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Sustainable water resource planning in a sub-humid tropical watershed using geo-spatial and remote sensing techniques

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ABSTRACT

Improper usage of water resource leads to water stress conditions in sub-humid areas of India. For sustainable development, a coordinated and planned utilization of available water resource in these areas should be executed on the micro-watershed level. Thus an attempt has been made in this study for planning of available water resource in a sub-humid watershed for judicious use of available water resource and sustainable agricultural growth. The study area was Ghumuda micro-watershed in Sundergarh block of Sundergarh district (Odisha). Using an integrated remote sensing (RS) and geo-informatics technology, several thematic maps like slope, land use / land cover (LU/LC), drainage, lineaments and hydro-geomorphology were developed. Using Arc-GIS software, integration and super imposition of these thematic maps were done to get the groundwater potential zone map. Four groundwater prospect zones were identified in the study area *i.e.* poor, moderate, good to moderate and very good. Based on lineament interaction points, seven tubewell construction sites were recommended for further groundwater development and year-round crop production. Overlaying all the thematic maps in the GIS environment, suitable locations for conservation structures like three nala bunds, nine percolation tanks, one check dam and two water harvesting structures were selected.

1. INTRODUCTION

Substantial impact of human activities is now altering the quality and declining the availability of freshwater resource in the world (Muhammad *et al.,* 2015). This water crisis is now the most dangerous risk for the human population (World Economic Forum, 2015). Most of the activities in agriculture, urban development and energy sectors generate waste, which not only significantly affects quality and quantity of water resource, but also influences the functioning and diversity of biological systems to a great extent (FAO, 2017; UNEP, 2016). Variability in distributions of freshwater resource leads to unevenness in access to water, with scarcities in some areas and excesses in others. Thus watershed action plan is an effective solution to manage water resource in a sustainable manner (Nigam *et al.,* 2017). Water resource action plan, if applied on a regional basis, will help to maintain the natural resource by developing green foliage and increasing flora and fauna in that area. So basically it is a sustainable method to create a balance between the components of the ecosystem on one hand and activities of human on the other (Bansode *et al*., 2018). Primarily, the physiography of the land, slope, nature of soil cover, hydro-geomorphology, climate, socio-economic aspects and the hydrological characteristics of watershed determine the productive interaction between natural resources like soil, vegetation and water. Watershed level planning and management have gained worldwide acceptance in recent years since it can be regionally applied and promptly managed. Watershed is recognized as the absolute unit for analysis, management, development and implementation of different measures for conserving natural resources (Akhouri, 1996; Ramchandran *et al*., 2001).

The rapid advancement of the remote sensing (RS) and geographical information system (GIS) has helped researchers to develop a natural resource management plan at micro-watershed level (Ansari *et al.*, 2012; Patel and Khalko, 2019; Kumar *et al.*, 2019). These methods act as an efficient and successful tool for analysing, predicting the actual condition, and also help to develop an integrated action plan based on that situation of the watershed for sustainable improvement of land and water resource (Das and Sarkar, 2014; Dutta *et al*., 2015; Singh *et al*., 2016). Using conventional methods to investigate the condition of both surface and groundwater resource in a watershed is very time-consuming and cumbersome. Also, the available data lack appropriate information, which leads to improper planning and management (Lakkad *et al.,* 2015). Data like geology, geomorphology, terrain condition, land use, and drainage at micro-watershed level are prerequisite in preparing water resource development plan for sustainable development (Mishra and Panda, 2015). In an ungauged watershed, this geo-informatics technology is the only way to assess the surface water and plan for its management (Shirahatti *et al.,* 2017).

Most of the watershed planning is done in GIS software overlaying the thematic maps like soil, slope, land use/land cover (LU/LC) and hydro-geomorphology. But watershed planning needs to be executed based on groundwater potential zones present within the boundary of the watershed as potential zones are the best sites to recharge groundwater. To ensure conservation and management of groundwater, locating potential zones is essential (Hutti and Nijagunappa, 2011). Various studies on groundwater prospecting showed that it is an efficient way to delineate zones for management of groundwater and ensure sustainability at the same time (Chowdhury *et al*., 2009; Mukherjee *et al.,* 2012; Nagarajan and Singh, 2009; Paramaguru *et al.,* 2019; Saha, 2017).

