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An Integrated Study on Sustainable Development of Groundwater Resources in Coastal Environs, Visakhapatnam District, Andhra Pradesh-A Watershed Approach

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Abstract: *The study area, centered around the Madhurawada structural dome, lies in Visakhapatnam District of Andhra Pradesh State on the east coast of India. Covering 192 km^2, the area consists of two non-perennial drainage basins of the Peddagedda River and Maddigedda rivulet. The average annual rainfall of the area ranges from 1000 to 1200 mm. There are about 50 surface water bodies of which eight are perennial. The population of the area in 2010 is estimated at 63,668. In this study, topographic maps, satellite images and geologic maps of the study area have been used to generate thematic maps of drainage, geomorphology, lineaments and land use/land cover. Cultivation is the major land use in the upper and lower reaches of the Peddagedda River whereas urban built-up occupies the watershed of Maddigedda rivulet. Twenty-four dug wells monitored during pre- and post-monsoon periods in 2010 revealed the area configuration of the water table. Analyses of these data in ArcGIS 9.2 environment helped to delineate zones with groundwater potential. Quality of groundwater revealing higher contents of hardness and fluoride in few villages have been affecting arthritis and mild gastrointestinal disorders as reported by Public Health Center. Following the guidelines of the Groundwater Estimation Committee-1997, studied available groundwater resources, current discharge and future requirements for the year 2025. The study area has been divided into run-off zones (about 57 km^2) and recharge zones (about 135 km^2) corresponding to hills and plains, respectively. The study area has total groundwater resources of 77,715,280 m^3. The groundwater requirement in 2025 is estimated at 1,621 h.m/day. The study revealing surplus groundwater resources, population boom and recent developments have significant impact which leads to stress on groundwater. Keeping in view of this, drainage and geology were intersected and buffered to locate potential areas for artificial recharge of groundwater for sustainable occurrence to meet the future demand.*

Key Words: *Watershed; Groundwater Estimation Committee; Buffer; Gastrointestinal*

I. Introduction

The Madhurawada structural dome and environs underlies an area of 192 km^2 northeast of the city of Visakhapatnam in Andhra Pradesh State on the east coast of India. The area consists of the watersheds of the Peddagedda River (181 km^2) and Maddigedda rivulet (11 km^2) (Figure 1). Geologically, the area is a structural dome rimmed by khondalite hills. The altitude varies from 1 to 253 m above msl is in Peddagedda River mouth and Madhurawada dome respectively. The study area has coast line of Bay of Bengal on the east side. The area is rapidly urbanizing, and its demand on groundwater is increasing. Agriculture is the major land use in the upstream and downstream reaches of the Peddagedda River, whereas the area drained by Maddigedda rivulet is completely built-up. In the 2001 Census, the area had a population of 52,000 with a decennial growth rate of 22.44%, thus the population in 2010 is estimated at 63,668. The annual rainfall in the area varies between 1000 and 1200 mm (Handbook of Statistics, Visakhapatnam District 2006–2008). Carried out 24 dug wells inventories in densely populated villages to assess water-table fluctuation, which is one of the parameters for groundwater quantification.

In this study, estimated groundwater demand for domestic and irrigation purposes for the year 2025 used Groundwater Estimation Committee (1997) norms. Erratic rainfall from 2001 to 2004, in addition to insufficient surface water, has led to severe drought and resulted in increasing exploitation of groundwater. Hence, this investigation was undertaken to identify potential groundwater sources to augment supplies during times of water scarcity.

Table 1: Characteristics of satellite data used in the study

S. No	Satellite	Sensor	Row/Path	Date of pass
1	IRS-ID	LISS-III	104/60	September 12, 2007
2	IRS-ID	LISS-III	104/60	April 6, 2008

DATA USED

This study used 65 O/5 Indian topographic map at 1:50,000 scale and Indian satellite IRS-ID-LISS-III data for the years 2007 and 2008 (Table 1). Twenty-four dug wells have been monitored during pre- and post-monsoon periods in 2010 and its coordinates measured with a handheld GPS (Mio) instrument. Limited field checks have also been carried out in doubtful classes of geomorphic units and land use/land cover.

