Artificial Recharge for Sustainable Management of Groundwater Resource in Over-Exploited Hard Rock Aquifers – A Case Study from Drought Prone Region of Andhra Pradesh, India

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Abstract : *In the absence of irrigation projects, there is increased stress on groundwater to meet irrigation and drinking water requirements in chronically drought affected Kadapa district, Andhra Pradesh. Excessive dependence coupled with low rainfall without proper augmentation has often resulted in over exploitation of the groundwater. In order to demonstrate the benefits of artificial recharge in such scenario, a project was takenup in drought prone Lingala, Pulivendula, Vemula and Vempalli mandals of Kadapa district. Based on hydrogeological and geophysical surveys, 7 percolation tanks and 15 check dams were constructed in upstream of irrigated areas. To assess the impact, water levels were monitored from 100 observation wells and 13 piezometers for 3 years. The data collected was analysed for pre and post construction stages and impact was assessed.*

After construction of recharge structures groundwater levels rose, sustainability of wells increased to meet peak demands. During pre and post monsoon period rising trend in water levels was observed from 0.8 m to11.16 m / year and 0.1 m to10.92 m/ year respectively in the vicinity of recharge structures and some dried up dug wells rejuvenated. About 50 hectares of area has been brought under additional irrigation in the influence zone and farmers could able to meet peak cropwater demands due to which crop yield increased by 15-30% and irrigated area per bore well by 10%. The average discharge and pumping hours of the wells increased by 30-40% and farmers stopped purchasing water from far off places. Recharge structures also helped in considerable dilution of fluoride content in drinking water sources from 6.15 to 2.9 and 3.74 to 2.5 mg/lit. The successful implementation of the project demonstrates to replicate in similar hydrogeological environs for sustainable development of groundwater to increase food production and better livelihood.

Key words: *Groundwater, Over-exploitation, Artificial Recharge structures, Sustainability.*

1..Introduction:

About two-thirds of India, comprising Southern Peninsula and Western India is underlain by hard rocks consisting of granites, gneisses, basalts, limestones, shales etc. Andhra Pradesh, a water scarce state, is underlain by hard rocks in 85 % area. Rapid industrialization and the need for food security for the ever-increasing population have led to increased demand for water. Due to limited groundwater availability in hard rocks there is an ever increasing stress on groundwater resource. It becomes more severe where the rainfall is low and no irrigation projects exist to meet the drinking and irrigation requirement. Most of the resource in the hard rocks is confined to the upper weathered zone and excessive groundwater withdrawal leads to the progressive lowering of water levels and drying up of open wells in the weathered zone which is otherwise the potential recharge source of bore wells rendering the latter extremely sensitive to rainfall vagaries (G.Sudarhan, P.N.Rao, A.D.Rao, 2008). This warrants the need to adopt rain water harvesting and artificial recharge to groundwater by harnessing the excess runoff to avoid water scarcity. Artificial recharge has now been accepted world-wide as a cost-effective method to augment groundwater resources in areas where continued overexploitation without due regard to their recharging options has resulted in various undesirable environmental consequences (CGWB, 2013). Many workers from all over the world have confirmed the potential of rainwater harvesting to enhance the water productivity (Handia et al. 2003; Concepcion et al. 2006; Sazakli et al. 2007; Abdulla and Al-Shareef 2009; Vohland and Barry 2009; Moon et al. 2012). The construction of rainwater harvesting structures decrease runoff rate, retard the soil erosion and recharge the aquifer (Ramakrishnan et al. 2009; Aladenola and Adeboye 2010). Under comprehensive watershed programmes, huge investments were made in the country for construction of various artificial recharge structures. It has been often reported these structures are constructed unscientifically, by which desired benefits have not been accrued. On the other hand, the success stories, where they have been constructed scientifically, are not properly documented. In this context, present attempt is a pragmatic approach carried out in low rainfall, chronically drought prone semi arid region representing Cuddapah Metasediments of Peninsular India to demonstrate the benefits of artificial recharge project where groundwater development is very high.

The objective of the study is to construct the artificial recharge structures scientifically to arrest the declining water levels by impounding surface runoff during rainy season, to augment the groundwater resource, improve the groundwater quality, enhance and increase the sustainability of existing bore wells and finally to showcase the results for replication in similar hydrogeological environs.

2. Study area:

The project area lies between North latitudes $14^0 16'20''$ - $14^0 34'10''$ and East longitudes $77^0 56'45''$–$78^0 33'45''$covering parts of Survey of India Topographical map numbers 57J/2, 3 & 7 with an areal extent of 848sq km covering Lingala, Pulivendula,Vemula and Vempalli mandals in Kadapa district of Andhra Pradesh (**Fig-1**).

