AN INTEGRATED RS&GIS BASED EVALUATION OF GROUND WATER QUALITY IN TELANGANA STATE, INDIA

Aswini Kumar Das [1], Prathapani Prakash [2] & G. Sreenivasa Reddy [3]
Telangana State Remote Sensing Applications Centre (TRAC), B-Block, Ameerpet, Hyderabad - 500 038, India
E-Mail - [1] aswini.das81@gmail.com, [2] prakashmhbd@gmail.com & [3] gantasreddy@gmail.com

KEY WORDS: Chemical element, Geology, Geomorphology, Ground Water, Landform, Quality, Rural, Source.

ABSTRACT: About 85% of drinking water needs in rural and 40% drinking water needs in urban areas are met from groundwater resources in Telangana state. There is a huge demand of ground water for different uses like agriculture, drinking and industrial purposes as the command area is very low in the state and it is evidenced by the fact that around 70% irrigation is dependent on ground water sources as compared to other surface sources like Tanks/Canals/Reservoirs etc. Climate change has affected the hydrological cycle with uncertain and increased variability in rainfall followed by with high rainfall in a short span of time resulting more surface runoff which ultimately decreases the recharge to groundwater. Decreased recharge to the groundwater and excess withdrawal of groundwater has accelerated the depletion of groundwater resources there by resulting in stress on groundwater regime in terms of quality as well as quantity. The groundwater quality evaluation of Telangana state is carried out by using legacy quality data (2012-14) collected from Rural Water Supply & Sanitation Department, Government of Telangana. Contamination spread of groundwater is one of the most important concerns that have received attention at regional, local and global levels because of their importance on public health and its further impact in ecosystems. The spatial distribution of chemical parameters like pH, Total Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Fluoride (F), Chloride (Cl), Iron (Fe), Nitrate (NO3) and Sulfate (SO4) are examined with respect to its contamination level. The spatial distribution and concentration of chemical elements is carried out by using spatial interpolation technique namely Inverse Distance Weightage (IDW) method from the point source data. The distribution maps reveal important information to understand the hot spot areas of the groundwater systems and for identification of potential areas for providing safe drinking water supply. Site specific water conservation and artificial recharge measures are needed to be taken up with scientific lines by using Remote Sensing & GIS techniques, for enhancing the groundwater storage and also improving its quality.

1. INTRODUCTION

The newly formed 29th state of Telangana is located in the southern peninsula of India is spread over a geographical area of 1, 11,834 Sq. Km and is the 12th largest State in terms of both area and population. The State is bounded on the north by Maharashtra, Madhya Pradesh, and Chhattisgarh States, on the west by Karnataka and Maharashtra States, on the east and south by Andhra Pradesh states. As per 2011 census, the state has a population of 3.5 crore and households of about 83.03 Lakhs. There are 10 districts in Telangana namely Adilabad, Karimnagar, Nizamabad, Warangal, Khammam, Nalgonda, Medak, Ranga Reddy, Mahbubnagar and Hyderabad. The state has a total of 444 Mandals (Taluqs); 11,160 villages; and 24,423 Habitations.

Water is a primary source of life and sustains all human activities such as domestic needs, agriculture, and industries etc. The allocation and management of water resource is becoming a difficult task due to increasing demands; decreasing supply and diminishing quality. This calls for judicious use and management of water resources.

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 the annual recharge.

2. STUDY AREA

Geographically the state lies in between northern latitudes of 15° 48’ and 19° 54’ and; eastern longitudes of 77° 12’ and 81° 50’. The location of the study area is as shown in Figure 1.

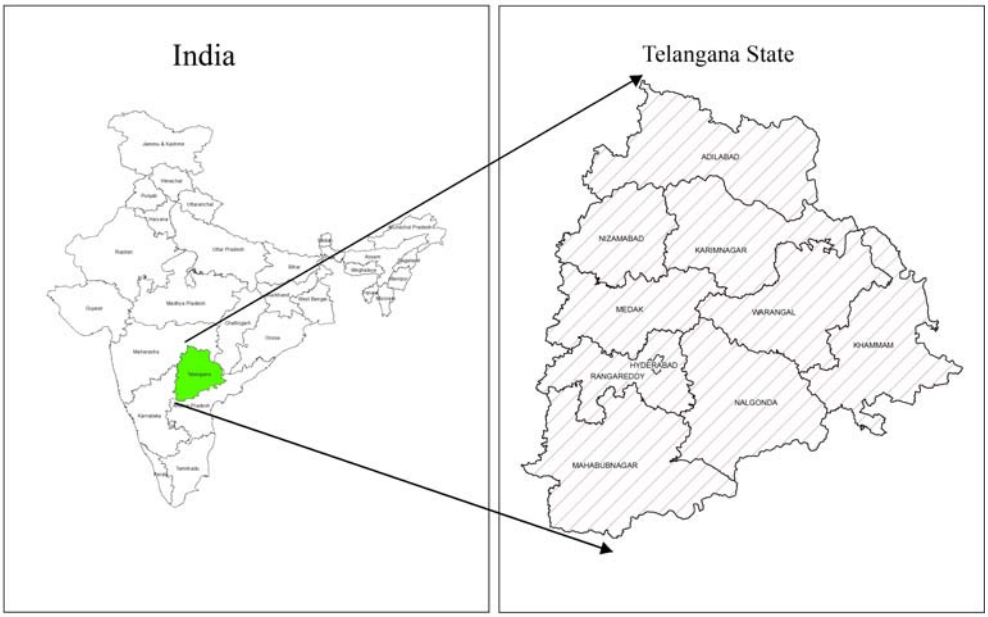

Figure 1. Location Map of the Study Area

3. GEOGRAPHY

Telangana state is drained by two major rivers, Krishna and Godavari. The river Godavari flows on the north, whereas Krishna flows in the south. Apart from these rivers, there are other small rivers such as Bhima, Dindi, Manjeera, Manair, Kinnerasani, Moosi etc, which also flow through Telangana. It has a forest area of around 23% of total area. It also has a vast coal deposit and around 20% of India's coal deposit lies in Telangana. The coal produced from this region is supplied to the states in south India. The state can broadly be divisible into two physiographic units namely (a) Gondwana graben and (b) the Deccan Plateau forming a wide expanse of flat to low-undulatory terrain of plains and small hills. The Plateau region is dotted with hills of low to moderate height, some of which rising to more than 1000 m above MSL.