The main objectives of this present study are to first delineate favourable zones for groundwater recharge and then based on the thematic maps and potential zones, preparation of watershed action plan for sustainable improvement of both groundwater and surface water resource in micro-watershed.

2. MATERIALS AND METHODS

Study Area

Ghumuda micro-watershed lies between 22°4'0"N to 22°5'42"N latitudes and 84°13'06"E to 84°14'46"E longitudes with a total geographical area (TGA) of 851.95 ha. It is situated in Sundergarh block of Sundergarh district of Odisha, India. The micro-watershed is placed in the survey of India topo-sheet number 73B4 in 1:50000 scale. The location map of the study area is given in Fig. 1.

The watershed comprises of upland, medium lands and low lands. Isolated patches of hills and hill slopes are also present in the study area. Several streams, hillocks and undulating tracts are present in the watershed, which influence drainage pattern and its characteristics. The watershed has humid subtropical climate due to its presence in north-western plateau agro-climatic zone of India. The

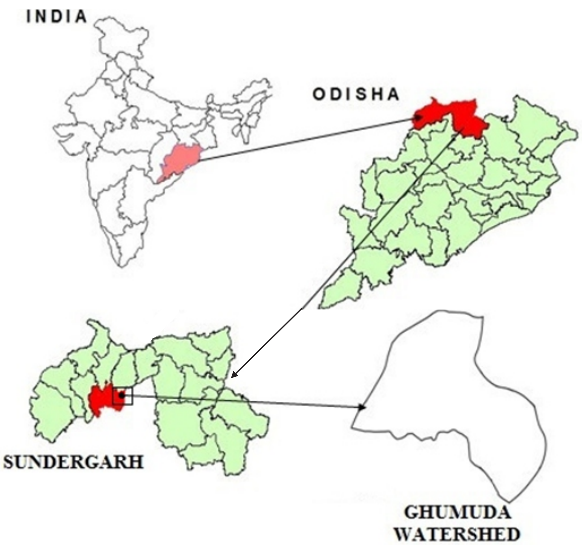

Fig. 1. Location map of Ghumuda micro-watershed

minimum and maximum temperature in the study area are 4°C and 46°C in the month of December and May, respectively. It is a rainfed area having an average annual rainfall of 1261.63 mm yr^{-1}. Most of the study area is having a moderate slope with occasional occurrences of foothills and hillslope. High undulating tracts in the study area is due to the presence of bisected uplands and ridges. Mostly soil types like red, sandy lateritic and alluvial are prominent in the study area. Soil is basically of moderate depth having slightly acidic pH. Out of the TGA, 49.62 ha is forest area. The forest area is categorized into two parts; one part is hilly while other lies on the bank of the river, which is devoid of any sort of vegetation.

Database Used in Preparation of Thematic Maps

Primary data

Survey of India (SoI) topographical sheet numbering 73 B4 on a scale of 1:50000 with a contour interval of 20 m was used to delineate the watershed boundary and to prepare the base map. Ground truthing, including field visit, was carried out to check and minimize the error which may be occurring during visual interpretation technique.

Satellite data

IRS sensor data in LISS-III-FCC were used for generation of thematic maps like LU/LC, hydro-geomorphology, land slope, drainage and lineament of the micro-watershed. The satellite data in 1:50000 scales from Bhuvan portal (ISRO geoportal) were downloaded for use in this study. Digital Elevation Model (DEM) primarily assists in the modelling, analysis, study and interpretation of topographic information in GIS. DEM was downloaded from USGS Earth Explorer: ASTER Global DEM, resolution 30 m×30 m.

Softwares

Arc-GIS 10.1 software was used for development of the thematic maps while ERDAS Imagine-2014 was used for development of LU/LC map. Arc-GIS 10.1 was also used for superimposition of thematic maps to develop groundwater potential zone map and watershed action plan map.