The annual normal rainfall of the study area is 612.2 mm and the deviation over normal rainfall varies from 27 to 44%. Lowest rainfall of 381mm is recorded in 2004. The north east monsoon rains during November to December months highly influences the crop production, crop plantation and other related activities in the area. The general slope of the area is less than 2% in the plains and about 15% in the hilly area. The area falls under Pennar River Basin and drains by its tributaries viz., Chitravathi River in the western part and Papagni River in the southern part. Agriculture is the mainstay of the rural population for livelihood. The principal crops in the area are groundnut, sunflower, citrus, banana plantain. Among the seasonal crops, groundnut, sunflower, ginger are grown as rain fed/Irrigated Dry (ID) crops, whereas banana and citrus crops require intensive irrigation and are mainly irrigated with drip where as groundnut, pulses etc are grown with sprinkler irrigation. Groundwater is the only source for irrigation developed through bore wells. The area is occupied by structural hills, and pediplains with plain to undulating topography.

3. Geology and Hydrogeology:

Granites of the Archaean age occupy in the south eastern part of the area. These rocks are overlain by Cuddapah Super Group formations consisting Gulcheru Quartzites, Vempalli Limestones/Dolomites and Quartzites, Pulivendula Quartzites and Tadipatri Shales of Pre-Cambrian age. They are intruded by numerous basic sills (**Fig.2).** The granites, Gulcheru Quartzites and Pulivendula Quartzites do not form good aquifers, whereas Vempalli Limestone and Tadipatri Shales form good aquifers in the area. The Pulivendula Quartzites overlie the Vempalli Limestone.

Groundwater occurs under unconfined, semi-confined and confined conditions. Due to the lack of primary porosity in these rocks, groundwater occurrence is controlled primarily by the presence of fractures and joints. Thus, weathered and fractured zones form aquifers. The limestones and dolomites are cavernous at places, the intrusion of sills in to limestones helped rendering the cavernous and forming very good aquifers. The Tadipatri Shales are poor aquifers when compared to limestones. The yields are found to be high at the contact zones of the sills. Almost all the irrigation dug wells are dried up except at hydrogeologically favourable locations. Groundwater extraction is mainly by means of bore wells (100-350 m depth) with yield varying from 2 to 5 lps. The depth to piezometric surface varies from 20 to 90 m bgl during the pre-monsoon period **(Fig.3)** and 10 to 75 m bgl during post monsoon period. The deeper water levels are reflection of cumulative effect of the intense pumping in the area. The long term piezometric levels indicate the declining trend @ 0.69 to 2.18 m/year.

4. Methodology:

Based on well inventory of groundwater abstraction structures, feasible locations were identified for taking up geophysical surveys to assess the subsurface conditions and to identify thickness of topsoil/weathered