4. RAINFALL

The average annual rainfall of the state is 923 mm of which about two-thirds is contributed from southwest monsoon season (June - September) of the annual rainfall and remaining covers from northeast monsoon (October to December) and other months. But the spatial distribution of rainfall is not constant and varies significantly from 732 mm in Mahabubnagar district to 1,121 mm in Adilabad district. It increases from less than 800 mm in southwest part of the state to more than 1,200 mm in north and northeastern part of the state. During the last decade the rainfall is erratic and does not follow the crop calendar.

5. WATER RESOURCES

5.1 Surface Water Resources

There are two major river basins namely Godavari and Krishna. The Godavari basin covers about half of northern Telangana state and remaining half of southern part is covered by Krishna basin. There are about 1,036 TMC of water in Godavari basin and 554 TMC of utilizable surface water resources in Krishna basin are there in the state, whereas availability of water as per records does not exceed 150 TMC in both the basins. This indicates the under utilization of river water sources in Telangana state though geographically about 70% of Telangana land is suitable for irrigation.

5.2 Ground Water Resources

Groundwater resource of the state is estimated on a regular basis by the Ministry of Water Resources (MoWR) in close collaboration with the Ground Water Department of Government of Telangana. As per recent Dynamic Ground Water Resources (2012-13) estimations, the annual replenishable ground water resources are estimated to be 15.54 BCM; out of which the net ground water availability is 13.67 BCM and Annual Draft for all uses like

Agriculture / Industry / Drinking combined is 7.50 BCM; and the state of ground water development expressed as a ratio of utilization to recharge is 55% which is falling under 'safe' category.

The assessment is carried out for 484 watershed assessment units spreading across the state of Telangana state. Recharge computations have been made separately for ayacut (command) and non- ayacut (non-command) areas. Out of a total geographical area of 1,11,834 Sq. Km in the state of Telangana, the ground water recharge worthy area is 1,00,575 Sq. Km and it is spread across of about 20,137 Sq. Km in command areas; and 80,437 Sq. Km in non-command areas. Out of the net annual ground water availability of about 13.67 BCM, it is 3.96 BCM in command areas and 9.71 BCM in non-command areas. Current gross annual ground water draft for all uses is 2.03 BCM in command areas whereas it is 5.46 BCM in non-command areas. Thus most of the groundwater development is confined to the non-ayacut areas.

5. GEOLOGY

The geology or rock types describe the environment in which the hydro-geological processes operate. A strong mutual correlation exists between geological variables and hydrological characteristics. Such relationship can be applied to both surface and groundwater regime. The state of Telangana is characterized by wide ranges of geological formations varying in age from Archaean to Recent times. Nearly 88 % of the state is underlain by hard rocks i.e. consolidated formations belonging to the Older Metamorphics; Peninsular Gneissic Complex; Pakhal Group of rocks belonging to Middle to Upper Proterozoic age; and Deccan Traps. The principal rock formations in hard rocks are Granite varieties (52 %), Gneiss varieties (14 %), Older Metamorphics (3 %), Pakhal group of rocks like Arkose / Quartzite / Sandstone / Lime Stone / Shale / Phyllite are occupied with around 11 % of total state area, and Deccan Trap Basalts are covered by 8 % of total areas. These rocks lack primary porosity and ground water occurrence is controlled by extent of weathering and fracturing. The thickness of weathering generally varies from 1 to 20 m and occasionally up to 40 m. The yield of bore wells depends on the number of fractures encountered.

About 12% of Telangana State is underlain by semi-consolidated sediment formations encompassing Gondwanas, Tertiary group of formations and Sub-Recent to Recent unconsolidated sediments. The principal rocks in these loose formations are Sandstone / Shale / Clay / Alluvium etc. In Gondwana formations, the Ground water occurs under unconfined to confined conditions and are the most promising aquifers in the state. The unconsolidated formations are represented with inland river alluvium. The alluvial aquifers have high porosity and permeability. Filter points are most common in these formations drilled to a depth of 1.5 to 20 meters below ground level (m bgl).