Generation of Thematic Maps

Delineation of boundaries up to a watershed level was done by overlaying the contour and drainage information of SoI topo-sheets and geo-coded satellite image in 1:50000 scale. Slope map was prepared using Arc-GIS 10.1 using the downloaded DEM. First, the DEM was used as an input file to get the slope map as output. Using a special analyst tool option of Arc-GIS 10.1, slope map was created by clicking on the surface option and slope option. To generate the scenario of LU/LC, the geo-coded standard FCC product IRS (LISS-III) of February month on scale 1:50000, when the maximum field was harvested, was used. LU/LC map was mainly prepared by supervised classification method in ERDAS Imagine-2014. In the process of preparation of hydro-geomorphology map of Ghumuda micro-watershed, the base map was superimposed on downloaded FCC satellite imagery and different geo-morphological units were demarcated by visual interpretation technique. Lineament map was developed from the ASTER Global DEM data from USGS Earth Explorer. Special enhancement methods were utilised to demarcate the lineaments from satellite imagery. Then the image was correlated with ground truth data after preliminary interpretation. Final lineament map of the study area was prepared by making necessary modifications and corrections.

Preparation of Groundwater Potential Zone Map

By integrating various thematic maps prepared in digitized form in Arc-GIS software, groundwater prospect map for Ghumuda micro-watershed was prepared. Demarcation of various groundwater prospect zones was done by superimposing different themes like drainage, slope, LU/LC, lineament and hydro-geomorphology (Hutti and Nijagunappa, 2011). Each thematic map was superimposed on another to get intersecting zones to get the final composite map. Weight to each polygon was assigned using the weighted index overlay method to depict the groundwater potential zones, which were classified into very good, good, moderate, poor groundwater potential zones (Ramamoorthy and Rammohan, 2015).

Preparation of Water Resource Action Plan Map

Terrain parameters like slope, drainage pattern, land cover and hydrological conditions, fracture, depth to water level etc. were reviewed and merged for the preparation of water resources development plan. The surface water resources within the micro-watershed, such as drainage lines, ponds, water harvesting structures, percolation tanks etc. were identified (Raut *et al.*, 2017). The locations favourable for groundwater recharge and further development were also proposed. The water resource action plan was developed by integrating hydro-geomorphological map, drainage map and slope map using Arc-GIS software. Suitable sites for soil conservation structures were determined by the superimposed map, but which structure is to place in which area were determined by the guidelines recommended by Integrated Mission for Sustainable Development, Indian National Committee on Hydrology (Paul *et al.*, 2008) (Table 1). The detail procedure used for preparation of watershed action plan is given in Fig. 2.

Table: 1
Common logic of providing different soil and water conservation structures for water resource development

S.No.	Water action plan units	Logic to allocate the site
1.	Nalabund	In lower order stream line (1st, 2nd Order) and nearly level to gently sloping land (0-3% slope)
2.	Percolation tank	Along or at the intersection of fracture / lineaments with nearly level to gently sloping land (0-3% slope)
3.	Check dam	Lower order streams (1st orders) and gently to moderately sloping land (3-10%)
4.	Water harvesting structure	Comparatively higher order (up to 3rd order), command area upto 50 ha and nearly level to gently sloping land (0-5%)
5.	Tubewell	At the intersection of lineament fractures

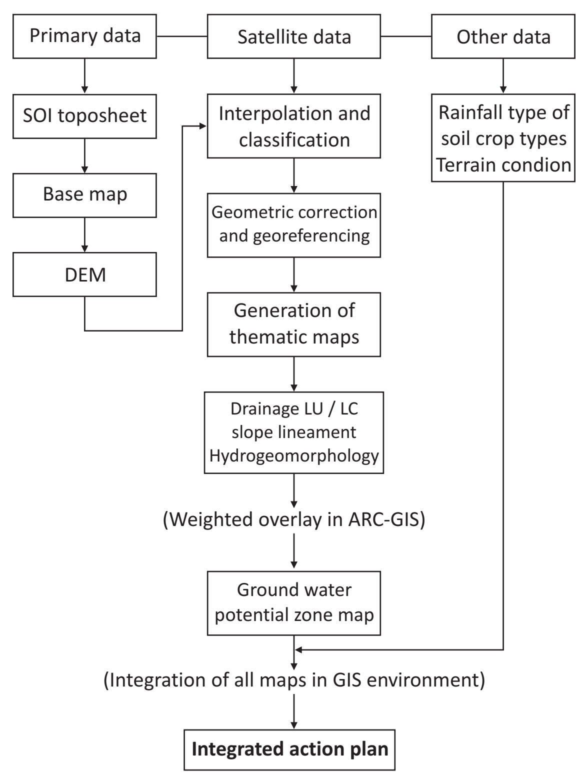

Fig. 2. Flow chart of methodological approach used in water resource plan preparation

