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GROUNDWATER RESOURCE CONSERVATION AND AUGMENTATION IN HARD ROCK TERRAIN: AN INTEGRATED GEOLOGICAL AND GEO-SPATIAL APPROACH

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Abstract

Digapahandi block of Ganjam district is a chronically drought prone and economically backward area of Odisha. The agricultural lands which are mostly rain fed bear the adverse effects of drought resulting in loss of crops. Surface water irrigation is very limited and not dependable due to vagaries of monsoon rainfall. Drinking water problem is very acute during summer as most of the wells go dry. Keeping this fact in view the research was aimed at locating site specific artificial recharge structures for groundwater resource conservation and augmentation in hard rock terrain. Satellite IRS- IC LISS III data have been used to prepare various thematic maps. The study reveals that the major litho units are granitic gneisses, khondalite and charnockite suite of rocks. The geomorphic units are pediplain, flood plain, denudational and structural hills. Four sets of lineaments have been identified. The trends of lineaments are broadly NE-SW, NNE-SSW, NW-SE and N-S. The interpreted data is cross-checked and confirmed during field visits. Based on the hydro-geological set-up, suitable site- specific artificial recharge structures such as percolation tank, check dam, contour bund, gully plug and vegetative measures have been suggested to maintain the balance between the recharge and draft.

Keywords: *Conservation; Artificial recharge; Hydro-geomorphology; Lineament; Drought prone*

Introduction

Groundwater is one of the most important natural resources required for human consumption, domestic purposes, irrigation, industrialization, urbanization etc. The demand for groundwater is increasing every year due to growing population, recurring drought and increased agricultural and industrial activities. To meet this increasing demand, proper understanding of the groundwater condition in terms of availability and distribution very important. Groundwater condition in hard rock terrain is multivariate because of heterogeneous nature of aquifer due to varying composition, degree of weathering and density of fracturing. Remote sensing has become an indispensable tool for groundwater exploration in hard rock areas because the topographic expression and terrain characteristics have a direct relation to the geological characteristics of the rocks and their structural set up.

Located on the east coast of India, Digapahandi block of Ganjam district, Orissa is bounded by 19°11’30” to 19°24’0” N Latitude and 84°19’50” to 84°41’24” E longitude falling in the Survey of India Topo Sheet Nos.74 A/7,74 A/8, 74 A/11 (Fig.1).

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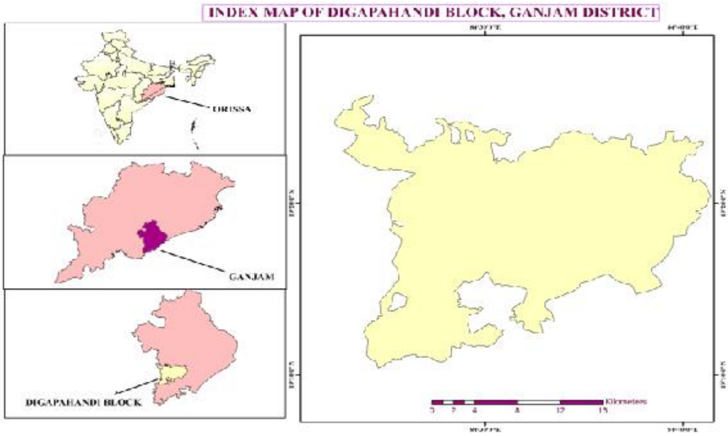

Fig. 1. Location map of the study area

It has a geographical area of 422.18sq.km. As per 2011 census, the total population of the block is 136618. The area enjoys a humid and sub-tropical climate characterized by cold winter and hot summer. The annual average rainfall is 1296mm. The most common soil types in the block are red sandy soils, red loamy soils and alluvial soils. The soils are mainly neutral to mildly acidic in nature. Digapahandi block shows wide variation in the pattern of land utilization. Nearly 75% to 80% of the geographical area is available for cultivation. The drainage pattern is dendritic (Fig. 2).

