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Bhu-Jal News - Quarterly Journal of Central Ground Water Board with the objective to disseminate information and highlight various activities and latest technical advances in the field of Ground Water.

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Profile

Dr R.C.Jain, Member(SAM), CGWB

Dr Ratan Chand Jain, has completed his Master degree in Applied Geology from University of Roorkee, Roorkee in 1977, and Ph.D from University of Rajasthan, Jaipur in 2010. Dr Jain joined CGWB in 1979 and has worked in various capacities. Presently he is holding the post of Member(SAM) entrusted with the responsibility for implementation of National Project on Aquifer Management and World Bank assisted Hydrology Project-II

During 34 years of career in CGWB, Dr Jain has worked on multifarious assignments like Regional Hydrogeological survey, ground water exploration, Applied ground water modeling and Data base management, Remote Sensing application to ground water, Managed Aquifer Recharge, Conjunctive use of Surface and Ground Water and implementation of World Bank assisted Hydrology Project etc. Dr Jain has also participated in policy level consultation with Planning Commission, World Bank, IWMI, UNESCO, UNEP and delegation from other countries

Dr R.C.Jain is also guest faculty for various National and state Level ground water training Institiutes, NGO'S and International training programme of UNESCO. He has undergone intensive professional training in premier institutes in India and abroad. He has also undergone training on Applied Ground Water Modelling and Data Base Management at IHE, The Delft, Netherlands in 1990. He has presented papers in International symposia held in Malaysia and in Sweden. He was the guest faculty for organizing the UNESCO sponsored International training course on Managed Aquifer Recharge at the University of Western Cape, South Africa in 2009. He has been involved in more than 20 research and professional projects in ground water sector and he is the author of more than 35 technical papers in peer reviewed journals and international conferences.

Profile

Arun Kumar, Member(SM&L) CGWB

Shri Arun Kumar completed his M.Tech degree in Applied Geology from University of Roorkee in 1976. He completed one year diploma course on "Photo-interpretation and Remote Sensing in Hydrogeology" from IPI, Dehradun (now IIRS) in 1981-82 with honors. After a brief stint of about one year as Geologist in ONGC, he joined Central Ground Water Board in 1978. He has worked in WCR, Ahmadabad, NWHR, Jammu and NHR, Dharmshala. He has also worked as Regional Director, (HP-II) in Ministry of Water Resources and in Central Ground Water Authority , New Delhi before becoming Member of CGWB in 2013.

During the professional service of more than 35 years, he was associated with Ground Water studies, Exploration, Assessment, Planning and Management of Ground Water Resources in various terrains of India. He has vast experience of working in arid and semi arid areas in western India, Desert Hydrogeology, Himalayan Geology, Hard Rock and Coastal aquifers, in the field of Water Conservation, Purpose Driven Studies (GW), IEC activities etc. He has authored number of technical reports, district reports, state reports and has a number of scientific papers to his credit.

During his career he has undergone number of specialized trainings both in India and Abroad. Shri Arun Kumar was deputed in East African country Eritrea during 1999-2001 as Ground Water Expert in Food & Agriculture Organization of United Nations programme on food security and carried out number of ground water related projects and investigations.

Profile

Ashish Chkraborty, Member(ED&MM),CGWB

Shri Ashis Chakraborty has completed his Mechanical Engineering degree from Regional Engineering College, Rourkela, (Orissa) in 1978 and Post-Graduate Diploma in Material Management in 1988. He was elected as Member of Institute of Engineers (India) in 1987. He had worked in Tripura Government from 1980. He joined Central Ground Water Board in 1984. Shri Chakraborty has served in various capacities as Assistant Executive Engineer, Executive Engineer, Superintending Engineer, Regional Director before becoming Member of the Board in October, 2013. He has worked in North Eastern States, CHQ, Faridabad, NCCR, Raipur and RGI, Raipur.

Presently he is holding the post of Member (ED&MM). During the professional service of more than 29 years, he was associated with Ground Water studies, Ground Water exploration, Planning & Management, Material Management in Central Ground Water Board. He has vast experience of Material Management, Ground Water exploration and conducting training courses for Central Ground Water Board and State Government officers. Under his leadership RGI Raipur was relaunched and could conduct 32 training programme per year on different subjects related to Ground Water.

Shri Chakraborty was associated with different committees/sub-committees in various capacities. He was a Member of multi-disciplinary team selected for International Co-operation Training Programme on Ground Water development in England in 1992. He was also deputed by Ministry of External Affairs to Nepal to assess the feasibilities of one proposed scheme related to farmers participatory ground water programme in 2004.

Profile

Anita Gupta, Member(TT&WQ), CGWB

Ms. Anita Gupta did her post graduation in Applied Geology in the year 1976 from University Of Roorkee, U.P., and was awarded the University Gold Medal. She joined Central Ground Water Board in 1977. Ms. Gupta has served CGWB in various capacities as Scientist, Regional Director, before becoming Member of the Board in 2013. She has worked in, NWR,Chandigarh, North Central Region Bhopal, Uttaranchal Region, Dehradun, Northern Region Lucknow and Central Headquarters, Faridabad. Presently she is holding the post of Member(TT&WQ), CGWB and also looking after the work of Member Rajiv Gandhi National Ground Water Training and Research Institute.

During the professional service of more than 36 years, she has acquired experience in different hydrogeological terrains in the fields of Ground Water studies, exploration, Planning, Management, ground water budgeting, Ground water conservation and Artificial Recharge, Data Base Management in Ground Water and GIS. She also has experience in the training function of the Board.

Ms. Gupta has been a Member of Departmental and Inter-departmental committees related to Ground Water. She was a Member of the committee for Vision Mission document of CGWB. She has many technical reports to her credit and has contributed several scientific papers. She was a member of the Indian delegation to Australia for collaboration between India and Australia in water resources sector in which she represented the Ground Water sector.

Editorial

In India, the development of ground water resource has gained momentum to meet the increasing need of ever growing population for drinking as well as industrial and irrigational purposes. India became the largest users of Ground Water in the world . Since our agriculture is predominantly dependent on vagaries of rainfall, importance of ground water is felt as dependable and most viable source for irrigation.. Several ground water related problems arises like decline in water level and ground water contamination, due to maximizing the use of ground water

The latest issue of Bhujal News has been prepared with 7 selected papers and one article . Two papers on Ground Water Modelling has been included. Dr S.Suresh, in his paper, elaborated about the management of Coastal aquifers in Chennai Metroplitan areas through Ground Water modelling, while Dr Krishnaveni has given a case studies of ground water modelling of a semi-arid tank cascaded catchment in a hard rock terrain using remote sensing and GIS. Vertika Singh & P. Deo has emphasized the need of Artificial recharge plan for ground water augmentation in Saharanpur area, UttarPrdesh. Dr K.K.Singh & Dr B.K.Mishra through their paper evaluated the deep aquifer resources in Lower Ganga plain of Patna Urban agglomerate. Mr D.Bagchi presented the Hydrogeological and Hydrochemical Scenrio around Garur-Baijnath area, District Bageshwar, Uttarakhand. Mr Rajendra Dhobal etal has narrated the programme of water quality map of Uttarakhand. Dr Jemini Khatik, etal have elaborated through paper on Fluoride Contamination in Ground Water in parts of the Tribal belts of Chhindwara district, Madhya Pradesh, India. A profile of National Geoscience Awardee-2010(Ground Water Exploration) Dr Dipankar Saha has been included in this issue.

It is hoped that the papers in this issue will benefit our readers. It is regretted that we could not publish it timely. However we assure our esteemed readers that it will be our endeavor to bring out more informative issues and timely publication in future

Dr. S.K.Jain

Editor

GROUNDWATER FLOW MODELING IN COASTAL AQUIFERS OF SOUTHERN PART OF CHENNAI METROPOLITAN AREA, TAMIL NADU, INDIA

S.Suresh
Central Ground Water Board, Faridabad

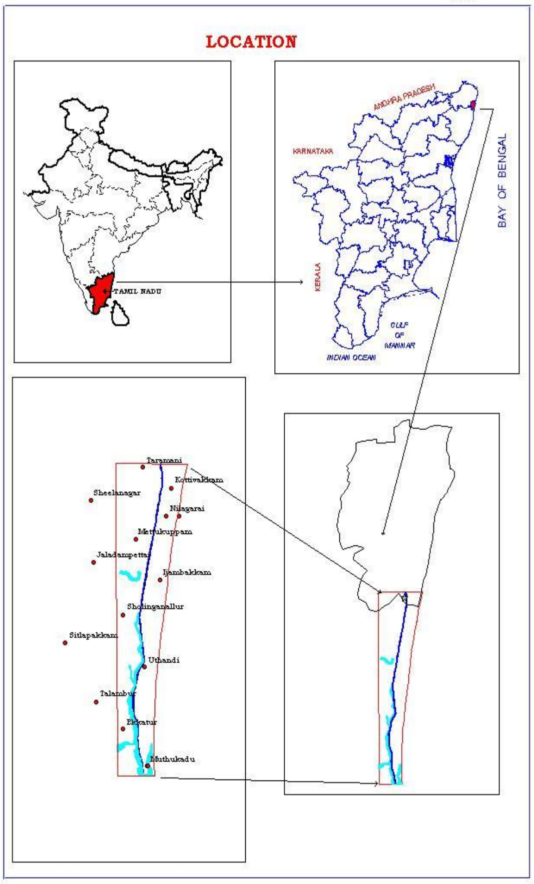
ABSTRACT

The phenomenal increase in population of Chennai city has resulted in water demand in excess of regular source of water supply. The water demand was 1026 million litres per day (MLD) in 2001 and would become 1980 MLD (2021), while supply is expected to be around 1586 MLD, if full capacity of the reservoirs and the groundwater supply are to be projected (Dayamalar, 2011). The deficit in water supply is being managed at many a places through groundwater extraction. The southern Chennai coastal aquifers have been a source of water supply for more than a decade and there is lot of apprehension that coastal aquifers would be affected by seawater ingress. An attempt has been made to study the hydrodynamics in coastal aquifers of southern part of Chennai Metropolitan Area using groundwater flow modelling. The model has been calibrated and validated with the observed data. For the period between 2000 & 2005 predictive simulation was carried out for another ten years up to 2015. The various scenarios, viz., continuation of present groundwater development, increased groundwater development, reduction in groundwater development, augmentation coupled with changes in groundwater development were studied in the developed model. The recommendations have been made taking into consideration of groundwater potential and acceptability of the strategy by the local population. It is seen that reduction of the groundwater extraction without the participation of all the stake holders including public & government would be difficult. It would be ideal to reduce the groundwater extraction but being on the pragmatic side, it is suggested that the strategy comprising continuance of existing groundwater draft with augmentation in the select cells by 10% during the monsoon period may be adopted for the management coastal aquifers in the southern part of Chennai Metropolitan area.

INTRODUCTION

The phenomenal increase in population of Chennai city has resulted in water demand in excess of regular source of water supply. The water demand was 1026 million litres per day (MLD) in 2001 and would become 1980 MLD (2021), while supply is expected to be around 1586 MLD, if full capacity of the reservoirs and the groundwater supply are to be projected (Dayamalar, 2011). In order to meet the deficit the private entrepreneurs have resorted to marketing of water by mining water. The phenomenon of seawater ingress in the coastal aquifers in Minjur in north has diverted the entrepreneurs to exploit the coastal aquifers in the southern part of Chennai Metropolitan Area (CMA) and there is lots of apprehension about the fate of the coastal aquifers in the southern part of CMA in the coming years. The mushrooming of dwellings on the southern part of Chennai has resulted in the more stress on the fragile coastal aquifer system. In this scenario, an attempt has been made to study the hydrodynamics in the coastal aquifer systems so as to formulate strategies for groundwater management.

Fig 1



BACKGROUND INFORMATION

The coastal area on the southern side of Chennai city in Tamil Nadu, India, has been considered for the study. It is bounded by Bay of Bengal in the east and Kovalam Creek on the south while in the north Tiruvanmiyur area was taken as boundary and about 1–3 km west of Buckingham canal was taken as western boundary (Fig 1). The area is characterized by sub tropical climate and has an average maximum daily temperature of 43°C during May/June and an average minimum daily temperature of 25°C during January/February. The area receives rain under the influence of Southwest and Northeast monsoons. The southwest monsoon stretches from June to September while northeast monsoon is active between October to December. The normal annual rainfall (1971-2005) is 1458 mm of which 33% is received from SW monsoon and 60% from NE monsoon. Rainfall received during winter (January – March) and summer (April – May) months account for 3% and 4% of annual rainfall respectively. The area is characterised by gently sloping terrain, with sand dunes in general formed parallel to the coast. The general elevation of the terrain is between 3 and 10 m above mean sea level. The area is underlain by sand-clay admixtures followed by crystalline basement of Charnockites.

In general, the aquifer system comprises fine to coarse-grained sand, sand – clay admixtures and weathered basement comprising Charnockites. The unconsolidated formation can be further segregated locally into layers comprising Grey sand- clay intercalation (Zone III), Grey sand with argillaceous intercalations and characterised by shells (Gastropods and Lamellibranches) (Zone II) and brown/red sand (Zone I). Charnockites are the rock types constituting the consolidated formations. Drilling of about 10 m in the basement has revealed that the weathered and fractured rocks are encountered down to the drilled depth.

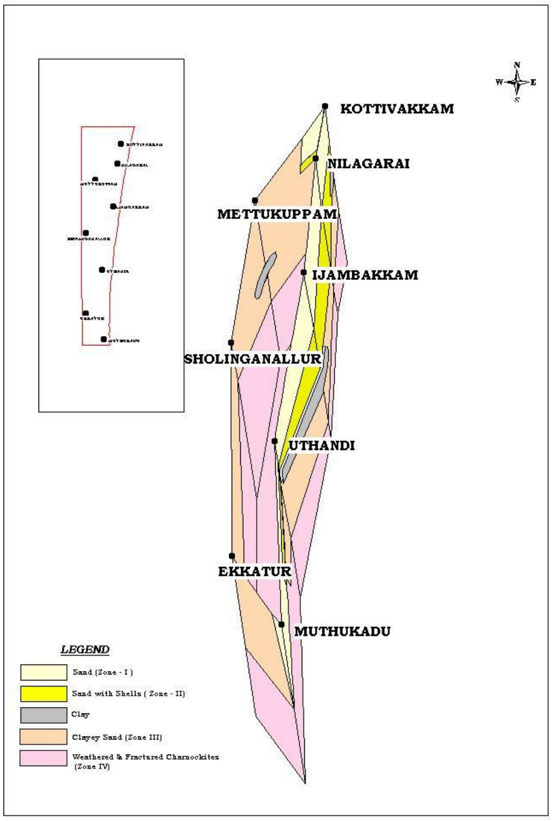
OBJECTIVE

The objective was to study the groundwater flow pattern in the coastal aquifer system, using the techniques of groundwater flow modelling

CONCEPTUALIZATION

In order to carry out the groundwater flow modeling, it is essential to delineate the aquifer extent, its interconnection, source of recharge etc., which can be termed as conceptualization of the aquifer system. The multi aquifers system can be visualized using the techniques of hydrogeology, hydrochemistry or isotope hydrology. Mazor (1973), Cotecchia et al., (1974), Mazor (1979), Hem (1985), Eriksson (1985), Mazor and George (1992) and Mazor (1997) have used hydrochemical techniques to study interaction between systems. Rajmohan & Elango (2004) have studied the chemical processes to bring out the process of mixing of water, water rock interaction, etc to bring out the causes for the chemical composition of water. The intermixing phenomenon has been clearly brought by the works of Mazor & Verhagen (1983) and (Mazor, 1997). In India, isotope techniques have been used to study the aquifer-aquifer interaction, lake-aquifer interaction, seawater intrusion studies by Sukhija and Shah (1976), Rao et al (1987), Navada & Rao (1991), Navada et al (1993), Nachiappan (2000), Shivanna et al (2006), Vaithianathan (2003), Gouthaman (2003) and Suresh & Lawrence (2006). In the present study, the techniques of hydrogeology, hydrochemistry and isotope hydrology have been utilised in the conceptualization of the aquifer (Fig 2).

Fig-2



Number and Nature of Aquifers: The aquifer system in the study area can be considered as two-aquifer system, viz., top sandy aquifer and weathered and fractured aquifer (basement). The groundwater occurs under unconfined condition in top sandy aquifer and under unconfined to semi-confined condition in the underlying basement.

Aquifer Boundary (Lateral Extension): The top sandy aquifer extends through out the area underlain by weathered and fractured Charnockites.

Aquifer Boundary (Vertical Extension): The thickness of the aquifer encountered during drilling of piezometers has given the vertical extension of the aquifer and has been interpolated to get the spatial variation within the study area.

Aquifer-Aquifer Interconnection: The presence of clay-sand admixtures in varying proportions throughout the area between top sandy aquifer and weathered & fractured aquifer deems it possible to have interconnection between the two aquifers. The vertical hydraulic conductivity also is not uniform as the clay-sand admixture is not uniform. It is supported by the results of hydrochemical and isotope studies and it can be inferred that the interconnection between the aquifers varies from limited to a complete interconnection (Suresh, 2006).

Source of Recharge: The seasonal variation in the elevation of water table and piezometric surface indicate a large contribution from precipitation. This is also supported by the plot of chemical species, ionic ratios and isotopic composition. The overall uniformity of the quality (brackish to saline) of the groundwater in weathered and fractured aquifer indicates that in addition to the precipitation, the lateral flow across the boundary of the study area could also form a source of recharge (Suresh, 2006).

Boundary Conditions: The area bounded by Bay of Bengal will have a constant head boundary on the east, while on the south, west and north, as there are no conspicuous hydrogeological barrier, they will be a varying head boundary.

MODELING

The modelling techniques have been used extensively in formulating sustainable management strategies for conjunctive use of surface water and groundwater, solute transport model for regulation & control of contaminant migration and for regulated groundwater development in coastal aquifers (Anderson & Woessner (1992), Lawrence (1995), Sorek and Pinder (1999), CGWB (1999), William and Turner (2000), Jha et al (2003), Mohan (2003), Satheesh (2005).

Processing Modflow Version 5.3 was used for groundwater flow modelling in the present study. The top sandy layer was only considered for modeling purposes and initially, the model has been run in steady state condition. The parameters were adjusted and smoothened head was taken as initial piezometric head for transient flow simulation.

The Model was started from the period July 2000 and initially the transient state condition was run for 11 months period ending May 2001. The length of each stress period was taken as 30 days period with one time step for each stress period and unit of time as day. The model was calibrated and validated with the observed water level data. The simulation was extended to 59 stress periods and model was run for the period July 2000 to May 2005.

The model was run and the results were studied. The water budget was taken up to 11th Stress Period, covering the period from July 2000 – May 2001. The cumulative water budget for the distributed model is given as Table 1.

Table 1 Cumulative Water Budget at the end of 11th Stress Period for Distributed Model

	IN	OUT	IN-OUT
STORAGE	4.314331	3.584748	0.729583
CHB	0.043251	3.801491	-3.758240
WELLS	0.000000	6.228037	-6.228037
GHB	0.029973	0.086453	-0.056480
RECHARGE	9.313188	0.000000	9.313188
Total	**13.700743**	**13.700729**	**0.000014**

A perusal of the table shows that there is an inflow of 13.700743 M.Cu.m while there is an outflow of 13.700729 M.Cu.m with a change in storage of 0.000014 M.Cu.m.

In order to validate and calibrate the model data, spatial variation of both observed and simulated water table elevation data of the study area at the end of stress period 11 (May 2001) has been compared and furnished in Fig.3. A perusal of the figure shows that there is a good match between the two values. Subsequently, the calibration and validation has been extended up to 59th stress period (May 2005) and plot of both observed and simulated water table elevation data is furnished as Figure 4. A comparison of the simulated and observed values showed there is a good match between the two.