3. RESULTS AND DISCUSSION

Thematic Layers of Ghumuda Micro-watershed

The description and spatial distribution of drainage, slope, LU/LC, lineament, hydro-geomorphology in the study area are presented below:

Drainage map

Drainage line is one of the effective ways to analyse the structural landform and runoff characteristics in an area. All the agricultural activities depend on those natural streams in the rainfed areas. The study area is comprised of many seasonal and perennial small streams. Drainage map showed that first, second and third-order streams are present in the study area (Fig. 3).

Slope map

The slope map (Fig. 4) was generated using DEM. The slope in the study area was classified into five slope classes (Anonymous, 1994) of <3, 3-5, 5-10, 10-20, 20-34%. 31.44% of the total study area has a slope of less than 3%. 29.16% of the study area falls under 3-5% slope (very gentle slope), 35.12% are under 5-10% slope (gentle slope) and around 3.08% area was observed under 10-20% slope (moderate slope) and 1.2% of total area falls under 20-34% slope (steep slope) slope classes. Slope plays a significant role in infiltration and groundwater recharge. Infiltration is inversely related to slope. Different slope units and their percentage area are presented in Table 2.

LU/LC map

LU/LC is the key factor which influences the hydrological processes and controls the movement of water to surface and groundwater resource (Anonymous, 1994). RS is an effective tool to get information on spatial distribution of land cover in an area which is the most variable thing and difficult to examine in conventional methods. The spatial data information of the LU/LC map with its different units

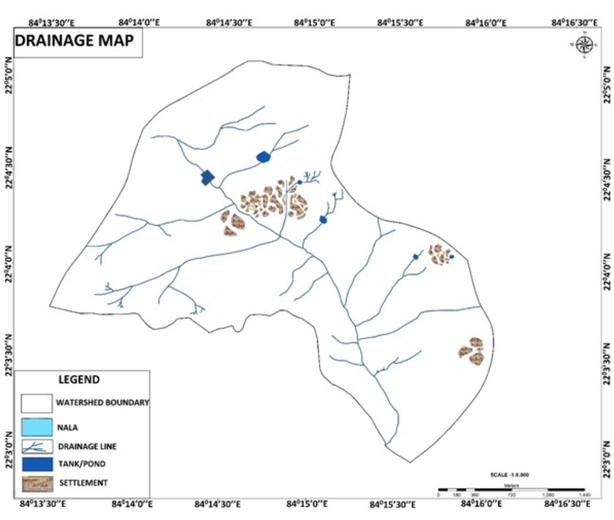

Fig. 3. Drainage map

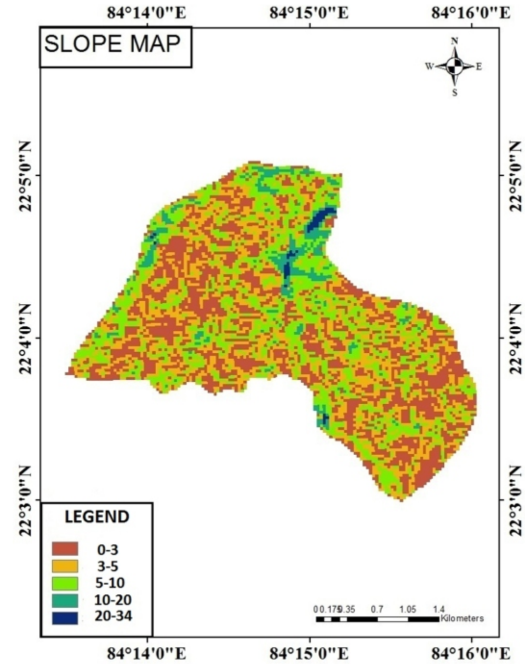

Fig. 4. Slope map

Table: 2
Slope attributes of Ghumuda micro-watershed

Map unit	Slope unit (%)	Area (ha)	% of total area
1	0-3	267.85	31.44
2	3-5	248.428	29.16
3	5-10	299.204	35.12
4	10-20	26.24	3.08
5	20-34	10.228	1.2

was classified by ERDAS imagine software (Table 3). The information on the LU/LC status of the micro-watershed is shown in Fig. 5.