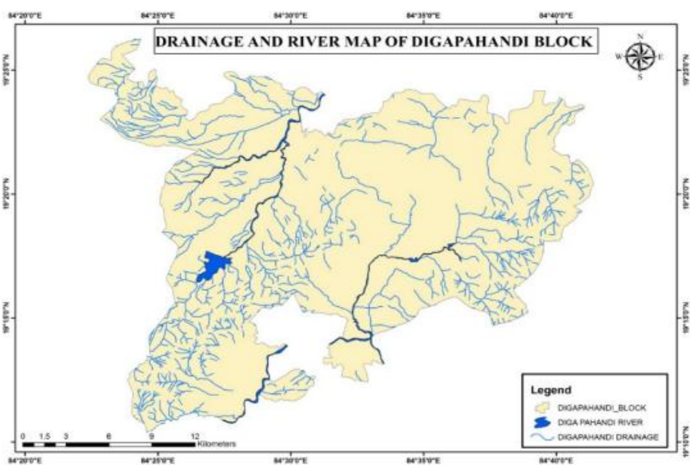

Fig. 2. Drainage map of the study area

Digapahandi block of Ganjam district is a chronically drought prone and economically backward area of Odisha. The area requires development of ground water through suitable structures to combat drought and to increase crop yield by covering more areas under irrigation. In this study an attempt has been made to synthesize all the hydro-geological data generated and related information collected from various sources for groundwater resource augmentation for sustainable growth of agriculture and mitigating drinking water in the study area. The literature available on ground water resource related studies was reviewed in detail. Some authors [1-6] in their studies relating to ground water exploration and targeting potential ground water zone, have emphasized that integrated geological, geophysical, remote sensing and GIS techniques should be adopted for targeting potential ground water zones in hard rock areas. Authors [7-15] have emphasized the need to adopt modern know-how i.e. Remote Sensing and GIS to evaluate the ground water potential in hard rock provinces. Authors[16-18] in their studies on ground water development and management has remarked that artificial recharge structures/rain water harvesting structures play a key role in sustainable development of ground water resources.

Methodology

The present study was carried out by interpretation of the Satellite Imageries of IRS- IC LISS III in the scale of 1:50000. Thematic maps on hydro geomorphology and lithology have been prepared. Reconnaissance survey with special reference to lithology, structure, topography and weathering characteristics was made during field visits. Resistivity Survey has been conducted to understand the sub-surface condition. Systematic collection of hydro geological data for both pre and post monsoon period during well inventory studies and interpretation of data was carried out. Collection of secondary data like population, rainfall, ground water abstraction structures and irrigation potential was made. Data generated have been analyzed, synthesized and interpreted. Suitable sites for specific water harvesting structures/artificial recharge structures have been demarcated in the map of the study area.

Results and discussions

Geological Aspect

The study area is underlain by the Eastern Ghats Group of rocks of Pre-Cambrian age, which includes granitic gneisses, khondalite and charnockite suite of rocks. Alluvium of Recent age occurs as the discontinuous patches in the close vicinity of river channels. Granitic gneiss is the dominant lithology of the study area. The lithology map prepared from satellite data, ancillary data and field checks is shown in the (Fig. 3).

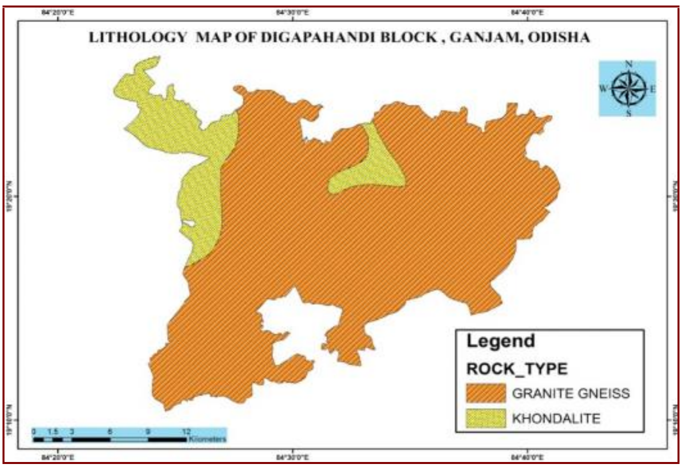

Fig. 3. Lithology map of the study area

The rocks have undergone intense structural and metamorphic deformation as revealed by features like foliation, lineation, shearing, joints, folds etc. Tectonic foliation is well developed in granitic gneiss and khondalite. The khondalitic suite of rocks are highly foliated, jointed and folded. Charnockites are usually compact and massive. Examination of sections of dug wells excavated in granitic gneiss at Bhismagiri, Jakarpali, Padmanavpur, Digapahandi, Ramachandrapur and Bomkei villages and analysis of litholog data revealed that the depth of weathering extends down to a depth of about 5m to 15m below ground level.