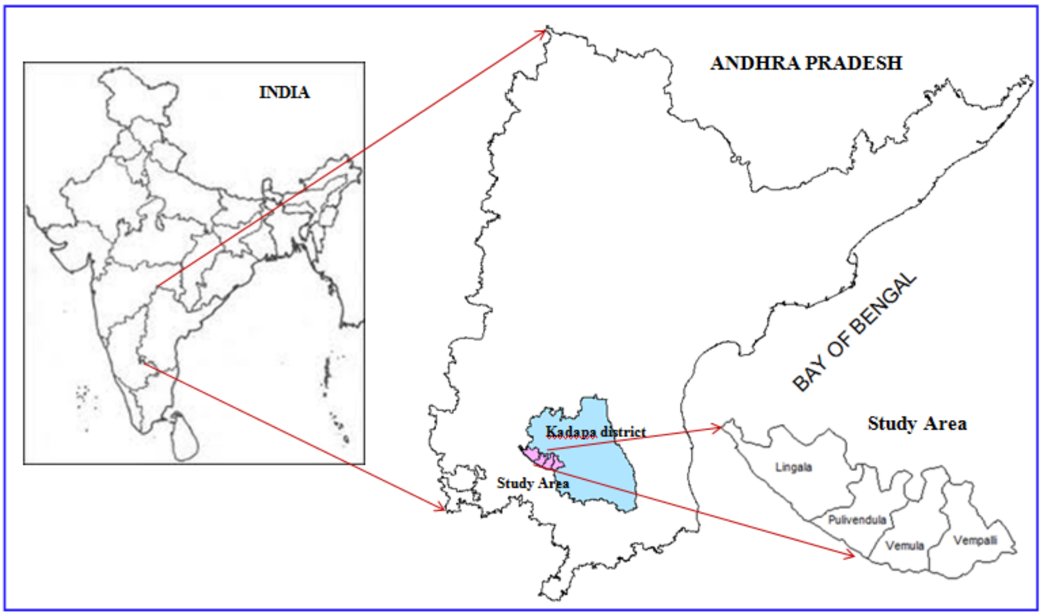

Fig.1 Location of Study Area

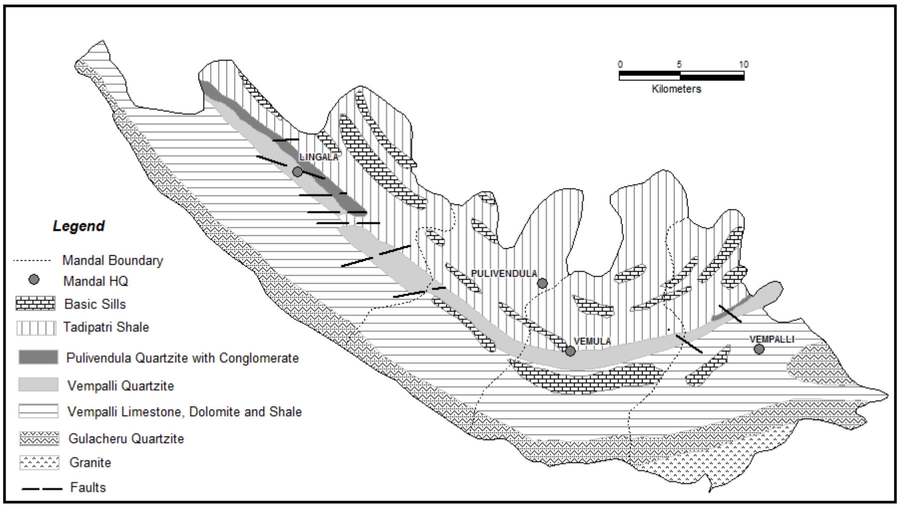

Fig.2 Geology of the area

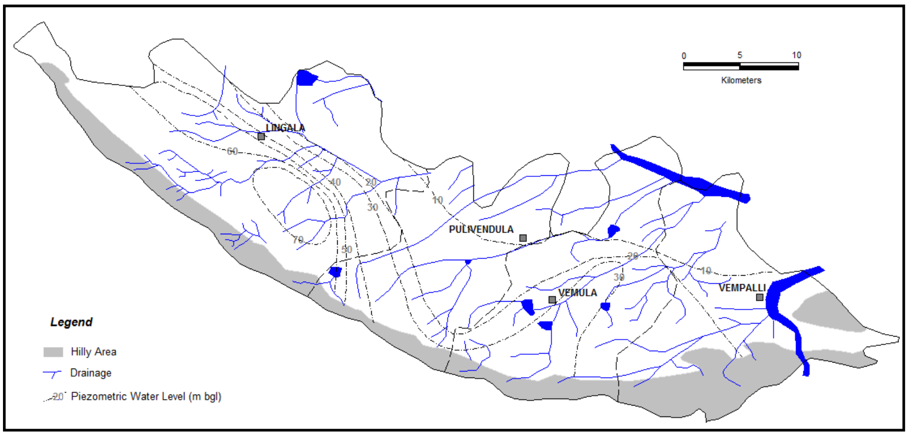

Fig.3 Piezometric Levels (March, 2007)

zone and depth to bedrock for pinpointing the suitable sites for construction of artificial recharge structures. The geophysical studies comprise 118 numbers of Vertical Electrical Soundings (VES), 0.10 line km profiling in a grid pattern using Schlumberger configuration. The maximum current electrode separation was kept as 200- 400 m depending upon the available spread length. The apparent resistivity curves were interpreted using two and three layer master curves of Orellana & Mooney (1966), IPI 2Win Software (2001) to determine geoelectrical parameters viz. resistivity and thickness of different layers and also to further construct pseudo cross-section and geo-electrical sections so as to develop a conceptual model of the layering and faulting in the area.

In order to assess the impact of the artificial recharge structures, 100 Key Observation Wells (KOW located in the zone of influence) were monitored for 3 years (Oct, 2006 to Nov, 2009). In addition 8 shallow and 3 deep piezometer wells were constructed and monitored from October 2007 to 2009. These wells were monitored on monthly basis to assess the recharge to groundwater system in the area.

A total of 131 Water samples were collected in the vicinity of the structures in 3 seasons i.e., 34 samples collected during post monsoon period 2006**,** 42 samples collected during pre monsoon period 2008 and 46 samples collected during post monsoon period 2008 to assess change in water quality due to construction of recharge structures.