Hydro-geomophology map

Fig. 6 depicts various features of structural landform which is an essential input for management strategies. These geological data like lithology, type of landforms and its characteristics are a vital source to delineate groundwater potential zones (Anonymous, 1995). The hydro-geomorphological units were recognized and demarcated through visual interpretation and GIS techniques on a scale of 1:50000. Various hydro-geomorphological units signifying their percentage area are presented in Table 4.

Lineament map

Lineaments are large-scale topographical cracks present in linear form under the structural features. These features can be located by interpreting valleys controlled by faulting and jointing, abrupt truncation of hillocks, straight and angular stream courses. The lineaments intersection points are considered as excellent groundwater prospect sites. In total, 10 lineaments were identified in the study area, and most of them are present in the eastern part of the watershed. The information on lineaments of the micro-watershed is shown in Fig. 7.

Table: 3
LU / LC classification of Ghumuda micro-watershed

Map unit	LU / LC Class	Area (ha)	% of the total area
1	Agriculture	776.98	91.2
2	Barren land	40.55	4.76
3	Establishment	14.95	1.755
4	Forest	13.26	1.557
5	Water bodies	6.21	0.728
	Total	851.95 ha	

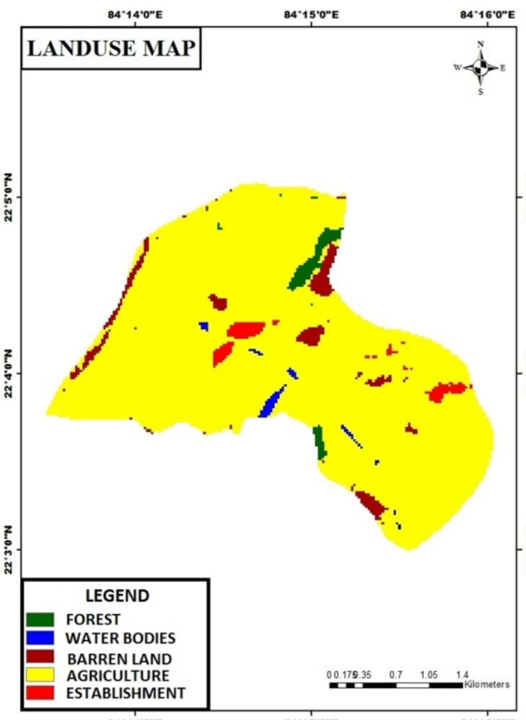

Fig. 5. Land use/land cover map

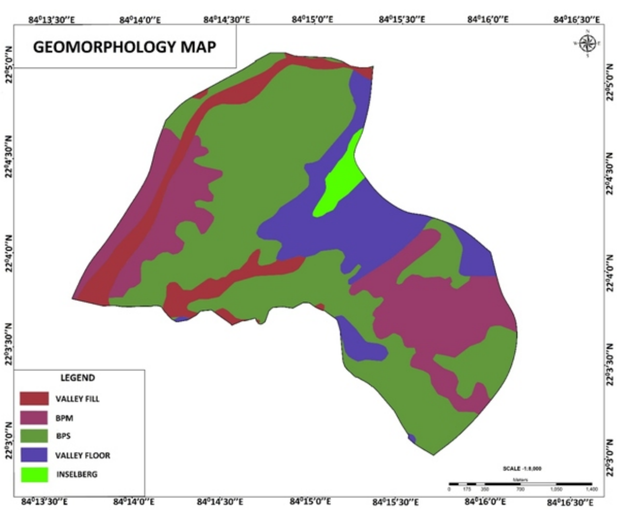

Fig. 6. Hydro-geomorphology map

GIS and weighted index overlay analysis

Due to their importance in the availability of groundwater source, more weights were assigned to geomorphology and lineament, whereas equal weights were assigned to drainage, slope and LU/LC themes. Individual ranks were assigned to each parameter in every thematic map after assigning their weights (Nag and Lahiri, 2011; Dwivedi *et al.*, 2016). All the thematic maps were examined in GIS environment thoroughly and each sub-variable parameter was assigned with suitable ranks (Asadi *et al.*, 2007).

