RS and GIS based integrated study on hydrogeomorphic unit wise ground water quality evaluation for Nalgonda district, Telangana state

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Abstract: Groundwater is the main source of water for domestic, agriculture and industrial uses especially in water scarce semi-arid regions. About 85% of rural and nearly 30% of the urban population depend on ground water for drinking and accounts for nearly 65% of the total irrigation potential in the country. The availability of ground water is dependent on many factors like geological history of the area, geomorphology, rainfall, geological structures that are controlled through the earth's history, porosity and permeability of soil or rock formations, depth of weathering and nature of weathered material etc. The quality of ground water deteriorates when there is overdraft of water for agriculture and industrial uses. The phreatic aquifer which was in use two decades ago, is not existing any more in major part of the study area and the water is being drawn from deeper aquifers beyond phreatic aquifers. As the ground water is the main source, states are being guided to prepare watershed wise Sustainability plans for all over-exploited blocks in the country for taking up groundwater recharge and water harvesting structures by converging different schemes of MNREGS, NRDWP etc. This will improve the condition of ground water in space and time. An integrated remote sensing and GIS study is taken up for Nalgonda district for studying the hydrogeomorphic unit wise ground water quality variation and its impact by using other collateral data like soils, land use, command area, ground water exploitation, rainfall etc.

Keywords: Ground water quality, Hydrogeomorphology, GIS, Remote sensing, Sustainability, Drinking water, Health, Water harvesting

1. Introduction

Nalgonda district, spread over a geographical area of 14,210 km^2 and with a population of 34,88,809 as per 2011 census, is chronically drought affected. Out of the total net area irrigated, about 36% is from surface water and 64% from ground water sources. This clearly indicates the stress on ground water in the district.

The objective of the work is to study hydrogeomorphology or ground water prospects unit wise ground water quality evaluation in relation to various parameters affecting it, like lithology, geologic structure, Land use and land cover, soils, rainfall and slope to know their relationship with one another. While rainfall is the source of recharge, geomorphology plays a vital role in controlling distribution of precipitation, runoff and infiltration contributing to recharge. Sustainability of ground water dictates that its extraction should be at a rate which does not exceed annual recharge and does not lead to ground water mining.

2. Study area

The Nalgonda district lies in between 16° 25' and 17° 50' North Latitudes and 78° 40' and 80° 05' East Longitudes covering the Survey of India toposheet Nos. 56 K, L, O, and P. It is bounded on the north by Medak and Warangal districts; on the south by Andhra Pradesh state and partly with Mahabubnagar district; on the east by Khammam and Andhra Pradesh states; on the west by Mahabubnagar district and partly by Ranga Reddy district (Figure 1) respectively.

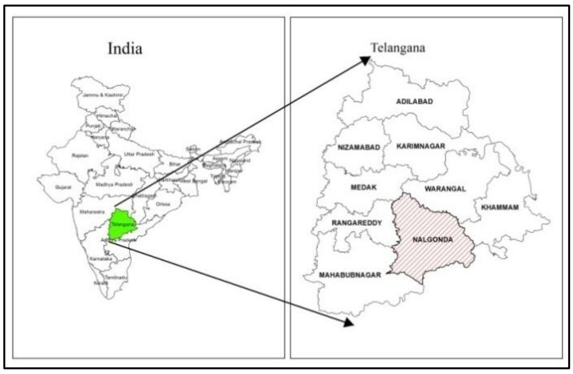

Figure 1: Location map of the study area

2.1 Physiography of the study area

Physiographically, the terrain, except for a small portion in the south, is a gently undulating country with hummocky hills, rocky knobs, denudational hills, ridges and inselbergs. The southern part of the district along the northern bank of Krishna river is a plateau. Based on photo-geological studies the terrain can be classified in to four major geomorphic units, viz, Denudational hills, dissected pediments, pediplains and valley fills. The mean elevation of the terrain is 150 m above mean sea level and general slope is towards southeast. The general drainage pattern in the granitic country is coarse dendritic to sub-dendritic, whereas in the lime stone dominant sediments, a trellis to radial pattern is found. Major rivers include Krishna, Dindi, Peddavagu, Musi, Aler, Hallia, Kongal and Paleru, which form a part of Krishna river basin.