5. Artificial Recharge Structures constructed:

Artificial recharge (AR) to groundwater through rainwater harvesting is basically intended to slow or stop the running water and to infiltrate into the underground. Central Ground Water Board, Government of India brought out a manual suggesting the comprehensive methodology for selection of sites for construction of different structures and accordingly site selection was made. Results of geophysical surveys (resistivity surveys) obtained from various VES soundings have been combined together along various profiles to get geo-electric sections. This information has been utilized for the preparation of 2-D geoelectrical sections for determining the thickness and the areal extent of the weathered/fractured zone. The interpreted results were correlated with the lithology obtained from the local bore well data. The electrical resistivity values of various litho-units have been arrived at based on the results of VES and the resistivity values of various litho units are shown in **Table-1**.

Table -1: Resistivity values of various litho units

S. No	Formation	Resistivity Ωμ
1	Top soil	50-500
2	Weathered rock (shale & Limestone)	90-500
3	Fractured (saturated) Shale/Limestone	100-300
4	Jointed/ Fractured (unsaturated) shale/Limestone	300-800
5	Compact and hard Limestone	>800

Based on hydrogeological, hydrological and geophysical information in respect of thickness of weathering, fracturing formation, depth to bedrock and infiltration characteristics, sites were finalized and constructed 7 percolation tanks (PT) and 15 check dams (CD in upstream areas of irrigated areas **(Fig.4 & 5).**

6. Impact of the Artificial Recharge:

The groundwater recharge was estimated by taking into consideration the quantum of water available for recharge, storage capacity of recharge structures and number of fillings. A total of 0.93 MCM of water was recharged into the groundwater system through the recharge structures constructed in a rainy year and 18.779 MCM is estimated to be recharged in the life span of 20 years of the structures (**Table- 2**).

6.1. Impact on Groundwater Levels:

The water levels reflect all the changes that take place in aquifer system in relation to recharge with respect to rainfall, applied irrigation, rain water impounding, natural discharge and extraction. In the project area, the piezometric (PZ) levels in the wells in the vicinity of the artificial recharge structures have risen when compared to the pre-construction both in shallow and deeper aquifers. The most conspicuous feature is the gradual building up of groundwater levels/ piezometric heads in the zone of influence after construction of the artificial recharge structures. It is observed that some of the dried up dug wells in the zone of influence got rejuvenated particularly at Bonala and Alavalapadu villages in Lingala and Vempalli mandals. Pumping was resumed from these dried up dug wells in downstream side of Bonala percolation tank. Seasonal free flowing conditions were also observed in bore wells in the downstream side of the Bonala site.

The rise in water levels in different years was analyzed through the composite hydrographs. Considerable rise in piezometric heads was recorded in almost all the bore wells in the area having very deep piezometric heads i.e more than 50 m in the vicinity of percolation tanks at Murarichintala, Ambakapalli and Lopatnuthala. Remarkable change was also recorded in the shallow aquifer zones at Bonala, Kattaluru PT sites and Chinnakudala, V.Kothapalli, K.K.Kottalu and Alavalapadu check dam sites. In some of the observation wells monitored at Murarichintala, Chinnakudala and Ambakpalli it was observed the trend of declining water level was arrested and sustainability of pumping improved.

The PZ levels observed from the key observation wells in each of the village were averaged to express the PZ heads village wise, considering the hydrogeological conditions of the specific site. The cumulative trend gives the holistic scenario of groundwater level depicting long term water level trend. The hydrograph analysis of piezometric head data of observation bore wells show rise in PZ surface at almost all the structures. It can clearly be observed that even after meeting the existing demand there is rise in PZ surface during summer of post construction period in comparison to summer of pre construction period (**Fig.6**).

The details of the village-wise hydrograph analysis of observation wells are presented in **Table-3**. It indicates that the pre-monsoon water levels trends in observation wells in almost all the villages, have shown rising trend. The post-monsoon water level trend analysis indicates that wells in 11 villages out of 16