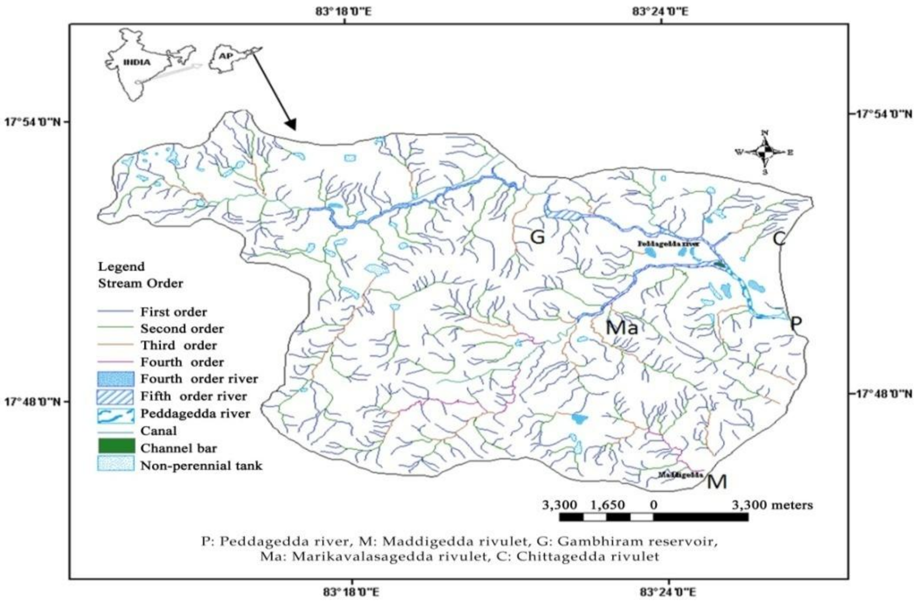
THEMATIC MAPS

Drainage pattern

The area has moderate to high drainage density. The Peddagedda River has two tributaries, Marikavalasagedda and Chittagedda. There are a variety of drainage patterns including dendritic, sub-dendritic, parallel, radial and annular are seen at places. The hills over the Madhurawada dome are characterized by radial and annular drainage (Figure 1).

The Peddagedda River is a sixth order stream (Strahler, 1952) where it terminates at the Bay of Bengal. Curvilinear and also broad 4th order streams courses seen at places. It is a minor category (Rao, 1970) non-perennial river. Maddigedda rivulet, in the southeastern side of the study area, is also non-perennial. The study area is covered about 50 tanks, out of which eight are perennial.

The Gambhiram reservoir was constructed on the Peddagedda River near Gambhiram village to provide a domestic water supply to Visakhapatnam. The storage capacity of the Gambhiram reservoir has been reduced to around 40% owing to siltation (Jagadeeswara Rao *et al*., 2006). In addition to water supply to



Visakhapatnam City, the canal from the reservoir is irrigating approximately 300 ha.

Figure 1: Location and drainage pattern of the study area

II. Geomorphology And Lineaments

Geomorphological studies, coupled with hydrogeological data and information on structure/lineaments, have proved to be effective for locating zones of groundwater potential (Bahuguna *et al*,. 2003; Jagadeeswara Rao *et al.*, 2004). Generated geomorphology and lineament maps of the area following standard visual interpretation techniques over the satellite images (Figure 2).

Of the denudational and fluvial landforms that have been delineated on IRS-ID-LISS-III digital data following the standard visual interpretation techniques, structural hills, denudational hills, residual hills, inselbergs and pediment-inselberg complexes are the run-off zones cover an area of 57.35 km^2. Similarly, the plains are infiltration zones which includes shallow valley-fill, piedmont slope, and three levels of pediplain (shallow, moderate and deep); they collectively make up about 134.65 km^2 (Table 2).