2.2 Geology andhydrogeology of the study area

The district forms a part of the stable Indian Peninsular Shield consisting of older Metamorphics, Peninsular Gneissic Complex (PGC), Dharwar Supergroup, Cuddapah Supergroup and Kurnool group of rocks. The Archaean crystalline rocks, which occupy 90% of the district, comprise granites, gneisses, schists and intrusives. The hornblende schists and amphibolites (Older Metamorphics) which are the oldest rocks occur as rafts, enclaves and discontinuous linear bands, within the Peninsular Gneissic Complex. The PGC occupies a major part of the district and comprises migmatites, granites, granodiorite, tonalite-trondhjemite suite of rocks and hornblende-biotite schists. The PGC and Dharwar rocks are intruded by younger granites, basic dykes and quartz-pegmatite veins.

In the southern part of the district along the northern bank of the Krishna river rocks of Archaean PGC are unconformably overlain by sedimentary rocks, constituting the Cuddapah Supergroup in the district is predominantly made up of arenaceous and argillaceous sediments respectively, represented by quarzite and shale of Cumbum Formation (Nallamalai Group) and SrisailamQuarzite. The Kurnool Group of rocks comprises calcareous (chemical precipitates) sediments and quartzite. These consolidated meta-sedimentary rocks of Cuddapah and Kurnool system comprising limestones, quartzites and shales occupy 9% in the southern part of the district.

The unconsolidated deposits comprising alluvial sands,clay occur as isolated and narrow patches along the major rivers and streams occupying around 1% of the area.

2.3 Soils

The soils of the district are mostly consisting of Red soil. Among the red soils 47% is Loamy soil, which has a very low moisture retaining capacity, and the rest is chalka soil, forming 44%. The fertile black cotton soil forms only 9% and occurs on the banks of Krishna and in isolated patches. Black soils of significant areal extent are found in the southeastern part of the district of where limestone formation occurs. Alkaline soil occurs as limited minor patches in the central part of the district. Alluvial soils occur along Alair, Musi and Kargal river valleys.

2.4 Land use

As per the Land use classification on 1:10,000 scale prepared by using high resolution (Cartosat–1 Pan + LISS-IV Mx) orthorectified satellite imagery (2013-2014), out of total geographical area of the district, agriculture land is 10,038 km^2 (71%); waste lands is 1,929 km^2 (14%); forest area is 706 km^2 (5%); water body is 1,006 km^2 (7%); built up land is 531 km^2 (4%) respectively.

3. Groundwater development: A spatiotemporal analysis

Groundwater is an invisible resource and the laws governing its storage, movement and exploitation are distinct from those of surface water.

3.1 Estimates of groundwater in Telangana

Based on Groundwater resource Estimation Committee report (GEC 2011), the annual replenishable ground water resource is 15.09 bcm of which the net ground water availability after deducting for natural discharge during non-monsoon season is 13.67 bcm. The annual ground water draft for irrigation, domestic and industrial uses combined is 7.5 bcm. The stage of ground water development in the state is 55% which is falling in safe category. Out of 447 mandals in the state, 343 mandals are falling in safe category, 55 mandals in semi-critical, 8 mandals in critical and 41 mandals in over exploitation category.

3.2 Estimates of groundwater in Nalgonda

Based on Groundwater Resource Estimation Committee (GEC-97) report 2010-11, the annual replenishable ground water resource is 2.11 bcm of which the net ground water availability after deducting for natural discharge during non-monsoon season is 1.91 bcm. The annual ground water draft for irrigation, domestic and industrial uses combined is 1.14 bcm. The stage of ground water development in the district is 59% which is falling in safe category. There are 47 mandals in safe category, 10 mandals in semi-critical, 1 mandal in critical namely Chandurmandal, and 1 mandal in over exploitation category namely Munugodemandal.

3.3 Why is water quality an issue?

In India about 73% waste water generated from different sources is being left out to rivers, canals, tanks or in to the Ground without proper treatment for which the ground as well as surface waters are at threat qualitatively. Water quality monitoring should be taken up regularly for taking up preventive measures in advance so that there may not be any health problems.

4. Methodology

The ground water quality data pertaining to Nalgonda district during the period from 2012-14 is collected for pre and post monsoon seasons separatelyfrom line department (Rural Water Supply & Sanitation Department, Govt. of Telangana). The drinking water sources are essentially Bore wells / Hand pumps with depth ranges varying from 30-90 metres. It consists of the ground water quality data pertaining to 9 elements pertaining to (1) Total Dissolved Solids (TDS), (2) Total Hardness (TH), (3) Fluoride (F), (4) Total Alkalinity (TA), (5) Chloride (Cl) & (6) pH. The legacy Ground water prospects maps prepared under Rajiv Gandhi National Drinking Water Mission (NRSA, 2007; NRSA, 2013) are used for correlation with respect to quality.