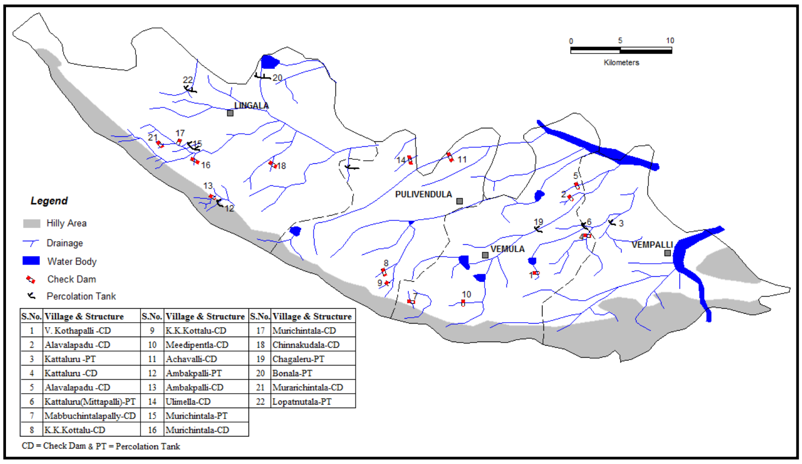

Fig. 4 Location of Artificial Recharge Structures Constructed


Bonala Percolation Tank, showing Seasonal Auto flow condition in nearby bore well

Kattaluru Mini Percolation Tank, before and after construction

Achavalli Check Dam before and after construction


Murarichintala Check Dam before and after construction

Fig. 5 Photographs of Artificial Recharge Structures

Table – 2: Details of Estimated Groundwater Recharge in the Study Area

Sl. No	Village	Mandal	Catchment area (Sq.Km)	Normal Rainfall (mm)	Storage capacity (MCM)	Cost of the Structure (Rs)	Number of fillings in a year	Actual Quantum of water available for Recharge (MCM)	Actual Ground water Recharge (MCM)	Actual Groundwater Recharge (MCM)/ Life (20Years)	Unit Cost of Water in Rs/cu.m
1	V.Kothapalli-CD	Vemula	0.58	501	0.006	150760	4	0.0227	0.0215	0.4305	0.350
2	Alavalapadu-CD	Vempalli	0.95	511	0.0085	317088	3	0.0255	0.0242	0.4843	0.6548
3	Kattaluru-PT	Vempalli	6.25	675	0.004	584089	4	0.0147	0.0140	0.2798	2.0875
4	Kattaluru-CD (Tallapallivanka)	Vempalli	11.5	675	0.011	486485	3	0.0340	0.0323	0.6457	0.753
5	Alavalapadu-CD (Muttukuru Rd)	Vempalli	0.95	511	0.007	250353	4	0.0283	0.0269	0.5381	0.465
6	Kattaluru-MPT	Vempalli	1.24	675	0.006	241104	4	0.0227	0.0215	0.4305	0.560
7	Mabbuchintalapalli-	Vemula	0.36	511	0.023	666300	2	0.0453	0.0431	0.8609	0.774
8	K.K.Kottalu-CD	Vemula	0.5	511	0.007	512599	3	0.0212	0.0202	0.4036	1.270
9	K.K.Kottalu-CD (West)	Vemula	0.4	511	0.004	313234	3	0.0127	0.0121	0.2421	1.294
10	Meedipentla-CD	Vemula	1	501	0.030	1182510	2	0.0595	0.0565	1.1300	1.047
11	Achavalli-CD	Pulivendula	5.5	677	0.0042	278968	4	0.0170	0.0161	0.3228	0.8641
12	Ambakpalli-PT	Lingala	0.31	620	0.009	452773	3	0.0263	0.0250	0.5004	0.9048
13	Ambakpalli-CD	Lingala	2.5	607	0.0057	351750	3	0.0170	0.0161	0.3228	1.0895
14	Ulimella-CD	Pulivendula	2.75	620	0.0071	278991	4	0.0283	0.0269	0.5381	0.5185
15	Murarichintala-PT	Lingala	0.37	546	0.027	1339699	3	0.0807	0.0767	1.5335	0.874
16	Murarichintala-CD (Boosammachenu)	Lingala	0.5	546	0.010	471114	3	0.0297	0.0283	0.5650	0.834
17	Murarichintala-CD (Gajjeletivanka)	Lingala	6.0	546	0.009	464398	3	0.0255	0.0242	0.4843	0.959
18	Chinnakudala-CD	Lingala	1.1	546	0.006	273198	5	0.0283	0.0269	0.5381	0.508
19	Chagaleru-PT	Vemula	13	501	0.034	622315	3	0.1020	0.0969	1.9371	0.3213
20	Bonala-PT	Lingala	14.65	546	0.071	2025419	4	0.2832	0.2690	5.3808	0.3764
21	Murarichintala-CD (Kommanuchenu)	Lingala	1.0	546	0.007	336599	3	0.0212	0.0202	0.4036	0.834
22	Lopatnutala-PT	Lingala	0.26	546	0.008	145529	5	0.0425	0.0404	0.8071	0.1803
Total						11745275		0.9884	0.9390	18.779	0.626

show a rising trend, where as the other 5 villages namely China Kudala, Alvalapadu, V.Kothapalli, Ulimella and Kattalur show falling trend.