Geomorphology

Geomorphology exercises a significant control over groundwater regime. The relief, slope, depth and type of weathered materials and the overall disposition of different land forms play an important role in defining the groundwater regime, more particularly in hard rock areas. Through remote sensing technique, various hydro geomorphic units within the block have been identified (Table 1). The different hydro-geomorphic units are shown in (Fig. 4).

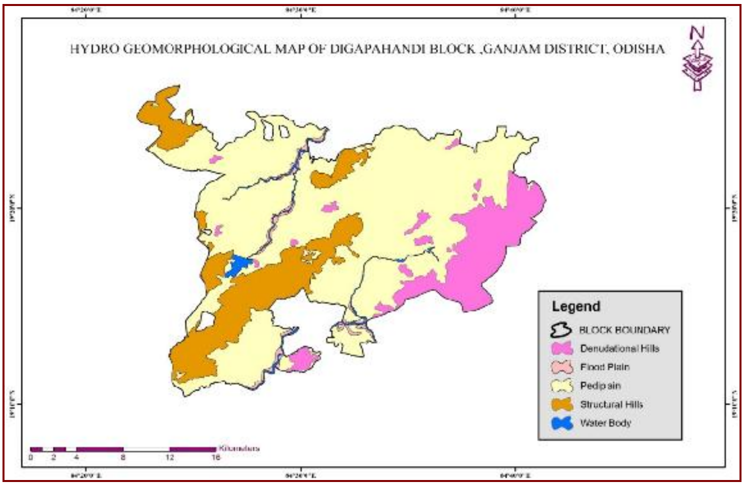

Fig. 4. Hydro-geomorphology map of the study area

Table 1. Hydro-geomorphology of the study area

Geomorphic unit	Lithology / Structure	Description
Deeply weathered buried pediplain	Granitic gneiss with lineaments	Flat surface with more than 10m thick weathered zone
Shallow weathered buried pediplain	Granitic gneiss with or without lineaments	Flat or slightly undulating land surface with less than 10m thick weathered zone
Pediment	Granitic gneiss, Charnockite and Khondalite, with or without lineaments	Gently sloping rocky floor, erosional surface of low relief covered with thin veneer of detritus
Flood plain	Sand, Silt and Clays	A level or gently sloping land surface produced by extensive deposit of alluvium, highly permeable zone
Structural valley	Granitic gneiss, fractured control	Flat valley surrounded by hills around, filled with colluvial deposits.
Denudational hill	Khondalite and Charnockite without lineaments	Relict hills which have undergone the process of extensive denudation
Inselberg	Ganitic gneiss, Khandalite/ Charnockite	Isolated hill with limited areal extension surrounded by plain lands

Lineament

Study of lineaments, which act as conduits of groundwater can help in identifying potential sites for groundwater recharging. The lineament and intersection of lineaments is favourable indicator for groundwater recharging sites. In hard rock terrain, lineaments are the most sought after features for groundwater development. Lineaments mapped from satellite data are natural linear or curvilinear features that can be correlated to faults, fractures, joints, bedding trace, lithological contact etc. The study area is characterized by NE-SW, NNE-SSW, NW-SE and N-S trending lineaments. The trends of dominant lineaments are NE-SW and NNE-

SSW characteristics of granitic gneisses. The lineament density is high in North-Western part of the area and some scattered pockets in eastern and southern part of the area.

Hydrogeology

The contrasting water bearing properties of different geological formations usually play an important role in the occurrence and movement of ground water. The crystalline rocks of Achaean age occupy about 95% of the total geographical area. The narrow discontinuous patches of recent to sub-recent alluvium along the river courses occupy small area in the block. Depending on the water yielding properties of various formations, the block can be broadly grouped into two distinct hydro geological units.