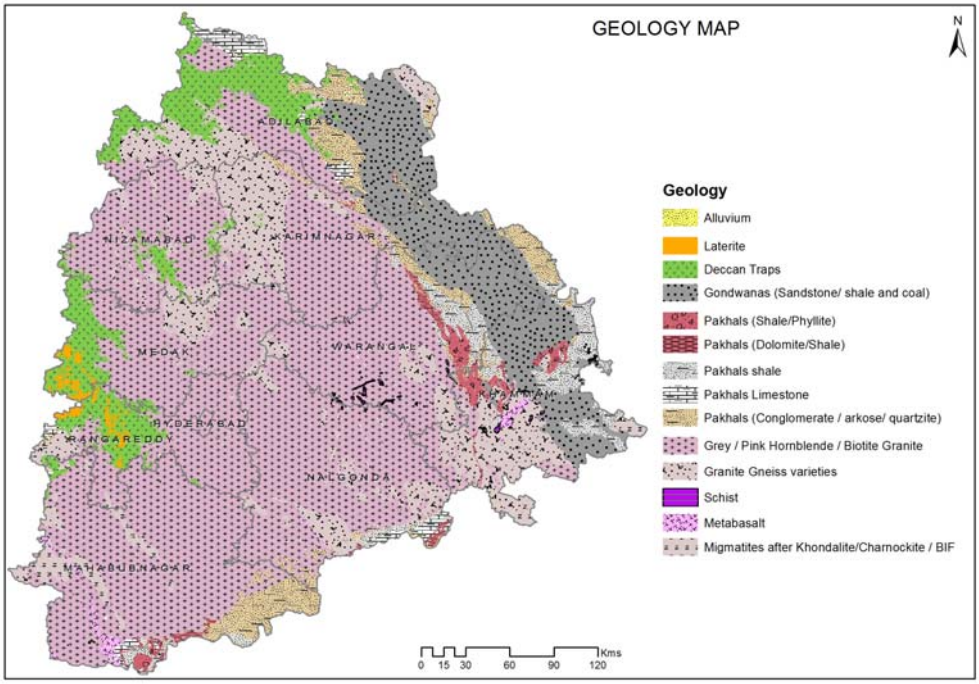

Figure 2. Geology Map of the Study Area

6. GEOMORPHOLOGY

The present day landforms are essentially the byproducts of different geomorphic processes such as erosion/denudation, deposition and crustal movements and climatic changes since Archean eon. The geomorphological map of Telangana state as interpreted from IRS-P6 LISS-III satellite imagery with limited field checks as given in figure 3. The major landforms in the state includes Pediplain (Shallow weathered - < 10 m) covering 30.5 % of total area; Pediplain (Moderate/Deep weathered - > 10 m) covering 20.3 % of state; about 14.6 % area is covered with pediment and inselberg zone. The area covered by Deccan basaltic / Cuddapah plateaus with medium or no dissections is 11.50 % of state and 0.50% of area is covered with Laterites. Valley zones like Valley or Flood Plains with or without filling material are covered by 4.6 % of the area. 12.4 % of area is covered by highly dissected hills/plateaus and remaining area (5.7 %) is covered by water bodies like river / stream / reservoir / tanks etc.

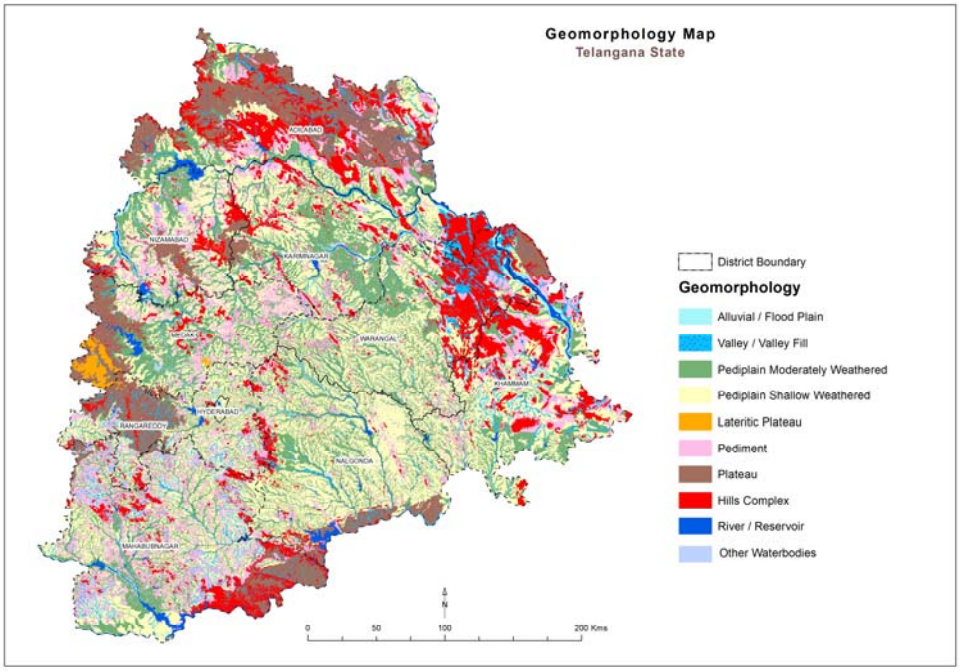

Figure 3. Geomorphological Map of Telangana State

7. STRUCTURES

The majority of the lineaments / faults identified are aligned with Godavari Graben which are occupied with Gondwana formations and are in the principal direction of NW-SE and NE-SW to N-S. There are several faults observed in the contact zones of Gondwana formations. There is a major fault observed in Adilabad District traversing the Kaddam Reservoir and the length is about 150 Kms. There are several structural joints / fracture / lineaments as observed from satellite imagery are in two principal directions ranging from NW-SE & NE-SW in rest of the state. Whereas, in southern part of the state and along the Krishna River (Cuddapah formations), series of WNW-ESE trending faults are seen. Generally dolerite dykes appear to be very hard and compact and poorly devoid of fractures, whereas the Pegmatite veins / Quartz reefs are highly fractured.

8. HYDROGEOLOGY

In the state Granite / Gneisses, Basalts, Sedimentaries, Laterites and Gondwana formations occur at various places. However majority of the area is occupied by hard rock formations like Granitic-Gneissic complex, Cuddapah / Pakhal group of rocks and Deccan Traps. In hard rock formations there is lack of primary porosity. However the aquifer system is developed because of secondary porosity due to various tectonic disturbances and weathering activity. The deeper aquifer system is developed due to major faults, joints, fractures, crevices, shear zones etc. The hydrogeological characteristics of a terrain are dependent principally on rock types and landforms. The ground water availability is Very Good to Good in Soft rock areas (Alluvium / Gondwanas etc) as compared to hard rock terrain (Archeans / Pakhals / Basalts etc) where the prospects is Good to Moderate and excluding the hilly terrain in both the cases. The ground water prospect is even more in structure / lineament controlled terrains within the lithological variants.

