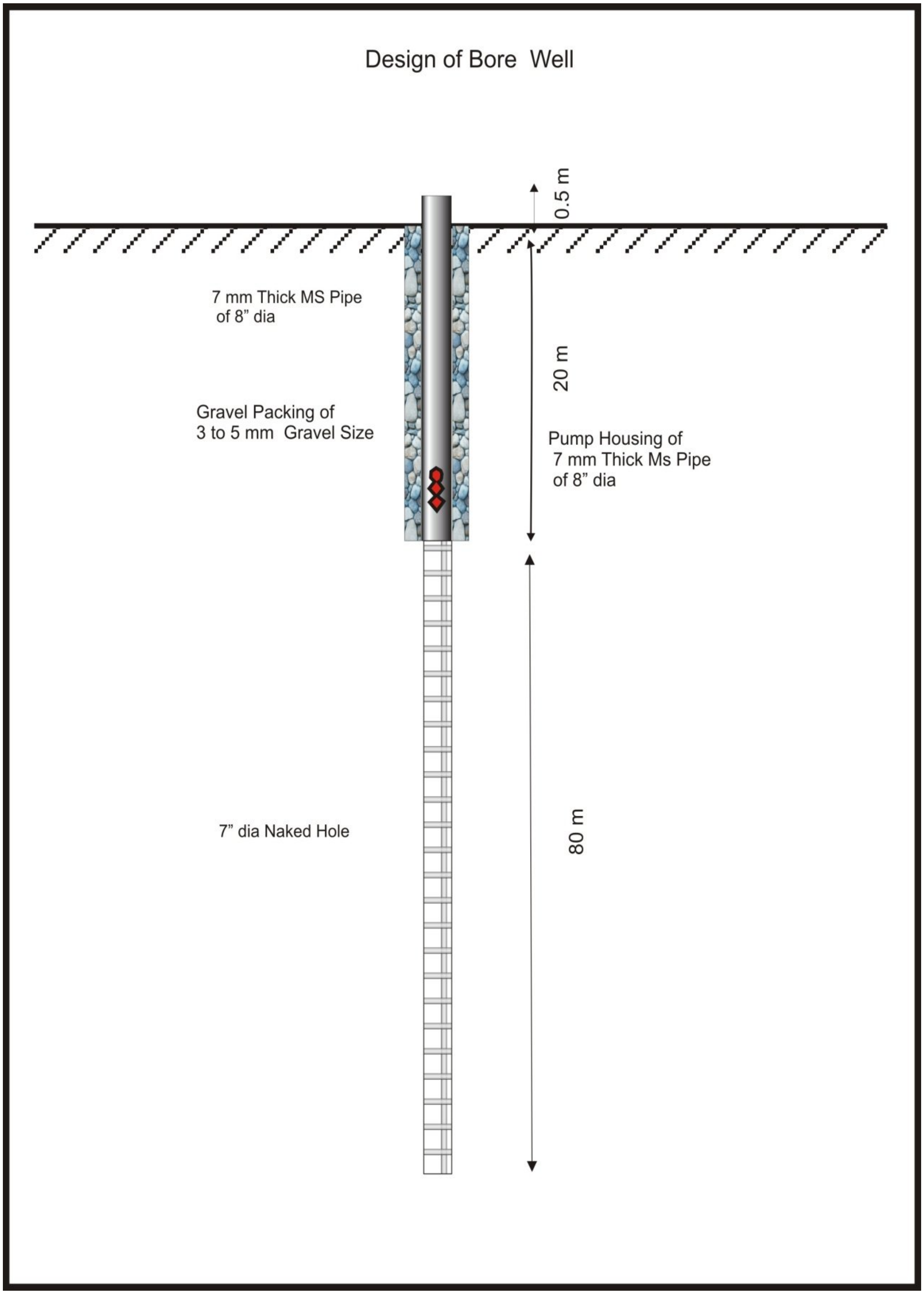

Fig: 7.3 Design of Proposed Bore well

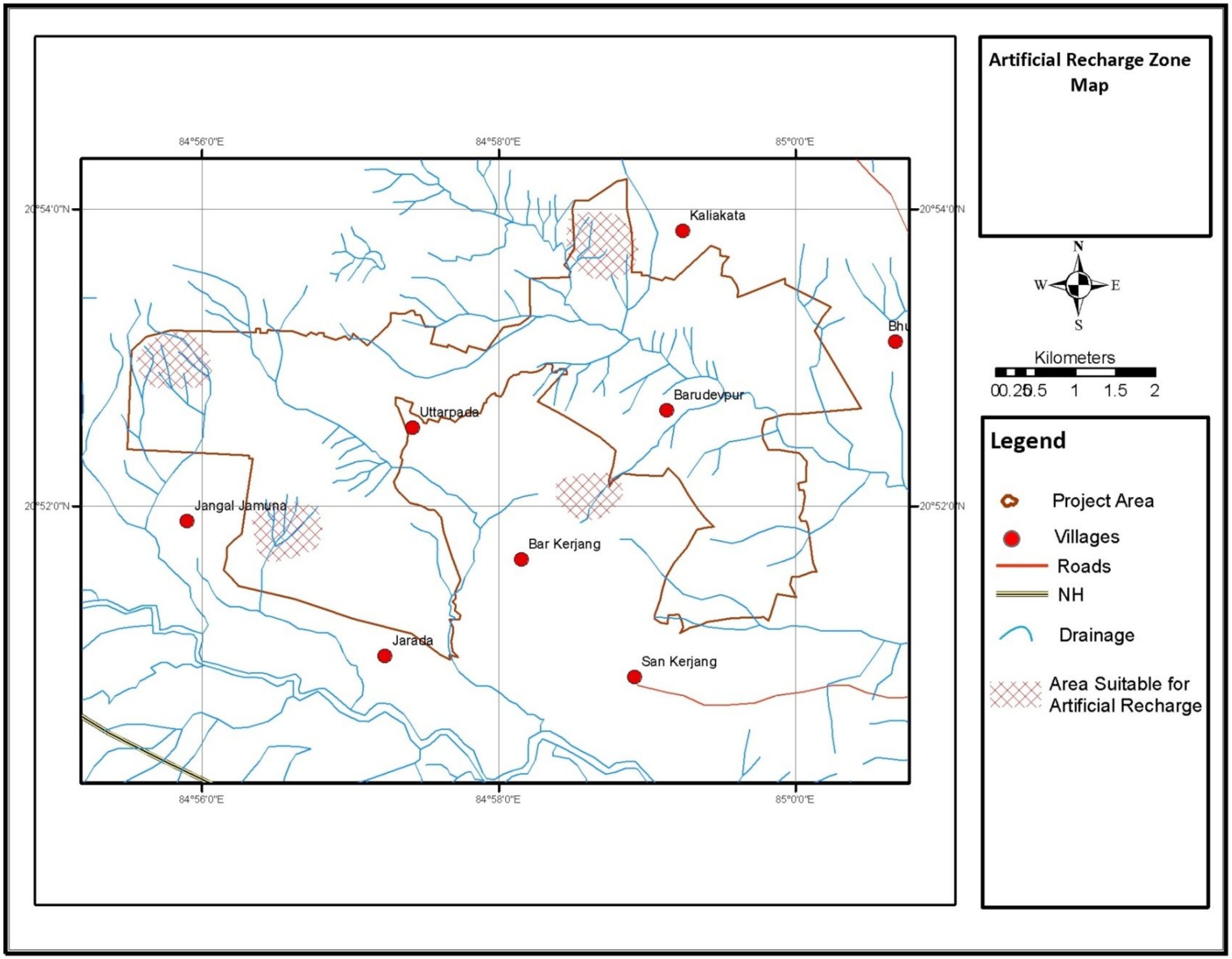

Figure 7.4: Artificial Recharge to Ground Water zone map

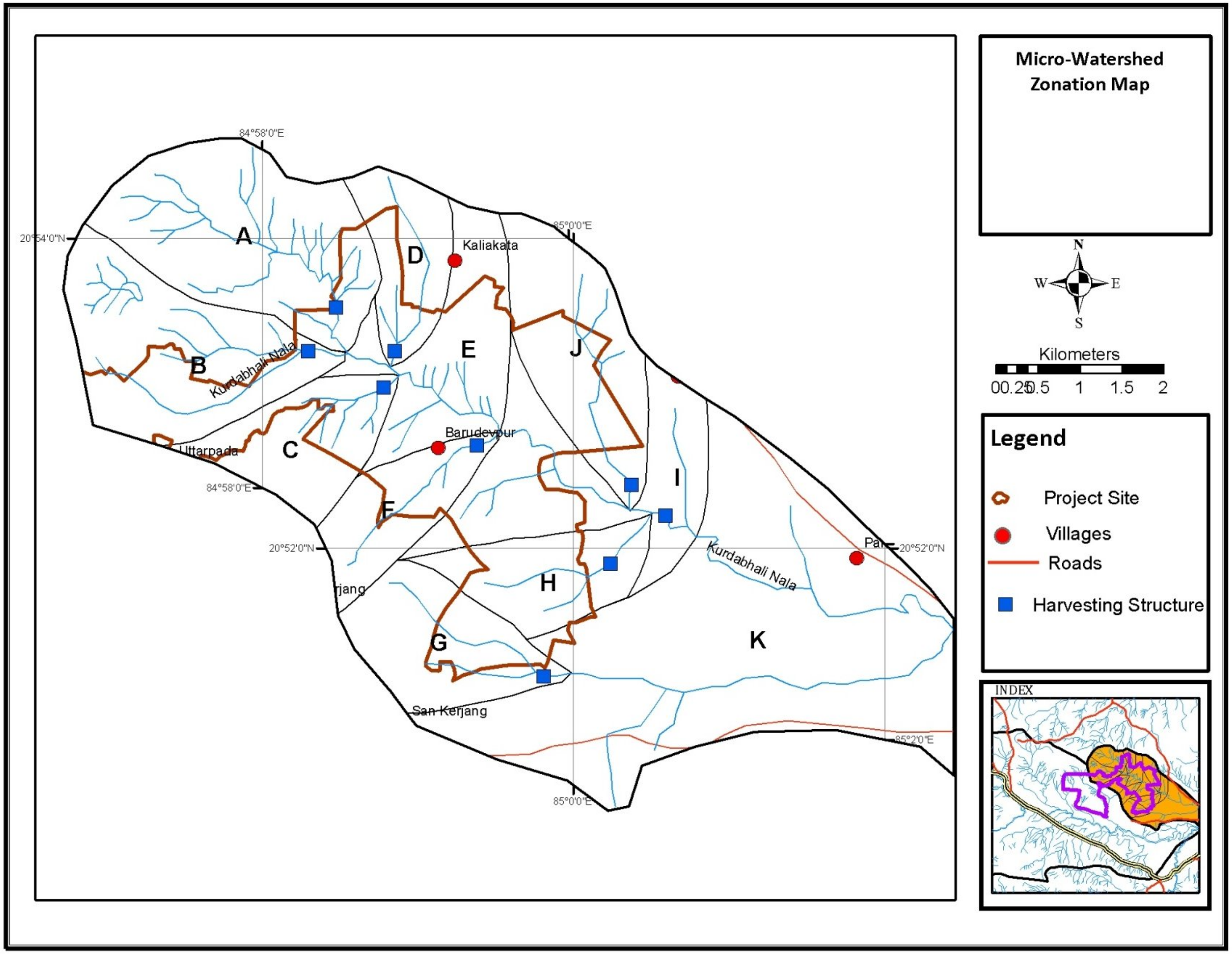