Each parameter of every thematic map was categorized into one of the following four classes *i.e.* very good, ii. good to moderate, iii. moderate, iv. poor. Based on their importance in creating favourable groundwater source, suitable ranks on a scale of '1-4' were assigned to each class in thematic maps. The weighted and rank assigned for various classes on all thematic layers are shown in Table 5.

After assigning weightage and ranking for the each layer, raster calculator of Arc-GIS software was used for generation of final composite map. The potential zones were identified by using the following relation (Biswas *et al.,* 2012).

$$GWP = \Sigma\, W \times R \quad ...(1)$$

Where, GWP = Groundwater potential, W = Weightage, R = Rank.

Groundwater potential index was calculated by employing the following formula (Biswas *et al.,* 2012):

Table: 4
Hydro-geomorphological parameters of Ghumuda micro-watershed

Map unit	Geomorphic unit	Area (ha)	% of the total area
1	Inselberg	36.207	4.25
2	BPM	165.704	19.45
3	BPS	459.286	53.91
4	Valley fill	39.189	4.6
5	Pediment / Valley floor	102.489	12.03

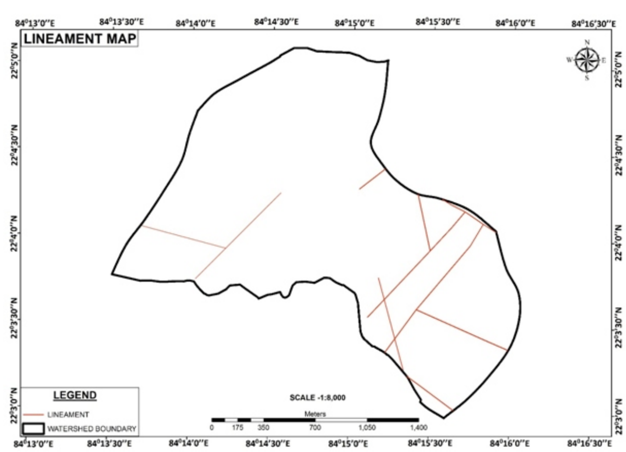

Fig. 7. Lineament map

Table: 5
Assigning ranking and weightages to various parameters

S.No.	Thematic Layer	Individual Feature	Map Weight	Ranks
1	Geomorphology	Valley fill	30	4
		BPM		3
		BPS		2
		Pediment / valley floor		1
		Inselberg		1
2	Lineament	Present	30	4
		Absent		1
3	Slope (%)	0-3	20	4
		3-5		3
		5-10		2
		10-34		1
4	Land use	Waterbody	20	4
		Forest		3
		Agriculture		2
		Barren land		1
		Establishment		1

$$GWPI = (G_W \times G_R + L_W \times L_R + S_W \times S_R + LU_W \times LU_R) \, / \, \text{Total weightage} \quad ...(2)$$

Where, *GWPI* = Groundwater potential index value, *G*= Geomorphology, *S* = Slope, *L* = Lineament, *LU* = Land use.

The thematic maps were superimposed to get final groundwater potential zone map (Fig. 8) utilising above technique.

Groundwater potential zone map

The groundwater potential zone map was obtained after the integration of all the thematic maps of the study area, performed through overlaying analysis in GIS environment. The delineation of the groundwater potential zones was performed by grouping the grids of the final combined layers into various potential zones.

Very good**:** These zones are having geomorphic units like lineaments and the intersection points of lineaments which are a very good source of groundwater as they act as the passage of groundwater runoff below land surfaces.

Good to Moderate**:** This zone includes alluvial plains and valley fills which are found in isolated patches in the study area. The unconsolidated sand and cracked landforms beneath the land surface store a good quantity of groundwater in this zone.