Landforms influence a profound influence on availability of water within a rock formation. It is observed that the ground water prospects in Alluvial / Flood Plain / Valley areas are Good to Very Good (> 400 LPM). In Moderately weathered basalts (with slight or no dissections) / granitoid rocks it is Good (100-200 LPM); whereas in Shallow weathered basalts (with moderate dissections) / granitoid rocks, the availability of ground water is Good to Moderate (50-100 LPM). In the pediment zones of granitic rocks and slightly / moderately dissected basalts it is of the order of Moderate to Poor (10-50 LPM). In highly dissected hills / plateaus, the prospects are low to Negligible and restricted to valleys portions only (< 10 LPM).

9. GROUND WATER QUALITY MAPPING

Habitation wise legacy ground water quality data for pH, Total Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Fluoride (F), Chloride (Cl), Iron (Fe), Nitrate (NO3) and Sulfate (SO4) elements (2012-14) are collected from Rural Water Supply & Sanitation (RWS&S) department. The data belongs essentially to drinking water sources like Hand Pumps / Bore wells / Infiltration wells. The data is segregated in to pre and post monsoon seasons based on date of collection of samples. As there are many sources in a habitation, element wise average values are calculated for each habitation in point form. The surface distribution of element wise ground water quality maps are prepared for pre and post monsoon seasons separately from this point data and interpolation is carried out by using Inverse Distance Weightage (IDW) method under Spatial Analyst tools of ESRI Arc GIS 10 software. Each element wise map is further re-classified in to 3 classes like Desirable (Potable); Permissible (Maximum allowable extent in absence of desirable water) and Non Potable following the guidelines given in revised Bureau of Indian standards (IS: 10500: 2012). It has been observed that for the elements pH, Chloride (Cl), and Sulfate (SO4) the quality is within the permissible limits except at isolated places. The distributions of other parameters are as given hereunder.

9.1 Fluoride

The habitation wise average values of fluoride in the state vary from 0.03-5.20 mg/L (Pre Monsoon) and 0.01-5.07 mg/L (Post Monsoon). The higher values (> 3 mg/L) are found essentially in Nalgonda / Ranga Reddy Districts. The spatial distribution of fluoride map is shown in Figure 4. The spatial distribution of fluoride concentration is less during post monsoon season as compared to pre monsoon season at some places. There are about 9% sources were quality affected with fluoride element during pre monsoon season whereas it is only 6.5% during post monsoon season in the state. The fluoride concentration is out of range (>1.50 mg/L) mainly in western parts of Nalgonda district; Southern part of Karimnagar; Eastern parts of Ranga Reddy district; and Northern parts of Mahabubnagar district; Central parts of Warangal District and it is also observed at some other isolated places in state. The sources for which the fluoride is out of range are found essentially in rock types belonging to Peninsular Gneissic Complex (Grey Biotite Granite, Alkali Feldspar Granite, Closepet Granite and Granite Gneiss (limited places) etc.) and at isolated patches in the rocks belonging to Cuddapah / Pakhal shale; Gondwana Sandstone / Shale / Limestone; and Lateritic formations.

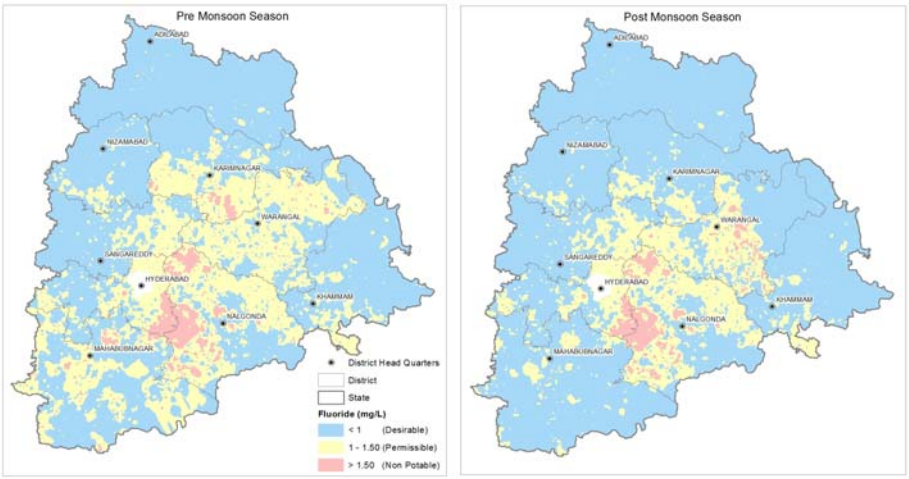

Figure 4. Spatial distribution of Fluoride

Within the fluoride affected areas (>1.50 mg/L), and as shown in Figure 5, the majority of the area is moderately high concentration of fluoride (1.50-3.00 mg/L) and rest of the areas is having high concentration of fluoride (3.00-5.20 mg/L). The high concentration of fluoride is observed mainly in western part of Nalgonda District (parts of

Chintapalle, Nampalle, Marriguda, Chandur, Narayanapur, Munugode, Kanagal, Choutuppal & M Turakapalle mandals) and South Eastern parts of Ranga Reddy districts (parts of Yacharam and Manchal mandals) during pre and post monsoon seasons. In post monsoon season high concentration of fluoride is observed at isolated places in Warangal district.