Figure 8.1: Proposed locations of Check Dams(Harvesting structures) in Micro-Watersheds

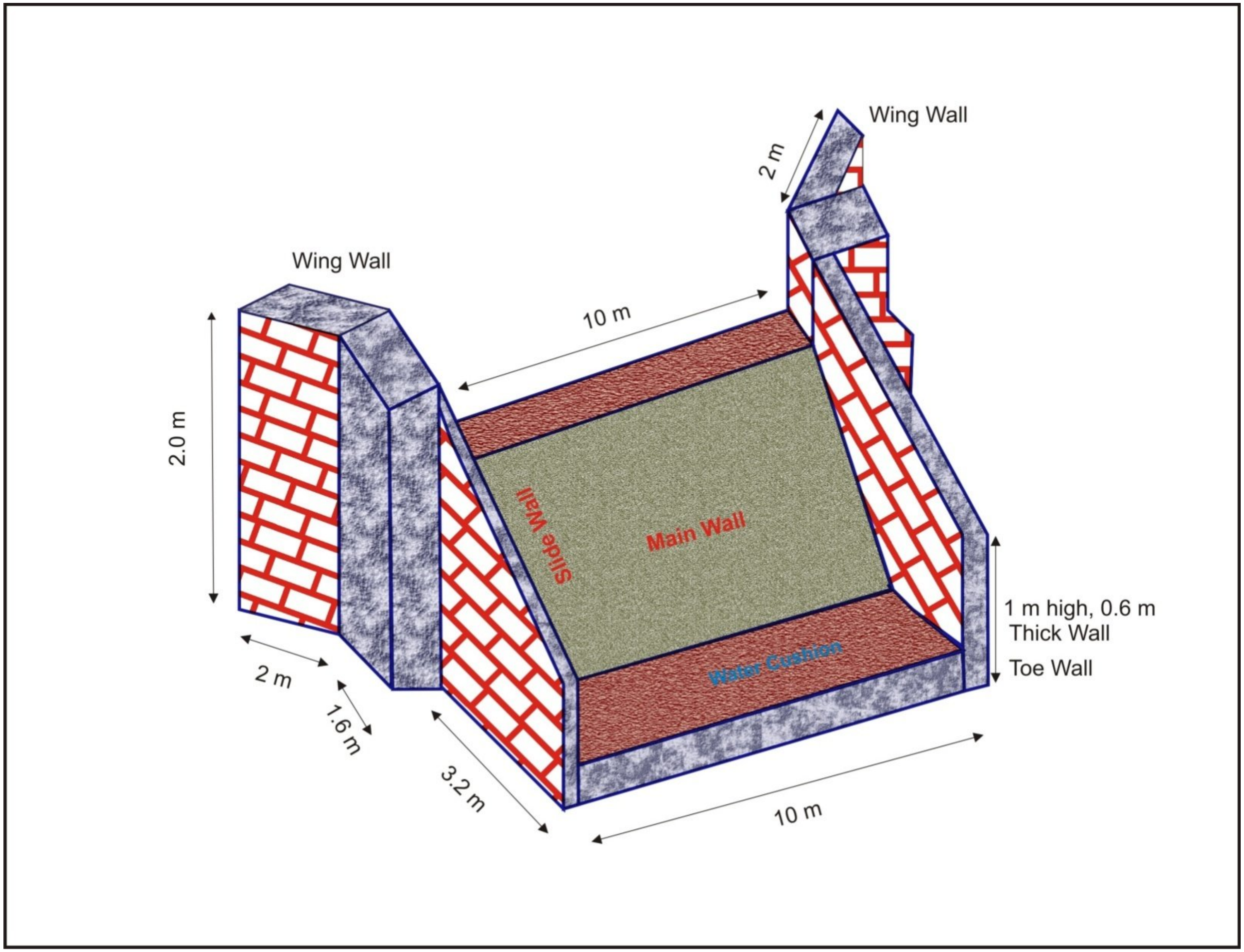

Figure 8.2: Horizontal Section of Check Dam for Micro Watershed ‘A’