Many of the major streams follow confirmed and inferred lineaments (as defined by Rajiv Gandhi National Drinking Water Mission, 1998) in the maps and satellite imagery. Lineament density is high in hilly terrain and moderate to low in the plains. Major streams flowing through narrow valleys have deposited large amounts of denuded material that is mapped as shallow valley fill in the landform map (Figure 2). The spatial arrangement of these streams with structural control can indicate conduits for groundwater recharge and storage in various places. Intersecting lineaments generally indicate high groundwater potential. Lineaments that extend down to the plains and are fed by river systems mark potential zones for groundwater exploitation (Sanjay Raj and Sinha, 1989).

Hydrogeomorphic classes (landform)	Geology (Rock types)	Area under each category (km^2)	Area in Percentage	Water table fluctuation
Run-off zones				
Structural hills	Khondalite	40.70	21.39	Area not covered by wells
Denudational hills	Khondalite	13.11	6.89	Area not covered by wells
Residual hills	Quartzite	2.16	1.13	Area not covered by wells
Pediment-inselberg complexes	Quartzite	2.06	1.08	Area not covered by wells
Inselbergs	Khondalite/Charnockite	3.17	1.66	Area not covered by wells
Infiltration zones				
Valley-fill shallow	Khondalite	7.82	4.11	0 – 0.95 (m bgl)
Piedmont slope	Khondalite	19.00	9.98	2 – 5 (m bgl)
Pediplain-shallow	Khondalite	57.22	30.08	2.5 – 6.8 (m bgl)
Pediplain-moderate	Khondalite	24.12	12.68	1.8 – 3 (m bgl)
Pediplain-deep	Flood plain/ Khondalite	20.83	10.95	2.3 – 2.95 (m bgl)

Table 2: Hydrogeomorphic classes – water table fluctuion

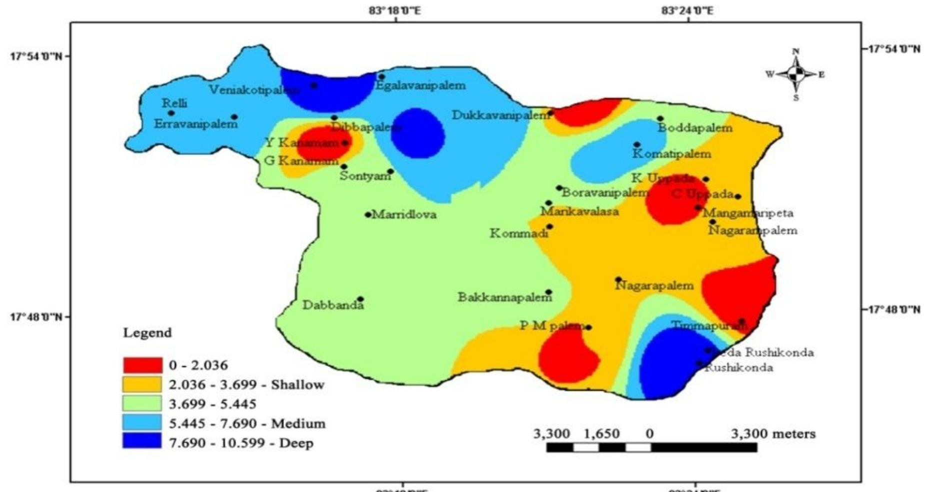


Figure 2: Hydrogeomorphology and lineaments pattern

WELL INVENTORY

Groundwater levels were measured in 24 dug wells during the pre- and post-monsoon seasons in 2010. The water table occurs in unconfined and semi-confined conditions. Well locations, determined with a handheld GPS instrument, were plotted to generate a groundwater table fluctuation map in ArcGIS 9.2 environment (Figure 3).