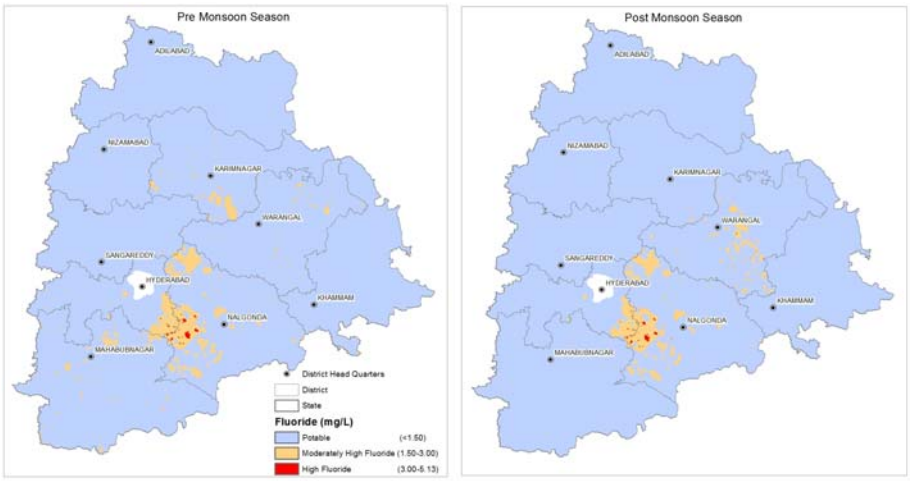

Figure 5. Spatial distribution of Fluoride

9.2 Total Dissolved Solids (TDS)

The spatial distribution of TDS map is shown in Figure 6. The habitation wise average values of Total Dissolved Solids in the state ranging from 122-5,543 mg/L (Pre Monsoon) and 131-5,215 mg/L (Post Monsoon). There are about 4% sources were quality affected with TDS during pre monsoon season whereas about 2% sources were out of range during post monsoon season in the state. The concentration of TDS is out of range (>2000 mg/L) in some isolated areas of Nalgonda, Warangal and Mahabubnagar Districts. In other places it is within the permissible limits.

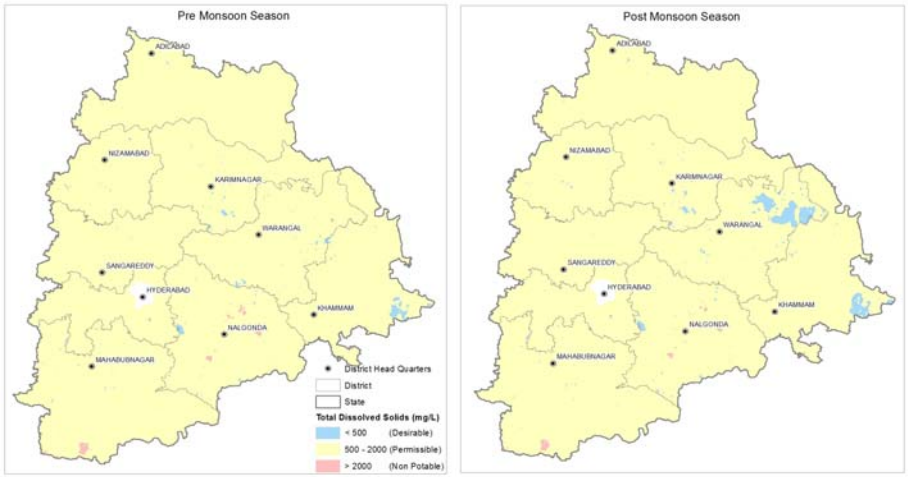

Figure. 6. Spatial distribution of Total Dissolved Solids

9.3 Total Hardness (TH)

The habitation wise average values of Total Hardness in the state vary from 40 - 2,335 mg/L (Pre Monsoon) and 38-2,277 mg/L (Post Monsoon). There are about 11% & 10% sources were quality affected with Total Hardness during pre and post monsoon seasons respectively in the state. The spatial distribution of Total Hardness reveals that it is out of range in some places belonging to southern Telangana districts of Nalgonda, Warangal districts; South Western part of Mahabubnagar district; South Eastern part of Khammam Districts (Figure 7) etc.

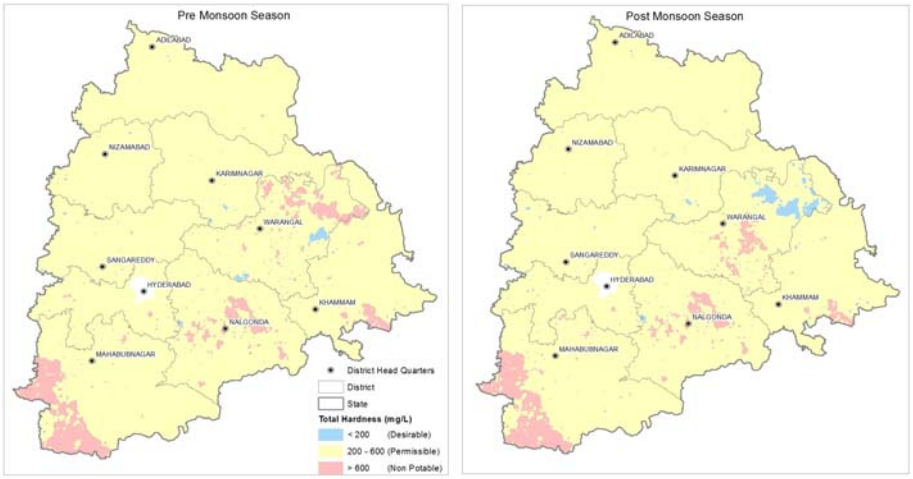

Figure 7. Spatial distribution of Total Hardness

It has been observed that the Total Alkalinity is out of range in majority of the areas where diversified rocks like Granite / Gneiss / Schist existing at a place within Peninsular Gneissic Complex. It is also out of range at some places of Gondwana sand stone / shale / lime stone & Pakhal sand stone / shale etc.