Moderate**:** Geomorphic units in this zone are loose sediments, fractured and weathered rocks, which significantly contribute water to the ground. The underground formations are moderate and shallow buried pediments so the below aquifer in this zone has less potential for groundwater and low yield.

Poor**:** This zone contains valley floor, pediments and residual hills, which has a substantial contribution of water to below aquifer. Presence of suitable slope and land features make it an ideal runoff generating area rather than groundwater development zone.

Best site for tube well construction

Lineaments are linear fractures below the landforms, so they act as aqueducts and contain sufficient groundwater in a particular area. The intersection points of these lineaments are potential sites for groundwater extraction with an average discharge capacity of more than 300 lpm. So for the construction of tubewell, intersection points of lineaments are most suitable as it can supply year-round discharge without creating groundwater mining (Paul *et al*., 2016). Depending on the lineament map and its intersection points, 7 tube wells were proposed in the study area (Fig. 9). The seven tube well points with their latitude and longitude are presented in the Table 6.

Ground truthing

Vertical electrical sounding (VES) test data nearer to a proposed tubewell location was collected from Ground Water Survey and Investigation Department of Government of Odisha, and it was observed that locations are feasible for groundwater extraction. Test data is presented in Table 7.

Water resources action plan

The water resource development plan (Fig. 10) of

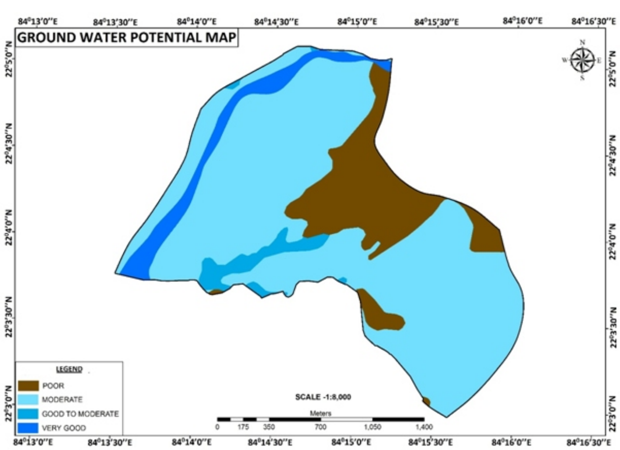

Fig. 8. Groundwater potential map

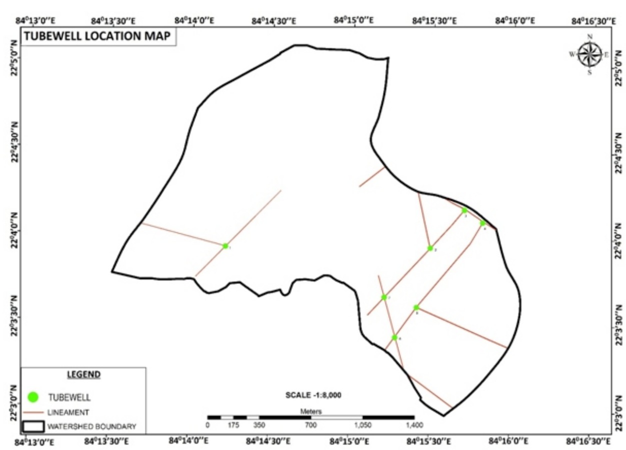

Fig. 9. Tubewell location map

Table: 6
Suggested tubewell location sites of the study area

S.No.	Village	Latitude	Longitude
1	Bijadihi	84°14'13''	22°3'57''
2	Bauridihi	84°15'30''	22°3'57''
3	Bauridihi	84°15'42''	22°4'10''
4	Bauridihi	84°15'49''	22°4'6''
5	Bauridihi	84°15'24''	22°3'36''
6	Kulta	84°15'16''	22°3'26''
7	Kulta	84°13'13''	22°3'39''

Table: 7
Vertical electrical sounding test data

Sundergarh	Depth below ground level	Lithological layer
Well code-29M16A18	0 m	Sandy clay with mica
Well type-Borewell	4 m	Weathered quartz, mica and schist
	12 m	Quartz, mica and schist