Fig.3

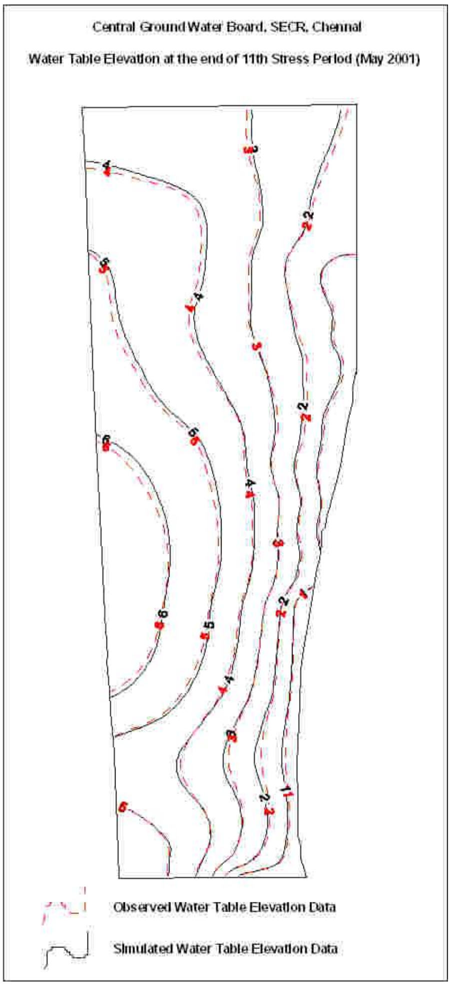
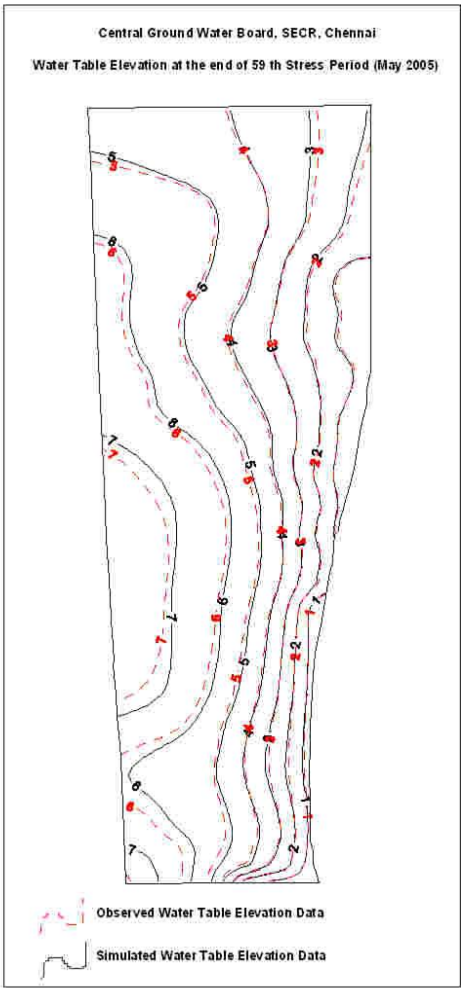


Fig.4



Further, the temporal variation of observed and simulated water table elevations has been compared using hydrograph analysis. The plot of observed and simulated for the select hydrographs have provided as Figure 5 along with the variance in the computed and observed values. A perusal of the figure shows that the difference in the observed and simulated values are less than 0.5m and the variance of the computed and observed values also range between 0.16 to 0.6, thereby indicating a sufficiently good match. In the present study, the model has been validated for the period of Jun 2000 to May 2005 for a period of 5 years. It was decided to carry out predictive simulation for additional 10 years, i.e., up to 2015, as the coastal system is fragile and sensitive to changes. Hence the predictive simulation has been restricted only up to 2015.

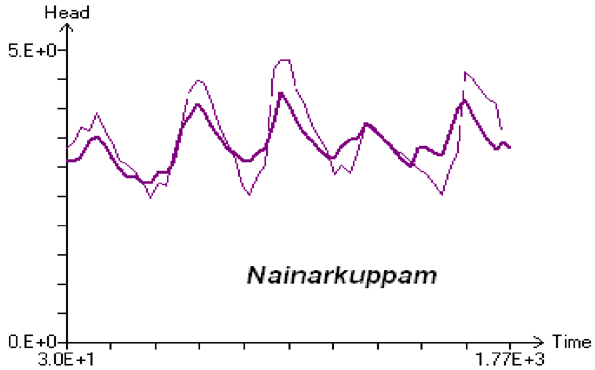
TESTING OF MANAGEMENT OPTION

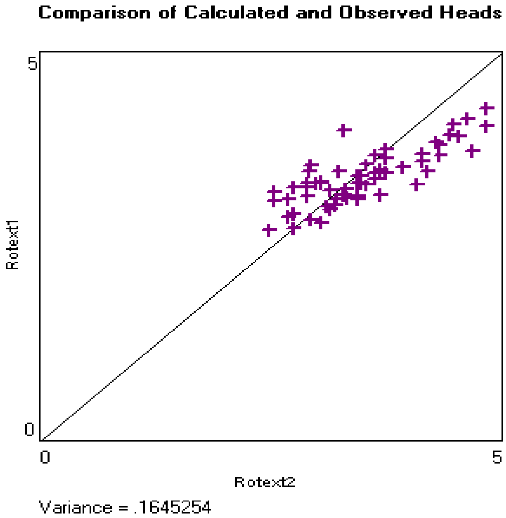
The predictive simulation was extended up to 179 stress periods (May 2015). The various option consisting of increasing draft, increasing recharge and its combination have been tested. The increase in draft has been uniformly spread all over the area in all the stress periods but the recharge has been restricted to the monsoon month (June-December) and only in the selected cells eastern side of Buckingham canal, which border the sand dune formations so as to have the maximum impact of recharge.
The various options tested are as follows.

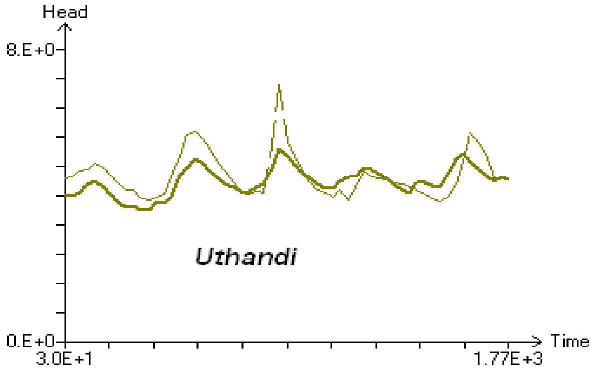
1. Recharge using Normal rainfall & same draft –**STRATEGY1**
2. Recharge using normal rainfall using 10% addition in draft- **STRATEGY2**
3. Recharge using normal rainfall using 25% addition in draft – **STRATEGY3**
4. 10% augmentation with 25% additional draft- **STRATEGY4**

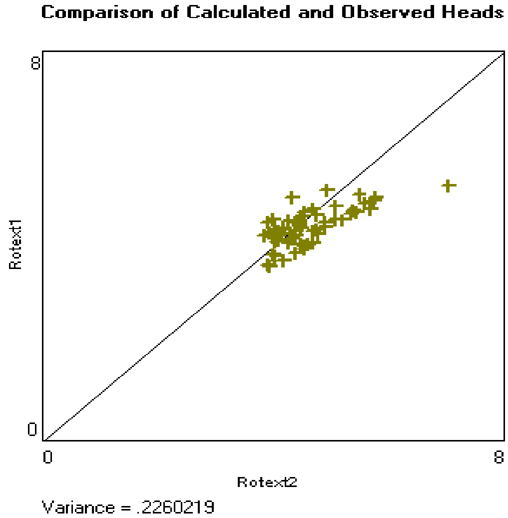
5. 25% augmentation with 25% additional draft- **STRATEGY5**
6. 10% augmentation with the same draft- **STRATEGY6**

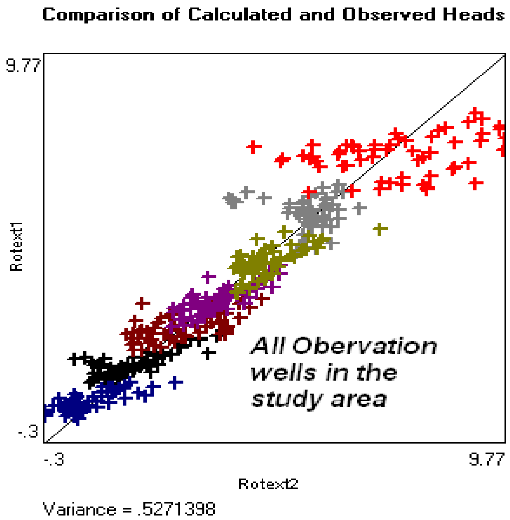
Fig 5











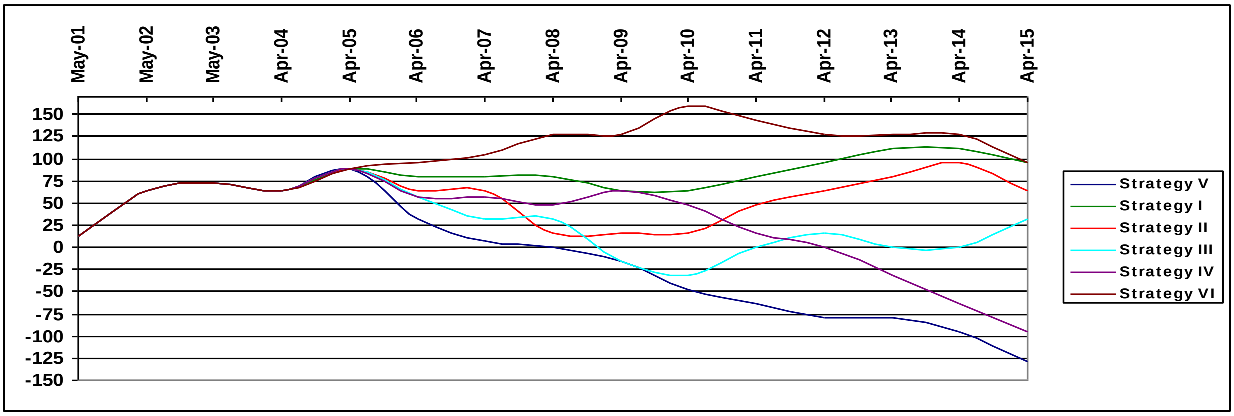
In order to study the impact of groundwater management strategy, the inflow-outflow at end of each year (May 01, May 02, May 15) have been compared for each strategy and presented in Table 2 & as Fig 6.

Table 2 Summary of inflow-outflow quantity in the modeling period

Month/ Year	Stress Period	In-Outflow (Cu.m)					
		Strategy I	Strategy II	Strategy III	Strategy IV	Strategy V	Strategy VI
May-01	11	13	13	13	13	13	13
May-02	23	64	64	64	64	64	64
May-03	35	72	72	72	72	72	72
May-04	47	64	64	64	64	64	64
May-05	59	88	88	88	88	88	88
May-06	71	80	64	56	56	32	96
May-07	83	80	64	32	56	8	104
May-08	95	80	16	32	48	0	128
May-09	107	64	16	-16	64	-16	128
May-10	119	64	16	-32	48	-48	160
May-11	131	80	48	0	16	-64	144
May-12	143	96	64	16	0	-80	128
May-13	155	112	80	0	-32	-80	128
May-14	167	112	96	0	-64	-96	128
May-15	179	96	64	32	-96	-128	96

A perusal of the table shows that in Strategy 1 & 6, where the groundwater draft has not been increased shows positive inflow-outflow, while Strategy 3, 4 & 5 show negative inflow-outflow, where groundwater draft has been increased. It is also to add that with increase in draft by 10% in Strategy 2, still the inflow-outflow has remained positive. In strategy 4 & 5, the recharge has also been augmented by 10% & 25% respectively and even then the inflow-outflow component is negative. The same results have been pictorially represented to visualize the changes in inflow-outflow component over the years.

Fig.6



It is very difficult to reduce the groundwater extraction with out the participation of all the stake holders including public & government. It would be ideal to reduce the groundwater extraction but being on the pragmatic side, it is suggested that the strategy 6 comprising continuance of existing groundwater draft with augmentation in the select cells by 10% during the monsoon period may be adopted for the management coastal aquifers in the southern part of Chennai Metropolitan area.

CONCLUSION

The aquifer system in the study area can be considered as two-aquifer system, viz., top sandy aquifer and weathered and fractured aquifer (basement). The thickness of the aquifer encountered during drilling of piezometers has given the vertical extension of the aquifer. It is found that the thickness of sandy aquifer varies and the same has been interpolated to get the spatial variation within the study area.

The modeling has been carried out using PM 5.3 version. The area has been modelled as single layered aquifer considering only the top sandy aquifer. The model has been run initially for 11 stress period for the period Jun 2000 to May 2001 and subsequently extended up to 59 stress periods (May 2005). The model has been calibrated and validated using the water table elevation data of observation wells by comparing both hydrographs (temporal variations) and water table elevation contours (spatial variation). The observed and simulated values are found to match reasonably well, there by indicating that regional model so developed is reasonably representing the field situations.

The simulation has subsequently extended as predictive simulation to year 2015 (15years as modeling period) to study the groundwater flow in and out of the system. Further, different management options of increasing the groundwater draft and effecting groundwater augmentation has been studied to work out a feasible management option considering the present socio economic conditions.

It is very difficult to reduce the groundwater extraction with out the participation of all the stake holders including public & government. It would be ideal to reduce the groundwater extraction but being on the pragmatic side, it is suggested that the strategy 6 comprising continuance of existing groundwater draft with augmentation in the select cells by 10% during the monsoon period may be adopted for the management coastal aquifers in the southern part of Chennai Metropolitan area.

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I would like to express my gratitude to Chairman, CGWB for all his encouragement and guidance in preparation of the paper. I take this opportunity to thank Dr N.Varadaraj, who was Regional Director, SECR at the time of work and Shri D.S.C.Thambi, who was Regional Director, SECR at that time of publication of the report for their moral support and encouragement. The data of CGWB, SG&SWRDC & Metrowater have been used in the studies and all responsible for collection, storage and dissemination of data in these departments are gratefully acknowledged.

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GROUND WATER MODELLING OF A SEMI ARID TANK CASCADED CATCHMENT IN A HARD ROCK TERRAIN USING REMOTE SENSING AND GIS

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ABSTRACT

Groundwater is a dynamic and replenishable natural resource, but in hard rock terrain availability of groundwater is of limited extent and its occurrence is essentially confined to fractured and weathered zones. The occurrence, origin, movement and chemical constituents of groundwater are dependent on the geologic framework. i.e., fissures, degree of weathering and permeability of the rocks through which it moves. Exploration and utilization of groundwater especially in hard rock terrains, requires thorough understanding of geology, geomorphology and lineaments of the area, which directly or indirectly control the terrain characteristics. With the increasing use of groundwater for agricultural, municipal and industrial needs, the annual extraction of groundwater is far in excess of net average recharge from natural resources. In a semi arid region, evapo- transpiration captures most of the water entering the soil, and recharge occurs only at extreme rainfall events. The study of ground water modeling in a semi arid hard rock region is important in order to estimate the available ground water resource for utilization without exploiting the resource.

Sindapalli-Uppodai sub basin is one of the sub basins of Vaippar river basin, Tamil Nadu is taken for the study. The sub basin is characterized as a semi arid region. There are 16 tanks connected in the form of cascades in the study area. The recharge from rainfall to the groundwater will take place during the monsoon seasons. The recharge from other sources such as the recharge from tanks and the recharge from the irrigation water is also an addition to the ground water. The ground water is used mainly for irrigation and also for meeting other demands such as domestic and industrial demands.

The GEC 1997 methodology was used to assess the various recharge and discharge components. In the present study the use of geospatial technology viz GPS, Remote Sensing and GIS to derive various parameters needed to estimate the spatially distributed recharge and discharge components was explored. These components are inputs to Visual MODFLOW to simulate the ground water dynamics in an unconfined aquifer of a semi arid region.

INTRODUCTION

Groundwater resource is a renewable resource subjected to periodic replenishment. National Water Policy, 2002 of India stresses that 'exploitation of groundwater resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity. The dynamic groundwater resource is essentially the exploitable quantity of groundwater, which is recharged annually. It is also termed as annually replenishable groundwater resource.

In India, dynamic groundwater resources are monitored and estimated jointly by the Central Ground Water Board (CGWB) and State governments at periodical intervals based on GEC methodology. The GEC 1997 has reported the following refinement and improvement for micro level studies.

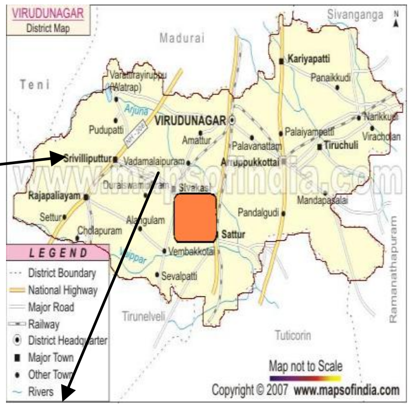
- Micro level studies in hard rock terrain should be based only on watershed as the type of groundwater assessment unit.
- Groundwater assessment for each unit should be computed adopting the recommended methodology and the field tested values for different parameters such as specific yield, transmissivity, storage and porosity to those of ad-hoc norms.
- The observation and pumping wells have to be monitored for the study period.
- The assessment may be made separately for monsoon and non-monsoon seasons as well as for command and non-monsoon areas.
- Remote Sensing techniques can be profitably employed for quantifying various components of the methodology. For example to demarcate cropped area under only groundwater, Remote Sensing and GIS may be advantageous.

In the present study, the above refinements are taken into account. Groundwater assessment unit is considered as watershed. The groundwater recharge is estimated by considering the different recharge components like recharge from rainfall, recharge from tanks, recharge from groundwater irrigation, separately for command and non-command areas. Pumping test was done to estimate the various parameters such as specific yield and transmissivity. The ground water wells are identified using the high resolution Cartosat imagery. The ground water levels are monitored on weekly interval during the study period. Remote Sensing imagery and GIS is used to prepare the land use map. GIS and GPS are used to demarcate the command area and non command area and the irrigation area under surface and ground water irrigation. Visual MODFLOW is used effectively to simulate the hydraulic heads and to predict water levels.

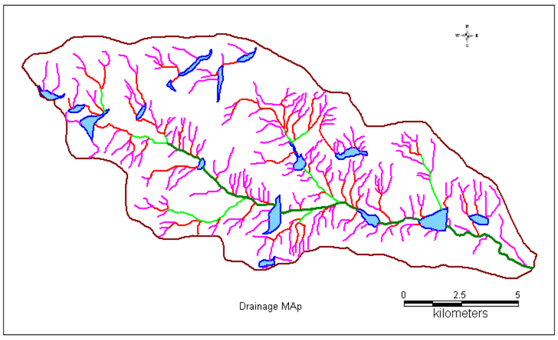
STUDY AREA AND LOCATION

Sindapalli Uppodai sub basin of Vaippar river basin, Tamil Nadu, India is chosen as study area. It receives drainage from its own catchment which originates from the plain terrain near by Duraiswamypuram village of Sivakasi taluk, runs for a distance of 26 km and it joins in Arjunanadhi at the downstream of Allampatti Village. The entire Sindapalli Uppodai sub basin falls under semi arid region. The base map of Sindapalli Uppodai is delineated from the Survey of India toposheet and presented in Figure 1. The total geographical area selected for study at Sindapalli Uppodai sub basin is 143.77 Km^2. The sub basin lies between the latitude of 9° 25’00”N to 9° 30’00” N and longitude 77° 45’00”E to 77° 55’00”E and Taluks of Sivakasi and Sattur in Virudhunagar District. The mean maximum temperature is 33.95 ºC to the mean minimum temperature is 23.78ºC. There are 16 tanks connected in the form of cascades. Total wells selected for the study is 71 out of which 14 wells are observation wells and the remaining are the pumping wells. Water level is monitored in each tank and in all ground water wells on weekly interval.