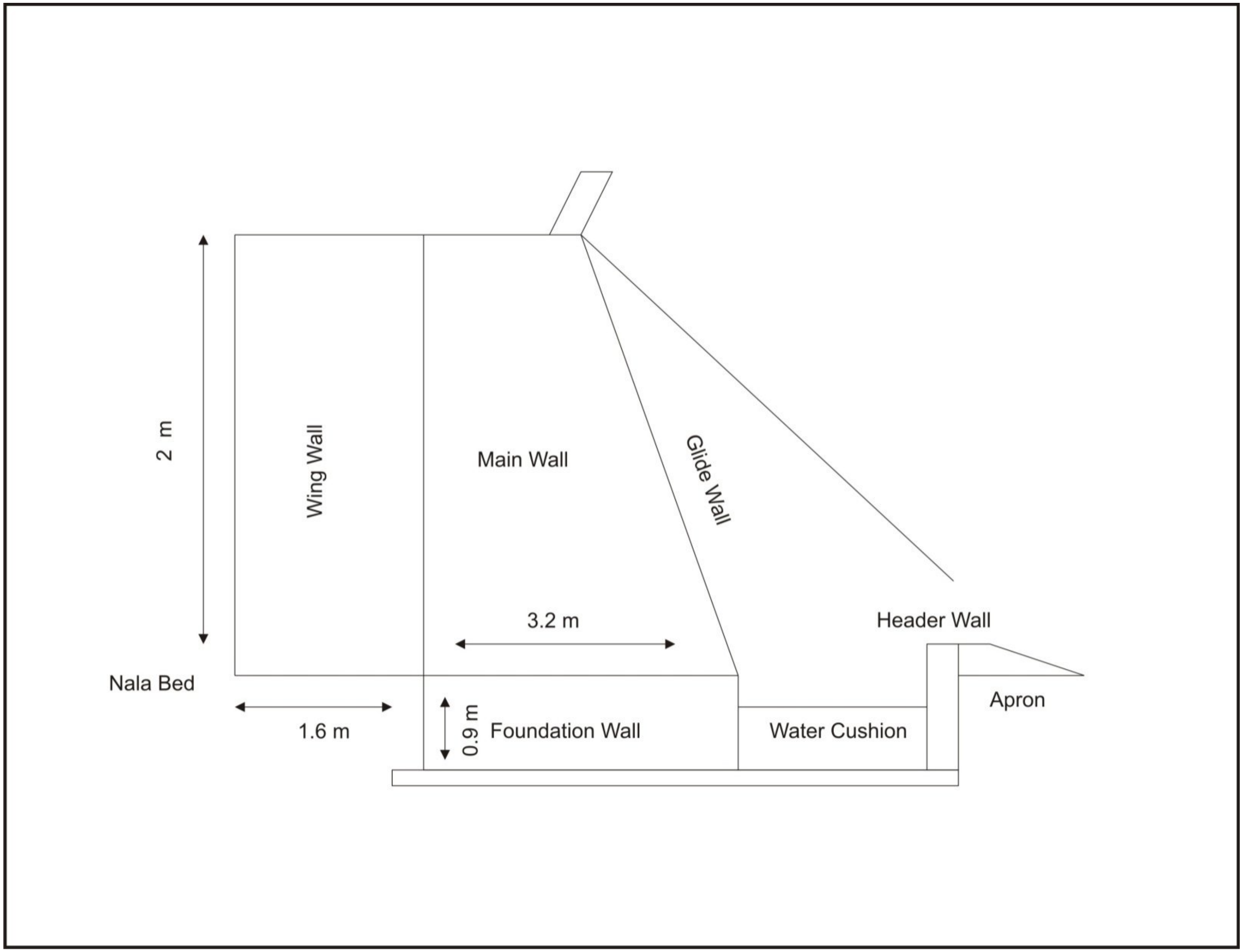

Figure 8.3: Vertical Cross Section of Check Dam for Micro Watershed ‘A’

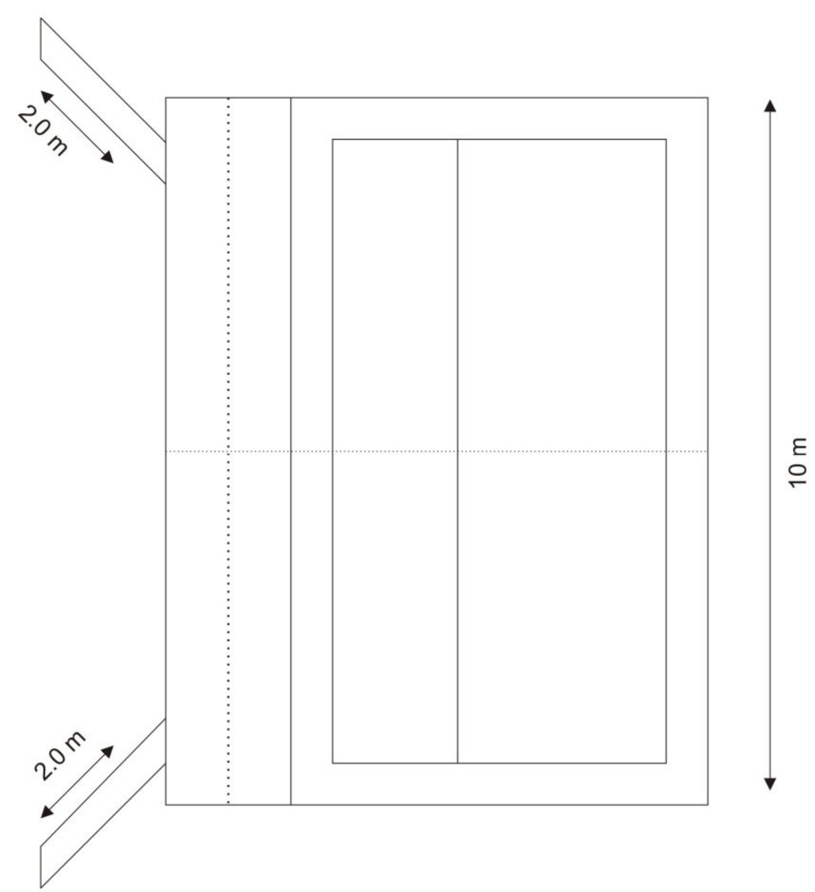

Figure 8.4: Plan view for Check Dam for Micro Watershed 'A'