9.4 Total Alkalinity (TA)

The spatial distribution of TA map is shown in Figure 8. The habitation wise average values of TA in the district vary from 40-2,050 mg/L (Pre Monsoon) and 38-1,998 mg/L (Post Monsoon). There are about 3% sources were quality affected with Total Alkalinity during pre and post monsoon seasons. The concentration of TA is out of range (>600 mg/L) in some of the areas of Nalgonda and Mahabubnagar Districts. In rest of the areas the concentration of Total Alkalinity it is within permissible limits except at isolated places.

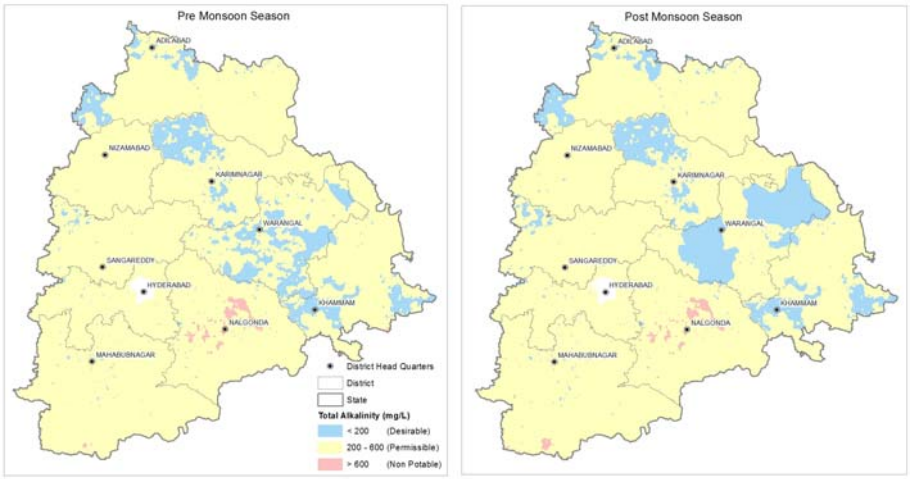

Figure 8. Spatial distribution of Total Alkalinity

9.5 Nitrate (NO3)

The spatial distribution of Nitrate is shown in Figure 9. The habitation wise average value of Nitrate in the district varies from 0.59-81.00 mg/L (Pre Monsoon) and 0.85-136.50 mg/L (Post Monsoon). There are about 4% & 3% sources were quality affected with Nitrate during pre and post monsoon seasons respectively in the state. The concentration of Nitrate is out of range (>45 mg/L) at isolated places belonging to southern Telangana districts of Nalgonda, Warangal, Mahabubnagar, Ranga Reddy and Khammam Districts.

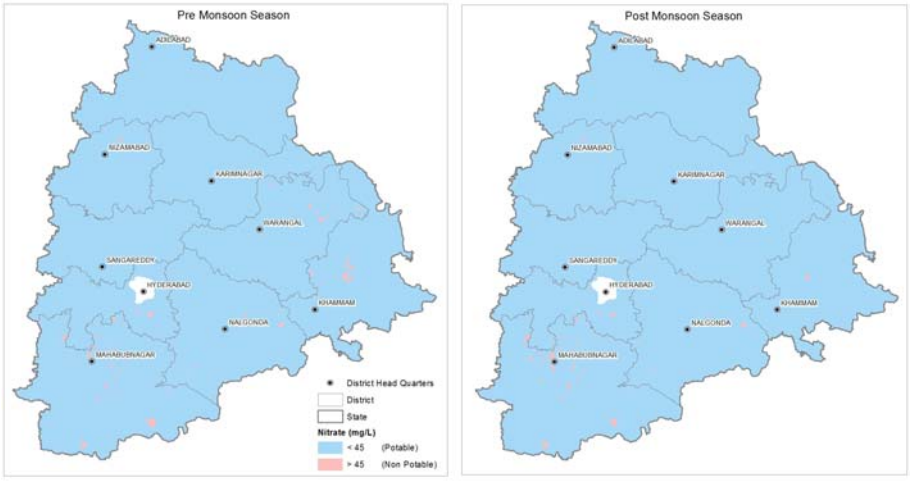

Figure 9. Spatial distribution of Nitrate

9.6 Iron (Fe)

The spatial distribution of Iron is shown in Figure 10. The habitation wise average value of Iron in the district varies from 0.00-0.80 mg/L (Pre Monsoon) and 0.00-0.98 mg/L (Post Monsoon). There are about 4% and 3% sources were quality affected with Iron during pre and post monsoon seasons respectively in Telangana state. The concentration of Iron is out of range (>0.30 mg/L) at isolated places in Southern part of Nalgonda District; at isolated patches in Khammam and Warangal Districts. It is within permissible limits in other places except at few places.