The rise in water level trends during pre-monsoon and post monsoon periods indicates the improved groundwater situation due the additional resource created by the recharge structures. The fall during post monsoon period attributed to excess irrigation. The falling trend in two villages during pre monsoon period can be attributed to the increased groundwater draft during the project period. The hydrographs of the observation wells shows that there is a overall improvement in the groundwater scenario in the project area.

6.2. Impact on Cropped area and Crop Intensity:

During the project period, the data collected on the agricultural activity of the farmers (**Table-4**) for two years indicates that there was an increase in cropped area. Growing pulses and millets as inter crops has increased due to assured groundwater irrigation due to the construction of recharge structures in Bonala, Murarichintala, Lopatnuthala, K.K.Kottalu and V.Kothapalli areas. Purchasing water from 4-5 km away and transporting through pipelines is completely stopped due to increased recharge to the groundwater system and rejuvenation of the present bore wells with good yields. The net cropped area of banana plantation

Table-3: Hydrograph Analysis of Key Observation Wells

Sl. No	Location	No. of structures	Pre-Monsoon (cm/month)		Post-Monsoon (cm/month)		All (cm/month)		Inference
			Rise	Fall	Rise	Fall	Rise	Fall	
1	Lopatnutala	1-PT	93		91		64		Additional groundwater resource created by the artificial recharge is reflected in the rising hydrograph trends.
2	Murarichintala	1-PT 3-CD	31		20		24		
3	Kattaluru (Mittapalli)	1-PT	49		14		19		
4	Chagaleru(DN Palli)	1-PT	45		15		17		
5	Kattalur	1-PT	24		32		37		
6	ChinnaKudala	1-CD	12			95		32	The rising pre-monsoon trend and the declining declining post-monsoon trends are attributed to poor rainfall coupled with excess irrigation.
7	Alavalapadu	2-CD	30			6	14		The rising trend during pre monsoon season can be attributed to the effect of recharge created due to AR and the declining trend in post-monsoon may be attributed to poor rainfall coupled with excess irrigation.
8	V. Kothapalli	1-CD	66			14	23		The rising trend during pre monsoon season can be attributed to the increased storage due to artificial recharge.
9	Kattalur (CD)	1-CD	34			9	19		The rising trend during Pre-monsoon period can be attributed to additional storage created by artificial recharge. Slight decline during post-monsoon may be due to poor rainfall and excess irrigation.
10	Ulimella	1-CD		7	6			5	The declining trend during pre monsoon period can be attributed to the increased groundwater draft during the project period.
11	Achavalli	1-CD	7		1			1	The rising trends during pre and post monsoon period can be attributed to the increased recharge created by the artificial recharge project.
12	Meedipentla (Rachakuntapalli)	1-CD		30	5			18	The declining trend during pre monsoon period can be attributed to the increased groundwater draft during the project period. Post monsoon water level rise owe to the increased recharge created by the artificial recharge project.
13	Mabbuchinthalapalli	1-CD	10		10		10		The rising trend indicate the improved groundwater situation from the additional resource created by the artificial recharge.
14	KK Kottalu	2-CD	21		36			6	Both the rising pre and post monsoon water level trends indicate the improved groundwater situation from the additional resource created by the artificial recharge.
15	Ambakpalli	1-PT 1-CD	61		68		59		The groundwater situation was improved by the additional resource created by the artificial recharge, which is reflected in the rising trend of groundwater.
16	Bonala	1-PT	56		34		33		