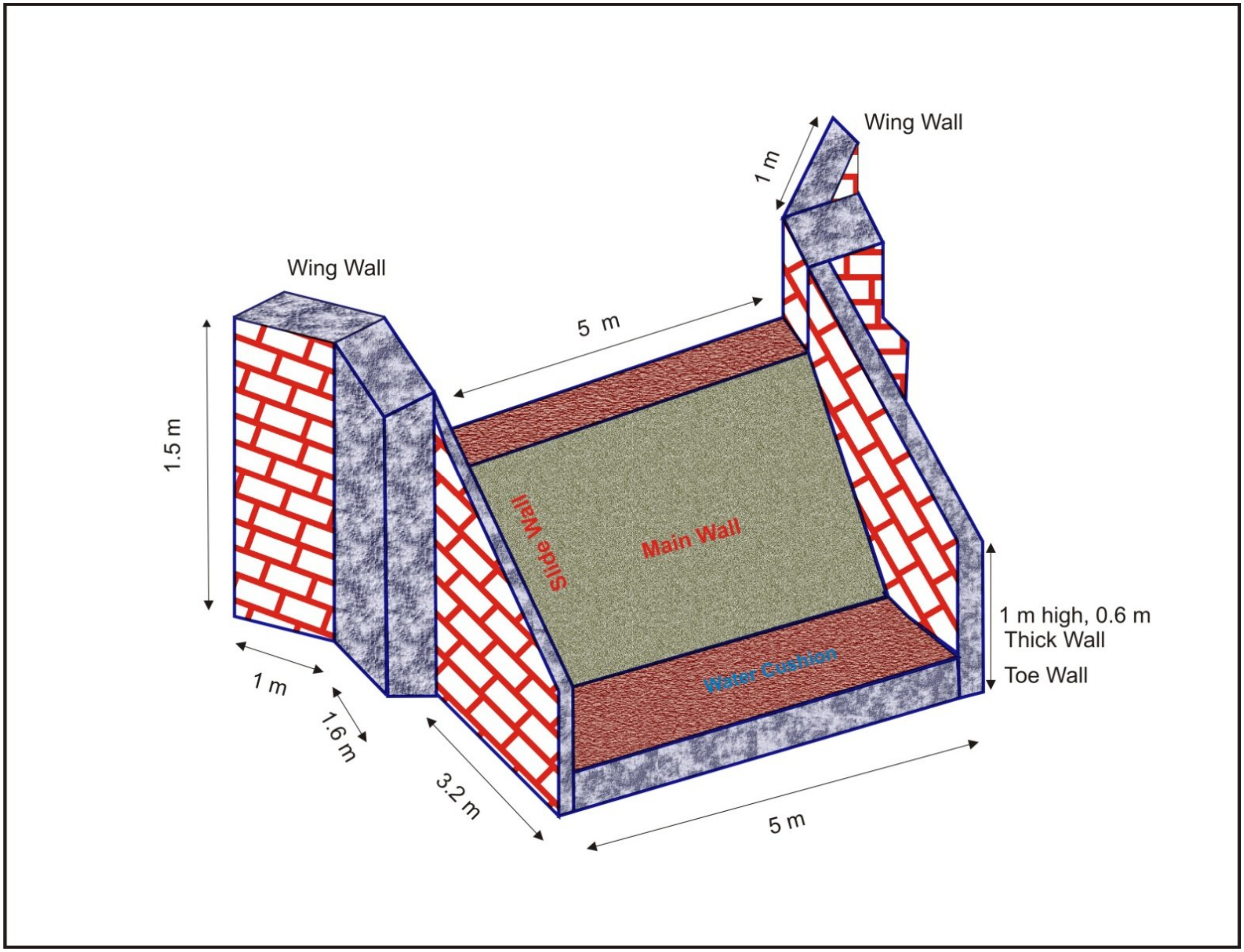

Figure 8.5: Horizontal Section of Check Dam for Micro Watershed ‘B’

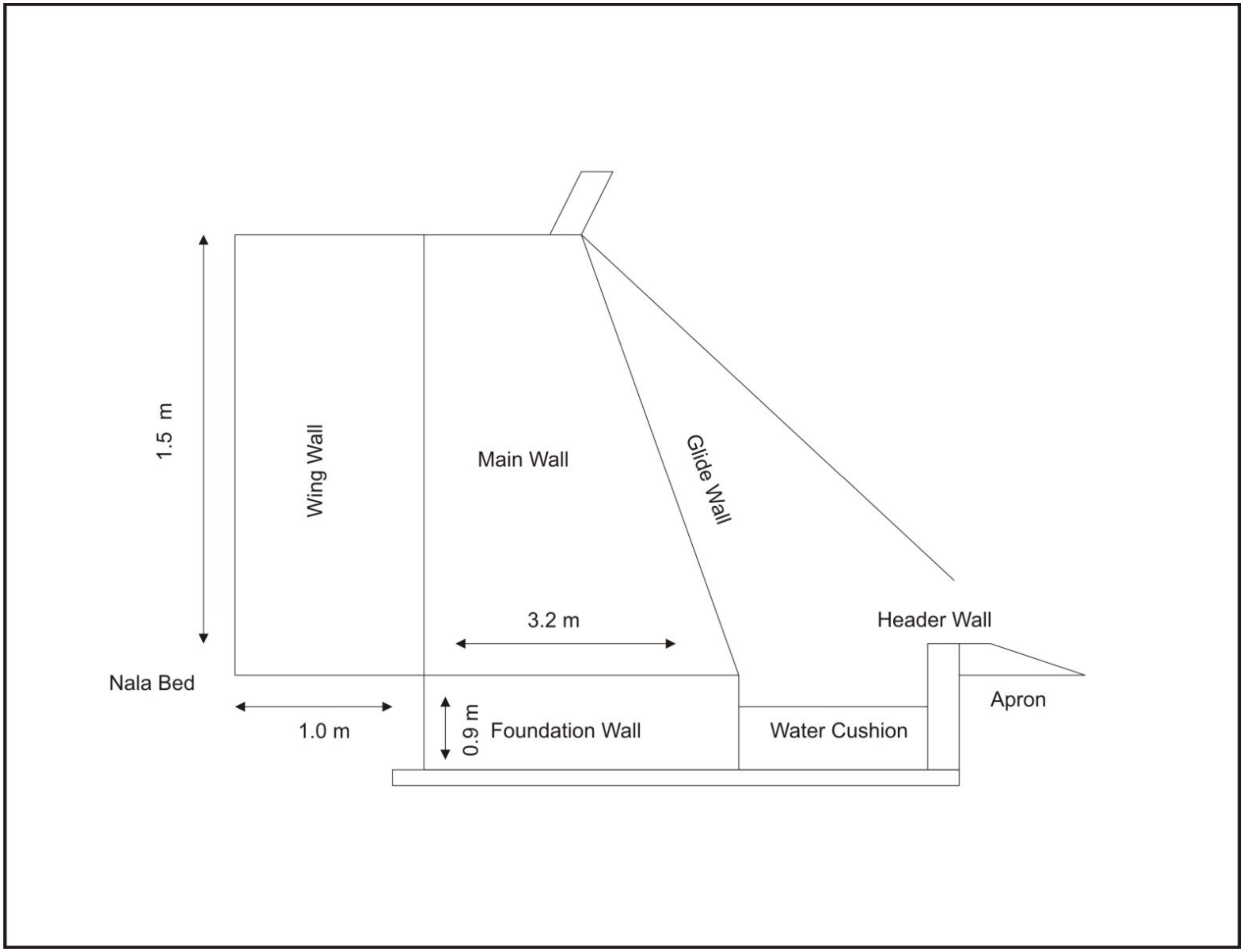

Figure 8.6: Horizontal Section of Check Dam for Micro Watershed ‘B’

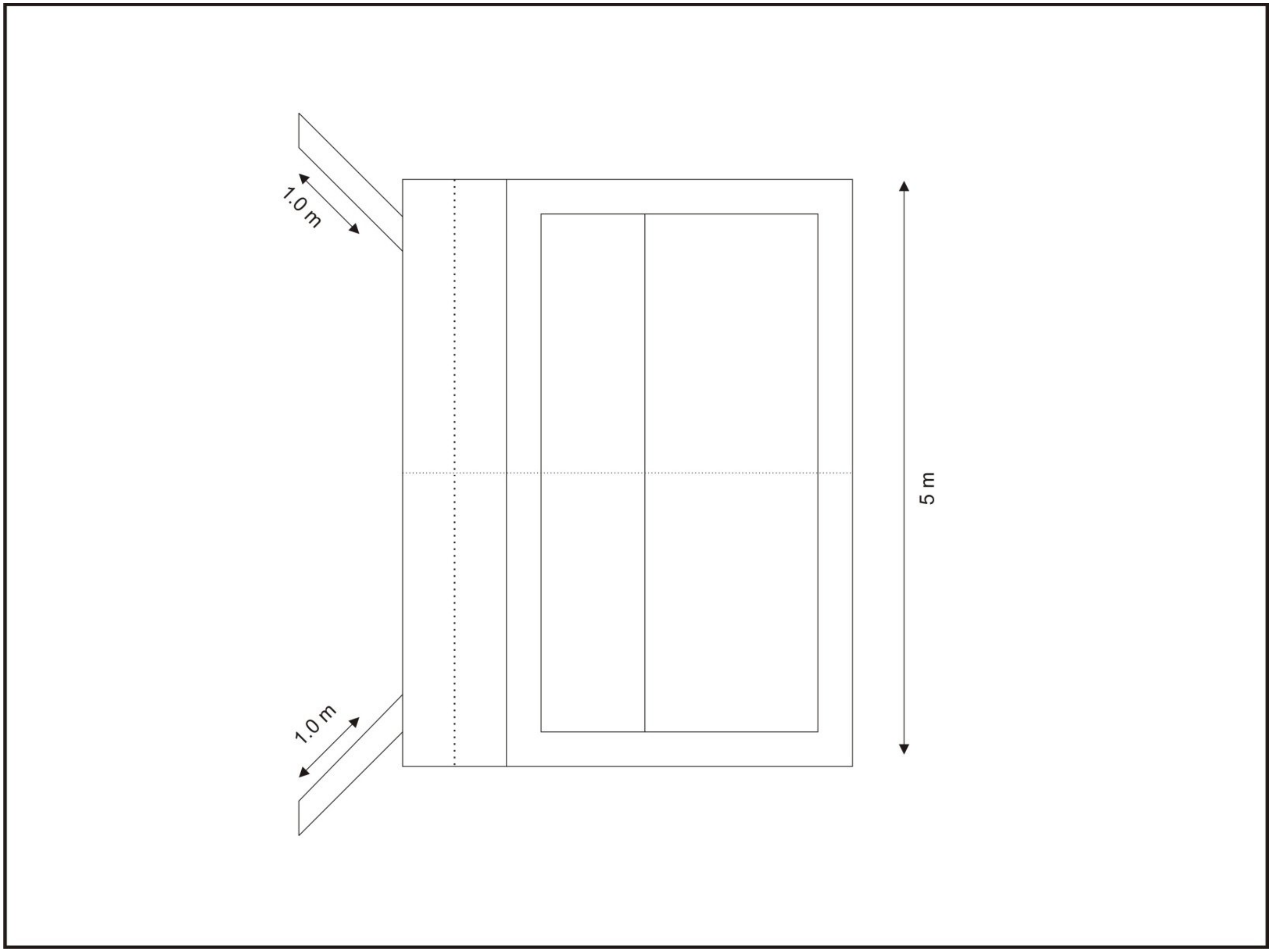

Figure 8.7: Plan view for Check Dam for Micro Watershed ‘B’