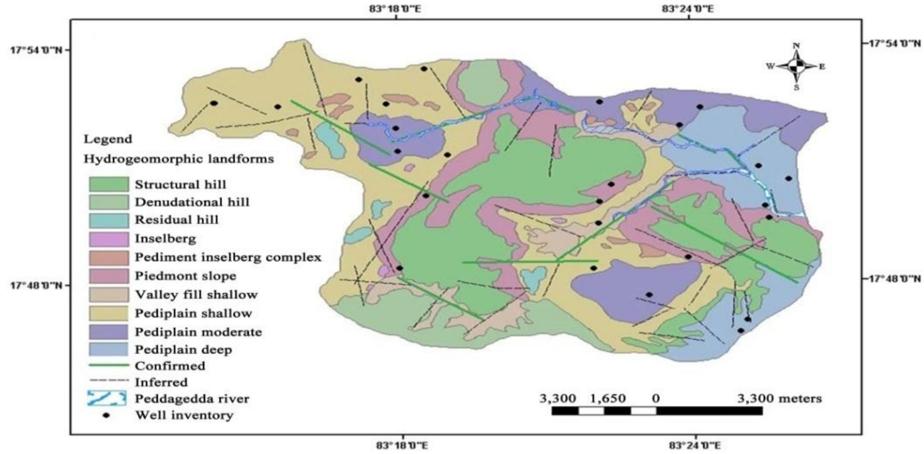


Figure 3: Groundwater fluctuation map of the study area

The spatial distribution of groundwater is not uniform. The area downstream from Gambhiram reservoir (Boyapalem well) has a shallow water table 0.95 m below ground level (bgl), whereas other areas have a medium (4.2 m bgl, Mindivanipalem well) to deep (8.15 m bgl, Rushikonda well) water table. In Sontyam village, the water table varies from ground level to 5.0 m bgl within a distance of 2 km because of the presence of shallow hard rock acting as a groundwater barrier. There is an area of deep water table adjacent to the northern foothills.

GROUNDWATER POTENTIAL ZONE

Thematic maps of geomorphology and lineaments were used in GIS analysis. The country rock khondalite (garnet ferrous sillimanite gneiss) was considered a groundwater source while intrusive dykes as barriers were ignored. All geomorphic landform classes suitable for groundwater recharge is shown in (Figure 4). With a view to recharge groundwater spatially, buffer zones of 300 m and 100 m were assigned to confirmed and inferred lineaments. All of this information was overlaid in the ArcGIS 9.2 environment to produce final groundwater potential zones (Murthy, 2000; Jagadeeswara Rao *et al.*, 2009). The resulting map was further classified into five categories (low, medium, high medium, high and very high) on the basis of the geomorphological units present in the groundwater potential zones. These zones and the villages in them are mentioned (Table 3).

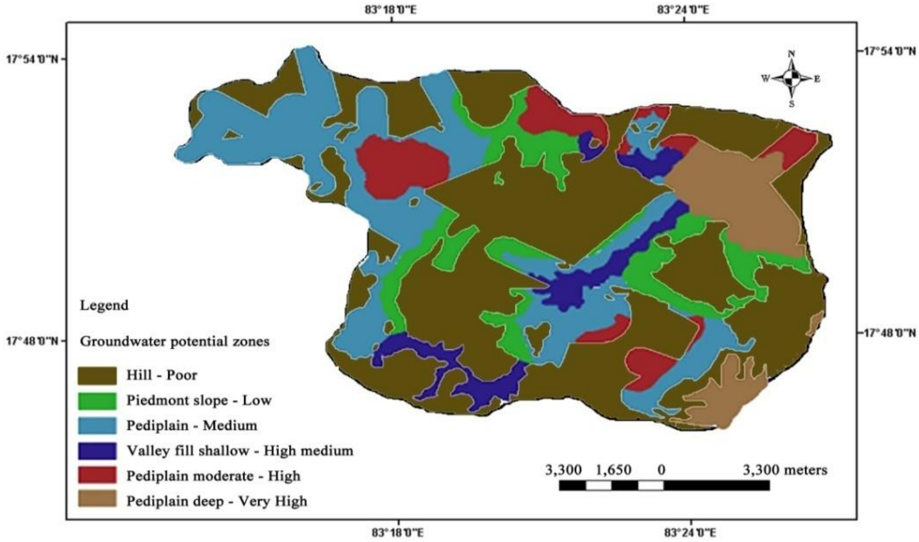


Figure 4: Groundwater potential zones in the study area

Table 3: Groundwater potential geomorphic class in the area

S.No	Geomorphic class/Groundwater potential	Name of the village	Area under each category (km^2)
1	Piedmont slope/Low	Kommadi, Boravainipalem	18.033
2	Valley-fill shallow/Medium	Dabbanda, Chemudupalem	10.05
3	Pediplain-shallow buried/High medium	Erravanipalem, Kottaparadesipalem	41.5
4	Pediplain-moderate buried/High	Sontyam, Madhurawada	13.66
5	Pediplain-deep buried/Very high	Mangamaripeta, Boyapalem	15.38