Tamilnadu Districts Map



Virudhunagar District Map



Sindapalli Uppodai Sub basin Drainage Map

Figure 1 Index Map of Sindapalli Uppodai Sub basin

DATA COLLECTION

The data needed for the study were collected from the field and other agencies as given in Table 1.

Table 1 Data Collected

Sl.No.	Primary Data	Details	Derived Data
1	Tank Capacity Survey	GPS survey for 16 tanks	Stage vs Storage Capacity Stage vs Water Spread Area
2	Tank Water Level (Weekly)	16 Tanks	Storage Estimation
3	Ground Water Level (Weekly)	71 wells	
4	Pumping test	S_y, and T	
5	Soil test	53 locations	Soil Map
Sl.No.	**Secondary Data**	**Details**	**Derived Data**
1	SOI Toposheet 58G11 & 58G15	1:50,000	Tank Network, Drainage Map
2	Meteorological Data Rainfall data – 35 years	Kavalur station	Spatial Distribution of Rainfall
3	Geology	Institute of Water Studies	

Software Used: Mapinfo 6.0, ArcGIS 9 Version 9.3, Erdas Imagine

GEOLOGY AND SOIL MAP

Weathered granite, gneiss and Schist with low clay content are present in the sub basin. While using the rainfall infiltration factor method apart from considering the rock type, the infiltration factor of the top soil has to be given due weightage. The soil type is identified by carrying out the soil texture analysis in the laboratory. The soil samples are collected at 53 locations selected in a distributed pattern. It was seen that the soil texture varies from loamy sand soil to silty loam. Soil classes and area covered by three soil categories are shown in Figure 2. The sandy loam soils covering around 86.938 km^2 of the study area was the dominant soil type and this soil is favorable for groundwater potential, Loamy sand group soil was found in an area of 3.995 km^2 and the silty loam covering about an area of 51.893 km^2.

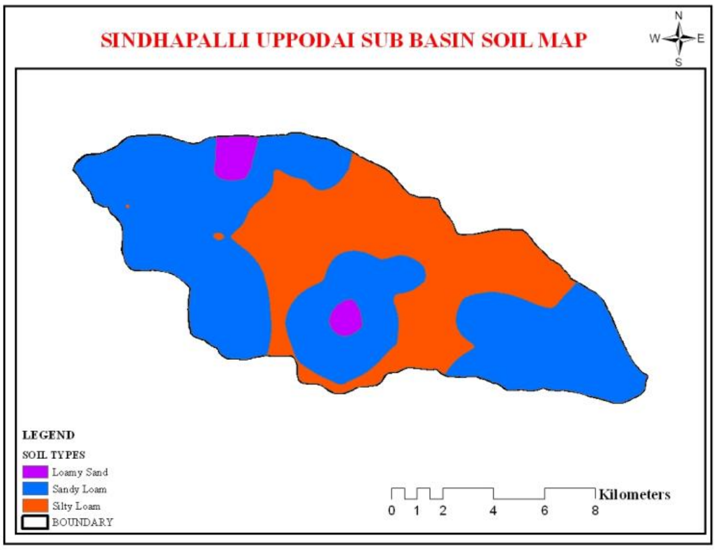


Figure 2 Soil Map of the Sindappali Uppodai sub basin

As per the GEC norms the infiltration factor for the various soil types in the Sindappalli Uppodai sub basin is shown in table 2.

Table 2 Rainfall infiltration factor

Sl. No.	Soil Type	Rainfall Infiltration Factor as a fraction
1	Sandy Loam	.11
2	Loamy Sand	.12
3	Silty Loam	.10

ESTIMATION OF RECHARGE COMPONENTS

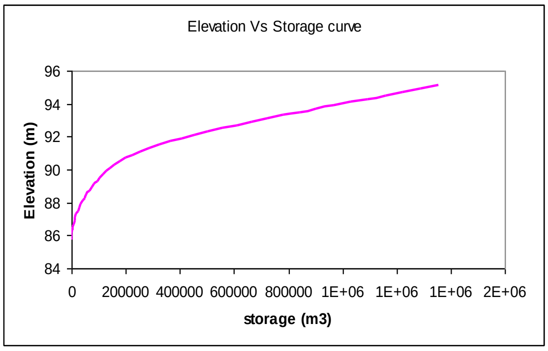
Ground water recharge may be defined as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. It is one of the key hydrological parameters for assessment, budgeting, modeling and management of ground water resources. Rainfall is the principal source of recharge. The other sources are seepage from tanks and canals and return flow from irrigation also contribute significantly to the ground water recharge.

Recharge from Rainfall

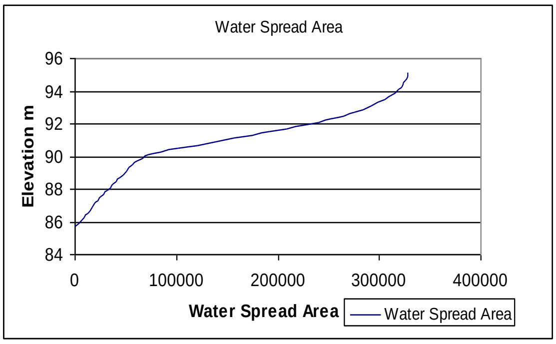
Rainfall recharge is one of the main components for groundwater recharge. The actual groundwater recharge during monsoon season and non monsoon season is calculated using the rainfall infiltration method as per GEC norm 1997. It says that the infiltration factor multiplied by the season rainfall to the corresponding area gives the recharge due to rainfall from the influencing station. There are 4 raingauge stations having their influence over the sub basin namely Sivakasi, Sathur, Vembakottai and Srivilliputhur. The infiltration factor depends only on the type of terrain in the case of hard rock terrain it again depends on the rock type. The type of rock present in the study area is verified during the well inventory.

Recharge from Tanks

The drainage map was prepared from the Survey of India toposheet and updated using high resolution Cartosat imagery. There are 16 tanks connected in the form of cascades in the sub basin. GPS survey was conducted in each tank to establish the Stage vs Water spread area and Stage vs Storage relationships The Stage vs Storage and Stage vs Water spread area for Annupankulam tank is shown in figure 3. Water level in all tanks during monsoon and nonmonsoon are being monitored on weekly interval.



Stage Vs Storage



Stage Vs Water Spread Area

Figure 3 Stage vs Storage and Stage vs Water spread area of Annupankulam Tank

As per GEC norms (1997), recharge from each tank in hectare meters can be obtained as the product of the average water spread area for the season and the number of days of water is actually available and a recharge factor of 0.00144 meters per day per hectare. The number of days the tank water is available is known from the observed data. The tank water level is recorded on weekly basis from which the average water spread area for the season can be found. The details of the tanks available in the study area and its hydraulic particulars are presented in Table 3.

Table 3 Tank Details

Sl. No.	Tank	Catchment Area(km^2)	Water spread Area (km^2)	Capacity (m^3)	Type of Weir	Length of Weir (m)	No. of Sluice
1	Duraisamipuram	2.92	0.2208	586383.3	Rectangular	17.2	2
2	Ammapatti	1.44	0.1293	295876.3	Stepped	19.6	2
3	Oorampatti	8.28	0.4644	1093061.0	Rectangular	26.6	1
4	Villampatti	3.68	0.1113	223109.2	Stepped	43.9	1
5	Sittarajapuram	15.09	0.0845	344319.9	Rectangular	58.4	1
6	Anaikuttam	19.65	0.5782	1444639.0	Rectangular	117	2
7	Thayilpatti	2.43	0.1606	275839.8	Rectangular	17	0
8	Minampatti	20.06	0.2896	-	Rectangular	55	1
9	Anupankulam	4.51	0.3058	842003.9	Rectangular	25	2
10	Melaottampatti	18.03	0.3035	-	Rectangular	120	3
11	Muthalanayakkanpatti	16.49	0.7894	2289163.0	Rectangular	115	2
12	Anayiur	0.92	0.0510	673098.8	-	-	1
13	Sengulam	4.35	0.2408	1181490.0	-	-	2
14	Kattalaipatti	4.72	0.2066	517438.5	Rectangular	12	0
15	Ciriyakulam	2.03	0.1548	-	-	-	0
16	Mettamalai	4.22	0.2498	503638.6	-	-	0

Recharge from Irrigation Water

Recharge from irrigation water applied from surface water irrigation and ground water irrigation has to be computed for the monsoon and non monsoon seasons. High Resolution Imagery CARTOSAT-1 was used to prepare the land use map. The land use map is shown in figure 4. The surface water and ground water irrigated area are delineated from the land use map and verified during field investigation.

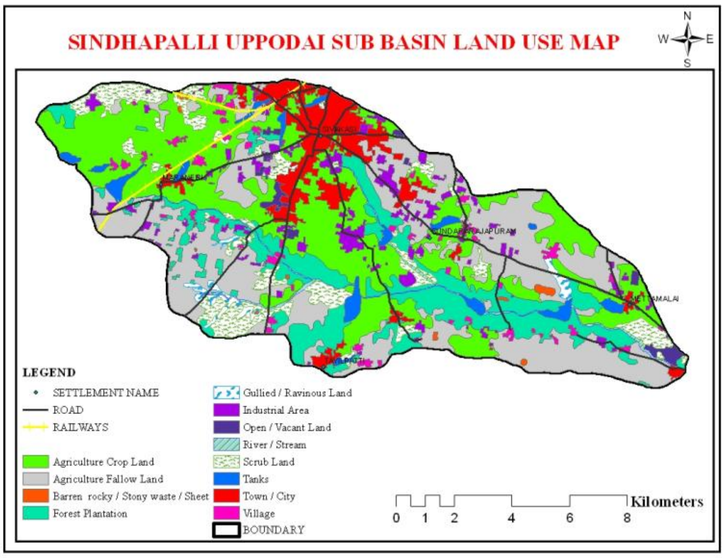


Figure 4 Land use map of Sindapalli Uppodai sub basin

Recharge from Surface Water Irrigation

The agricultural crop land nearer to the tank area is commonly irrigated from the tank water. This is verified by field survey and using GPS. The amount of water supplied to each field through canal system has to be known for each tank command area. The water released from the outlet is obtained from the Publics Work Department database and also the number of days it is actually released. The water levels are obtained from the observation wells and interpolated for the sub basin using GIS.

The computation of recharge from irrigation water applied by surface water irrigation in hectare meters can be obtained as the product of the irrigation water applied in hectare meters and return flow factor as a fraction. The irrigation water applied is considered as the sum of the water released from all outlets in the canal system. The water released in hectare metres from each outlet can be computed as the product of the design discharge of the outlet in hectare metres per day, number of days water is actually released from the outlet and a factor 0.6 (assuming the actual average discharge is 0.6 times the design discharge). The return flow factor depends only on the crop irrigated is paddy or non paddy, whether the range of depth to water table below ground level is less than 10 metres, between 10 and 25 metres or greater than 25 metres and whether the release from outlets is continuous or rotational.

Recharge from Ground Water Irrigation

The agricultural crop land that are irrigated from ground water are identified by the field survey and using GPS. The water levels are obtained from the observation wells and interpolated for the sub basin using GIS. The computation of recharge from irrigation water applied by ground water irrigation in hectare meters can be obtained as the product of the irrigation water applied in hectare meters and return flow factor as a fraction. The return flow factor depends only on the crop irrigated is paddy or non paddy, whether the range of depth to water table below ground level is less than 10 metres, between 10 and 25 metres or greater than 25 metres.

In the study area, it was observed that the water table condition is less than 10m below ground level and the crop rose during monsoon and Non-monsoon season are paddy and non-paddy. Therefore the recharge from surface water irrigation is taken as 30% of the gross surface water applied for non-paddy crop and 50% of the gross surface water applied for paddy as recommended by GEC. The recharge from Ground water irrigation is taken as 25% of the gross surface water applied for non-paddy crop and 45% of the gross surface water applied for paddy as recommended by GEC.

Groundwater Draft

Well inventory survey was done using Cartosat Imagery. Field investigation was carried out to identify the type of well. Ground water is primary made use of to meet domestic water supply and irrigation water requirements. Now it is also important to meet industrial water supply requirements. For the current study 71 wells are totally identified using Remote Sensing Imagery. There are 14 observation wells and 57 pumping wells. 51 wells were located inside the boundary are shown in figure 5. All other wells are located outside and nearer to the boundary. These wells are used to give general head boundary condition for ground water modeling.

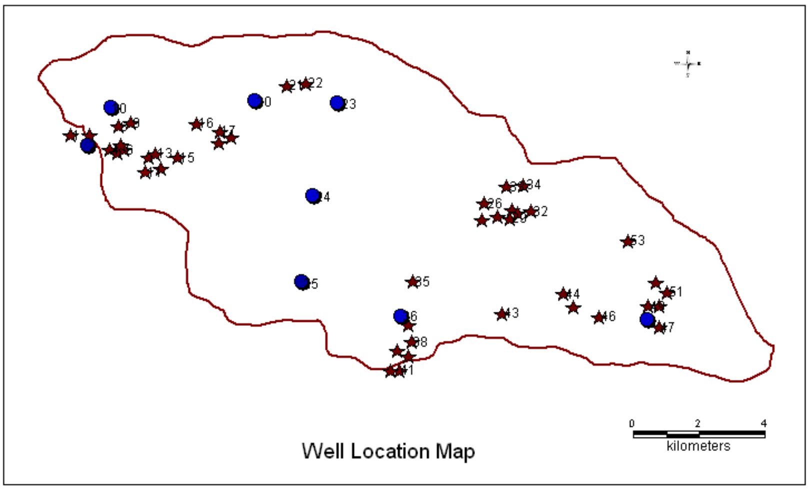


Figure 5 Well Location map of the Sindappali Uppodai sub basin

Current annual gross ground water draft is assessed using GEC ('97) norms. The type of well found in the study area is the dug well with pump set. The wells found using the imagery is grouped in to the wells in the command area and non command area. As per GEC norms the average annual ground water draft per well from dug well with pump set is 0.4 to 1.00 hectare metres. The average annual ground water draft for all uses in command area and non command area can be calculated.

GROUNDWATER MODELLING

The simulation of groundwater flow requires a thorough understanding of the hydro geologic characteristics of the site. The hydro geologic investigation should include a complete characterization of the following:

- The top soil extends to a depth varying from 1 to 3 metres in the sub basin. Followed by the weathered formations up to a depth of 8 metres, below 8 m is the hard rock with the Granite- Gneiss.
- Hydrologic boundaries considered here in this modeling is General Head Boundary condition. Flow into or out of a cell from an external source is provided in proportion to the difference between the head in the cell and the reference head assigned to the external source. The recharge boundaries (recharge from rainfall and recharge from tanks calculated from GEC norms) are also considered.
- Hydraulic properties of the aquifers such as conductivity and storage co efficient and specific yield and the porosity are given for each layer. The model consists of two layers, first layer is soil and the second layer is weathered formations.
- The initial head for the observation well is monitored in the field on weekly interval and the model is simulated under equilibrium condition.
- Distribution and magnitude of groundwater recharge is calculated as per GEC norms, pumping of groundwater is from the dug wells and the pumped water is used for irrigation and for drinking water. Some of the industries located in the sub basin are also depend on ground water. As per GEC norms the irrigation draft and the domestic and industrial allocation of ground water is calculated.

Visual MODFLOW

Model Simulation

At first the boundary of the study area map is imported into the model and the map is shown in Figure 5A. The study area has been discretized into an orthogonal grid of 60 rows, 60 columns and 2 vertical layers. The vertical cross-section of the aquifer is shown in Figure 6. This spatial discretization has been found to be adequate in view of the available data and the computational time. For the finite difference solution, a grid of 190m x 120m was used furthermore, such a grid spacing, given the step chosen for the solution, meets the requirements for numerical stability, even in areas with intense pumping activity.

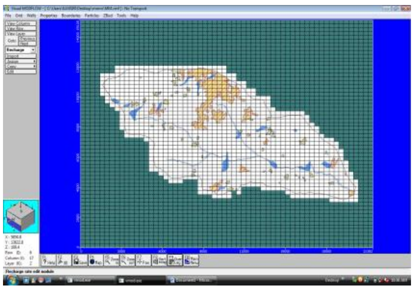


Figure 5A Study area map with grids

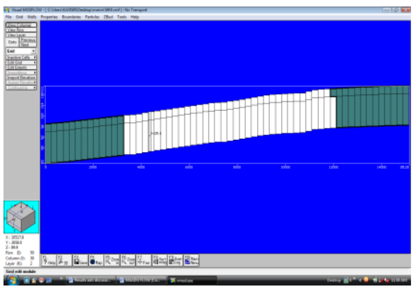
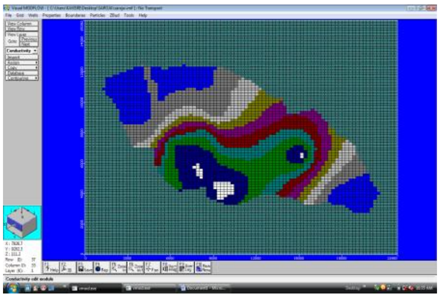


Figure 6 No of layers

- The details about pumping wells and water levels in observation wells during the period of 2007 to 2009 were imported into the model.
- The hydrologic properties like hydraulic conductivity and storage coefficient based on lithology were imported for each layer is shown in Figure 7 & Ground Head Boundary condition is shown in fig-8.



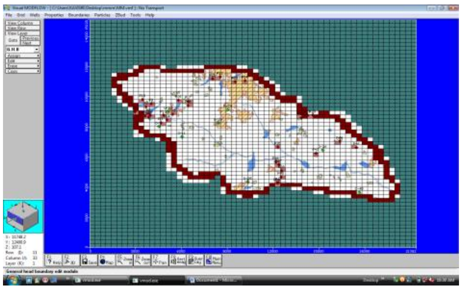


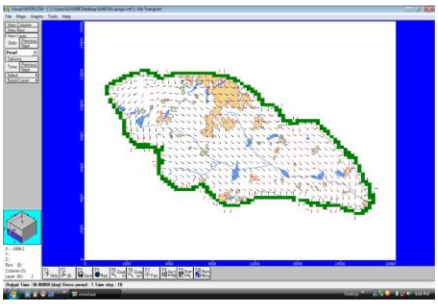
Figure 7 Hydraulic conductivity **Figure 8 General Head Boundary Condition**

Model Calibration

The purpose of model calibration is to establish that the model can reproduce field measured heads and flows. Calibration is carried out by trial and error adjustment of parameters or by using an automated parameter estimation code. The flow directions and the dry cells in the study area are shown in Figure 9 and 10. The water table elevation in the model is shown in figure 11. The recharges from the study area i.e. recharge from rainfall and recharge from tanks is shown in figure 12 and figure 13.

Steady state conditions are usually taken to be historic conditions that existed in the aquifer before significant development has occurred (i.e. inflows are equal to outflows and there is no change in aquifer storage). In this model, Steady state calibration comprised the matching of observed heads in the aquifer with hydraulic heads simulated by MODFLOW. The calibration was made using 8 observation wells monitored during 2007-2009. Hydraulic conductivities estimated from Pedo Transfer Function (PTF) were used as initial values for the steady state simulation. By trial and error calibration, the conductivity values were increased during many sequential runs until the match between the observed and calculated water level values were obtained (Fig. 14,15, 16 &17). The computed water level accuracy was judged by comparing the mean error, mean absolute and root mean squared error calculated. Mean error is -0.096 m. Root mean square (RMS) error is the square root of the sum of the square of the differences between calculated and observed heads, divided by the number of observation wells, which in the present simulation is 1.297 m. The absolute residual mean is 0.956 m.

The model was calibrated to transient state from 2007 to 2009. Since data on various flows in transient state were available for a period of 2007 to 2009, simulation was performed for that period taking the 2007 water levels as initial condition and then the simulation was carried out under transient conditions 2007 onward to 2009. The time steps in transient simulations run from 2007 to 2009 were divided into 20 time steps. Each year was also divided into two stress periods of 152 days (monsoon period) and 213 days (non- monsoon period) respectively. Recharge boundary were initially set using 30-days stress period, which was gradually increased to 152 and 213 days. The actual amount of recharge was calculated for each year using GEC'97 methodology. Visual MODFLOW uses boundary condition imposed by the user to determine the length of each stress period.