Consolidated formation

These include granite and granite gneisses, khondalite and charnockites of Eastern Ghats Group of rocks. These rocks are devoid of primary porosity and are usually very hard and compact in nature. The secondary porosity in the consolidated formation developed as a result of weathering and fracturing due to major and minor tectonic movements, form the conduits for movement of ground water as also act as reservoir of ground water. This fractured and jointed rocks when interconnected form potential aquifers, which sustain limited to moderate yield. Ground water occurs under water table condition in the weathered residuum while it occurs under semi-confined to confined conditions in the fractures and jointed rocks.

Unconsolidated formations

Alluvium of Recent to Sub-recent age constitutes the unconsolidated formations. The alluvium deposits along the bank of river course form the most potential aquifer due to high degree of porosity and permeability. The alluvium comprises an admixture of gravel, sand and clay derived from eroded and weathered country rocks. The thickness of the alluvium in flood plain vary from 10m to 30m.

Water bearing properties of major lithounits

Most prevalent rock types occurring in the block are granites and granite-gneisses. These are reduced to loose kaolinised granular materials on weathering. The thickness of the weathered mantle ranges from 5m to 15m and some times up to 20m. The weathered, fractured and fissured granites, granite gneisses occurring on topographic low form potential aquifers. The water yielding fracture zones are generally restricted within a depth of 100m bgl. However, some water yielding fractures have been encountered even at a depth of 160m to 180m bgl. In most of the bore holes two or three water bearing fractures zones have been encountered within 100m depth. Bore wells up to a depth of 100m are the typical ground water structures for fractured rocks. The yield of the well depends upon the thickness of the water saturated zones as also numbers of intersecting fractures tapped.

Nature of aquifer

Groundwater in the study area occurs mainly in (i) weathered mantle (ii) fractured zone of hard rocks and (iii) narrow zone of unconsolidated sediments consisting of younger alluvium along river valleys. Groundwater occurs under water table condition mainly in the weathered mantle and narrow zones of unconsolidated sediments along river valley. The weathered zone (saprolite) is of importance as storage zone of groundwater. The yield of individual well is dependent largely on the saprolite and for the deeper rocks well yield is dependent upon intensity of spatial extent of interconnected fractures. Large diameter dug wells of depth up to 15m are the typical groundwater extraction structures for weathered rocks. The open wells may sustain yield of 3 to 18 LPS. The average thickness of weathered zone ranges from 5m to 15m. The more productive wells are generally limited to highly weathered, jointed and fractured rocks. In less productive wells, saprolite is generally underlain by massive rocks or bedrocks with meager fractures. Groundwater occurs under semi-confined to confined condition in the fractured rocks depending on the depth. The water yielding fracture zones are generally restricted within a depth of 100m bgl. However, some water yielding fractures have been encountered even at a depth of 160-180m bgl. In most of the boreholes two or three water bearing fractures zones have been encountered within 100m depth. Bore wells up to a depth of 100m are the typical groundwater structures for fractured rocks. The discharge varies from 2 to 27 LPS.

Status of water table

The depth to water table during pre and post monsoon period varies form 2.75m to 9.6m bgl and 0.33 to 2.45m bgl respectively. Seasonal fluctuation in the wells located in upland areas in higher than that in the low laying areas. The value of seasonal fluctuation of water table varies from 2.1m to 7.5m. Most of the areas show fluctuation between 3 to 6m. The water table contours are generally in conformity with the topography. The water table gradient varies from 1.9m/km to 2.85m/km. The groundwater flow direction do not show any definite trend but is highly influenced by topographic and geologic setting. In general, the groundwater flow direction is towards SE.

Groundwater Potential Zones

Integrating all the above mentioned information such as geology, geomorphology, drainage, lineament, and aquifer system, Digapahandi block has been classified into different groundwater potential zones viz. "**High**", "**Moderate**" and "**Low**" (Table 2).

A perusal of the map showing groundwater potential zones indicates that the potentiality of aquifer system for groundwater development is moderate to good in 60% of the study area (Fig. 5).