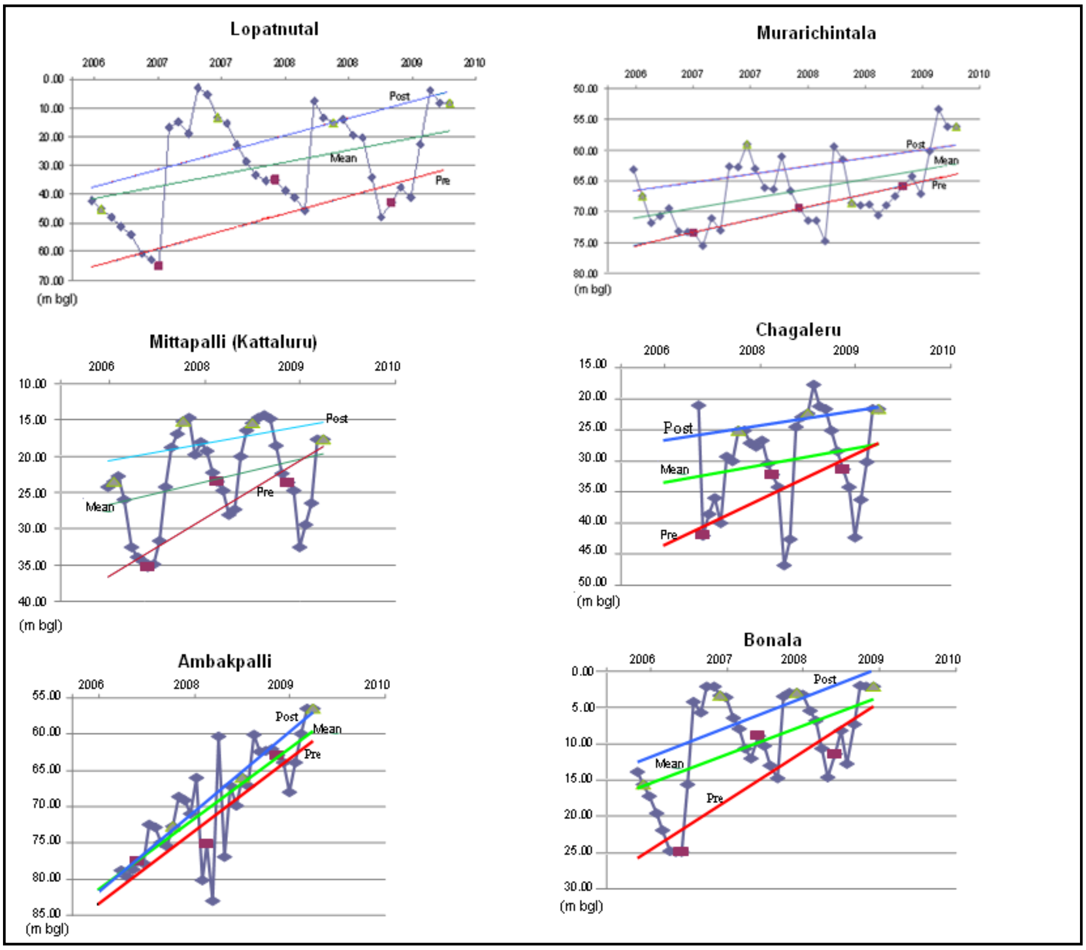

Fig. 6 Village wise Hydrographs of observation wells of Recharge Structures

has increased considerably at Murarichintala (about 12 ha.), Lopatnuthala (6 ha.), Chinnakudala (about 4 ha), and K.K.Kottalu (about 1 ha.), Kattaluru (about 1ha) villages and sweet lime orchid's in Bonala village has also increased by 15 ha. The area under irrigated dry crops (ID) like ground nut, sunflower, chillies etc have been reduced but farmers have resorted for cash crops like banana, sweet lime due to assured irrigation available by augmenting groundwater by creating the recharge structures. Due to creation of recharge structures, the yields of the bore wells increased by 15 to 20% and farmers were able to meet the peak crop water demand. It is noticed that due to increase in yields irrigation per bore well, was also increased from 1.25 to 1.5 ha. It is also observed that profit margins were also increased with the decreased cost inputs like purchasing water, laying of pipe lines and drilling additional bore wells at the time of peak demand.

6.3. Impact on Pumping Hours:

The data on the average discharges and impact on pumping hours for pre and post construction periods from the irrigation wells (**Table-5 and 6**) shows that as a result of recharge structures**,** the number of pumping hours had been increased during the Kharif and Rabi season in the zone of influence.

6.4. Impact on Drinking Water Sources:

The permissible limit of fluoride in drinking water is 1.5 mg/l. Higher concentration of fluoride causes health hazard "Fluorosis". The concept of groundwater recharge and quality improvement is often complementary in arid and semi-arid areas with depleted aquifers. In endemic fluoride area, the initial fluoride concentration in groundwater had reduced from 2 to <0.9 mg/l over the micro-watershed, which is below the permissible limit as per Indian drinking water standards, over a period of three hydrological cycles (Andrade Rolland, 2011). In the project area, dilution in concentration of fluoride is observed after construction of artificial recharge structures **(Table-7)**. In some villages like Achampalli, Mittapalli, Alavalapadu there is considerable dilution to the extent of 212, 197, 150 and 308 % respectively.