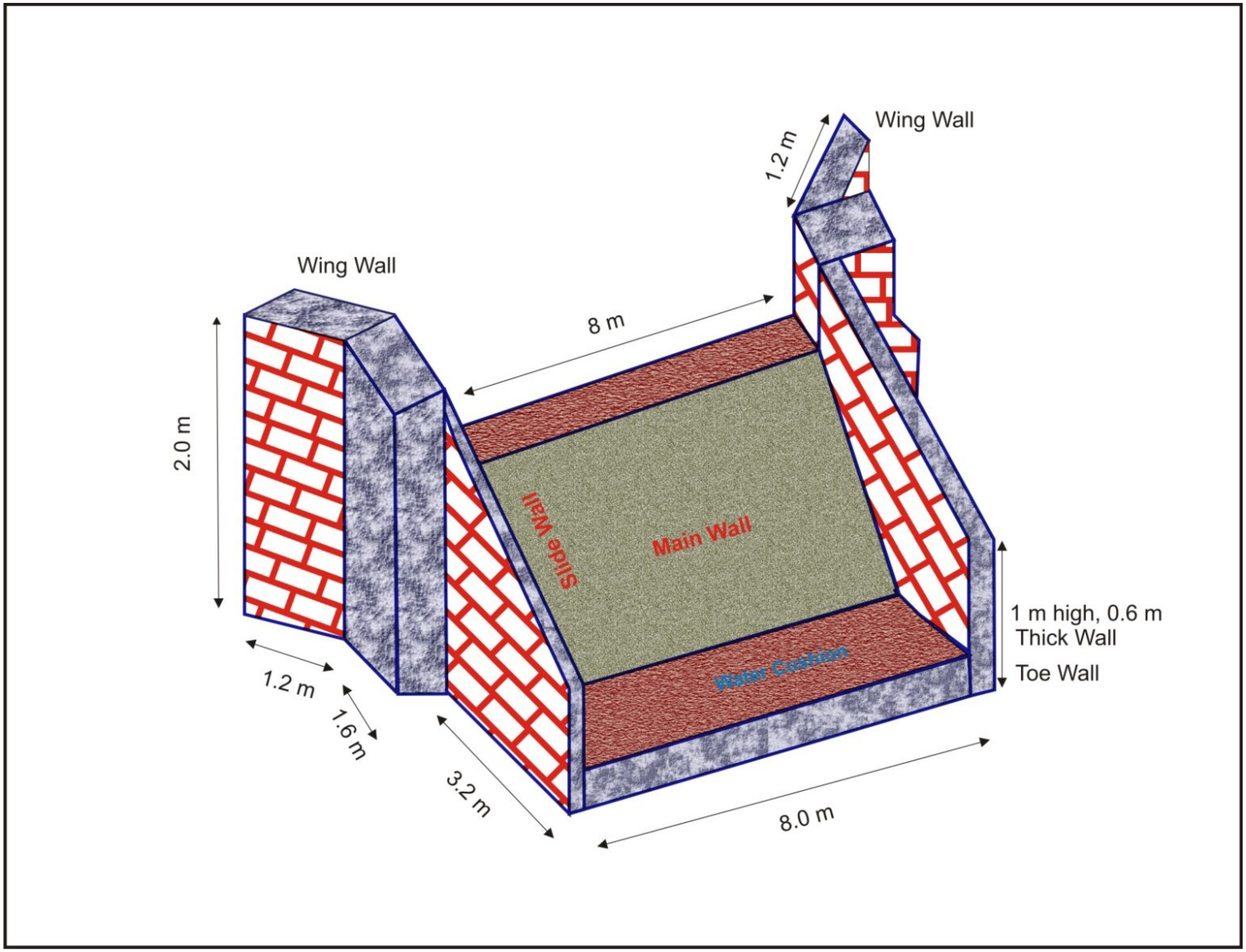

Figure 8.8: Horizontal Section of Check Dam for Micro Watershed ‘C to H & J’

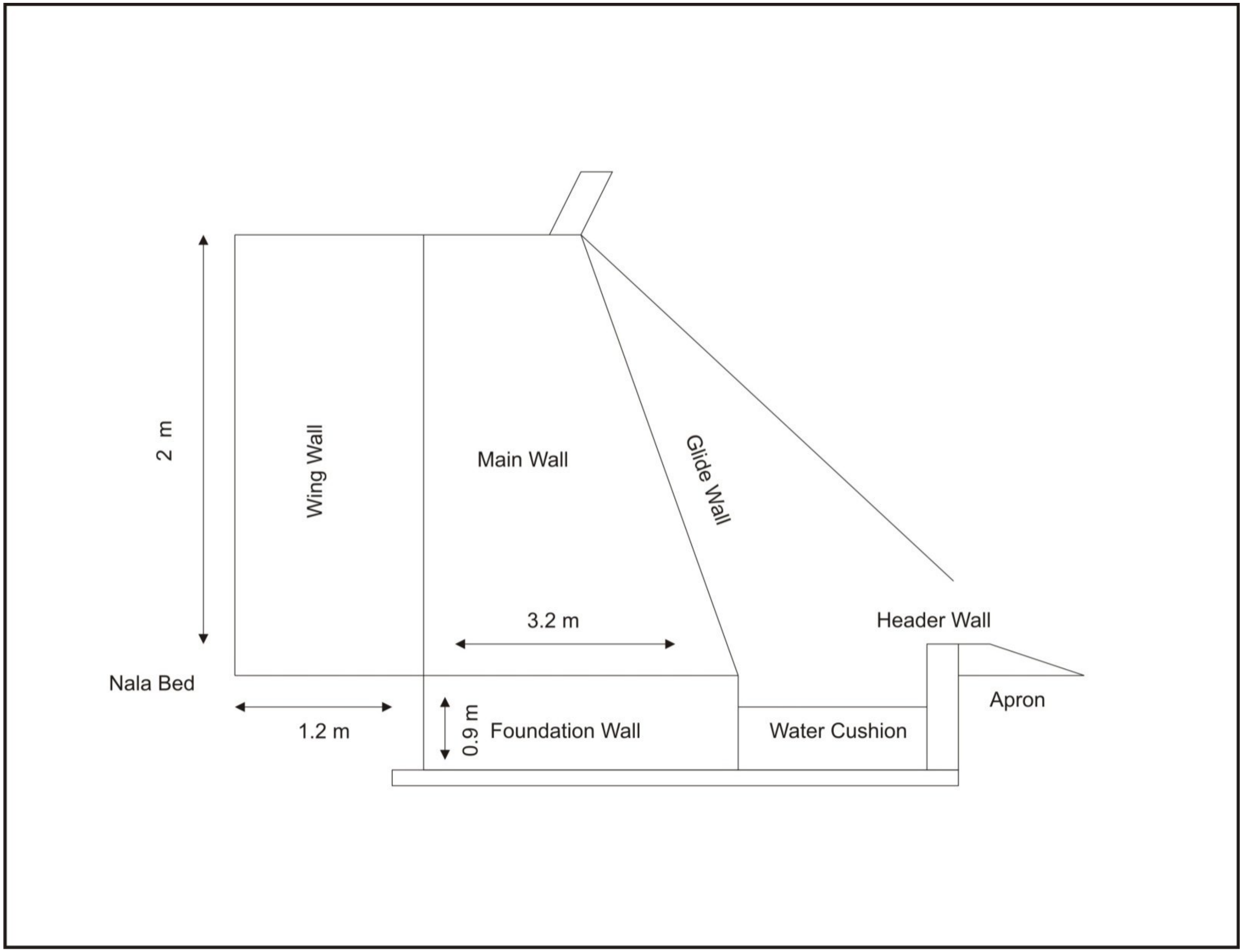

Figure 8.9: Horizontal Section of Check Dam for Micro Watershed ‘C to H & J’