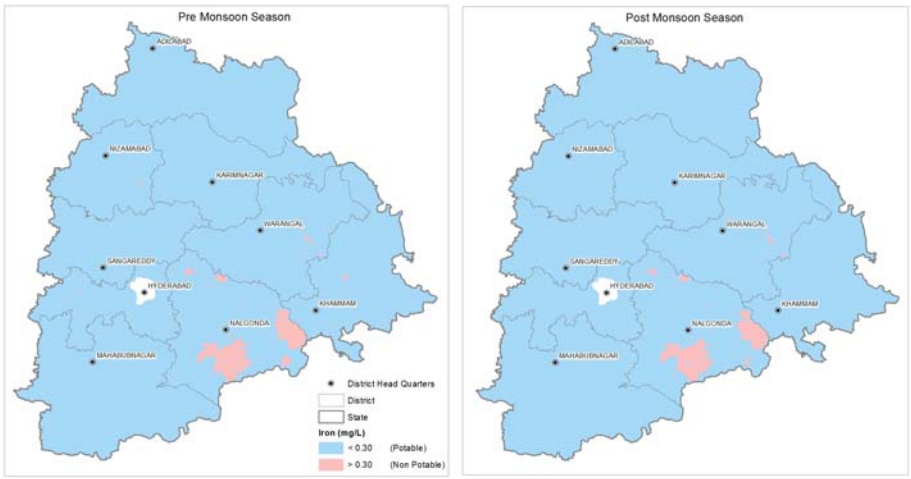

Figure 10. Spatial distribution of Iron

9.7 Integrated Ground Water Quality Map

The integrated ground water quality map is prepared by combining all the elements pH, TDS, TH, TA, F, Cl, Fe, NO3 and SO4 during pre and post monsoon seasons and as shown in Figure 11. The chemical element of a particular area is assigned either to Desirable (1) / Permissible (2) for potable water and Non Potable (3) as per ISO standards. If the quality of ground water with respect to all the elements belongs to class 1; then the quality of the ground water of that particular area is categorized as class 1. The quality of the ground water is classified as class-3, if the quality of ground water with respect to some elements belongs to class1 & class 2 and other elements belong to class 3. In other words, the worst quality of ground water in respect of individual elements present in the unit becomes the overall quality of the ground water of a given ground water quality unit. From the map, it is revealed that Nalgonda district is worst affected followed by Warangal, Mahabubnagar, Karimnagar & Ranga Reddy districts. In Khammam District, the Total Hardness is out of range in South-Eastern part of the district and rest of the areas the quality is within the permissible limits except at a few locations. In overall the quality is good in the districts of Adilabad, Nizamabad, Medak, Northern and Eastern part of Karimnagar; Western party of Ranga Reddy; and Khammam (Except central part). In other areas the quality is out of range for at least one element.

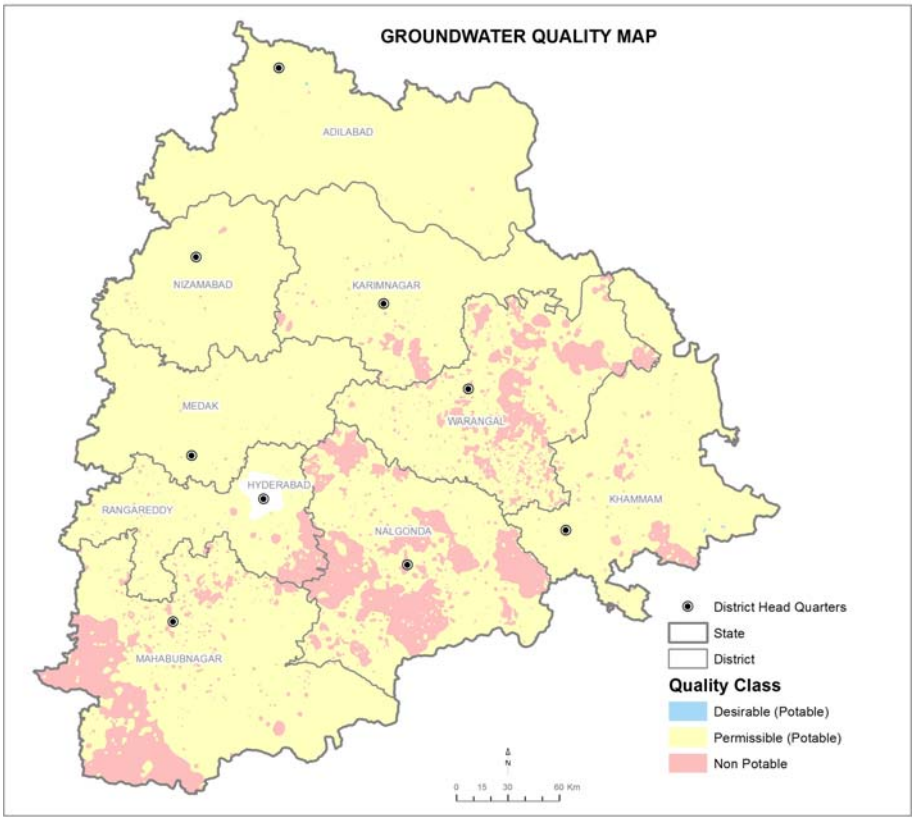

Figure 11. Integrated Ground Water Quality Map for Pre and Post Monsoon seasons

10. RESULTS AND DISCUSSIONS

The habitation–wise chemical analysis data is subjected to detailed analysis and the following observations are made. Among all the mandals, the average fluoride concentration (>1.5ppm) is highest in some of the areas of mandals belonging to Nalgonda District (Rajapet, M. Turkapalle, Yadagirigutta, Alair, Bommalaramaram, Bibinagar, Bhongir, Choutuppal, Narayanpur, Munugode, Chandur, Marriguda, Chinthapalle, Nampalle, Gurrampode, Gundlapalle, Devarakonda, Chandampet, Peddaadiserlapalle, Peddavora, Thipathi, Narketpalle, Kattangoor, Nakrekal, Kodad Mandals; Ranga Reddy District (Yacharam, Manchal, Ibrahimpatnam, Hayathnagar, Moinabad Mandals); Mahabubnagar District (Balanagar, Amanagal, Dhanwada, Devarakadra, Ghattu, Gopalpeta, Kothakota, Mahabubnagar, Alampur Mandals); Warangal District (Venkatapur, Govindaraopeta, Mulug, Tadvai, Kesamudram, Nellikuduru, Nekkonda Mandals); Karimnagar District (Bheemadevarapalle, Saidapur, Chigurumamidi, Gambhiraopet, Konaraopeta Mandals) . It is observed that the fluoride concentration is more in shallow and moderately weathered pediplains and valleys in granitic rocks like Alkali Feldspar Granite and Grey Biotite Granitic rocks. Most of the quality affected sources are having marginally high concentration of fluoride (1.50-3.00 ppm) who is at risk for dental fluorosis.