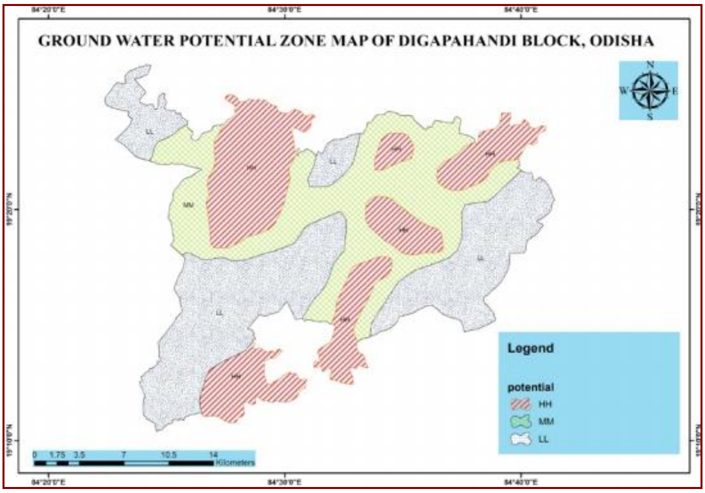

Fig. 5. Groundwater potential zone map of the study area

High potential areas are scattered throughout the area in pockets. In areas of high and moderate potential, groundwater can be exploited with suitable abstraction structures like dug wells, dug-cum-bore wells and bore wells. Where the groundwater potential is low, water table is more than 7-8m bgl and dug wells go dry during summer, the existing dug wells can either be deepened or bore well can be drilled to meet the water requirement. Further, rainwater harvesting and artificial recharge techniques should be implemented effectively to augment the groundwater resources. The groundwater potential zones map can form the base map for the concerned authorities to take necessary action in planning of land use and to identity sites for groundwater exploitation in future.

Table 2. Groundwater Potential Zones of the study area

Groundwater Potential Zone	Characteristic features of the zone	Areal distribution (Approx.)	Important Locations
HIGH	Deeply weathered buried pediplain, flood plain, high lineament density, Intersection points of lineaments, flat to gentle slope, depth to water table 1m to 5m bgl	30%	Ganeswarpur, Denkari, Gokarnapur, Digapahandi, Khamarigam, Pentha, Santarapur, Bhismagiri, Jakamari, Sahadeb, Gajapatipatna, Padmanavpur, Bajragumma, Jakarapali,Sanakelajhori, Jakar, Dekali and Bomkei
MODERATE	Shallow weathered buried pediplain, moderate lineament density, moderate slope, depth to water table 5m to 8m bgl, extension of lineament to pediment.	32%	Talapada, Talasingi, Bhusanda, Ankorada, Kusapada, Jharipadar, Turubudi, Komarada, Karapada, Dharmapada, Nandagaon,Sidheswar, Kotinada and Shyamasundarpur
LOW	Pediment without lineaments, depth to water table greater than 8m bgl, high to moderate slope	38%	Gumma, Engarsing Padmapur, Rajghada, Badapur Bidyadharpur, Tada, Dhepaguda, Kusaput, Kinchirida, Allalingi, Dhamanapadar, Mahulpaa, Rangaputa, Arakhapada, Keshapur, Kuruma, Damapur and Mahulapada

Groundwater Resource Conservation and Augmentation

Keeping in view the above facts, groundwater conservation and augmentation is considered to be the only solution to maintain a balance between the annual recharge and discharge. Artificial recharge techniques play a major role for conservation of groundwater [19-26]. The main source of groundwater recharge is rainfall, which is mostly lost as surface runoff and hence the only alternative to replenish the groundwater is by artificial means.

Groundwater Recharge Zones

Digapahandi block can be grouped into 4 natural groundwater recharge zone based on the porosity, permeability and runoff characteristics of the land. The landforms, lithology, presence of lineaments, slope factor, land use/land cover and surface water bodies available play an important role to select these natural recharge sites (Fig. 6).