6.5. Impact on Socio-Economic Conditions:

Before construction of artificial recharge structures the availability of groundwater in the bore wells was hardly sufficient for the crop yields of rainfed/ID crops like groundnut and sunflower owing to acute shortage of water. Dug wells were dried up, and defunct. Farmers are forced to opt for drilling more number of deep bore wells incurring huge expenditure. The commercial crops

Table -4: Increase in Crop Yields and Electricity Savings in the Project Area

Sl. No	Name of crop	Increase in crop Yield %	Electricity saving in %
1	Ground nut	20-30	15-20
2	Sunflower	20-30	15-20
3	Citrus fruits	10-15	15-25
4	Banana	15-20	15-25
5	Miscelleneous	10-15	15-20

Table – 5: Average Discharges (in lps)

Month/Year	Lopat Nutala PT	Murari Chintala 1-PT & 3CD	Mittapalli (Kattaluru) PT	Chagaleru PT	Kattalur PT	Chinna Kudala CD	Alavalapadu 2-CD	V.Kothapalli CD	Kattalur CD	Ulimella CD	Meedipentla CD	MabbuChinthalapalli CD	KK.Kottalu 2-CD	Ambakpalli PT & 2CD	Bonala PT
Pre Project (Jan-May 2006)	1.70	1.75	1.50	1.25	1.40	1.30	1.25	1.30	1.10	1.10	1.25	1.40	1.50	1.75	1.00
Pre Project (Jun-Dec 2006)	3.50	3.00	3.25	2.25	2.25	3.00	2.00	2.25	2.00	2.00	2.10	3.15	2.25	3.50	2.75
Post Project (Jan-May 2008)	2.50	2.75	2.25	2.00	2.25	2.10	2.00	2.00	2.20	1.75	2.00	2.25	1.90	2.50	2.50
Pre Project (Jun-Dec 2008)	4.25	4.25	4.50	3.25	3.76	3.75	3.25	4.50	3.25	2.80	2.75	3.75	3.25	3.75	5.00

Table – 6: Pumping Hours

Month/Year	Lopat Nutala PT	Murari Chintala 1-PT & 3CD	Mittapalli (Kattaluru) PT	Chagaleru PT	Kattalur PT	Chinna Kudala CD	Alavalapadu 2-CD	V.Kothapalli CD	Kattalur CD	Ulimella CD	Meedipentla CD	Mabbu Chinthalapalli CD	KK.Kottalu 2-CD	Ambak palli PT & 2CD	Bonala PT
Pre Project (2006-07)	830	1250	640	560	720	1120	440	570	540	360	660	950	1020	1260	420
Post Project (2007-08, 2008-09)	1680	1890	980	980	1060	1820	840	1050	840	540	1080	1620	1460	1800	1200

like banana and citrus orchards (Sweet lime) were badly affected. This scenario had been reverted after construction of artificial recharge structures. The availability of additional storage created made it possible to provide 2-3 numbers of wettings to the ID crops during the Rabi season which resulted in increase of crop yields by 20 to 25%. In addition the amount spent towards purchasing water, laying pipe lines for 4-5 km distance, maintenance of pipelines etc., was also saved. Farmers stopped purchasing water and were able to save the citrus crops in about 80 ha in the Bonala village. The total savings towards one hectare of citrus crop/year was estimated to be Rs. 4,000/- and total savings in the entire area of Bonala village alone is worked out to be Rs. 3.2 Lakhs/ year during the study period.

Table-7: Fluoride concentration (mg/l) in different periods

S. No	Location	Pre-Implementation Period (Post Monsoon 2006)	Post-Implementation Period (Post Monsoon 2008)
1	Alavalapadu-1	3.74	2.5
2	Alavalapadu-2	2.77	0.9
3	Chagaleru-1	1.44	1.2
4	Chagaleru-2	1.61	1.5
5	V. Kothapalli-1	1.1	1
6	V. Kothapalli-2	1.48	1.2
7	Mittapalli-1	1.86	1.5
8	Mittapalli-2	3.16	1.6
9	Ulimella	2.13	1.6
10	Achavalli	6.15	2.9

7. Conclusions:

Demonstrative Artificial Recharge Project was implemented successfully in the present area. As per the aims of the project, the declining water levels were arrested, the yield prospects of the wells were improved. The drying up of bore wells was minimized and the sustainability of pumping and pumping hours was increased. Farmers have stopped purchasing the water and transporting through tankers and pipelines. Crop yields and crop production were increased. The quality of groundwater was improved through dilution in respect of fluoride content. Rural employment was generated under the National Rural Employment Guarantee Scheme and the migration of people for want of works was minimized.

The study demonstrated that the artificial recharge, if implemented scientifically, augments groundwater resources for sustainable management. The success story can be replicated in similar hydrogeological environs.

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