Contamination spread of element-wise distribution from a single element to 9 elements are plotted against to each habitation for pre and post monsoon seasons separately and its spatial distribution is studied using satellite remote sensing techniques (IRS P-6 LISS III, 2012-13) and with respect to other collateral data as mentioned below:

1. Geology
2. Geomorphology
3. Hydrogeomorphology
4. Groundwater Exploitation (GEC) report
5. Forest layer
6. Irrigation command area map
7. Rainfall data
8. Land use land cover
9. Soils

5. Results and discussion

5.1 Groundwater prospects

The occurrence and spatial distribution of ground water is not uniform throughout the district and it is dependent on different aspects like porosity and permeability of underlying rock / soil formations, structural fabrics, distribution of water bodies and slope etc. Due to erratic rainfall there is tremendous stress on ground water for meeting the agriculture needs in the district and consequently many of the existing wells are getting dried-up due to depletion of water table as the natural recharge is not sufficient. Ultimately this leads to water quality problems for the elements like Fluoride, Total Hardness, and Total Dissolved Solids etc day by day.

Satellite data provides cost and time effective information on different variables like hydrogeological properties of geological materials, distribution of water bodies, and history of regional structures etc that govern the availability and movement of ground water by integrated study of different factors and evaluating the ground water condition of an area. By using the IRS-1C/1D, LISS-III satellite data the ground water prospects maps are prepared under Rajiv Gandhi National Drinking Water Mission (RGNDWM) project (NRSA, 2007; NRSA, 2011). The hydrogeomorphic units are derived by integrating lithology and land forms layers.

The following (Table 1) are the different hydrogeomorphic units depicted based on integrated satellite remote sensing study in the study area:

Table 1: Hydrogeomorphic units

Geomorphic Unit	**Area (km^2)**	**Percentage**
Hills	724	5
Pediment	1070	8
Pediplain Shallow (PPS)	6868	48
Pediplain Moderate (PPM)	3510	25
Plateau	837	6
Valley	215	2
Alluvium / Flood Plain	75	1
Waterbody	911	6
Total	**14210**	

5.2 Groundwater quality study in pre-monsoon season

The following is the status of element-wise number of sources potable and or contaminated during the pre monsoon season (Table 2).

Table 2: Status of sources in pre-monsoon season

Total sources quality tested	19,407	-
All elements potable	10,001	51.53%
At least one element quality affected source	9,406	48.47%

The following is the list of number of elements contaminated with respect to total number of sources affected during pre-monsoon season (Table 3andFigure 2):

Table 3: Status of percentage of elements contamination

Sl No	**Element(s) contaminated**	**Total sources quality affected, nos**	**% of quality affected to total sources in Nalgonda dist.**
1	1	5,933	30.57 %
2	2	1,952	10.06 %
3	3	943	4.86 %
4	4	448	2.31 %
5	5	115	0.59 %
6	6	12	0.06 %
7	7	3	0.02 %

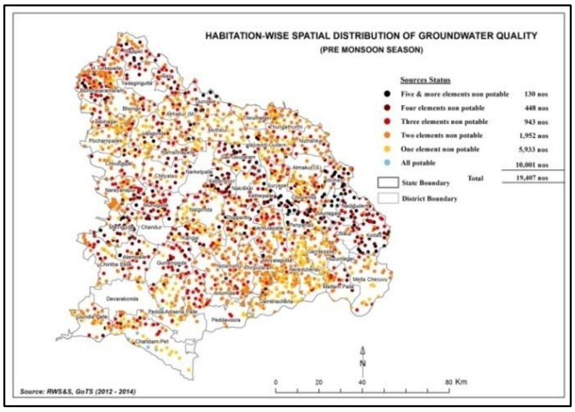

Figure 2: Element wise ground water quality during pre monsoon season

The following table shows the major contaminated elements out of total quality tested sources in Nalgonda district (Table 4).