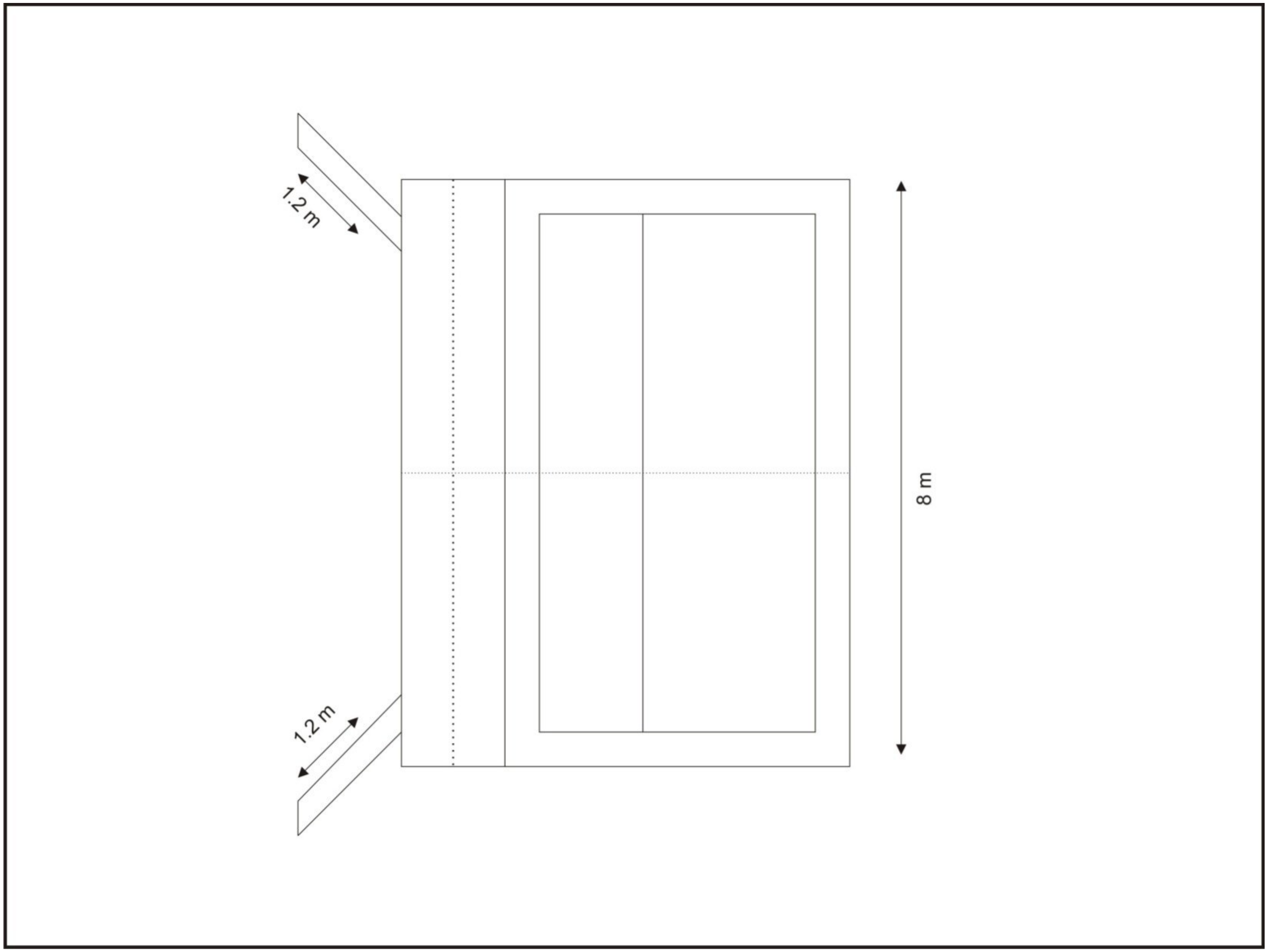

Figure 8.10: Plan view for Check Dam for Micro Watershed 'C to H & J'

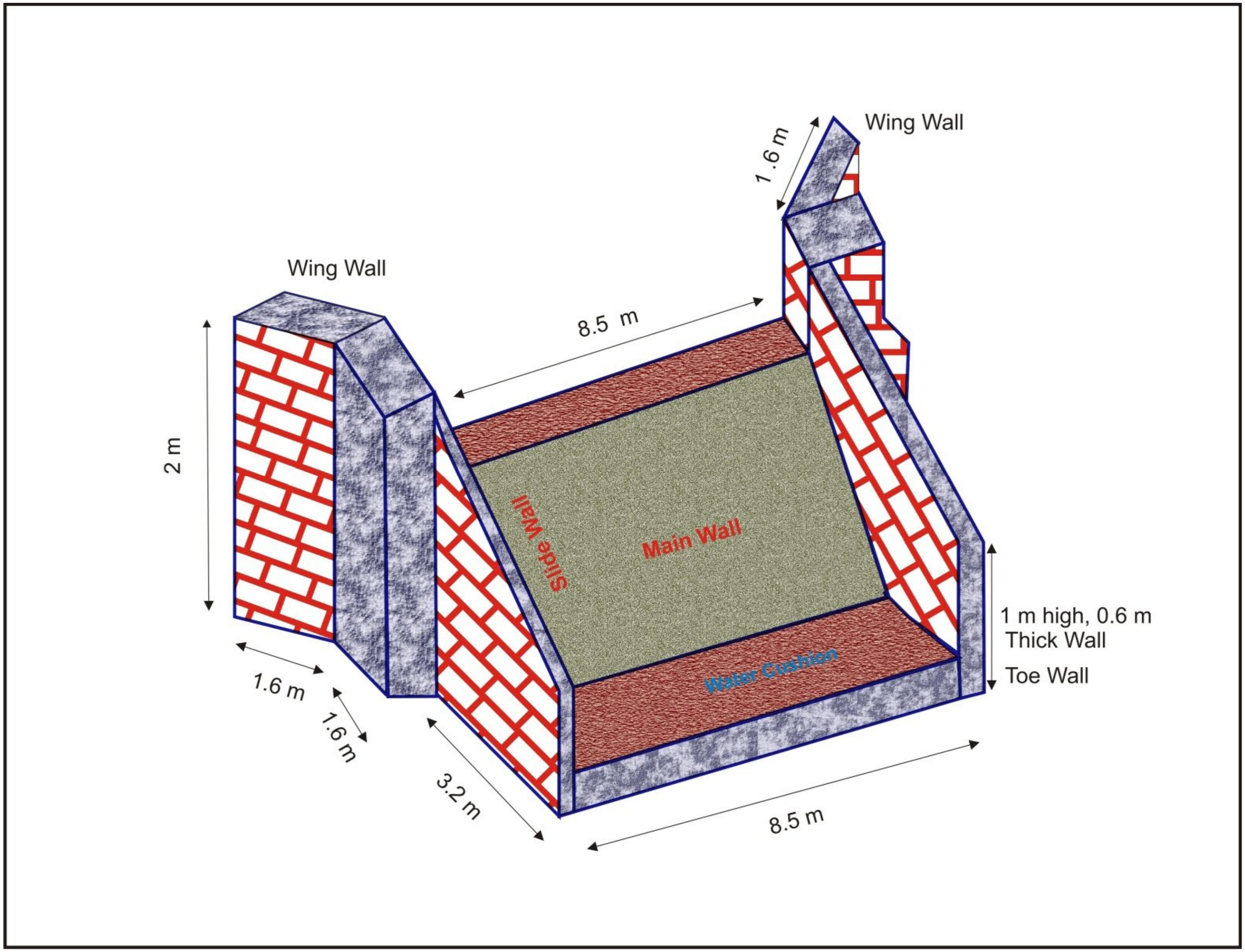

Figure 8.11: Horizontal Section of Check Dam for Micro Watershed 'I'