GROUNDWATER RESOURCE ESTIMATION

To estimate groundwater resources for a drainage basin, data on pre- and post-monsoon rainfall, surface water bodies (tanks), canals and surface irrigation practices are required (Table 4). Computed groundwater potential on the basis of norms was recommended by the Groundwater Estimation Committee (GEC, 1997). The study area has been divided into areas unsuitable for rainfall recharge and areas suitable for recharge (Janardhana Raju *et al.,* 1994). The area unsuitable for recharge (57.35 km^2) consists of structural hills, denudational hills, pediment-inselberg complex, inselbergs and residual hills. The area suitable for groundwater recharge (13,465 km^2) consists of pediplains, piedmont slope and valley-fill shallow (Figure 5). There are several groundwater estimation norms suggested by the GEC, only applicable five norms have been considered in this study. To get available groundwater resources through rainfall infiltration method, recharge area is multiplied with normal rainfall and infiltration factor, similarly, the area has an unlined canal, which is recharging more groundwater than other methods. The recharge of groundwater is arrived by taking the wetted area of the canal and multiplying it with the seepage factor and the number of days the canal is in operation. Taking into consideration of these norms, the study area has total groundwater resources of approximately 77,715,280 m^3 (Table 4).

The population of the study area was 51,924 in the 2001 Census with a decennial growth rate of 22.44%. Therefore, the population for the year 2025 is estimated at 81,054. Presently, the per capita water requirement is around 140 L/day. If this increases to around 200 L/day by 2025, the estimated water demand for 2025 is around 16,210 m^3/day. The area has excess groundwater resources, however, urban built-up and industrialization may come up in a big way in coming years which leads to scarcity and depletion. Identified groundwater potential zones may cater the future needs. However, these recharge zones are properly managed to sustainable occurrence of groundwater.

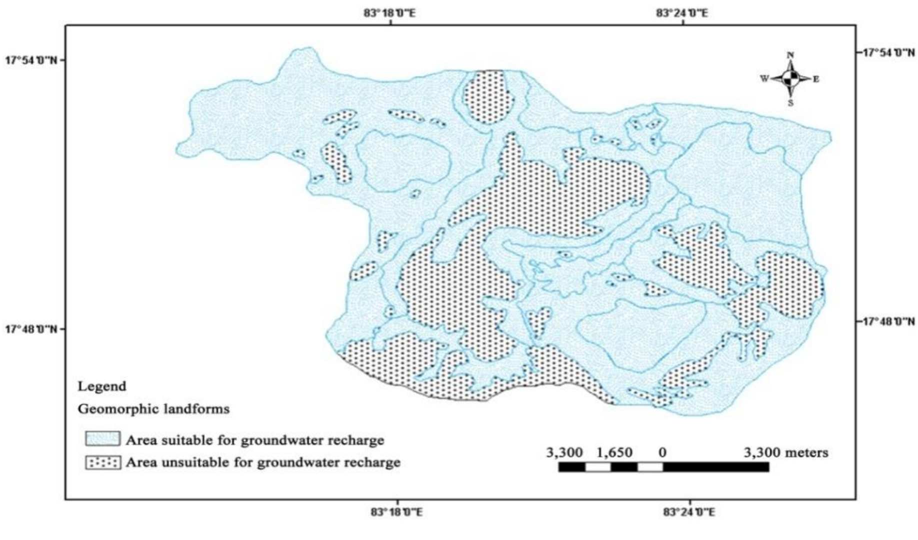


Figure 5: Areas suitable and unsuitable for groundwater recharge
(Lines represent the borders between geomorphic landform classes)

Table 4: Quantification of groundwater estimated by different methods

Method	Available groundwater resources (m^3)
Rainfall infiltration method	14,310,000
Water table fluctuation method	11,755,000
Recharge from tanks	67,400
Recharge from unlined canals	119,880
Recharge from surface water irrigation	51,463,000
Total groundwater resources	77,715,280