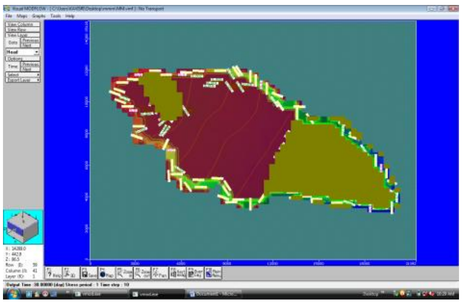
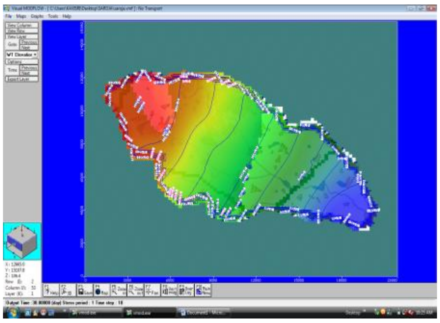


Figure 9 Flow Direction in the Study area **Figure 10 Dry cells in the area**



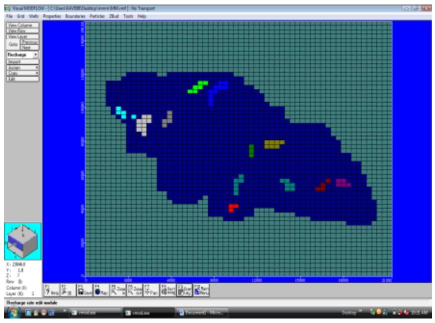


Figure 11 Contours of Water table Elevation **Figure 12 Recharge from Rainfall**

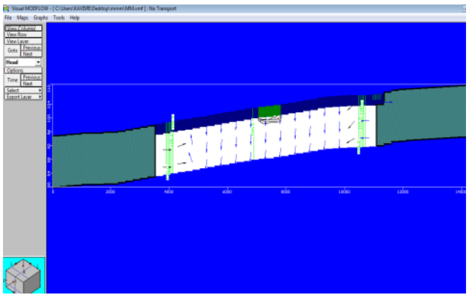


Figure 13 Recharge from tanks

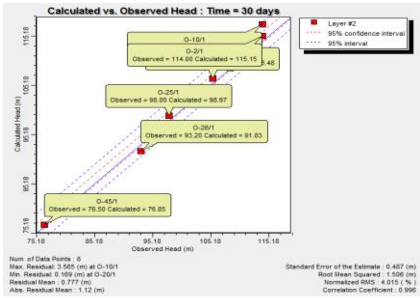


Figure14 Water Level Comparison for a period of 30 days

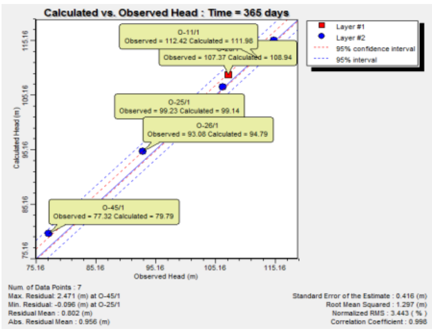


Figure 15 Water Level Comparison for a period of 365 days

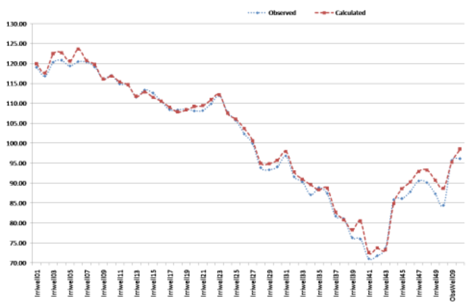


Figure 16 Water Level Hydrograph for a period of 365 days

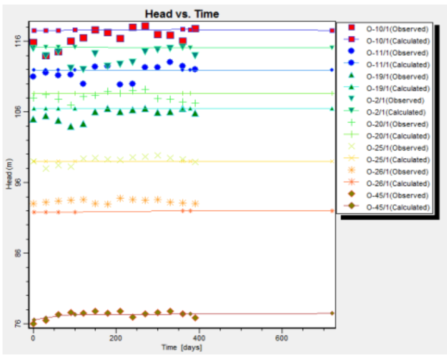


Figure 17 Water level variations with respect to time

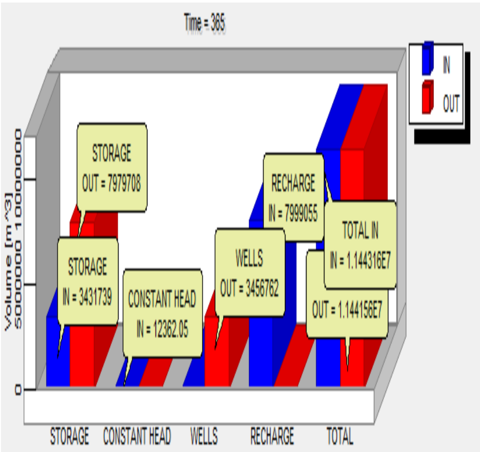


Figure 18 Aquifer Zone Budget at 365 days

Zone Budget

Zone Budget calculates sub-regional water budgets using results from steady-state or transient MODFLOW simulations. Zone Budget calculates budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. At a period of 365 days, storage in to the aquifer is 3.43 Mm^3/day and flow out of the aquifer from storage is 7.97 Mm^3/day. The water pumping out from the wells is 3.4 Mm^3/day. Recharge into the aquifer is 7.99 Mm^3/day. The total inflow into the aquifer is 11.443 Mm^3/day and total outflow into the aquifer is 11.441 Mm^3/day. At the period of 365 days, the outflow is more than the inflow by an amount of 0.0016 Mm^3/day. This has been shown in the Figure 18.

CONCLUSION

The dynamic groundwater resource is the exploitable quantity of groundwater, which is recharged annually. In the present study groundwater recharge in the tank cascaded catchment, Sindapalli Uppodai sub-basin in Vaippar river basin has been estimated by using Groundwater Estimation Committee (GEC-1997) norms. The Groundwater assessment unit is considered as watershed and the groundwater recharge is estimated by considering the different recharge components like recharge from rainfall, recharge from tanks, recharge from groundwater irrigation, separately for command and non-command areas. GIS is a powerful tool successfully used to prepare the soil map, land use map and drainage maps from the high resolution satellite imagery and SOI toposheet and field survey. Visual MODFLOW is used effectively to simulate the hydraulic heads of an unconfined aquifer. The hydraulic heads have been simulated and it shows a good relation with observed values. The predicted ground water levels are used to study the ground water balance for proper ground water estimation and management. Various scenarios can be built by changing the pumping rates, by varying the recharge from irrigated area and tanks.

ACKNOWLEDGEMENT

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OPERATIONAL NEED OF ARTIFICIAL RECHARGE PLAN FOR GROUND WATER AUGMENTATION IN SAHARANPUR AREA, UTTAR PRADESH

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ABSTRACT

Artificial recharge is a renowned and generally used popular system to augment the ground water reservoirs all over the globe. The need of execution of artificial recharge plan has been discussed with a view to supplement the ground water in adequate capacity to cater the demand for domestic, drinking, agriculture, industries, energy and sport sectors by selecting an example from the vicinity of Saharanpur and adjoining region, located in Uttar Pradesh. The artificial recharge methods such as surface spreading, injection wells and water harvesting, facilitate successful results in case of aquifers. Based on geology, meteorology, and other allied data base information, an attempt has been performed to formulate a plan for the construction of artificial recharge structures such as the gully plugs, nalah bunds, check dams, pits, trenches, percolation tanks, and injection wells besides, development of a forestation for increase of the ground water system in Saharanpur region to develop buffer stock that will greatly help in times of natural calamity. It is suggested that the operation of artificial recharge plan will provide better results provided if it is added with quality monitoring of recharge water, rain water harvesting, conservation of water resources, and public awareness relating to significance of ground water use.

Key Words: Artificial recharge, Plan, Saharanpur, Uttar Pradesh. Augumentation, Ground water system.

INTRODUCTION

The ground water resource has played an important role in improving the India's agricultural economy as controlling factor of the drought phenomena. Ground water plays a key role to agricultural GDP and drought mitigation. The spread of ground water irrigation supports employment generation and thus rural development and poverty alleviation. It is necessary to augment the available resources to maximum possible extent. The recognized concept of artificial recharge for augmentation of ground water system has been frequently in practice for a period of more than last three centuries. This concept has been discussed with a prime objective to apply artificial recharge plan for augmentation of ground water system in vicinity of Saharanpur City and adjoining area. It requires water supply for domestic, irrigation, and industrial purposes. Due to increasing trend of water demand, the ground water withdrawal is rather in a state of overdraft, hence, in the light of importance of water as an elixir of life, it is considered valuable to formulate a plan for the sustainable development of ground water resource with a view to provide regular water supply throughout the span.

Study Area

Saharanpur study region is located in the Uttar Pradesh. (Survey of India Toposheet no 53 G/9 and 53 F/12). The surface drainage comprises Dhamola and Paondhoi rivers. A branch line of East Yamuna Canal flows through the city area. The climate is mostly tropical, witnessing cold winter season due to near distance from Siwalik Hills. The temperature is recorded within range of 6.6°C to 45°C with an average of 20.1° C. The rainfall is rather heavier as compared to surrounding region. Rainfall data indicate a fairly good range of variation from 497.70 to 1566.10 mm with an annual average value of 1058.82 mm (Singh, 2007; Singh and Dev, 2009). The humidity ranges from 70 - 85 %.(rainy season) and from 29 to 55% (summer season). Wind plays an effective impact on climate. The prevalence of dry and wet seasons is very common in Saharanpur area.

Geological Setting

Saharanpur and adjoining area is mainly occupied by the alluvium and lower piedmont plain. The older and younger alluvial plains consist of various grades of sand bars, flood plains, point bars, paleo - channels, and meanders have also been created by the revering agencies in younger alluvium along the river banks. Geologically, Saharanpur area is characterized by development of the Quaternary Alluvium with varying combinations of clay, silt, sand and gravel. The generalized geological sequence of Saharanpur district is displayed (Table-:1).

The lithology of study area is monotonous comprising of Khadar, Bhangar and Alluvial plain. except for some variations in the northern part where Bhabars of the Himalayas grade into the plains. Alluvium consists of mainly fluviatile and sub-aerial deposits of clay, sand, and gravel. Khadar represents alluvial deposits in the riverine tracts or the flood plains of rivers,

Table-:1 Geological succession in Saharanpur study area, Uttar Pradesh (After, Saini, 2003)

S. No.	Age	Formations	Lithology
1	Recent	Younger alluvial plains including flood plains	Sand and clay
2	Upper Pleistocene to Recent	Older alluvial plains including Bhabar and Tarai	Boulders, pebbles, gravels, sands, silt and clays
3	Middle Miocene to lower Pleistocene	Middle Siwaliks	Sandstones with boulders cobbles, conglomerates & clays

The constituents of Khadar i.e. sand, silt, and clay are renewed almost every year due to alleviation followed by floods. On the other hand, Bhangar represents older alluvium of relatively higher lands, which are not submerged under water during floods.

HYDROGEOLOGICAL SETTING

The well inventory involves collection and monitoring of relevant data in respect of available shallow wells and tube wells. The hydro-geological survey reveals the mode of occurrence of ground water under both unconfined and confined conditions. Saharanpur area is characterized by predominance of the Alluvium. Ground water in Bhabar zone occurs under confined water table in the southern direction, and become comparatively shallow in the peripheral tract. Tarai formation is separated from the Bhabar belt by a spring line. The water level ranges from 2 to 3 m b.g.l. and the water occurs both under unconfined and confined conditions. The water level range between 7 to 10 m bgl in the eastern part of Saharanpur. The water level gradient is about 0.5 to 1.3 m/km range in southern part of the city with the direction from NE to SW and north to south.

The existence of a three - tier aquifer system in Saharanpur area has been observed. The first aquifer (sand thickness is about 88 m with 64% of sand) system lies down to 147 m b.g.l. (metre below ground level). The second aquifer (granular material is found upto 64 m thickness with 54% sand) starts from 167 to about 267 m b.g.l. and third aquifer (sand range up to 63%) is at depth below 290 m b.g.l. The Transmissivity of shallow aquifer system ranges from 338 to 2500 m^2/day. The field permeability lies between 15.44 to 17.09 m/day and yield of the wells are 1610 to 2210 l.p.m. The examination of long term water level data collected from national hydrograph stations of Saharanpur district has revealed a range of water level fluctuation from 0.1 to 2.5 m for 20 years. In Saharanpur city, the water table has been reducing at a rate of 0.047 metre/year (CGWB, 2000).

RECHARGE OF GROUND WATER

The recharge criterion is important factor for augmentation of ground water reservoir. Water supply of basin may be limited either by storage volume of under-ground basin or by the rate of water movement through basin from the recharge area to withdrawal area. The quantity concept is usually applicable to unconfined aquifers where supply and disposal areas are near, whereas the rate concept applies more to confined aquifers where supply and disposal areas are widely separated (Vocational Business, 2003). Ground water recharge has been explained as a process involving the amount of water present in or flowing through interstices of sub-soil increases by natural or artificial means. Important features of recharges are described.

(1) Natural Recharge

The principal source of natural water includes the precipitation, stream flow, lakes and reservoirs. Practically ground water originates as surface water. The rainfall is most important source for replenishment of moisture in soil water system and recharge of ground water, The amount of moisture that will eventually reach water table is defined as natural ground water recharge, which depends on rate and duration of the rainfall, subsequent conditions at upper boundary, antecedent soil moisture conditions, water table depth and nature of soil.

The methods of ground water recharge estimation directly from precipitation can be divided into three – (a) inflow, (b) aquifer response and (c) outflow methods (Kumar, 1977). The commonly used methods for estimation of natural ground water recharge (Chandra, 1979) includes: (i) soil water balance method, (ii) zero flux plane method, (iii) one-dimensional soil water flow model, (iv) inverse modelling technique,(v) ground water level fluctuation method,(vi) hybrid water fluctuation method, (vii) ground water balance method, and (viii) isotope and solute profile techniques.

(2) Artificial Recharge

The term artificial recharge refers to augmentation of the natural movement of surface water into underground formations by some technique of construction spreading of water, or by artificial changing natural setting (Todd, 1959, 1980). Walton (1970) considered artificial recharge as the practice of increasing, by artificial means, the amount of water that enters a ground water reservoir. Artificial recharge has been measured as "replenishment of ground water brought about by man's action. This replenishment, however, could be a result of a planned activity like structure of wells or pits" (Charlu and Dutt, 1982). According to Fetter (1988, 1990), the artificial recharge is a process by which water can be injected or added to an aquifer. Karanth (1987, 1994, 2003) has considered artificial recharge as **"*the process by which infiltration of surface water into groundwater systems is increased by altering natural conditions of replenishment*"**. The artificial recharge of ground water has also been defined as 'the recharge that occurs when the natural pattern of recharge is deliberately modified to increase recharge '(A.S.C.E, 2001).Artificial recharge occurs from excessive irrigation, seepage from canals, and water purposely applied to augment ground water supplies. A variety of methods have been developed, including water spreading, recharging through pits, wells and pumping to include recharge from surface water bodies. Numerous criteria for selection of artificial projects have been suggested by different workers (Muckel, 1948, Todd, 1959, 1980, Charlu and Dutt, 1982; Karanth, 1987, 1994, 2003; and others.

The basic prerequisite for taking up any artificial recharge scheme is availability of source water, which may be the precipitation in area, nearby stream or aquifer, surface water supplies (canal, trans basin). The major source of water for artificial recharge of ground water includes the rainfall and runoff. Rainfall is the primary source of recharge in to the ground water reservoir. A large percentage of artificial recharge projects are designed to replenish ground water resources in depleted aquifers and to conserve water for future use. Artificial recharge is becoming increasingly necessary to ensure sustainable ground water supplies.

The significant advantages of artificial recharge are: (1) Subsurface storage space is available free of cost and inundation is avoided, (2) Evaporation losses are insignificant, and (3) Quality improvement by infiltration through the permeable media. The successful implementation of artificial recharge projects depends on the major components such as (1) assessment of source water, (2) planning of recharge structures, (3) finalisation of specific techniques and designs, (4) monitoring and impact assessment, (5) financial and economic evaluation, and (6) operation and maintenance (Karanth, 2003).

ARTIFICIAL RECHARGE PLANNING

The vital necessities for artificial recharge plan have been elaborated by some workers including Shrivastava (2000) under three modules: (1) Planning of artificial recharge scheme, (2) Monitoring and (3) Technical Auditing. The planning phase of artificial recharge schemes involves formulation of a proper plan, under a given set of natural conditions, to augment the natural ground water recharge. An artificial recharge scheme may be aimed at increase of recharge process in a specific area for making up shortage in ground water recharge compared to ground water draft. It is necessary for developing a realistic technical plan for an artificial recharge project to consider appropriate aspects such as the ground facts, need, prioritization of areas, accessibility of source water, aptness of area, hydrogeological factors climatic and topographic system, and soil - land use environment.

ARTIFICIAL RECHARGE STRUCTURE

The construction of following important artificial structures in Saharanpur area will be more suitable for the process of augmentation of ground water system.

Gully Plugs, Nalah Bunds and Check Dams

Gully plugs are usually constructed across 1st order streams, nalah bunds and check dams are constructed across bigger streams and in area having gentle slopes. Competent civil and agro-engineering techniques are to be used in the design, layout and construction of permanent check dams to ensure proper storage and adequate out flow of surplus water for long-term stability of the dam (Centre Science and Environment, 2003).

Nalah bunds are fairly large structures and commonly constructed across the selected nalahs. Nalah bed must have good permeable soil.

Check dams are normally constructed to augment recharge from existing streams or ephemeral channels (Pettyjohn, 1988), Check dams are generally 10 to 15 m long, 1 to 3 m wide and 2 to 3 m high and generally constructed in a trapezoidal from. The site selected for check dam should have sufficient thickness of permeable soil or weathered materials to facilitate recharge of stored water within a short span of time. The water stored in these structures is mostly confined to stream course and height is normally less than 2 m. They are designed based on stream width and excess water is allowed to flow over the wall. .

Pits, Trenches

Pits are commonly used for artificial recharge purposes as well and depth can range from 2 to 40 m. These dams can be constructed in channels. The aquifer is recharged by diverting water from main channel to the pit. Trenches can be constructed for artificial recharge of water. A trench filled with porous material and a large perforated pipe can serve as recharge facility (Karanth, 2003).

Percolation Tanks

The building of percolation tank is one of most significant artificial recharge method to augment ground water system. It helps in providing water supply during summer season. Percolation tanks are generally made on streams having a sizeable catchment area. The site selection is taken at place having adequate sub-surface storage space.

Injection Wells

Injection wells are structures generally constructed on the dry lands. for the augmentation of aquifer by transmitting contamination free surface water. It has been considered that injection wells can be drilled down stream of a dam and water released from the spillway is conveyed into the wells (Raghunath,1982).The operation of recharge by injection wells involves treatment of suspended matter so that aquifer should be clean.

Roof Top Rainwater Harvesting

Rainwater harvesting involves tapping the rainwater where it falls. A major portion of rainwater that falls on the earth's surface is runoff in to the streams, rivers, and finally in to the sea. The rainwater harvesting technique involves collecting the rain from localized catchment surfaces such as roofs, plain or sloping surfaces etc., either for direct use or to augment the ground water resource. Roof top rainwater harvesting is one of the appropriate options for augmenting ground water recharge / storage in urban areas. The simplest method of roof top rainwater harvesting is the collection of rainwater in a large pot /vessel kept beneath the edge of the roof. The water thus collected can meet the immediate domestic needs. In this method, water is collected from roof using drain pipes/ gutters fixed to roof edge. Central Ground Water Board is already implementing the roof top rainwater harvesting scheme in different parts of the country.