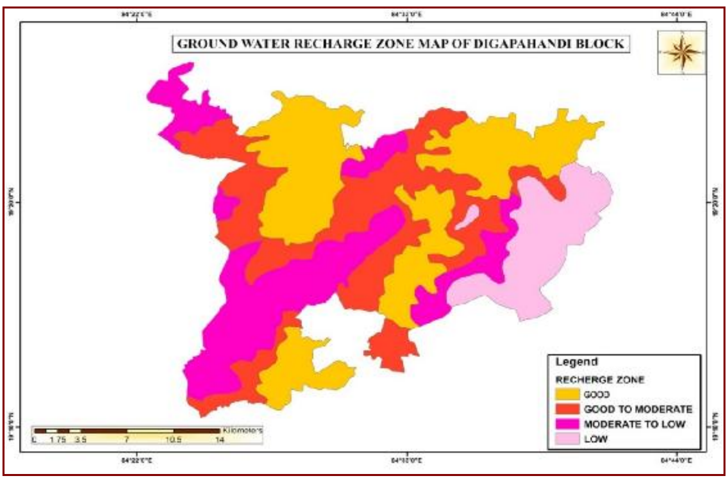

Fig. 6. Ground water recharge zone map of the study area

Zone 1. The fracture controlled small valleys filled with unconsolidated sediments, buried pediments with thick weathered zones and areas with good vegetative covers in the foothill regions are the zones of good recharge. These areas are very gently sloping and are mostly cultivated land, which help in the retention of surface water.

Zone 2. This zone occupies the shallow weathered pediplains adjacent to the zone 1, with good concentration of lineaments. The recharge rate is good to moderate.

Zone 3. This zone represents the higher slope area of buried pediments with scanty vegetation and structural hills traversed by fractures and fissures. The groundwater recharge rate is moderate to low.

Zone 4. The denudational and residual hills of the study area which have only open and degraded forest cover with steep slope are runoff zones and categorized as zone 4, where the minor fractures are the only linear area through which percolation may take place.

Artificial Recharge

Considering the hydro geological set-up, natural recharge conditions, groundwater potential, future optimal use of groundwater, soil and slope of the area, prevailing land use and cropping pattern in the study area, suitable sites for specific water harvesting structures/ artificial recharge structures such as percolation tank, check dam, gully plugs have been demarcated. Besides these, sites for agriculture- related measures which will aid artificial recharge have also been shown in the map. The construction of artificial recharge structures will not only augment groundwater resources, but also will help in solving geo-environmental problems like land degradation by soil erosion and loss of soil moisture (Fig. 7).

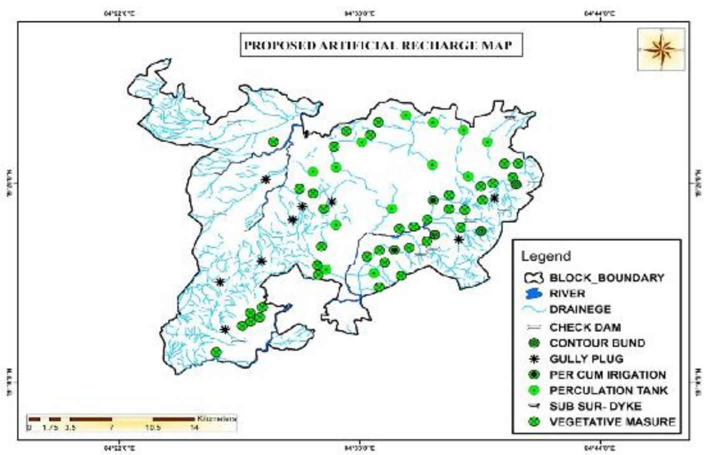

Fig. 7. Proposed artificial recharge structure map of the study area

Percolation Tank

Percolation tanks are shallow tanks constructed at appropriate places in natural or diverted stream courses and provided with a waste weir to allow excess water to continue its course. The ideal site for construction of percolation tanks are gently slope, terrain of light soils, weathered materials of moderate thickness and fractures zones. However, these tanks need scraping of bottoms once in a year or two depending on the rate of accumulation of fine sediments at the bottom of the tank. Percolation tank is the most suitable structure for recharging groundwater in the hard rock areas, because in addition to artificial recharge it contributes directly to irrigation from the stored water. Percolation tanks in the study area may be selected at comparatively higher elevations with creation of embankments only on sideways and on down slope sides. The upslope sides should remain open for easy entry of surface runoff water. Within the study area such structures may be constructed around Kotinada, Ganeswarpur, Sidheswar, Basudevpur, Gokarnapur, Jagannathpur, Bhusanda and Dekhali.