Artificial recharge of groundwater

In view of tremendous pressure on groundwater in the area, artificial groundwater recharge techniques are the alternative methods to overcome the problem and to sustain water for the future generations. Quartzites and charnockites are occurring as ridges, whereas khondalite is the country rock. Buffer of 200 m is assigned to 3rd streams and intersected with geology of the area. On the basis of rock type and structure, check-dam is a suitable artificial recharge technique to augment groundwater. The study area has about 50 surface water bodies, most of them are non-perennial filled with sediment. Desiltation enhances the storage capacity of the tanks which in turn recharge the groundwater (Fig.6).

Groundwater quality revealing, the study area is underlined by slightly alkaline and fluoride and total hardness concentrations are in higher in the villages of Kommadi and Kapula Uppada villages respectively. A few cases have been registering with arthritis and mild gastrointestinal disorders as reported by Public Health Center, Madhurawada.

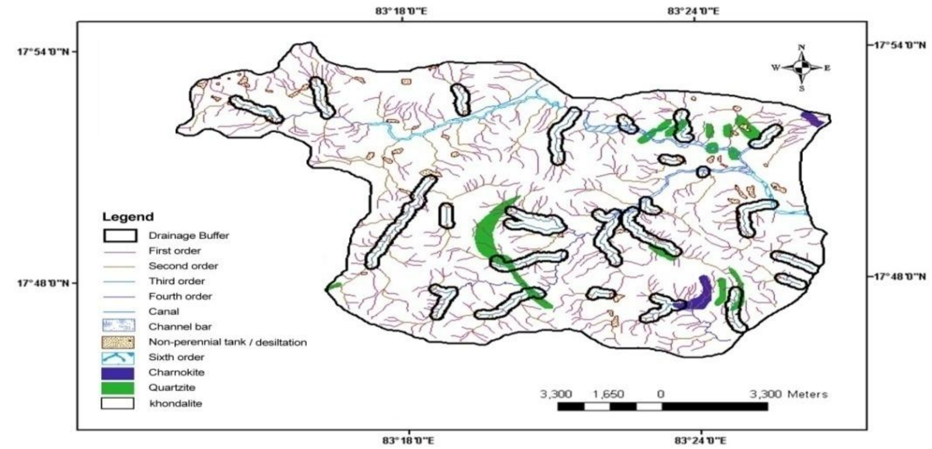


Figure 6: Artificial recharge techniques

LAND USE/LAND COVER AND MANAGEMENT OF GROUNDWATER RESOURCES

Land use/land cover categories can be mapped from remote-sensing data on different scales (Bishat *et al*., 1995, Brahmabhatt *et al*., 2000, Bansal *et al*., 2008). In this analysis, identified 10 land use/land cover level-II classes (NRSA, 1990) from IRS-ID-LISS-III data for 2007 and 2008 through standard visual interpretation techniques (Figure 6).

Madhurawada mandal (municipal ward) is the only built-up urban area. Built-up rural land and village road networks were not identified because of the coarse resolution of the satellite data. The study area includes the ephemeral Peddagedda River and Maddigedda rivulet system and 47 surface water tanks. Most of the tanks are filled with silt, dried up or covered with weeds, thus only eight perennial tanks were identified on satellite images. The areas under each category of land use/land cover are given in Table 5.

The built-up area, around 13 km^2 today, is likely to increase to around 40 km^2, given the expected population of about 81,000 in 2025. Similarly, construction activities are encroaching into the area of scrubland (about 7 km^2). The area of deciduous forest (about 72 km^2) is considered a permanent feature. Groundwater demand for domestic activities for 2025 is estimated at around 16,210 m^3/day. The total groundwater resource, estimated to be around 77,715,280 m^3 in this study, is sufficient to meet domestic and irrigational requirements.