Source: Groundwater survey and investigation office, Sundergarh

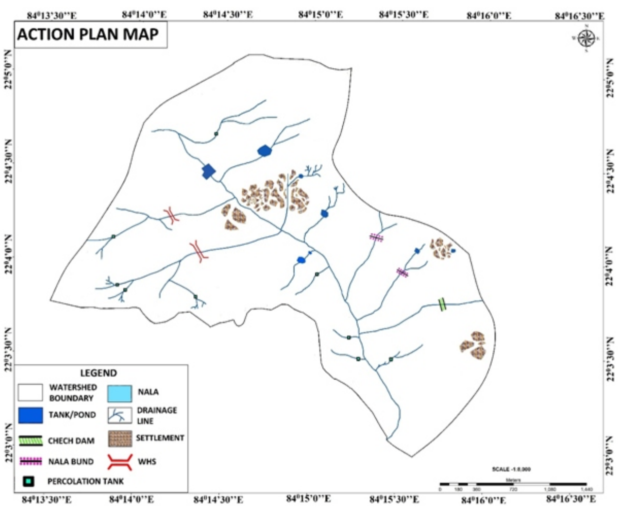

Fig. 10. Water resource action plan map

Ghumuda micro-watershed was obtained by overlaying hydro-geomorphological map, slope map and drainage map using Arc-GIS 10.1 software packages in GIS. This action plan was prepared for judicious and planned management of water resource of the study area for sustainable agricultural development and to mitigate natural calamities like drought.

Suggested Recommendations

Renovation of water bodies

Renovation of 2 water bodies is needed in the study area for groundwater recharge and providing irrigation facility to farmers. Currently, due to lack of maintenance and siltation, these water bodies are not used properly for irrigation and drinking purpose. Renovation work may include removal of deposited silt at the bottom of the pond, improvement of the conveyance system, deweeding, catchment treatment, maintenance of existing dykes, seepage control measures and soil erosion prevention measures.

Nala bund

Nala bunds are constructed on agricultural land with the intention of reducing soil erosion and maintaining the soil moisture regime. It would help to conserve the water in the field and maintain *in-situ* moisture in the field. The erosion of the field can be lessened by these structures. Three nala bunds are recommended in the study area for improvement of the water resource.

Percolation tank

Percolation tanks are artificial groundwater recharge structures constructed across streams to store excess runoff. Percolation tank can be used to replenish and restore surface water as well as groundwater resource by conserving excess surface water and allowing it to penetrate into the ground for augmentation of groundwater table in a permeable area. Nine percolation tanks are suggested in the watershed action plan.

Check dam

Check dams are small-scale barriers constructed across streams having a gentle slope. The site selected for check dam construction should have an adequate depth of unconsolidated alluvial formation to aid ingress of ponded water within a very short period of time into the ground. In the study area, only one check dam is suggested for augmenting groundwater resource.

Water harvesting structure

Water harvesting structures are structures built across the small streams having a limited height of drop to store surface runoff in monsoon rains, reduce runoff velocity, augment groundwater and prevent soil erosion. Two water harvesting structures are proposed in the water resource plan for the study area.

4. CONCLUSIONS

The required thematic maps namely LU/LC, drainage, slope, lineament, and hydro-geomorphology for development of groundwater potential zones of the study area were prepared. Ghumuda micro-watershed comprised of mostly agricultural land and barren lands. It is one of the potential regions for agricultural development, as agriculture alone occupies about 69.01% of the total micro-watershed area. The micro-watershed has mostly moderate groundwater prospect occupying an area of 659.92 ha, which is 77.46% of the TGA. Depending on the availability of groundwater resource, seven tubewells were suggested to explore groundwater resource at the intersection of lineaments. Integrating all the prepared thematic maps in a GIS environment, a water resource action plan was prepared. Different soil and water conservation structures like three nala bunds, nine percolation tanks, one check dam and two water harvesting structure are proposed in the action plan for erosion control, to replenish and restore both surface and groundwater resource in the micro-watershed. In this water resource action plan, renovation of two existing water bodies are proposed for increasing water availability.

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