ENVIRONMENTAL MANAGEMENT

It involves implementation of scheme for a forestation including optimum growth of plants. This effort will enhance the amount and frequency of rainfall, which in turn, would help in the augmentation of ground water system. A flow chart of the artificial recharge plan for the dround water reservoir of Saharanpur study area has been illustrated (Figure 1).

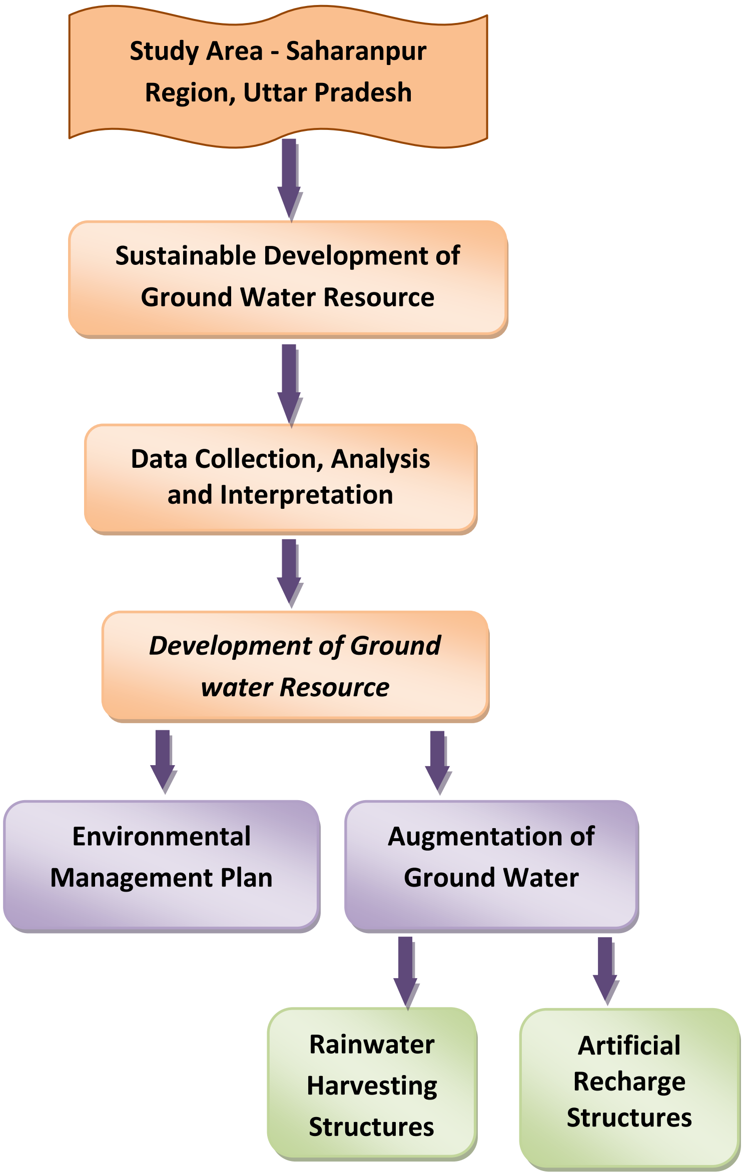

Figure 1 Conceptual model of sustainable ground water development with reference to Saharanpur region located in Western Uttar Pradesh

CONCLUSION

The sustainable development is a balanced process which enhances both current and future potential to meet human needs and aspirations. The sustainable development concerns with the optimum realization of different social, environmental and economic objectives of society at one and the same time. Ground water is a renewable natural resource, however, it has limited extent and hence, only a definite quantity of water must be withdrawn annually from a ground water basin. Artificial recharge is a common globally used technique to augment the ground water system

The need of implementation of artificial recharge plan has been discussed to increase the ground water expediency in Saharanpur area, located in Uttar Pradesh, to cater the present demand for domestic, drinking, agriculture, irrigation, industries, energy and sport sectors.

The paper deals with planning and operation of artificial recharge plan for proper augmentation of ground water system of Saharanpur area by construction of artificial recharge structures such as the gully plugs, nalah bunds, check dams, pits, trenches, percolation tanks, and injection wells. It is suggested that the operation of artificial recharge plan will provide better results provided if it is added with quality monitoring of recharge water, benefit-cost analysis, rain water harvesting, conservation of water resources, development of a forestation and public awareness programmes relating the significance of ground water use.

It is considered that the operation of artificial recharge scheme would greatly help in the increase of ground water system that would make available a buffer stock in Saharanpur region, which will provide timely help in combating natural hazards.

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EVALUATION OF DEEP AQUIFER RESOURCES IN LOWER GANGA PLAIN OF PATNA URBAN AGGLOMERATE, BIHAR

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ABSTRACT

Ground water, once in abundance, is now becoming a critical resource with fast development and ballooning population. Thus the precise estimation of this resource becomes imperative for sustainable development of the country in future. Patna urban agglomerate lies in the Lower Ganga plains and depends completely on ground water resources. On an average about 76 mcm of water is being withdrawn annually. It is seen that there is a large gap between ground water recharge of 45 mcm/ year calculated on water level fluctuation basis and the draft of over 76 mcm/ year. But there is no appreciable decline in water levels. Thus, it is obvious that calculated resource on the basis of water level fluctuation method does not reflect the true potential of deeper aquifer as it is laterally being recharged from distant sources. Aquifers of the Patna urban area are under semi-confined condition with storativity value as high as 0.008 i.e. almost on the threshold of the unconfined aquifer and yet yielding copious volume of water without any significant decline in water table over the decades. Thus, it is apparent that ground water resources of 124 mcm of deep aquifers calculated on the basis of storativity value is sufficient enough to sustain that massive withdrawal. It is thus, safe enough to calculate the ground water resources of deep aquifers in general by considering the storativity value of 0.0099, of the aquifers lying under semi-confined to confined conditions, and without causing any appreciable decline in water level over the time.

Key Word: *Evaluation, Aquifer, Resource, Ganga Plains.*

INTRODUCTION

Ground water, once in abundance, is now becoming a critical resource with a fast development and urbanization, thus the precise estimation of this resource becomes imperative for its planning, development and conservation. Patna urban agglomerate having population of over 1.9 million and lying on the southern bank of the river Ganga of Lower Ganga Plain depends completely on ground water resources for all its water requirements. There are about 93deep tube wells besides innumerable shallow tube wells dug in almost every house and tapping the same aquifers. A very large volume of water to the tune of 76 million cubic meters (mcm) is being withdrawn annually within the Patna urban area to cater its requirement. Thus, the ground water comes under stress and there is some decline in water table which may aggravate in future. This paper deals to establish a mass balance relation in ground water recharge & draft by estimating the resources with storativity of the aquifers.

HYDROGEOLOGY

Patna urban agglomerate, lying in the lower Ganga plain, is underlain by the typical sediments of Sone-Ganga flood plains. It is a monotonous plain with subdued relief feature other than the marked levees on the bank of Ganga river. Exploratory drilling carried out down to a depth of over 300 m in Patna town by Central Ground Water Board revealed that there is thick sequence of alluvium sediments having the basement over 600 m deep as estimated by Geological Survey of India (GSI). Alluvial sediments are cyclic in nature and generally it is fining upward. The sediments lying below the Ganges sediments are in contrast and it is very coarse sand to gravely in nature. There are three sets of aquifers (fig-I) within the explored depth of 300 m, namely (i) The Ganga Aquifer, (ii) The Sone Aquifer and (iii) The infra Sone Aquifer. The infra Sone aquifer lying below about 120 m comprises highly angular, medium to very coarse grained to gravely, grey coloured sediments attains the thickness of 60-90 m. Lying above the infra Sone aquifer is the Sone aquifer and comprises well rounded, medium to very coarse grained of typical yellow colour sediments attains the thickness of over 60 m in general and large thickness in palaeocourses of the Sone river. Lying on the top and separated from the Son aquifer by thick clay is the Ganga aquifer comprising medium to fine grained platy sediments of typical grey colour which attains the small thickness of about 15-20 m. The Sone aquifer system is very prolific aquifers. It is apparent from the geological section (fig-II) across the river Ganges from Karbigahia (near Patna Railway Station) to Golghar to Konhraghat on the northern bank in Vaishali district that the aquifers of Patna area are abutted against a 80 m thick clay in the river bed and there is no hydraulic continuity with the river water for an appreciable length. Thus, they are not receiving any water as affluent recharge from the Ganga river.

Fig : - 1

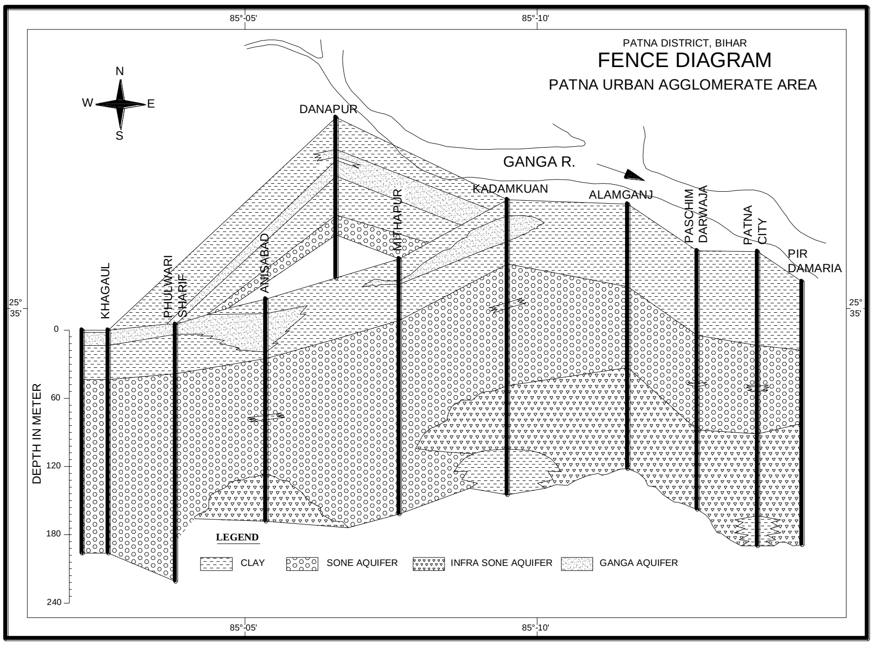
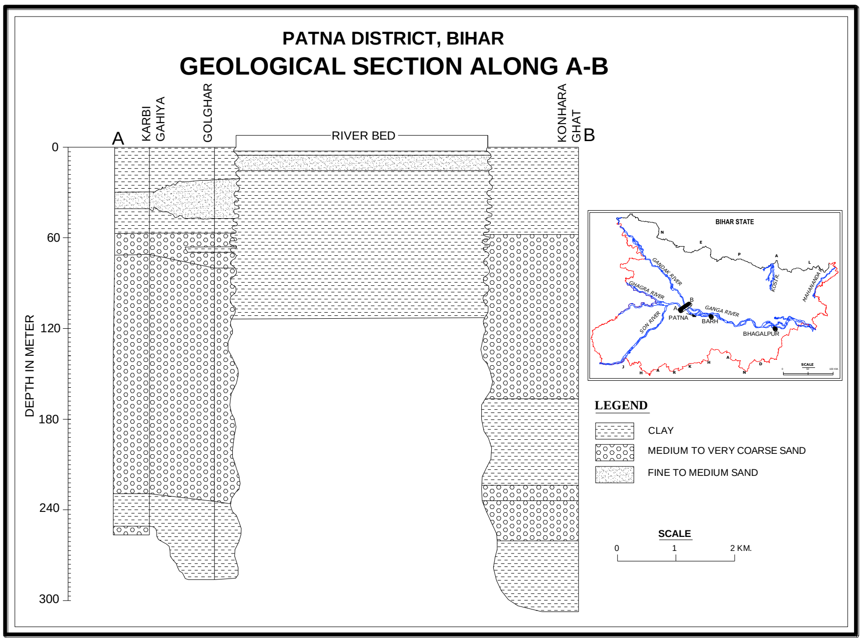


Fig : - 2



AQUIFER CHARACTERISTICS

Deep aquifers of the study area are under semi confined condition. Individual aquifer characteristics are not known. However, tube wells constructed under exploratory drilling program of Central Ground Water Board (CGWB) have tapped number of aquifers within the depth range of 75-200 m below ground level (m bgl). Thus, a combined aquifer properties of about 125 m thick aquifers of this area are known.

Depth to water level of deep aquifer varies from 9.00 to 16.00 m bgl during pre-monsoon period. The specific capacities of 18 tube wells of this area vary from 74 to 94 m^3/ hr/ m. The transmissivity of aquifer system has been found to vary from 5900 to 9900 m^2/ day with storativity value varying from 0.5×10^{-2} to 0.77×10^{-2}.

RESOURCE ESTIMATION

Patna urban agglomerate is spread over an area of about 100 sq km along the Ganga river with a stretch of about 20 km from Danapur in the west to Patna city in the east, having average width of 5 km. Considering the average annual ground water fluctuation of 2.50 m over the area and the specific yield of 18%, the resource as per norm of the Ground Water Estimation Committee-1997 (GEC-1997) would be as follows:

$$Ground\ Water\ Recharge = Area \times Specific\ Yield \times Fluctuation$$
$$= 100 \times 10^6\ m^2 \times 0.18 \times 2.50\ m$$
$$= 45.00 \times 10^6\ m^3$$
$$= 45.00\ \text{mcm/ year}$$

GROUND WATER WITHDRAWAL

A total of 93 deep tube wells, within the depth of 200 metres and tapping the aquifer in the depth range of 70- 200 m bgl, are catering the entire water requirements of the Patna urban area apart from a large number of shallow tube wells dug in individual houses and tapping the same aquifers. The discharge of deep tube wells on an average is 225 m^3/ hr and each one is being run on average for 10 hrs/ day during the year. Thus, the total annual ground water draft would be as follows:

$$Annual\ Ground\ Water\ Draft = No.of\ Tube\ well \times Discharge \times Running\ Hrs \times Running\ days$$
$$= 93 \times 225\ m^3 \times 10\ hrs \times 365\ days$$
$$= 76.40 \times 10^6\ m^3$$
$$= 76.40\ \text{mcm/ year}$$

Now, it is seen that there is a large gap between ground water recharge of 45 mcm/ year and the draft of 76.40 mcm/ year. It is, thus, apparent from this fact that aquifers would have been desiccated drastically and water level would have gone down considerably whereby causing the failure of tube wells within few years. But this is not the fact. Then there should be an inflow of excess volume of water exceeding the draft component. Thus, it is obvious that calculated resource on the basis of water level fluctuation method does not reflect the true potential of deeper aquifer as it is laterally being recharged from distant sources and having rich potential.

GROUND WATER RESOURCE OF DEEP AQUIFER

It is found that storativity of aquifer systems in Patna urban areas varies from 0.5×10^{-2} to 0.77×10^{-2} and the tube wells are yielding copious volume of water(250m^3/yr) with a meager drawdown of 3-4 m. It is testified that with these storativities the peizometric head in the semi-confined aquifers would not fall appreciably unless it becomes unconfined i.e, storativity value increases above 0.0099. This value is slightly above the observed storativity value of 0.008. Thus, we can take this storativity value of 0.0099 safely for resource estimation of deep aquifers.

$$Ground\ Water\ Resource = Area \times Storativity \times Aquifer\ thickness$$
$$= 100.00 \times 10^6\ m^2 \times 0.0099 \times 125.00\ m$$
$$= 123.75 \times 10^6\ m^3$$
$$= 123.75\ \text{mcm}$$

Thus, it is apparent that the ground water resource of 124 mcm of deep aquifers calculated on the basis of storativity is sufficient enough to sustain the massive withdrawal of ground water in Patna urban area.

CONCLUSION

The aquifers of the Patna urban area are under semi-confined condition with storativity value as high as 0.008 i.e. almost at the threshold of unconfined aquifer value and yet yielding copious volume of water with a meager drawdown and without any significant decline in water table over the decades. It is, thus, safe enough to calculate the ground water resources of deep aquifers lying under semi-confined to confined conditions by considering 0.0099 as storativity value for resource estimation for safe use of deep aquifers over the time.

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HYDROGEOLOGICAL AND HYDROCHEMICAL SCENARIO AROUND GARUR-BAIJNATH AREA, DISTRICT BAGESHWAR (UTTARAKHAND)

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ABSTRACT

Garur-Baijnath area falls in Garur Valley, Bageshwar District. Geologically, the area is represented by the Lesser Himalayan Tectonic Zone. Hydrogeology of the area is complex owing to the structural and tectonic settings, characterized by multiple phases of deformation and high-grade metamorphism. Cold-water springs are the primary source for drinking and domestic use for the local populace. Hand pumps constructed by Uttarakhand Jal Sansthan also form additional source of drinking water supply. Small irrigational canals (Guls), storage tanks (Hauj) and lift irrigation schemes (Hydrums) are water sources for agriculture and irrigation purposes both during monsoon and non-monsoon periods. Hydrogeological studies in parts of Garur Valley have shown that discharge of springs has been reduced over the years and the existing water supply schemes are inadequate as far as the needs of the local people are concerned. The possibility of large-scale groundwater development in Garur Valley is negligible but small to moderate development is feasible through renovation of spring-based water supply schemes and construction of tube wells after proper hydrogeological investigations followed by groundwater exploration. Hydrochemistry of ground water from seepages and hand pumps indicate that quality of groundwater is excellent for irrigational and drinking purposes. However, high nitrate and fluoride are observed in isolated pockets of Garur Valley. The high nitrate is attributable to anthropogenic sources whereas the high fluoride is due to the geogenic source.

Keywords: *Garur Valley, nitrate, fluoride, hydrochemistry, anthropogenic, geogenic*

INTRODUCTION

Hydrogeological and hydrochemical studies are concentrated in an area of about 50 km^2 in the Garur Valley, around Garur and Baijnath. The Garur Valley is named after Garur, the block headquarter and an important hub for trading and commercial activities in Bageshwar district. The study area falls between north latitudes 29º50' and 29º59'; east longitudes 79º34' and 79º42'. Garur Valley has the most fertile land in the entire Bageshwar district and exhibits a typical U-shaped profile characteristic of glaciations, which has been incised in the lower portion into V-shape by the river action. The area forms part of Lesser Himalayan Zone and has a highly undulating topography. The general elevation lies between 1200 and 1500 m amsl. The area is drained by the perennial rivers Gomti and Garur Ganga along with their tributaries like Ghanghali Gadhera, Latoliya Gadhera and Mate Gad, which are seasonal. The area experiences a sub-tropical to temperate climate having mean minimum and mean maximum temperatures of 5ºC and 35ºC respectively. Agriculture is the principal source of employment for the local populace, followed by animal husbandry. Due to high production of rice, the Garur Valley is also known as "Rice Bowl of Kumaun".

Systematic hydrogeological surveys were carried out in parts of the area by Central Ground Water Board (e. g. Venkatesan and Bhattacharya, Bhattacharya) during the period 1975-79 and brought out as unpublished reports (Zaidi, 1996). However, for the first time, data on spring discharge and drilled depth and discharge of India Mark-II hand pumps were analysed. Hydrogeological study in the area shows that groundwater scenario in the hilly tracts is quite different from the valley portions of Gomti River which is the major perennial river flowing along the Garur Valley. Scarcity of lift schemes and accessibility problems for the drilling rigs along with non-availability of working space in the hills are causes of concern to the villagers residing in such tough terrains. As the immediate surface runoff is extremely high in the hill slopes, hence the recharge through infiltration is very low. As a result, very little natural groundwater recharge takes place in the hilly terrain.