Percolation - Cum- Irrigation Tank

The main purpose of this tank is for collection of surface runoff to facilitate percolation and to hold flow of silt. In addition, the stored water is used for cultivation in the nearby areas through field canals. This type of tank is usually created on the upstream side of first order stream having a good catchments area for sufficient entry of runoff water. Accordingly suitable sites can be selected around the villages Ramachandrapur, Digapahandi, Samantarapur, Jharipadar, Jakar and Bajraguma.

Check dam

The purpose of check dam is to reduce runoff velocity, to minimise erosion and to allow percolation of surface water. Sites for check dams have been selected on lower order stream (up to 3rd order) with catchments area of about 40ha, where the level of groundwater fluctuation is high and slope is moderate. Such structures can be of help around villages Dhepaguda, Kinchirida, Guma, Kesapur, Sahabeda, Santarapur and Dharmapadar.

Subsurface Bund/ Artificial Dyke

Artificial subsurface dykes are feasible in hard rock areas in narrow gently sloping valleys where bedrock occurs at shallow depth and valley fills consists of about 4 to 8m of pervious materials. Groundwater reservoirs can be created by constructing subsurface dykes across the flow direction of groundwater. Subsurface dykes of 1 to 4m height are found to be effective in augmenting the groundwater resources particularly in hard rock areas underlain by fractured aquifers. By keeping the top of the dyke 1m below the land surface, the riparian rights of the farmers downstream are not violated and water logging or salt accumulation on the upstream side of the dam is prevented. The dyke can be constructed with materials like clays, bitumen, polythene sheets besides bricks and concrete depending on local conditions.

Contour Bunding

Contour bunding is the construction of small bunds across the slope of the land on a contour. Each contour bund acts as a barrier to the flow of water and check the runoff water, thus contributing a part to recharge of groundwater through water spreading. In the study area suitable sites are in upland and hilly regions of Digapahandi block. The upslope of the cultivated lands may be selected for contour bunding to save the cultivated areas from soil erosion and to facilitate groundwater recharge.

Gully Plugging

In the hard rock areas particularly in plateau regions, formation of numerous gullies is a common phenomenon and the study area is not an exception to that. The main cause of formation of such gullies is large-scale deforestation followed by heavy soil erosion due to surface runoff creating waste land on both sides of the stream courses. In such a rocky area, where scope for cultivation is limited, the land suitable for agriculture is being converted to waste land rapidly. In the study area there is an urgent need for plugging the gullies with the use of locally available materials. By adopting such measures, the top soil can be protected as well as the rate of infiltration of water can be increased.

Hydro-fracturing

The unconventional technique of hydro-fracturing may be undertaken for improving the yields of bore wells in hard rock areas. This technique has the following advantages.

1. Widening of existing fractures
2. Removal of clogging in the fracture connectivity.
3. Creation of interconnection of fractures
4. Extending the length of the old fractures
5. Creation of new fractures in the aquifers.

Conclusions

Since the block is drought prone, there is an urgent need of ground water exploitation to save the crops and provide safe drinking water. The ground water abstraction through open wells restricted up to the weathered mantle can not meet the requirements of the inhabitants throughout the year. Most of the wells go dry during summer. The only alternative is to get water from fracture zones through suitable ground water structures, which may be helpful for the development of the agrarian based poor socio-economic conditions of the people in the study area, because till now mostly dug/ open wells are being utilized for domestic and agricultural purpose. The present study emphasizes on the need and scope for artificial recharge to augment groundwater, scientific well siting on the basis of the result of the present hydro geological studies aided by remote sensing and GIS techniques. Optimal and judicious utilization of ground water through properly designed abstraction structures constructed at suitable locale with accompanying protection, augmentation and conservation measures can being about laurels to the agrarian economy of the area and can mitigate the problems of drinking water scarcity faced during summer.

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