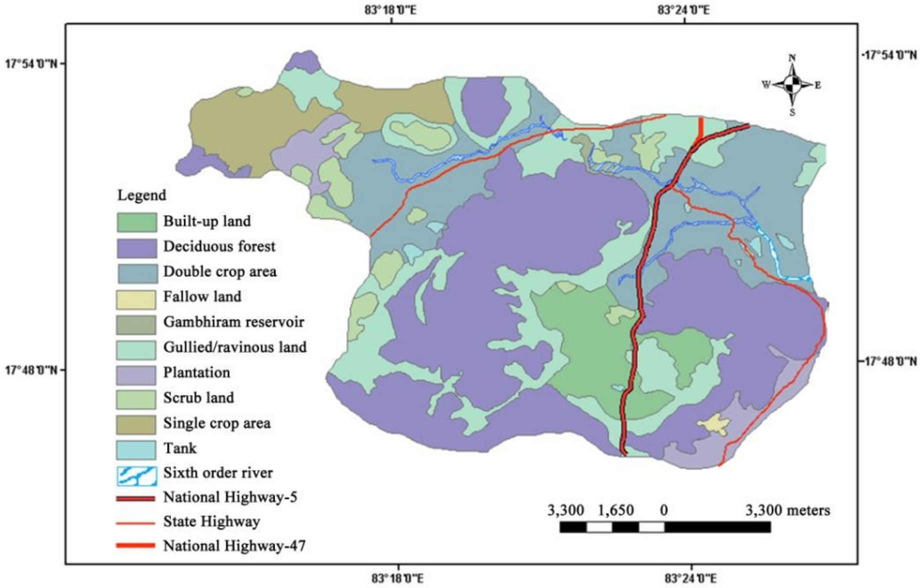


Figure 6: Land use/land cover of the study area

Table 5: Area under land use/land cover classes

S.No	Land use/land cover category	Area of each category (km^2)	Percent area of each category
1	Built-up (urban)	13.03	6.78
2	Deciduous forest	71.95	37.47
3	Double crop area	41.09	21.40
4	Single crop area	12.97	6.75
5	Fallow land	2.92	1.52
6	Gambhiram reservoir	0.70	0.36
7	Gullied/ravinous land	31.08	16.18
8	Plantation	7.80	4.06
9	Scrub land	6.93	3.61
10	Tank	4.2	2.18

III. Conclusions

The study area is one of the fastest developing suburban areas in the Greater Visakhapatnam Municipal Corporation (GVMC) area. The Peddagedda River, being non-perennial, is not a major water source. Thus, groundwater usage is increasing each year. The GVMC has constructed deep bore wells in Madhurawada to provide drinking water.

The well inventory shows that the weathered zone is more than 12 m thick in the deeply buried pediplain unit and up to 12 m thick in the two shallower pediplain units. The spatial distribution of groundwater configuration is not uniform. In Sontyam village, water table varies from ground level to 5 m bgl within a distance of 2 km. This is due to hard rock substratum is occurring as ridge. The water table is shallow in Kapula Uppada (1.5 m bgl), Marikavalasa (1.8 m bgl) and Mangamaripeta (2.7 m bgl) villages. A few villagers are suffering from arthritis and mild gastrointestinal disorders, owing to higher contents of fluoride and total hardness, In these villages, paddy is under cultivation in both monsoon (*kharif*) and post-monsoon (*rabi*) seasons. Groundwater-fed agriculture is the major land use upstream and downstream of the Gambhiram reservoir. In addition, canal from the Gambhiram reservoir is irrigating approximately 300 ha. The groundwater demand for a projected population of 81,054 in 2025 is estimated to be around 16,210 m^3/day. The area has 77,715,280 m^3 of groundwater resources to meet the demand. The study revealed surplus groundwater resources occurring in the area. The 13 km^2 area under single-crop paddy can be improved into double-crop farming (which would then total 54 km^2) with effective utilization of groundwater. Similarly, fallow and gullied land (36 km^2) can be effectively used for agriculture/plantation with the available groundwater resources. These activities reduce soil erosion, improve groundwater and provide livelihoods for the rural poor. Owing to urbanization and industrialization, load on groundwater is increasing year after year this is very severe during drought periods. In view of that, groundwater potential zones identified in this study may cater to the groundwater demand. However, these land parcels should be properly managed by adopting artificial recharge techniques in sustainable manner, to overcome water woes.

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