GEOLOGY

The geology of the area is quite complex owing to repeated phases of deformation and metamorphism. It is difficult to build a precise chronologic stratigraphic column in the absence of fossil record, in the deformed rock units. The rock types exposed in Garur and Baijnath consists of metamorphosed igneous and sedimentary rock suites with prominent terrace and channel alluvium along the course of Gomti River. Detailed geological mapping in the area was carried out around Dangoli. Heim and Gansser (1939) took a traverse through this area and identified the quartzo-feldspathic rocks as granite gneisses. Pande (1956) opined that the quartzo feldspathic rocks are actually migmatites. Pande and Verma (1970) carried out detailed structural mapping in the area and identified complex systems of folding and faulting in the medium to low-grade polymetamorphosed tectonites around Dangoli. The tectonites show mineralogical composition varying from metasemipelites to metapsammites and occur in close association with migmatites and amphibolites. The general strike, in this area, is NNW-SSE with dip ranging from 20º to 55º towards WSW. Amphibolites occurring in north-western part of the area represent the metabasics. Massive, coarse-grained micaceous quartzites form tectonic lenses in the area. Migmatites around Dangoli show interbanding with metasemipelites, the junction between them is gradational. Rafts of country rocks, paper-thin to 10-15 m thick, occur in migmatite bodies and show parallelism and structural continuity.

HYDROGEOLOGY

Twenty four cold-water springs and small seepages (locally called naolas) were inventoried during the pre-monsoon (Pre-monsoon 2004) and the same were monitored in the post-monsoon in parts of Garur Valley. A detailed map of the study area showing the locations of springs, seepages (naolas) and hand pumps (see below) is shown in Figure 1.

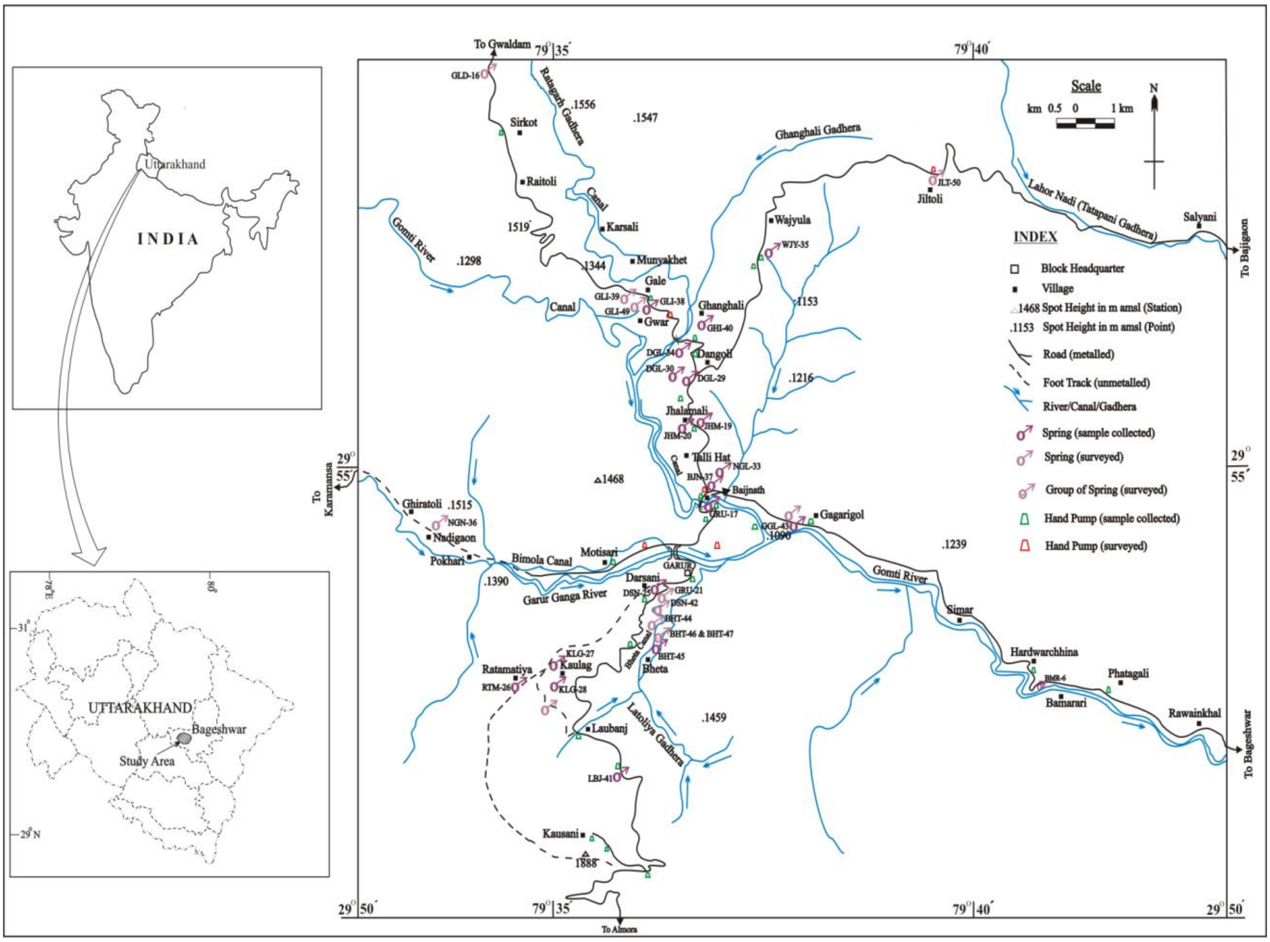

Fig. 1. Location map of the Study Area, Gaur block, Bageshwar district

Apart from the springs and seepages, India Mark-II hand pumps have recently been installed in the area by Uttarakhand Jal Sansthan. These hand pumps are installed along all-weather motorable roads and are being extensively used for drinking and domestic work. They have replaced the traditional source of water supply to a great extent.

The discharge of springs and seepages in the study area varies from 0.06 to 4.8 lpm. Considering the local hydrogeological condition and spatial distribution, nine springs/seepages are selected for analysis of discharge and water temperature (2004-05) and the data are compared with the studies undertaken earlier (1978-79). The relevant observations are summarized in Table 1.

Table 1. Comparison of Discharge and Water Temperature of Selected Springs and Seepages

Sr. No.	Location	Period 1978-79		Period 2004-05	
		Discharge (lpm)	Water Temperature (ºC)	Discharge (lpm)	Water Temperature (ºC)
1.	Near Jhalamali, ~1.6 km NNW of Baijnath on Baijnath-Gwaldam road, naola	2	21.5	0.06	21.0
2.	Near Titatappar, ~1 km from iron bridge, Baijnath; on southern bank of Gomti River, naola	1	23.0	0.06	20.0
3.	~100 m down slope of Baijnath-Gwaldam road, NW end of Dangoli, naola	1	19.5	0.06	17.5
4.	~200 m SSE of Forest Rest House Wajyula, down slope of road, near Primary School, naola	1	24.0	0.06	18.0
5.	~200 m NNE of Baijnath-Gwaldam road crossing, near a Nala, naola	3	28.0	1.2	20.0
6.	~50 m NE of Gagarigol Pool (culvert no. 4/1) on Bageshwar-Baijnath road, naola	3	22.5	3	20.0
7.	Near Bheta, ~11 km from Kausani on Baijnath-Kausani road, naola	4	21.0	0.06	15.0
8.	Near Gale (Galoi), ~200 m south of .1334 m on Baijnath-Gwaldam road, naola	1	22.0	0.06	18.5
9.	~1 km WNW of Jiltoli on Wajyula-Salyani road, naola	2	26.0	0.06	17.5

The spring discharge data given in Table 1 shows the spring discharge are reduced considerably over the years, except for one naola at Gagarigol where the variation is nil. A comparison of discharge of a naola at Jhalamali reveals that the discharge has been reduced from 2 lpm (Pre- monsoon, 1978) to 0.06 lpm (Pre-monsoon, 2004), thus indicating the reduction in discharge to 97%. The maximum reduction in the spring discharge (3.94 lpm) is observed at Bheta, which is a reduction of 98.5% of the original value. The springs and naolas in the area, based on the classification of discharge, are classified of 7th and 8th order (Meinzer, 1923).

The spring water temperature reveals that all the springs and naolas are of cold water. The absence of hot water/thermal springs in the area indicates that igneous intrusive (granite plutons) do not affect the localised aquifers in the area. However, a comparison of water temperature data for the periods 1978-79 and 2004-05 reveals that there is a general reduction in water temperature over the last twenty six years. The minimum reduction of 0.5ºC is recorded near Jhalamali whereas the maximum reduction of 8.5ºC is observed near Jiltoli. However, when the fall in water temperature is analysed in percentage, the reduction is only 32.69%. The reduction is also considerable (8ºC) in a naola near Baijnath-Gwaldam road crossing. However, again in percentage terms, the reduction is only 28.57%. A reduction of 6ºC is observed near Forest Rest House, Wajyula and near Bheta. However, the reductions are not significant in in terms of percentage; the reduction near Wajyula is only 25% and near Bheta, it is 28.57%.

The pipe line drinking water supply in the area is provided by Uttarakhand Pey Jal Nigam through domestic connections and Universal Stand Posts. As far as India Mark-II hand pumps is concerned, 12 such hand pumps were installed in Garur block and two were under installation (November 2004). Besides the India Mark-II hand pumps, some shallow hand pumps were also installed by local authorities and non government organisations. One such hand pump, in front of Block Development Office Garaser, was installed by a local drilling unit with the funding of local Gram Panchayat. The hand pump was installed by digging a shaft manually up to a depth of 11.28 m and constructing a storage tank (1.22m x 1.22 m x 0.61 m) at the bottom of the shaft and subsequently lowering the assembly. The water level was reported to be 4.27 m bgl, which may not reflect the actual water level in the area as the hand pump may be tapping a shallow, perched aquifer. Some shallow hand pumps are also constructed by some of the Non Government Organisations in the study area. However, such hand pumps may not be able to give a sustainable discharge due to reasons mentioned above.

The discharge of the India Mark-II hand pumps ranges from 15 to 25 lpm (2003-04). A primary analysis of the discharge data reveals that 50% of the hand pumps have shown the highest discharge of 25 lpm, 33.33% have shown intermediate value of 20 lpm and the rest 16.67% have recorded the least discharge of 15 lpm. The depth to water, in the India Mark-II hand pumps, varies from 45.10 to >100 m bgl (2003-04). The static water level at Baijnath was 112.78 m bgl (May 2004) and at Laubanj, 99.06 m bgl (November 2004). The drilled depth of India Mark-II hand pumps varies from 69.00 to 121.95 m bgl. DTH method with ODEX attachment is suitable for this terrain. Auto flow or artesian condition is observed in a hand pump at Pingalkot, about 3.2 km NNE of Kausani on Baijnath-Kausani road.

HYDROCHEMISTRY

A total of thirty representative water samples were collected from different sources like springs, naolas and hand pumps during Pre-monsoon 2004. Another thirty three water samples were collected from these sources in Post-monsoon 2004. Out of these, the samples collected during Pre-monsoon are analysed for E.C., pH, bicarbonate (HCO_3), chloride (Cl), total hardness (as $CaCO_3$), nitrate (NO_3), fluoride (F), calcium (Ca) and magnesium (Mg). The samples collected during Post-monsoon are analysed for sodium (Na) and potassium (K) also.

An effort is made to assess the suitability of water for irrigational use. Suitability of water for irrigation purposes is generally assessed using geochemical parameters like Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Kelly's Ratio (KR) and Puri Salt Index (PSI). Sodium Adsorption Ratio, Soluble Sodium Percentage and Kelly's Ratio are calculated for ten representative samples collected from springs and hand pumps in the area and are given along with pH, Electrical Conductivity (E.C.) and Total Dissolved Solids (TDS) in Table 2.

A study of Table 2 reveals that groundwater in the study area is mildly alkaline having pH from 7.8 to 8.0. The values indicate suitability of groundwater for irrigational purpose. Electrical Conductivity (E.C.) of groundwater in the study area are generally low and ranges from 142 to 640 µS/cm at 25°C. As per the quality classification of water for irrigational use (IS: 2296, 1963), the E.C. values are expressed as salinity hazard. Based on the classification, it is found that 6 out of 10 samples fall under "excellent" category (E.C. <250 µS/cm at 25^{o}C) whereas remaining 4 samples fall under "good" category (E.C. 250-750 µS/cm25^{o}C). This indicates the suitability of groundwater for irrigational use. Sodium Adsorption Ratio (SAR) in the study area varies from 0.21 to 0.85. The SAR values of all the samples, expressed as alkali hazard in the quality classification (IS: 2296, 1963), again indicates that groundwater of naolas and hand pumps is of "excellent" category (SAR up to 10). However, it is found that SAR values of water samples collected from hand pumps lies between 0.28 and 1.02, which is generally higher than corresponding SAR values in naolas. The values of salinity hazard (C) and sodium (alkali) hazard (S) clearly indicate 70% of water samples fall under C_1S_1 class as per the salinity classification adopted by the United States Department of Agriculture (Richards, 1954). Only three water samples (30% of total) collected from Garur market, TRC Baijnath and near Iron Bridge, Baijnath fall under the C_2S_1 class. The SAR values calculated for all the water samples in the study area are also within the permissible limit (<3.0) as per the guidelines of Food and Agriculture Organisation of the United Nations (Ayers and Westcot, 1985).

Soluble Sodium Percentage (SSP) in the naolas ranges from 7.88% to 38.0%. Corresponding values obtained from water of hand pumps show a variation from 11.89% to 28.84%. The values indicate that groundwater is suitable for irrigational use.

Table 2. Analytical results of Representative Groundwater samples from Seepages and Hand Pumps in the Study Area

Sr. No.	Sample No.	Location	Type of structure	pH	EC (µS /cm) at 25°C	TDS (mg/l)	NO_3 (mg/l)	F (mg/l)	Na^+ (me/l)	Ca^{+2} (me/l)	Mg^{+2} (me/l)	Sodium Adsorption Ratio (SAR)	Soluble Sodium Percentage (SSP)	Kelly's Ratio (KR)
1.	SP-GRU-21-04	Garur market	Seepage (Naola)	7.85	340	221	1.90	0.192	0.26	1.40	1.56	0.21	7.88%	0.09
2.	SP-DSN-25/04	Darsani	Seepage (Naola)	7.80	142	92.3	1.30	0.06	0.30	0.60	0.70	0.37	17.24%	0.23
3.	SP-DGL-34/04	Dangoli	Seepage (Naola)	7.80	150	97.5	46.0	ND	0.57	0.60	0.30	0.85	38.00%	0.63
4.	SP-KLG-27/04	Kaulag	Seepage (Naola)	7.95	640	416	40.0	ND	0.52	2.00	3.77	0.31	8.05%	0.09
5.	SP-GHL-40/04	Ghanghali	Seepage (Naola)	7.85	160	104	9.70	ND	0.33	0.60	0.70	0.41	19.76%	0.25
6.	HP-PGK-12/04	Pingalkot	Hand Pump	7.80	180	117	0.50	ND	0.30	1.00	0.39	0.36	16.67%	0.22
7.	HP-KSN-13/04	TRC, Kausani	Hand Pump	7.90	230	149.5	2.30	ND	0.27	1.00	0.90	0.28	11.89%	0.14
8.	HP-BJN-28/04	TRC, Baijnath	Hand Pump	8.00	350	227.5	16.0	1.70	1.22	1.80	1.07	1.02	28.84%	0.43
9.	HP-BJN-29/04	Near iron bridge, Baijnath	Hand Pump	7.90	290	188.5	0.65	0.54	0.70	1.20	0.90	0.69	24.31%	0.33
10.	HP-GLI-31/04	Gale (Galoi)	Hand Pump	7.85	230	149.5	0.25	0.06	0.61	0.80	0.80	0.69	26.87%	0.38

Computation of Kelly's Ratio (KR) shows that values for water collected from seepages (naolas) range from 0.09 to 0.63. Corresponding KR values obtained for water samples collected from hand pumps vary from 0.14 to 0.43. Kelly's Ratio of groundwater from different sources also supports the contention that the groundwater is suitable for irrigation purpose.

Based on concentration of major ions and hydrochemical parameter like Total Hardness and Total Dissolved Solids (TDS), an attempt is made to assess the suitability of groundwater for drinking purpose. .The Total Hardness of groundwater in the area varies from 10 to 232 mg/l. Even the maximum value of Total Hardness is less than the desirable limit of 300 mg/l as per the Drinking Water Standard (BIS, IS: 10500, 1991). This reveals that groundwater in the area is quite suitable for drinking purpose.

TDS of groundwater in the study area is calculated by applying the empirical relationship: TDS (mg/l) = 0.65 x E. C. (µS/cm) applicable for most natural waters having E.C. ranging from 100 to 5000 µS/cm at 25°C (Todd, 1980). The TDS values range from 92.3 to 416 mg/l. Even the maximum value of TDS in the area is below the desirable limit of 500 mg/l (BIS, IS: 10500, 1991), which indicates that groundwater is fresh and potable.

Concentration of nitrate in groundwater of the study area is generally very less (<10 mg/l) except in two naolas where high nitrate is reported. The first one is near Kaulag (40 mg/l) and the second, near Dangoli (46 mg/l), the later value being marginally above the desirable limit of 45 mg/L (BIS, 1991). Concentration of fluoride in groundwater varies from 0.01 to 1.7 mg/l. The later value, obtained from a hand pump near Tourist Reception Centre Kausani, is marginally higher than the maximum permissible limit of fluoride in drinking water (BIS, 1991).

DISCUSSION

The springs and seepages in the area cater to drinking and domestic demands. However, due to the low discharge, many of them are being tapped along road sides in tanks (locally called Hauj). The Hauj based water supply is primarily maintained by Minor Irrigation Department along with some specific project based schemes under the aegis of District Project Management Unit under the "Swajal Pariyojana". Artificial outlets in the form of PVC pipes, wood etc. are constructed in many Hauj that results in channelised flow of water for public use.

It is observed that groundwater in the area is generally colourless and odourless. However, water of some naolas is quite unsuitable for consumption as both solid and liquid waste is being disposed near them by humans. Such type of unhygienic practices need to be stopped immediately by creating awareness among the villagers about the availability vis-à-vis scarcity of safe drinking water in the mountainous tract. Also some hand pumps yield slightly to highly turbid, yellowish brown to brown water in places like Wajyula, Gale (Galoi) and Garur Market. The yellowish brown colour is due to high iron content, which is also confirmed by the typical bittersweet taste of water. The local populace, consuming the water over long periods, runs the risk of chronic gastrointestinal disorder.

To overcome the problem of excess iron in groundwater, hand pump attachable Iron Removal Plants need to be installed in the area. The plant is based on an average discharge of 1 m^3/hr (or about 16.67 lpm) of India Mark-II or equivalent hand pump. The hydraulic loading of the plant is adequate to serve a population of 250 at the rate of 100 lpcd. The plant comprises three chambers. Water from the outlet of the hand pump is sprayed over an oxidation chamber. The aerated water flows over baffle plate to a flocculation chamber and finally enters the sedimentation chamber. Subsequently, the filtered water from the sedimentation chamber is drawn through a tap after chlorination. The ferric precipitate settles as sludge and requires periodic scouring depending upon the quality of raw water and the quantity drawn through the hand pump. In this plant, no chemical is used except solution of chlorine for disinfection. The capital cost of this iron removal plant is about Rs. 15,000. Except for cleaning twice in a month, the operation and maintenance cost of this plant are low. Hence they are quite suitable in locations having problem of high iron in groundwater.

During the survey, it is observed that villagers are generally aware of the problem of high iron and they have devised remedial measures at community and Gram Panchayat levels. For instance, residents of Garur, in association with the local Udyog Byapar Sangh, have constructed a large storage tank (similar to Hauj) and are tapping water from a spring located in higher reaches. By adapting this method, they have avoided drinking the water with high iron content, which is coming from the nearby hand pump. The local populace, however, are using the water of the hand pump exclusively for domestic work.

Coming to the contamination aspect of groundwater in the study area, only nitrate and fluoride concentrations higher than the maximum permissible limit (as per BIS guidelines on drinking water) are recorded in isolated pockets in the area. The high nitrate concentration may be attributed to anthropogenic sources of contamination and hence need to be monitored more closely in future through detailed hydrochemical studies. Keeping in mind the maximum permissible limit of 1.5 mg/l for fluoride (BIS, 1991), it may be prudent to carry out extensive hydrochemical surveys in and around Baijnath to avoid any possible health hazard due to fluoride contamination. However, the sporadically high fluoride concentration in the area may be attributed to geogenic factor like leaching of fluorine from the source (e.g. granites and/or other fluorite and apatite bearing country rocks) to the aquifer system.