High Fluoride concentration of more than 3.00 mg/L and up to 5.20 mg/L is observed in some of the villages belonging to Nalgonda and Ranga Reddy districts as given below who are at risk for dental/skeletal fluorosis in the long run. Nalgonda District: Chandur Mandal (Idikuda, Nermata); Chinthapalle (Godkondla, Kurmaidu, Polepalle Ramnagar, Takatlapalle, Ummapur, Vinjamoor); Choutuppal (Peepal Pahad); Kangal (Boinapalle); Kattangoor (Dugnevally); M. Turkapalle (Mulakalapalle); Marriguda (Damera Bheemanpalle, Indurthi, Kondur, Marriguda, Sarampet, Tammadpalle, Vattipalle, Venkepalle, Yargandlapalle), Munugode (Ipparthy, Kompalle, Kothularam), Nampalle (Damera, Hydelapur, Tungapathi Gouraram); Narayanapur (Chillapuram, Jangam, Narayanapur, Vailapalle); Ranga Reddy District: Manchal (Dadpalle Village); Yacharam (Gungal, Nllavelly Villages).

The high concentration of fluoride rich ground water can be diluted with the augmented infiltration from a surface water body downstream of it. In view of this, rainwater harvesting structures can be suggested upstream of moderately / high fluoride zones so that the impounded water would not only recharge ground water but also helps in diluting fluoride rich ground water, thus serves for dual purpose of both quality and quantity. Increasing population and increasing standards of living drive demand ever higher for drinking water, for irrigation of crops,

and for process water for industry. As these sectors take more water, less is available for the natural environment. Untreated waste water discharge from industry is a major cause of pollution in rivers, lakes / tanks and from there to ground water reservoirs through infiltration, which reduces availability of clean water. The situation is further aggravated by the disposal of untreated municipal sewage into these water bodies.

11. CONCLUSIONS

The utility of Remote sensing and GIS technique helps in delineating groundwater prospects zones represented with various hydro-geomorphic units. It is observed that the percentage of contaminated sources is more in high yielding hydrogeomorphic units as compared to less yielding hydrogeomorphic units. The other observations are as follows:

- The results obtained in this study and the spatial database established in GIS will be helpful for monitoring and managing ground water pollution in the study area.
- The analytical results of sampling sites, monitored in this study irrespective of pollution source, revealed that groundwater from these sites required further purification to ensure its suitability for human consumption. For this, public awareness on the present quality crisis and their involvement and cooperation in the actions of local administrators are very important.
- Continuous monitoring of groundwater levels along with quality study will minimize the chances of further deterioration.
- The government needs to make a scientific and feasible planning for identifying an effective groundwater quality management system and for its implementation.
- To minimize the marginal chemical contamination of elements, groundwater recharging locations and structures can be identified by making use of geospatial technologies like RS, GIS, & GPS etc with the required spatial and non-spatial data as a tool. Designing site specific recharging structures is to be done.
- As the non-command area is more 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 out the water demand qualitatively and quantitatively in the same ratio as today.
- The intake of fluoride above the permissible limit in drinking water is the major reason for fluorosis in some parts. Hence fluoride mitigation measures like taking safe drinking water with sufficient dietary food needs to be encouraged.

ACKNOWLEDGMENTS

Authors would like to thankful to Telangana State Remote Sensing Applications Centre (TRAC) for providing support and encouragement to carry out the study.

REFERENCES

1. Aswini Kumar Das, Prathapani Prakash, Gade Kumar & N. Ramudu (2017), RS & GIS based integrated study on hydrogeomorphic unit wise ground water quality evaluation for Nalgonda District, Telangana State, Journal of Geomatics, Vol 11, No. 1, April 2017, pp. 31 - 37.
2. CGWB (2014-15), Ground Water Year Book, Telangana State Southern Region, Hyderabad, Ministry of Water Resources, Government of India
3. Geology and Mineral Resources of Telangana (2015), Miscellaneous Publication no. 30, Part VIII A, First edition, Geological Survey of India, Govt. of India
4. Indian Standards Institution (1992), Indian standard for drinking water ISO 10500.
5. NRSA (2007), Groundwater Prospects Mapping using Remote Sensing Techniques and Geographic Information System under Rajiv Gandhi national drinking water mission (RGNDWM), Technical Manual, National Remote Sensing Agency, Department of Space, Government of India (2007)
6. NRSA (2013), Groundwater Quality Mapping for Rajiv Gandhi national drinking water mission (RGNDWM) - Methodology Manual, National Remote Sensing Agency, Department of Space, Government of India (2013)
7. Prakash, P., Kumar Das, A., and Sandilya, C. V. S.: Study Relating to the Spatial Distribution of Ground Water Quality for Different Elements using Legacy Data of RWS&S, Andhra Pradesh, India, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-8, 383-390, doi: 10.5194/isprsarchives-XL-8-383-2014, 2014.
8. Sabins, F. F., (1997), Remote Sensing Principles and Interpretation, W. H. Freeman & Company., Newyork
9. Thornbury, W. D. (1984). Principles of Geomorphology, Wiley Eastern Limited, New Delhi
10. Todd DK. (2007), Groundwater Hydrology, Wiley- India Edition.