Table 4: Status of percentage of major elements

Only Fluoride contaminated	14.32 %
Only Iron contaminated	9.07 %
Only TDS contaminated	5.24 %
TDS & TA contaminated	3.32 %
TDS, TH, TA contaminated	2.71 %
TDS & F contaminated	2.51 %
F & Fe contaminated	2.10 %
No3 contaminated	1.36 %
TDS & Iron contaminated	0.80 %
Other elements combinations of contamination	0.63 %
All potable sources	57.94 %

5.3 Groundwater quality study in post-monsoon season

The following is the status of element-wise number of sources potable and or contaminated during the post monsoon season (Table 5).

Table 5: Status of sources in post-monsoon season

Total sources quality tested	19,408	-
All elements potable	10,247	52.80 %
At least one element qualityaffected source	9,161	47.20 %

The following is the list of number of elements contaminated with respect to total number of sources affected during post-monsoon season (Table 6andFigure 3):

Table 6: Status of percentage of elements contamination

Sl No	Element(s) contaminated	Total sources quality affected, nos	% of quality affected to total sources in Nalgonda dist.
1	1	5,930	30.55 %
2	2	1,849	9.53 %
3	3	895	4.61 %
4	4	386	1.99 %
5	5	87	0.45 %
6	6	12	0.06 %
7	7	2	0.01 %

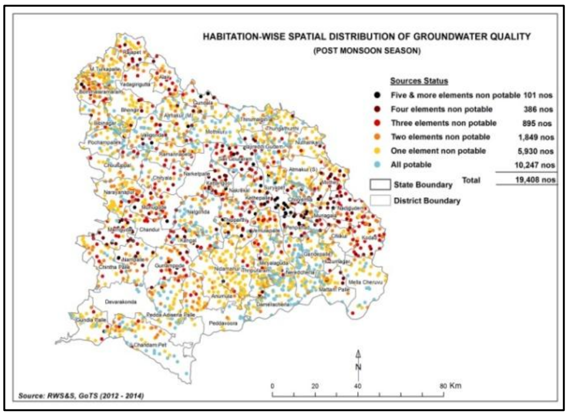

Figure 3: Element wise ground water quality during post monsoon season

The following table shows the major contaminated elements out of total quality tested sources in Nalgonda District (Table 7):

Table 7: Status of major contaminated elements

Only Fluoride contaminated	14.34 %
Only Iron contaminated	9.08 %
Only TH contaminated	4.94 %
TH & TA contaminated	3.29 %
TDS, TH, TA contaminated	2.64 %
F &Fe contaminated	2.07 %
No3 contaminated	1.80 %
TDS, TA, F contaminated	1.22 %
TH & Iron contaminated	1.09 %
TH & F contaminated	0.98 %
Other elements combination contamination	0.56 %
All potable sources	57.99 %

5.4 Groundwater quality vs groundwater prospects during pre and post monsoon seasons

Hydrogeomorphic unit wise ground water quality variation is studied using satellite remote sensing techniques. It is observed that the major ground water quality problem exists in granitic terrain as compared to Meta-sedimentary rocks.

It is observed that majority of the area is contaminated with at least 2 or 3 elements from a combination of F, TDS, TH, TA, Fe, No3. The Fluoride contamination exists predominantly in older Metamorphics, Dharwar Supergroup and Peninsular Gneissic Complex (PGC) except Grey Hornblende Granite rock formations, whereas, it is minimal in Meta-sedimentary formations belonging to Cuddapah Supergroup and Kurnool Group of rocks. In command areas underlain by Grey Hornblende Granite, the contamination is observed with at least 2 elements from a combination of TDS, TH, Fe, or No3 only. The density of fluoride affected sources is very less in Grey Hornblende Granite as compared to other rock formations like Grey / alkali feldspar Granite, Leuco Granite, Grey biotite granite gneiss etc. The Majority of Chloride contamination (in command as well as no-command areas) is dominated in the areas underlain by Grey / alkali feldspar Granite.

Major geomorphic unit wise quality variation is studied in conjunction with other ancillary data. It has been observed that in plain areas, as compared with shallow (PPS) and moderate (PPM) weathered zones, percentage of contaminated sources is 55% in PPM areas whereas in that of PPS it was 45% only. There is major contamination for a combination of one or two elements from F, Fe, TDS/TH in plain areas. In pediment zones 43% sources are contaminated of which the majority of sources are affected with one or two elements from F, Fe, TDS/TH. In plateau areas (meta-sedimentary rocks), 29% sources are quality affected of which the majority of the sources are contaminated with at least one element from TDS/TH or Fe only. In Valleys portions 49% of the sources are contaminated primarily one or two elements combination from F, Fe, TDS/TH. In Alluvium areas 45% sources are contaminated for which the majority of the sources are at least one or two elements from a combination of F, TDS/TH. In post monsoon season, the TH contamination is more as compared to TDS. It is observed that longer residence time in aquifers with fractured fluoride rich rocks increases fluoride levels in the groundwater.