The natural groundwater recharge in the hilly tracts of the area is very low due to extremely high surface runoff. Construction of artificial recharge structures like check dams, gully plugs, contour bunds and/or contour trenches can facilitate greatly in increasing the groundwater recharge in the hilly tracts of the area. Gully plugs and contour bunds are suitable for implementing artificial recharge schemes in low order small streams whereas check dams may be constructed in higher order streams. The artificial recharge structures, when constructed after carrying out site-specific hydrogeological surveys in a scientific manner, can aid in recharging the shallow aquifers in the area. They are also cost effective and have multifarious benefits like arresting surface run off, increasing soil moisture, helping in preventing soil erosion and increasing the discharge of nearby springs and seepages (naolas). Contour trenches may be constructed along hilly tracts with high land slope depending upon the local hydrologeological conditions. These trenches would cover the entire slopes uniformly whereas nala bunds constructed in a series would cover the entire stretch of drainage in the area.

CONCLUSIONS

Hydrogeology of Garur Valley is complex due to the structural and geotectonic characteristics of Lesser Himalayan Zone. The dominant rock types are high-grade metamorphic and metasedimentary rocks and terrace and channel alluvium in sections along the course of Gomti River. A study of twenty four cold-water springs and seepages (naolas) inventoried in the study area reveals that the discharge has been reduced considerably from the period 1978-79 to the period 2004-05. Many naolas recorded negligible discharge, both during the pre-monsoon and post-monsoon measurements. When compared with the measurements taken during earlier studies, a reduction in water temperature is observed in all the naolas in the area. However, the reduction, though considerable in magnitude, are usually low (<35%) when seen in percentage terms. Available discharge data of India Mark-II hand pumps indicates that majority of them (50%) have a discharge of 25 lpm. The depth to water in the hand pumps ranges from 45.10 to 112.78 m bgl whereas the drilled depth varies from 69.00 to 121.95 m bgl.

Except for high iron content in some hand pumps, the quality of groundwater in the area is good and suitable for human consumption. Study of geochemical parameters like Sodium Adsorption Ratio, Soluble Sodium Percentage and Kelly's Ratio indicates that groundwater of representative naolas and hand pumps are excellent for irrigational use. Range of values of Electrical Conductivity and Total Dissolved Solids also indicate the suitability of groundwater for irrigation. Total Hardness and Total Dissolved Solids are well below the desirable limit as per the BIS guidelines for drinking water. The problem of excess iron in groundwater may be tackled by installing Iron Removal Plants with India Mark-II hand pumps. The plant is cost-effective and provides iron-free water if maintained regularly to retain its effectiveness. Nitrate concentration in the area is marginally higher than the desirable limit (45 mg/l) and fluoride concentration is marginally higher than the maximum permissible limit (1.5 mg/l) in locations like Kaulag, Dangoli and Kausani. However, the high nitrate is attributed to unhygienic practices by humans around the naolas whereas high fluoride may be due to leaching of fluorine from the source to the aquifer system.

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DEVELOPMENT OF WATER QUALITY MAP OF UTTARAKHAND

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ABSTRACT

It is essential to know the quality of water before its consumption for human and agricultural and industrial uses. A number of Central and State government agencies are working in water sector in Uttarakhand and joint efforts are being made to prepare water quality map of the State. Uttarakhand State Council for Science and Technology (UCOST), Dehradun; DAV (PG) College, Dehradun and Uttarakhand Jal Sansthan (UJS), Dehradun are jointly working for development of Water Quality Map of Uttarakhand as per BIS specifications of water quality parameters and APHA guidelines. Under this Water Technology Initiative Programme of DST, GOI, a "State Level Water Quality Analyses Laboratory" has been setup in UJS campus at Dehradun. The majority of sources covered under the study are ground water sources and raw as well as treated water samples have been used for water quality analyses. As an outcome, assessment of 27 physical, chemical and biological water quality characteristics of 13 districts of state will form a standard data resource for those working in drinking water sector and water pollution. The prospective results will be helpful in providing safe drinking water and thus improving health status of common mass who in turn will contribute in developmental process of State and Nation.

Key Words: Water Quality Map, Water Analysis, Water Pollution and Uttarakhand.

INTRODUCTION

Water quality analysis is essential to know the scenario of water of any particular region for various consumptions. The assessment of water quality reveals the purity of water which is being used for drinking and other domestic purposes. Presently, water scarcity and water pollution are two major concerns for all those associated with water sector. The level of water resources is getting diminished day by day due to uncertainty in arrival of monsoon as well as drying of existing sources in summers. Also less rainfall causes less recharge to ground water and depletion of water bed. Besides, the available water sources get deteriorated by the different natural, human and other activities. Hence, the water quality analysis becomes of prime importance before it is being supplied for human consumption. More than 75 Central and State Government departments and organizations are established in Uttarakhand and working for Science & Technology (S&T) development as per their mandate including water sector. Uttarakhand Jal Sanathan (UJS), Dehradun; Uttarakhand Peyjal Sansadhan Vikas Evam Nirman Nigam, Dehradun; Cooperation Centre River Bank Filtration (CCRBF), Haridwar; Uttarakhand Environmental Protection and Pollution Control Board (UEPPCB), Dehradun; State Water Supply and Sanitation Mission, Dehradun; Swajal, Dehradun are some of the important state bodies whereas National Institute of Hydrology (NIH), Roorkee; Central Soil and Water Conservation Research and Training Institute, Dehradun; Central Pollution Control Board (CPCB), New Delhi centers of Uttarakhand; Regional Centre of Central Ground Water Board (CGWB), Dehradun etc. are representative establishments of Central Government working for water supply, quality and water management for sustainable use and development. Besides as international collaborator of UCOST and UJS, University of Applied Sciences, Dresden, Germany is providing technical support for ground and surface water monitoring. Peoples Science Institute, Dehradun and SPECS, Dehradun are established NGO's working in Dehradun having their credits upto national level for their work in water quality sector.

In spite of presence and efforts of all concerned agencies, there is one gap in providing safe drinking water to mass population of state. The water quality assessment of 13 districts of State has not been thoroughly carried out by any Government or Non-Government organization and most importantly Water Quality Map of Uttarakhand has not yet been prepared so far. Scanty and random reports of important districts are available about water quality but details of their scientific methods of analysis as well as Center/Lab used for analysis are not provided in order to establish the creditability of data. Moreover, the available reports do not cover most of the water characteristics as per BIS norms. Also, most of the studies are one time analysis and no regular updation of available data is being taken care off by any agency.

In order to meet out the above requirement and development of Water Quality Map of Uttarakhand, concerned organizations namely Uttarakhand State Council for Science and Technology (UCOST), Dehradun; DAV (PG) College, Dehradun and Uttarakhand Jal Sansthan (UJS), Dehradun have been jointly working under Water Technology Initiative Programme of Department of Science and Technology (DST), Government of India, New Delhi to provide the water quality status of all districts of Uttarakhand including effect of seasonal variation.

PROBLEMS OF WATER SECTOR OF UTTARAKHAND

The extensive evaluation of major water supply schemes has not been done in Uttarakhand. Most of the schemes are very old and face severe problems owing to different reasons. People are, thus facing the water quality related problems that directly affect the human life. Therefore, some important problems, which have now become challenge in providing safe drinking water to mass population of state, are summarized below-

a) **Increased Population**- Rapidly increased population in certain locations/pockets is main factor that is responsible for major water scarcity and water pollution. As the population is increasing, the requirement of water has also enhanced manifold. To meet out high demand, sometimes the poor quality water available is supplied for consumption without pretreatment through bypass channels.

b) **Industrialization and Urbanization**- The growth of industrialization and urbanization is necessary for the development of any region but both are major sources of water pollution and main cause of poor water quality. In Uttarakhand too, the large quantities of industrial effluents, waste by products, solid wastes etc. are directly dumped in nearby water streams without any treatment that deteriorates the surface as well as ground water quality of the surrounding areas and water becomes unfit for drinking purpose.

c) **Use of Chemical Fertilizers by Agricultural Sector**- Excessive amount of fertilizer, germicide, insecticide and other chemicals are being used mostly in plain areas for farming for good agricultural production (Bhatnagar and Sharma, 2002). These chemicals are absorbed in soil and mixed with ground water or directly runoff in open streams through the rain and other processes to lead the contamination of available water sources used for domestic water supply.

d) **Sewage and Sanitation Problems, and Slope Factor**- Due to the lack of proper sewage disposal facilities through pipe lines and sewage treatment plants, faecal waste and domestic waste water is directly disposed off in open sources which deteriorate the water quality. Moreover, in hilly region, lack of sanitation facilities, human and animal excreta are directly mixed in rivers, gadheras and other prominent water sources of domestic supply due to the slope factor and thus, pollute water sources.

e) **Mass Bathing and Spiritual**- During important days of bathing and other festival seasons, people come to Prayags, Haridwar, Reshikesh and other important places to take a holy dip in scared rivers and also offers flowers, idols, ashes, curd, ghee and other religious things along with the polythene bags in the river (Semwal and Akolkar, 2006). The organic matters from these items get mixed with water and contaminate the water. The other non biodegradable materials also flow with water and get settled on the river bed which severely affects the natural replenishment and self purification process of rivers.

f) **Natural Factors**- Water quality is also contaminated by some natural factors. Due to the geological differences, water contaminations in hilly region are more than the other regions because of leaching of variety of minerals of hilly terrains. Due to difference in geochemistry of different regions and flow of rain water to nearby streams/rivers, water contamination gets increased specially in rainy season with cations and anions.

g) **Gaps w.r.t. Water Quality Map of Uttarakhand-** Besides, above problems, there is another significant factor responsible for quality problems of domestic water supply and need detailed analysis and study. In the present communication, the water quality problem has been mainly identified from Uttarakhand point of view. As mentioned earlier, the main objective of the study is development of Water Quality Map of Uttarakhand, which is not so far prepared by any organization of centre or state working in water sector. The detailed analysis of water quality parameters of 13 districts is much needed exercise, which is under progress with joint initiative of UCOST, UJS and DAV (PG) College, Dehradun. One of the major reason of lack of development of water quality map of state was absence of any State Level Water Quality Analyses Laboratory within the preview of any concerned agency of water supply of state owing in-house facility of analysis as per BIS and APHA requirements. Also comprehensive and regularly updated data about the region wise water quality is no where available in literature and at any website.

The above said gaps have now been tacked with a great degree of efficacy and precision, and will shortly see and taste the fruits of success.

DISTRICT WISE DATA AVAILABLE ABOUT ASSESSMENT OF WATER QUALITY OF UTTARAKHAND

Sincere efforts have been done by some researchers, groups and organizations for surface and ground water quality analyses and monitoring/assessment and have been summarized district wise as under:

1. Dehradun: The ground water quality of Dehradun district has been studied by the Central Ground Water Board in 2009 that indicates the higher nitrate concentration (CGWB, 2010) than the desirable limit. The water quality assessment has also been done in 2007-08 by adopting various physico-chemical parameters like pH, EC, carbonate, bicarbonate, chloride, total hardness, calcium and magnesium for handpump, springs and river water samples. During the study, concentrations of total hardness, calcium, magnesium were found high than the desirable limits in some locations of the district (CGWB, 2009b). The water quality of Dehradun district has also been studied by the Ministry of Rural Development in 2009 w.r.t. iron, fluoride, salinity, nitrate, arsenic, faecal coliform and other contaminations out of which faecal coliform was of major concern in three water sources of district (IMIS, 2009). Some water quality data has also been provided by different institutional departments in 2006 which indicated high concentrations of different ions like total hardness, TDS, chloride, sulphate, nitrate and iron than the permissible limits in their studied areas (Ziauddin and Siddiqui, 2006). Further study in 2007, also showed high concentrations of total hardness, TDS, chloride than the permissible limits of drinking water (Ziauddin and Siddiqui, 2007). Water quality analysis of ground as well as surface raw water and supply water of Dehradun district by authors group is under progress in which concentrations of some of the parameters are found high and yet to be reconfirmed by further detailed analysis to see the effect of seasonal variation. Water containing high concentrations of heavy metal ions than the permissible limit in different samples is not suitable for drinking purpose and likely to cause harmful diseases.

2. Haridwar: In Haridwar, Ganga river is the main source of water supply for domestic uses in different areas. Ganga river water quality has been studied by GOI, under Ganga Action Plan (GAP). The different parameters have been adopted like DO, BOD, total coliform (Tc), faecal coliform (Fc) in which Tc and Fc in most of the sites were found higher than the permissible limits (GAP, 2009). Out of 14 sources, 9 water sources were also affected by various chemical or bacteriological contaminants, during the water quality analysis carried out by the Ministry of Rural Development (IMIS, 2009). The numbers of faecal coliform were also found higher than the permissible limit in Ganga river during the regular monitoring of Central Pollution Control Board from 2002 to 2008 (Sharma *et al.,* 2009). Ganga river water quality has also been found to be deteriorated due to excess contamination of Tc and Fc during study of Uttarakhand Urban Development Project in 2007 (CDP, 2007). The groundwater quality of Haridwar district has also been analysed by Central Ground Water Board in 2009. Under the analysis, all the parameters have been found within the limit and revealed fresh water quality that is being used for drinking purpose (CGWB, 2009a). Some other institutions have also provided data about the assessment of water quality in different seasons that show the contaminated water quality of Ganga river due to high turbidity (Joshi *et al*., 2009) and excess coliform contamination (Baghel *et al*., 2005 and Sood *et al*., 2008). High nitrate concentration has also been observed in water quality study carried out by Central Ground Water Board in 2009 (CGWB, 2010). But the pollution load has rapidly increased in Ganga river due to the disposal of garbage and religious activities. Hence, to meet out the problem, government of India has established the authority of National Ganga River Basin that has the power to control the pollution and its causes (MOEF, 2010).

3.Chamoli: The ground water and spring water quality analysis of Chamoli district indicate the water quality deteriorated owing to increased concentration of magnesium, nitrate, fluoride, sodium and total hardness in ground water at different locations. This water quality analysis has been done by Central Ground Water Board in

2009 (CGWB, 2009a). One contaminated source is also observed by the Ministry of Rural Development in 2009 (IMIS, 2009) out of 21 analyzed water sources due to high faecal concentration.

4.Rudraprayag: The ground water scenario of Rudraprayag district has been described by Central Ground Water Board in 2009 with high fluoride concentration than the permissible limit of 1.5 mg/l in Usyan village of Rudraprayag (CGWB, 2009a). The water quality of Rudraprayag has also been studied by the Ministry of Rural Development in 2009 (IMIS, 2009) in which faecal coliform was of major concern. Faecal coliform was also reported in higher concentration during the Ganga river water monitoring through Central Pollution Control Board (CPCB, 2009). No another referential data have been provided by the other organization about the water quality of the district.

5.Uttarkashi: The analyzed ground water and spring water quality of Uttarkashi through the Central Ground Water Board in 2009 revealed the deteriorated water quality of both type of sources due to high concentration of nitrate, sodium and magnesium (CGWB, 2009a) than the desirable/permissible limits that indicate high pollution load in these sources. The polluted water quality of district is also exhibited by the Ministry of Rural Development in 2009 due to excess faecal contaminations in 13 sources out of 23 sources (IMIS, 2009). But no detailed water quality analysis data is available. Uttarkashi district has also been covered under present phase of study by authors that reveals the higher concentrations of some water characteristics than the permissible limit in different samples.

6.Pauri: The water quality of Pauri district has been studied by Ministry of Rural Development in 2009, where all the water sources have been found free from any chemical and bacteriological contaminants (IMIS, 2009). No other regional data have been found for the area by other organizations. Water quality status of Pauri district has been scrutinized as part of ongoing studies. The water quality analysis of Pauri district using physico- chemical parameters as per BIS standard for drinking water, reveals the high alkalinity values than the desirable limits.

7.Tehri: Similar to Pauri, Tehri district has also been covered by Ministry of Rural Development in 2009 for 8 parameters in which most of the sources were found with bacteriological contaminations (IMIS, 2009). High concentrations of physical and chemical parameters than the desirable or permissible limit, are observed during water quality analysis under the so far studies carried out by authors.

8.Almora: During the water quality study of Almora district in 2009 by Central Ministry of Rural Development, the faecal and chemical contaminations have been found high in three and two blocks, respectively of Almora district (IMIS, 2009). The nitrate concentration had also been found high in some other studies (Kumar *et al*., 1997) but no proper authentification was found for some of the data.

9.Nainital: In Nainital, Nainital lake water is mainly used to meet out the demand of water for domestic uses. Water quality characteristics have been determined by Uttarakhand Environmental Protection and Pollution Control Board (UEPPCB) in 2007-08 by using color, odour, TDS, EC, pH, DO, BOD, hardness, calcium, magnesium, alkalinity and chloride. Except calcium, magnesium and alkalinity, all the parameters have been found under the limit (UEPPCB, 2009) but updated data of these water characteristics is not available at website of UEPPCB. In water quality study of Nainital district through the Centre for Water Policy in 2005, the nitrate concentration was found higher than the desirable limit of BIS standard (CWP, 2005). Lake water quality of Nainital has also been determined by some institutional departments that indicates high coliform contamination (Dash *et al*., 2008 and Pande *et al*., 1983) than the permissible limits.

10.Pithoragarh: The water quality of Pithoragarh district has been assessed by the Ministry of Rural Development in 2009 that expressed the contaminated water quality of 17 sources out of 74 water sources due to high faecal and other multiple contaminants (IMIS, 2009).

11.Udham Singh Nagar: The water quality scenario of Udham Singh Nagar shows the high concentrations of iron and chromium (CGWB, 2009a) and also nitrate (CGWB, 2010) than the desirable/permissible limits. The Ministry of Rural Development has also showed the contaminated water quality of Udham Singh Nagar in 2009 (IMIS, 2009). Another study also reported the ground water quality of the district where water was found contaminated with higher concentration of fluoride, magnesium and TDS than the permissible limits (Banerjee *et al*., 2009).

12.Bageshwar: Central Ground Water Board has done the quality assessment of ground water of Bageshwar district in 2009 that indicates the high quantity of fluoride, magnesium and sodium in ground water at different sampling sites (CGWB, 2009a). However, 58 water sources of Bageshwar district have also been studied by Ministry of Rural Development in 2009 and all sources have been found free from any pollutant (IMIS, 2009).

13.Champawat: The groundwater quality status of Champawat district has also exhibited by Central Ground Water Board in 2009 which expressed that EC, pH, Ca, Mg, bicarbonate, cloride, total hardness are under permissible limits. Hence, the overall quality of water is good and suitable for domestic and other purposes (CGWB, 2009a). But large numbers of sources have been found contaminated due to the faecal coliform through another study of Ministry of Rural Development in 2009 (IMIS, 2009).

WATER QUALITY MAP OF UTTARAKHAND

The present programme of "Development of Water Quality Map of Uttarakhand" is being run under Water Technology Initiative Programme of DST, GOI in association with UCOST, Dehradun which in turn has collaborated with the user department of water sector UJS, Dehradun and academia partner DAV (PG) College, Dehradun.