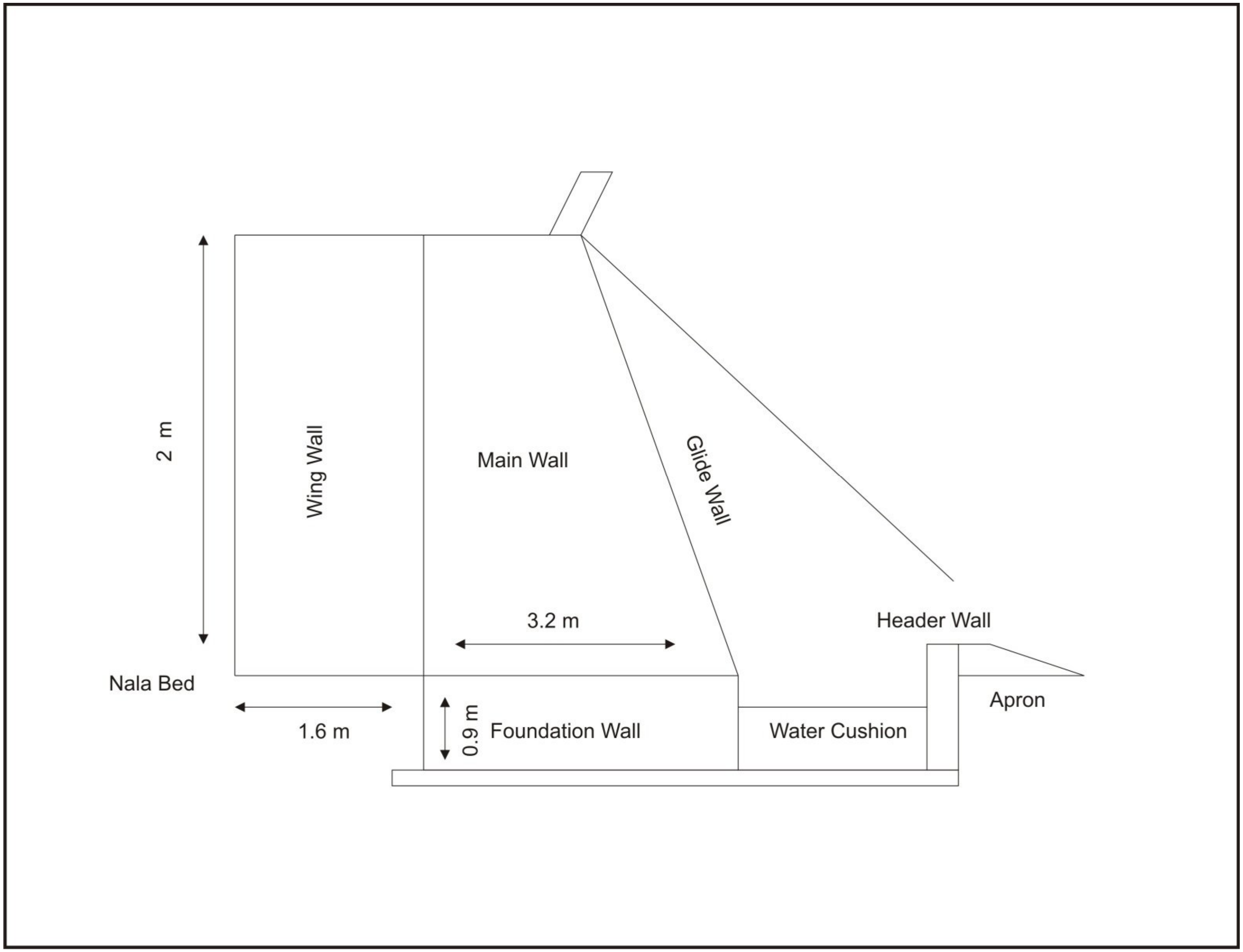

Figure 8.12: Horizontal Section of Check Dam for Micro Watershed ‘I’

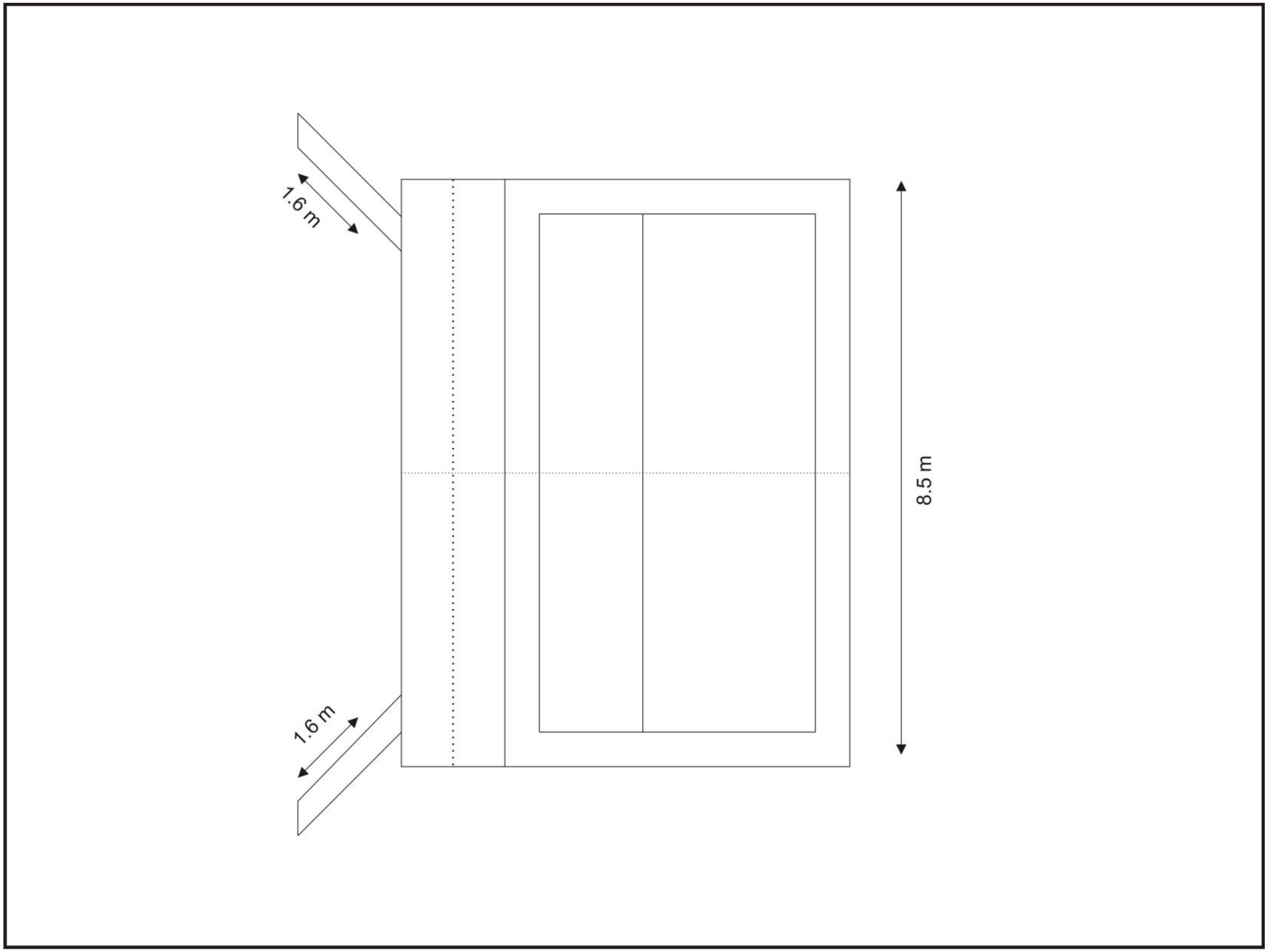

Figure 8.13: Plan view for Check Dam for Micro Watershed ‘I’