5.5 Groundwater quality vs rainfall

The mandal wise average normal rainfall for the past 21 years is calculated based on the data collected from the Directorate of Economics and Statistics for studying quality problem with respect to rainfall. It is found that the rainfall is inversely related to ground water quality i.e. in high rainfall areas there will be less quality problem is there. It is observed that in low rainfall areas (Below 652 mm), there is contamination of 59% of sources for at least one element whereas in 653-802 mm rainfall areas the percentage of quality affected sources is 47% and it is 45% in 803-953 mm rainfall areas. This clearly indicates that rainfall is also one of the contributing factors for water quality.

5.6 Waterconservation and artificial recharge

For ground water conservation and artificial recharge, number of structures have been constructed since 1995 by District Water Management Agency (DWMA) in a big way in the district under DPAP, IWDP, RIDF, APRLP, EAS, NEERU MEERU and other programmes in the non- command area. About 3,684 Hactares land is brought under irrigation facility up to 2012-13under different watershed programmes in the district. During 2011-15, about 5,847 water harvesting structures like Recharge of dried up open wells, farm pond, percolation tank, dugout pond, Gabion WHS, sub surface dykes, check dam, recharge of dried up bore wells, recharge pit etc., are taken up.

The rain water harvesting structures sites must be selected scientifically on watershed basis especially in non-command areas on war foot basis for the benefit of farmers/people as well as for drinking water purpose, as most of the water is being used for agriculture and industrial needs. As per the hydro-geomorphic study in the area, most suitable recharge structure is percolation tanks / check dams. In addition, gully controls and bunding may be taken up where considerable gradient and length of slope is available. For those who take up roof top harvesting structures in urban and rural areas should be given incentives for enhancing groundwater recharge.

5.7 Groundwater quality: Causes, implications and mitigation measures

Out of a total of 19,408 sources quality tested; about 4,208 sources (22%) have been affected with fluoride during pre and post monsoon seasons. Fluoride is the major element contaminated in the district. The district is witnessing the dental as well as skeletal Fluorosis and is a renowned place in the world.

Fluoride is one of the important micronutrient in humans which is required for strong teeth and bones. Fluoride concentration of at least 0.6 mg/l is required for human consumption as it will help to have stronger teeth and bones. BIS (Bureau of Indian Standards) (1992) has prescribed the range of fluoride from 0.6 to 1.0 mg/l in drinking water as suitable for human consumption and has set the maximum permissible limit of fluoride in drinking water to be up to 1.5 mg/l. Drinking groundwater with fluoride concentration above 1.50 mg/l is the main cause of fluorosis in the area. The other possible sources of intake of fluoride apart from drinking water are through food, beverages and dental products like tooth paste.

As the district is falling in semi-arid tract, due to which the intake of ground water is more as compared to other non-tropical areas. This is also causing to increase the fluorosis problem. Phosphate containing fertilisers add up to the fluoride content in soil and groundwater (Motalane and Strydom, 2004; Farooqi et al., 2007). Intake of fluoride higher than the optimum level is the main reason for dental and skeletal fluorosis. The health outcome by consuming fluoride at different concentration was given by Dissanayake (1991) i.e. when fluoride concentration in drinking water is below 0.5 mg/l it causes dental carries; fluoride between 0.5 to 1.5 mg/l results in optimum dental health; 1.5 to 4 mg/l causes dental fluorosis; 4to 10 mg/l induces dental and skeletal fluorosis while fluoride above 10 mg/l results in crippling fluorosis. However, fluorosis results not only due to the presence of high concentration fluoride in drinking water but also depend on other sources such as the dietary habits which enhance the incidence of fluorosis. The malnutrition adds to fluorosis. If sufficient dietary food is taken, there are chances of less effect on fluorosis.

Exposure to very high fluoride over a prolonged period of time results in acute to chronic skeletal fluorosis. It was stated in 1993 that crippling skeletal fluorosis might occur in people who have ingested 10 to 20 mg of fluoride per day for over 10 to 20 years (National Research Council, 1993). The district has high fluoride due to the inherent fluoride rich granitic rocks. The granitic crocks in Nalgonda district contain fluoride from 325 to 3200 mg/kg with a mean of 1440 mg/kg as compared to the world average fluoride concentration of 810 mg/kg (Wedepohl, 1969).