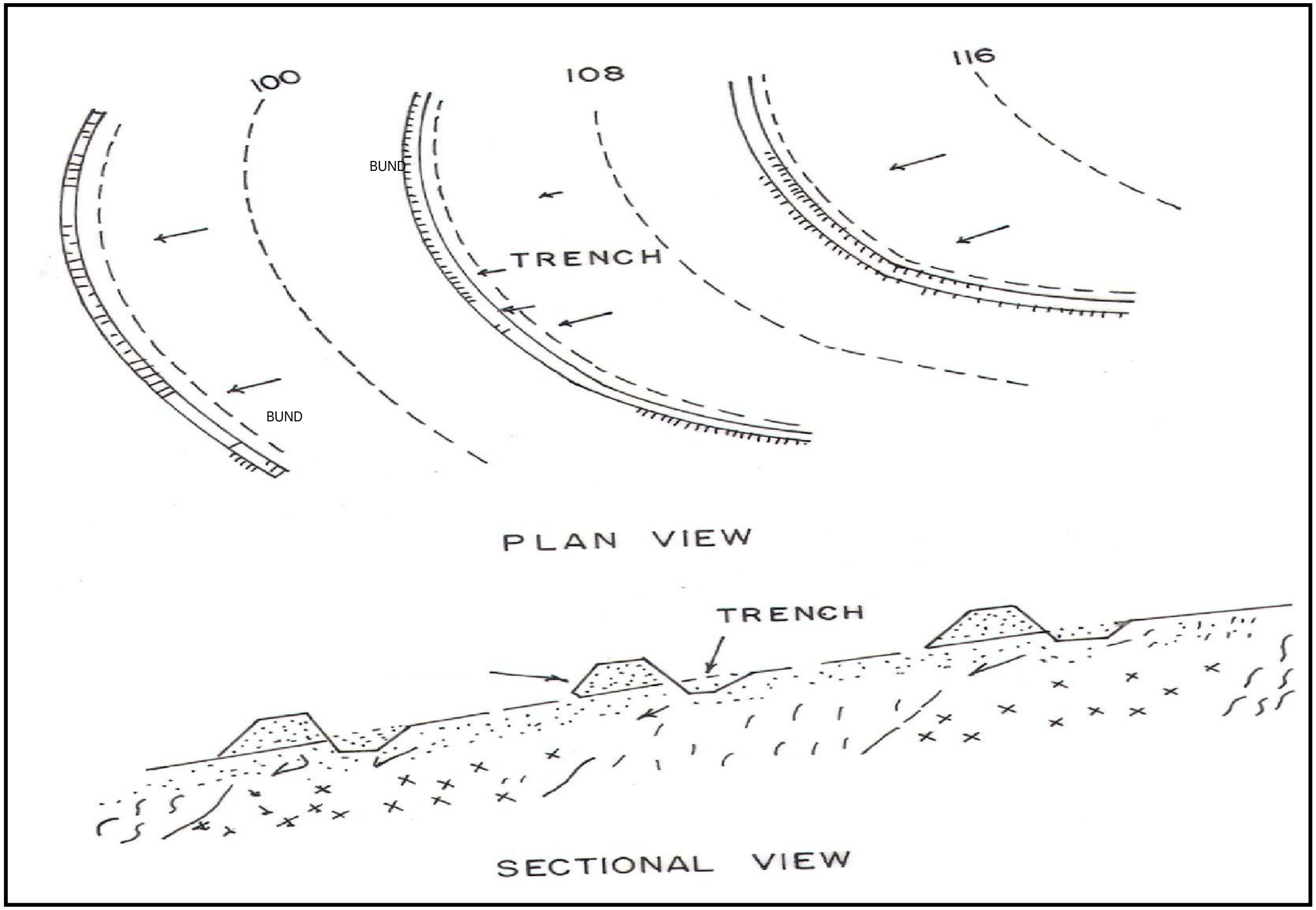

Figure 8.14: Schematics of a Typical Contour Bund

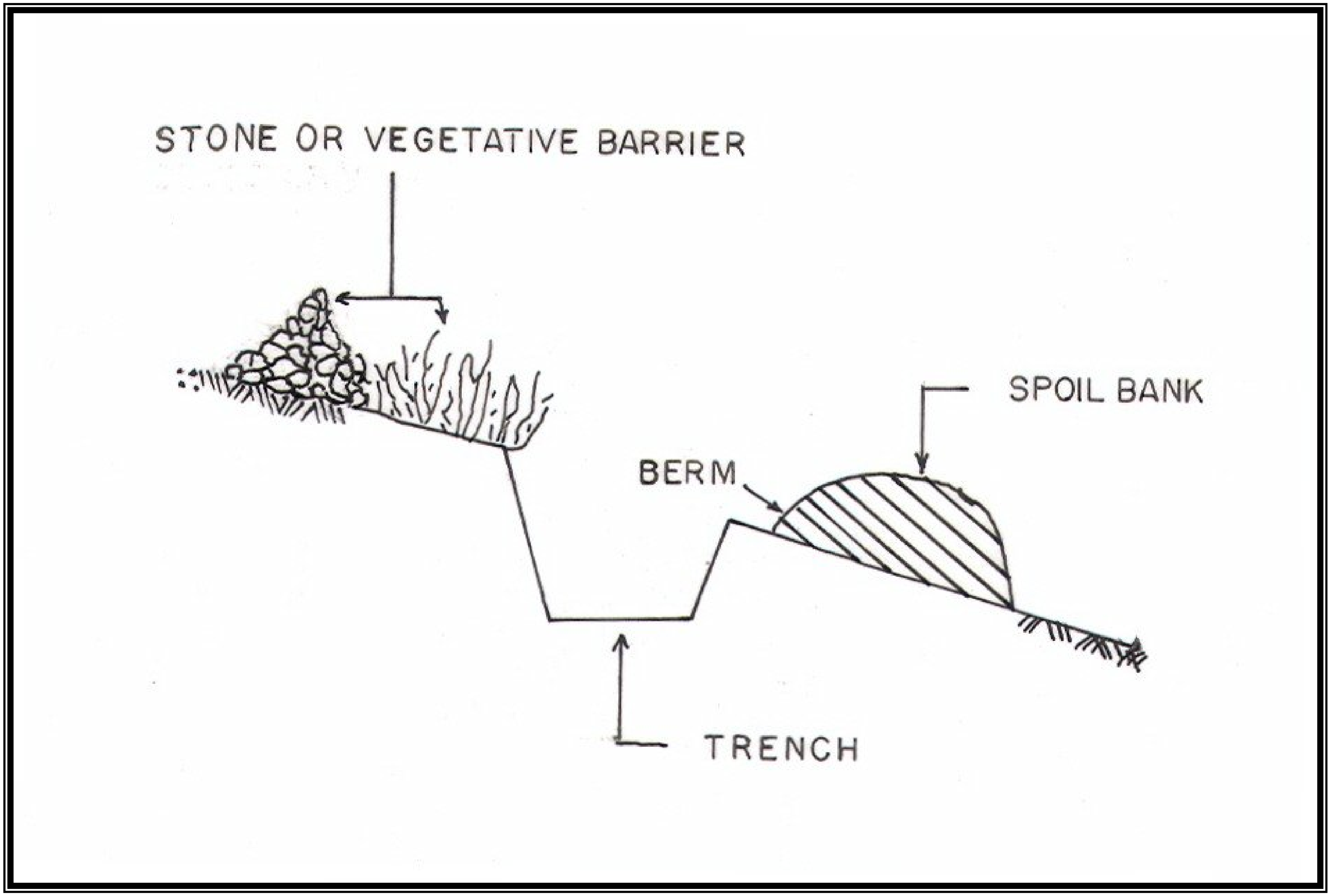

Figure 8.15: Schematics of a Contour Trench

Plate 1: Location of Recharge structure and design