When the fluoride rich water is used for agriculture purpose, the fluoride is entering in to the food grains indirectly and when these food grains are consumed, the concentration of fluoride is getting added to fluoride rich drinking water.

To mitigate the fluoride problem, one should shift to safe ground water sources available nearby or use the defluoridated and safe drinking water with changing dietary habits like to avoid use of fluoride rich foods like black rock salt, canned fruit juices / other domestic market products etc. Avoid use of fluoride rich dental products or drugs. Use food which is rich in Calcium, Vitami C, Anti-Oxidants etc.

High TDS in ground waters causes Gastrointestinal irritation and may damage the kidneys in human beings.

Iron although having Aesthetic taste and is an essential for human health [Heamoglobin Synthesis], but its excess is stored in Spleen, Liver, Bone marrow & causes Haemochromatosis.

Nitrate if beyond 45mg/l in drinking water, methaemoglobinamia takes place and may be indicative of pollution

The most common problem associated with ground water after Fluoride and TDS is hardness, caused by an abundance of calcium or magnesium ions. Hard water causes no health problems, but it may cause soap curds to form on pipes and other plumbing fixtures.

6. Discussion

Various hydro-geomorphic units are classified as high, medium low and poor zones of groundwater. Groundwater development is more promising in the alluvial plains, which are associated with thick alluvium and weathered material due to high porosity and permeability which are limited in the area. Shallow (< 10m) and moderate (10-20m) weathered pediplains are distributed in majority of the area and they can be classified as medium to good favourable zones of groundwater. Dissected pediment zone with poor weathering and rugged appearance is a poor zone of groundwater. The geomorphological units like residual hills and linear ridges acts as runoff zones. Other observations are as follows:

- Overall water quality of the study area was found unsatisfactory for drinking purposes. Pollution of the groundwater due to geogenic and anthropogenic factors often render the groundwater unsuitable as consumption of such water can lead to various health-related complications.

- The occurrence and quality of groundwater in an area is largely controlled by rainfall and the characteristics of the terrain features like landforms, geology, soil, drainage, topography. The information provided in the groundwater prospect zones helps in identifying areas suitable for artificial recharge to ensure sustainable groundwater draft.

- The intake of fluoride above the permissible limit in drinking water is the major reason for both dental and skeletal Fluorosis diseases in part of the study area.

- For fluoride mitigation preventive measures like taking safe drinking water with sufficient dietary food needs to be encouraged.

- Health education with focus on fluoride toxicity and the need to avoid fluoride consumption to be encouraged to each and every citizen.

- Training for local government functionaries, NGOs, voluntary organizations engaged in watershed development activity are to be trained in scientific techniques in the selection of sites, design of structures, etc. for construction of rainwater harvesting and artificial recharge structures.

- Conjunctive use of groundwater and surface water are to be encouraged for irrigation purpose to enhance yield potential and at the same time improving the water quality in non-command areas and minimizing the water logging threat in command areas.

- Mass awareness programmes need to be conducted on regular basis in the rural areas to educate the farmers regarding the water management like water saving methods or to use less water consuming crops like maize, jowar etc and to update their knowledge.

7. Conclusions

The utility of remote sensing and GIS technique helps in delineating groundwater prospects zones as well as to relate its association with ground water quality. It is observed that the percentage of contaminated sources is more in high yielding hydrogeomorphic units as compared to less yielding hydrogeomorphic units in non-command area as it is wholly dependent on ground waters for all its uses. From the study the following conclusions can be made:

- As the non-command area is extensive, there is tremendous pressure on ground water for agriculture and industrial uses which results in pollution of ground water resources and in future these limited resources will not be able to meet the water demand qualitatively and quantitatively. Therefore, it is imperative to make the fruitful long term planning like transfer of perennial river water to the area to conserve these resources and utilize it in systematic way for the maximum benefit of society.

- Groundwater conservation and artificial recharge structures are needed to be taken up watershed wise on war footing, on scientific lines, for enhancing the groundwater storage so as to make the existing bore wells sustainable.

- Scientific mapping of resources needs to be taken for preventing quality problem with remedial measures. It is important to look for holistic and people-centred approaches for water management.

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