The main outcome of the overall programme will be an updated Water Quality Map of Uttarakhand having data from reliable source. Moreover, awareness will be created and training will be imparted about the quality of water which is being used for drinking purpose to the community and users. The so far outcome of the studies carried out are as under:

a) 27 physico- chemical and biological parameters have been identified and being used for the assessment of water quality of 13 districts as per BIS standard for potable water namely are color, odour, taste, turbidity, pH, total hardness, iron, chloride, residual free chlorine, dissolved solids, calcium, copper, magnesium, manganese, sulfate, nitrate, fluoride, phenolic compound, cadmium, arsenic, lead, zinc, chromium, pesticides, alkalinity, aluminium, coliform bacteria.
b) The results include effect of seasonal variation of monsoon season i.e. pre and post monsoon samples are being collected. Also, 3 samples are collected from each site as per standard methods of APHA (APHA, 2005) and average value is reported.
c) Major state of art analytical instruments are being used for the assessment of water quality parameters which detect the different ions, metal ions and characteristics/parameters upto ppm and ppb levels through UV-VIS Spectrophotometer with bar coded reagents and kits and Atomic Absorption Spectrophotometer along with others and give the more accuracy, reliability and reproducibility during analyses.
d) The water quality data of 60 locations of 13 districts have been so far covered.
e) "State Level Water Quality Analyses Laboratory" for physical, chemical and biological parameters of water quality has been established in UJS campus, Dilaram Bazar, Dehradun.

CONCLUSION

Water quality analysis of water as per norms of Drinking Water Standards is necessary to know about the scenario and extent of pollutants being consumed by the mass population, which may otherwise cause risk to their health. The water quality map of all the 13 districts of Uttarakhand will express the status of water quality which may also be used as reference data by researchers, scientists and social scientists working in water sector for analysis, testing, training and awareness. Moreover, the State Level Water Quality Analysis Lab being set up under the programme is likely to become a State Referral Lab for the analysis of water quality as per BIS norms for concerned state department of water supply sector.

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FLUORIDE CONTAMINATION IN GROUND WATER IN A PART OF THE TRIBAL BELT IN CHHINDWARA DISTRICT, MADHYA PRADESH, INDIA

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ABSTRACT

Hydrogeochemical study of ground water samples from tube/bore-wells in the pre- and post-monsoon periods, in five-blocks of the Chhindwara district, Madhya Pradesh points to noticeable health problems in peoples due to higher/lower fluoride values than the desirable World Health Organization (WHO) limits. The geological reasons for high fluoride release in the ground water in the deep tube wells in granites and basalts in pre- and post-monsoon periods has been discussed.

Keywords: Fluoride, Ground water, Dental fluorosis, Dental carries, Central India.

INTRODUCTION

Fluorine is widely dispersed in nature as the 13th most abundant element in the earth crust. As per the WHO, the Indian Council of Medical Research (ICMR, 1975) and Vishwanathan, (2009) standards the drinking preferred values of fluoride should range from 0.6-1.5 ppm for the development of strong-bones and teeth; values lower than this may cause dental caries, while above it may causes dental/skeletal fluorosis (Agrawal, 1997 and Duraiswami, 2011).

The rural population in many parts of India is suffering from fluoride-contaminated ground water, especially where people totally, depend on ground water rich in fluoride. Madhya Pradesh is one of the states in India where fluorosis is emerging as a health-problem in different districts (Chatterjee, 1998 and Susheela, 1999).

Granites/granitoids and basalts are thought to be the main sources of F^- in the ground water in many parts of the world. As these rocks occur most of the parts of Chhindwara district, therefore qualitative study of ground water in this area without a noticeable industry can has been found mainly due to geological reasons discussed in the paper.

Chhindwara district is situated in the southern part of Madhya Pradesh. The study area, approximately located between latitude 21˚52' N to 22˚17' N and longitude 78˚45' E to 79˚20'E (Fig.1) is traversed by Pench and Kulbehra rivers.

GEOLOGY OF THE AREA

Geologically, the main formations are: (a) Archaeans- mainly granites, granitic-gneisses (granitoids) intruded by pegmatites and qrtzo-feldspathic veins; (b) Gondwanas- mainly shales and sandstones; (c) Deccan basaltic lava flows; and (d) Quaternaries- black cotton soil and river-alluvium (silty and clayey-loam, Fig.2).

In general, the main source of F^- in ground water is fluoride minerals {fluorspar (CaF_2), fluorapatite [$Ca_5(PO_4)_3F$], cryolite (Na_3AlF_6) and hydroxyl-apatite} in granites (Rafique, 2008 and Carrillo-Rivera, 2002). Such minerals occur in basalts in 'lattice-locked' state of other minerals (Wedepohl, 1972). In Gondwana sediments, however, only dug well (not exceeding 30 feet depth) have been developed in the area that did not give abnormal values of F^- sampling. While the deep tube wells, whether in granitoids or basalts show values above/below the desirable limits (0.6 to 1.5 ppm).

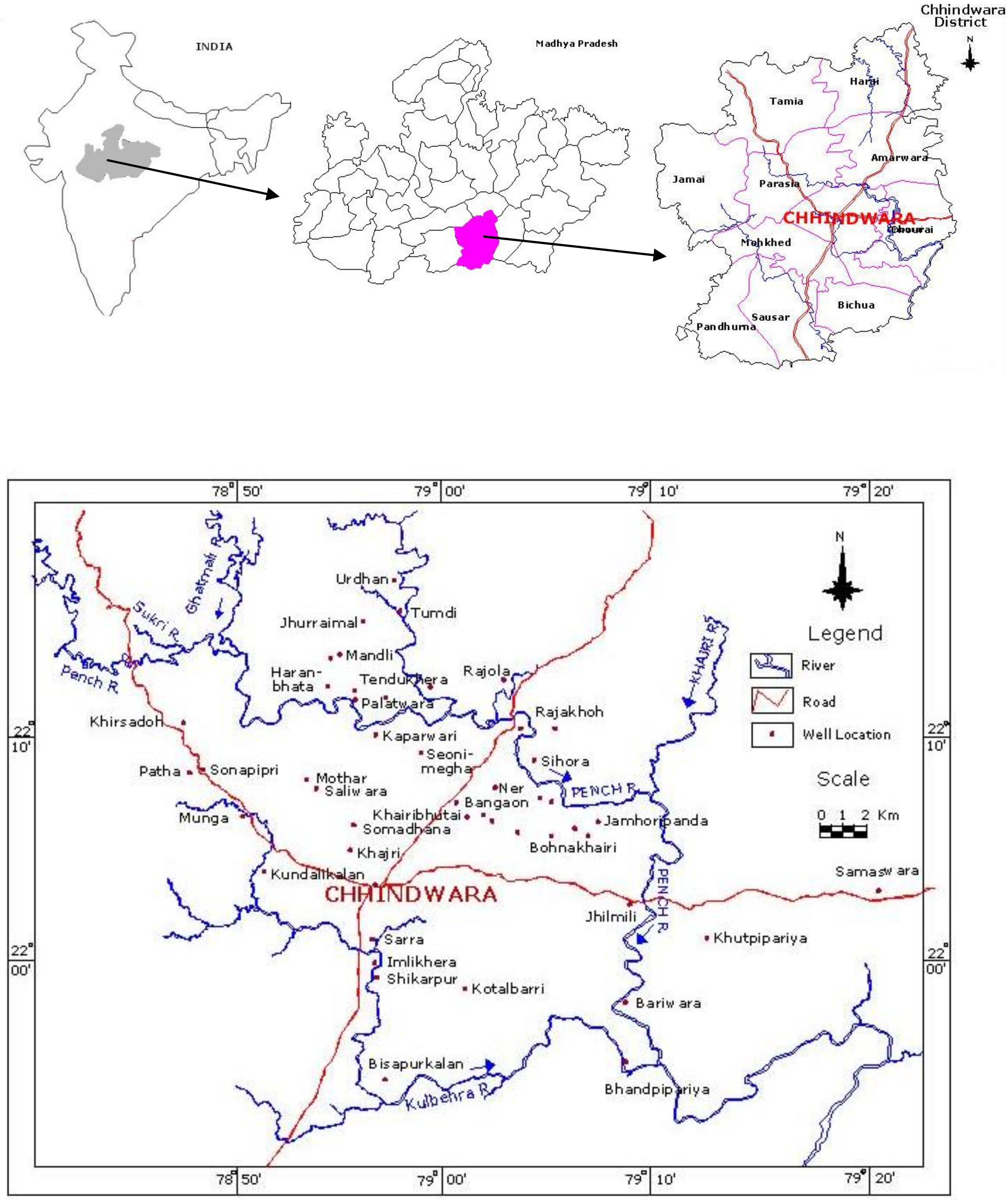
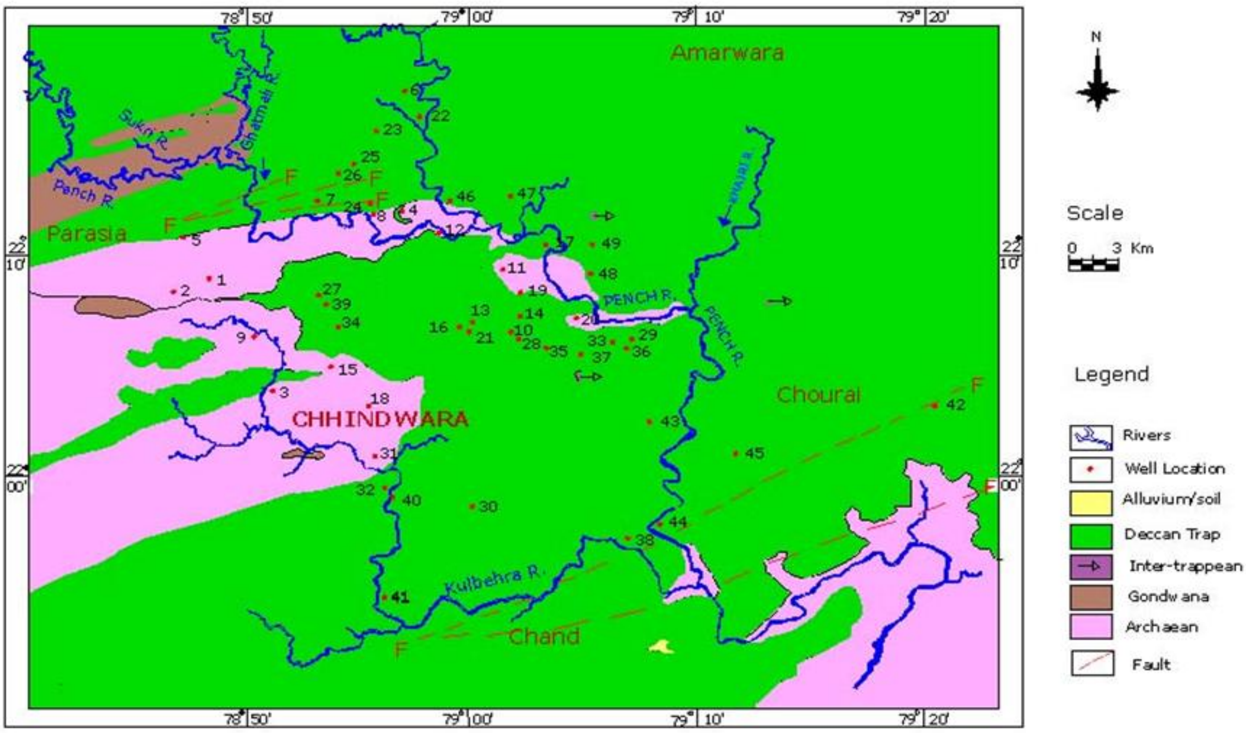


Fig.1 Location map of the study area



Well-Locations: 1.Sonapipri, 2.Patha (A&B), 3.Kundalikalan, 4.Babai, 5.Khirsadoh, 6.Urdhan, 7.Haranbhata, 8.Palatwara, 9.Munga, 10.Panjra, 11.Seonimegha, 12.Kaparwari, 13.Bangaon, 14.Ner, 15.Khajri, 16.Sarna, 17.Rajakhoh, 18.Chhindwara, 19.Deverdhatolla, 20.Karaghat, 21.Khairibhutai, 22.Tumdi, 23.Jhurraimal (A&B), 24.Tendukhera, 25. Mandla, 26.Mandli, 27.Mothar, 28.Chanhiyakhurd (A&B), 29.Jamhoripanda, 30.Kotalbarri, 31.Sarra, 32.Imlikhera, 33.Kakai, 34.Somadhana, 35.Chanhiyakalan (A&B), 36.Bilva, 37.Bohnakheri, 38.Bhandpipariya, 39.Saliwara, 40.Shikarpur, 41.Bisapurkalan, 42.Samaswara, 43.Jhilmili, 44.Bariwara, 45.Khutpipariya, 46.Baregaon, 47.Rajola, 48.Sihora, 49.Mahendrawara.

Fig.2. Geological map of the study area (after: Geol. Surv. Ind., 2003)

METHODOLOGY

Water-sample from the tube-wells (in pre- and post monsoon periods) were collected in one-liter plastic-bottle each from 53 bore-wells in the five blocks namely- Parasia, Amarwara, Chourai, Mohkhed and Chhindwara blocks of the Chhindwara district in pre-monsoon (June, 2010) and post-monsoon (January, 2011) months. Since the ground water samples from dug wells in Gondwanas (in pre-monsoon) show normal values of F^- they were not sampled in the post monsoon period.

The concentrations of major ions (Table 1, 2 & 4) in the ground water samples were determined as per the American Public Health Association (APHA), 1975. The values of pH and EC were measured by pH/ion meter, concentration of Ca^{2+}, Mg^{2+}, HCO_3^- and Cl^- were determined by titrimetric method. Flame photometer was used to determine Na^+ and K^+. Ion, F^- was determined using ion selective electrodes, UV Spectrophotometer for SO_4^{2-}, NO_3^- and Fe.

DISCUSSION

Groundwater occurs under phreatic conditions in the weathered zone, fractured, vesicular basalts and under semi-confined to confined conditions in the fractured zone (deep aquifer). The depth of water level varies from 54 to

150 ft below ground level (bgl) in the granitoids and from 45 to 180 ft bgl in the basalts in deeper aquifers. Rainfall is the main source of ground water recharge.

Fig.3. Dental fluorosis: a, 12 years old boy showing early dental-fluorosis in Amarwara block; b, 11 years old girl showing progressive, c, 13 years old girl showing advanced dental-fluorosis in Parasia Block; and d, advanced dental fluorosis in 20 years old girl in Chanhiyakhurd village of Chhindwara Block. Dental caries: e, 9 years old boy showing early dental caries in Parasia Block

Ground water from tube-wells is alkaline (pH 6.5 to 8 in pre and 6.4 to 9.3 in post-monsoon) from the granitoids, while that from neutral to highly alkaline (pH 7 to 9 in pre- and 6.6 to 9.7 in post-monsoon) from the basalts. The samples have electrical conductivity (EC µS/cm) values in the range of 201 to 1031 in pre- and 348 to 1236 in post-monsoon periods from granitoids, while 252 to 1173 and 311 to 1583 in pre- and post-monsoon periods respectively from basalts. The average calcium (Ca^{2+}) concentration from granitoids is in the range 19 to 98.8 ppm and 6.1 to 91.2 ppm; and from basalts 15 to 95 ppm and 4 to 95.76 ppm in the pre- and post-monsoon periods respectively. Similarly, sodium (Na^{+}) concentration ranges from 8.1 to 116.6 ppm and 11.8 to 112 ppm in the pre- and post-monsoon periods respectively from the granitoids; and from basalts range from 14 to 119 ppm and 14 to 98.5 ppm in the pre- and post-monsoon periods, respectively (Table 1 & 2). The concentration of chloride (Cl^{-}) in granitoids and basalts from deep aquifers is within the permissible limit in both the periods.

The F^{-} concentration ranges from 0.11-7.9 ppm and 0.27-17 ppm in pre- and post-monsoon periods, respectively from granitoids; while in the basalts it ranges from 0.2-7.4 ppm and 0.3-10 ppm in the pre- and post-monsoon periods, respectively. Ground waters of the study area are of bicarbonate-type.

The range of F^{-}-concentration in ground water has figured out to be 1.45 ppm at an average with standard-deviation of 1.94 ppm and coefficient-variation of 1.34 ppm, with the wide range of 0.11-7.9 ppm in the pre-monsoon period (Table 4).

The analysis shows high-concentration of F^- in pre- and post-monsoon periods in Bangaon and Seonimegha villages in Chhindwara; Mandla and Urdhan villages in Parasia; Rajola village in Amarwara; and Jhilmili and Khutpipariya villages in Chourai blocks of Chhindwara district (Table 3).

The F^--concentrations above permissible limits (>1.5 ppm) occur in 25% samples from 4 villages in Parasia; 7 in Chhindwara; 1 in Chourai; and 1 in Amarwara blocks in the pre-monsoon and in 43% samples from 11 villages in Parasia; 7 in Chhindwara; and 2 Amarwara; and 2 in Chourai blocks in the post-monsoon periods, causing dental-fluorosis in villagers (Table 3, 5 & Fig. 3a-3d,). The highest-concentration of F^- occurs in the Bangaon village, Chhindwara block (7.9 ppm) in pre-monsoon and in the Seonimegha village, Chhindwara block (17 ppm) in the post-monsoon periods. Figure 4 a, and b show that a high F^- belt trending NNE-SSW occurs along the Pench valley in the north-eastern part of the area, in both the periods. About 51% of all the samples from 27 villages (15 in Chhindwara; 8 in Parasia; 2 in Chourai and 2 in Mohkhed blocks) in pre-monsoon and 27 % samples from 13 villages (10 in Chhindwara; 2 in Parasia and 1 in Mohkhed blocks) in post-monsoon are below the desirable limits of F^- (0.6 ppm), causing dental-carries in villagers (Table 5 & Fig. 3 e).

At higher pH (alkaline medium) such minerals release F^- gradually into the ground waters because of increased anion-exchange of OH^- with F^-.

In general, the varying concentration of F^- in ground water depends on the geological formations due to pH and solubility of F^- bearing minerals and the presence or absence of other precipitating or complexing ions. However, in this study F^- shows negative correlation with Ca^{2+} and positive with Na^++K^+ in the granitoids and basalts in the pre- and post-monsoon periods (Fig. 5 & 6). The high Na^++K^+ from basalts in a sample (No. 49) in the pre-monsoon period and two samples (Nos. 40 and 42) of the post-monsoon period seem to be anomalous due to presence of calcareous Intertrappeans within basalts (Fig 6).

The main source of F^- in natural water are the F^- bearing minerals (fluorspar, fluorapatite, cryolite and hydroxyl-apatite) as well as F^- replacing OH^- in the ferromagniseum silicates (amphiboles and micas) and soils consisting of clay minerals (Madhnure *et al*, 2007). Besides the basalts with calcareous veins and clays like can also release F^- to some extent (Khatik, 2012).

The F^- contamination in the basalts is mainly due to presence of Intertrappeans (calcareous sandstones) along with locally concentrated calcareous veins (Gupta, *et al*., 2006) and secondary matter like montmorillonite (Khatik, 2012) and long ground water residence time. Fluoride has a unique chemical behavior towards most of the anions and it can be easily replaced by them even under normal pressure and temperature conditions (Wenzel and Blum, 1992) causing concentration/pollution in ground waters.

The geochemical type of fluoride-bearing waters (Table 1, 2 and Fig. 7 & 8), based on the trilinear/Piper-diagram (Piper, 1944) show high F^- values besides changes in 'ground water-chemistry' in different rocks in different periods. It reveals that most of the samples (belonging to granitoids and basalts in both the periods) fall in 'Ca-Mg-HCO_3' field, with an exception of two 'low F^- values samples' (pre-monsoon) one each from granitoids (No. 15) falls in 'Cl-Mg-K-HCO_3' and other from basalts (No. 36) falls in 'Na-HCO_3' fields.

However, in ground water granitic areas soils being the end product of weathering of the parent granitoids become progressively rich in sheet-silicates (micas) that host F^- in fairly high concentration (Khatik, 2012).

Clay-bands in fracture-zones, responsible for controlling the local ground water regime, prolong soil/rock water interaction in weathered granitoids. Also, as shown in the Fig. 9 (a-d) and Table 3 high alkalinity of water is responsible for higher concentration of F^- in ground water in both granitoids and basalts in the pre- as well as post-monsoon periods that attest to the earlier views. Due to strong electro-negativity, F^- is attracted by positively-charged Ca^{2+} in teeth and bones and cause dental-fluorosis, teeth-mottling, skeletal-fluorosis and deformation of bones (Figure 3.a-e).

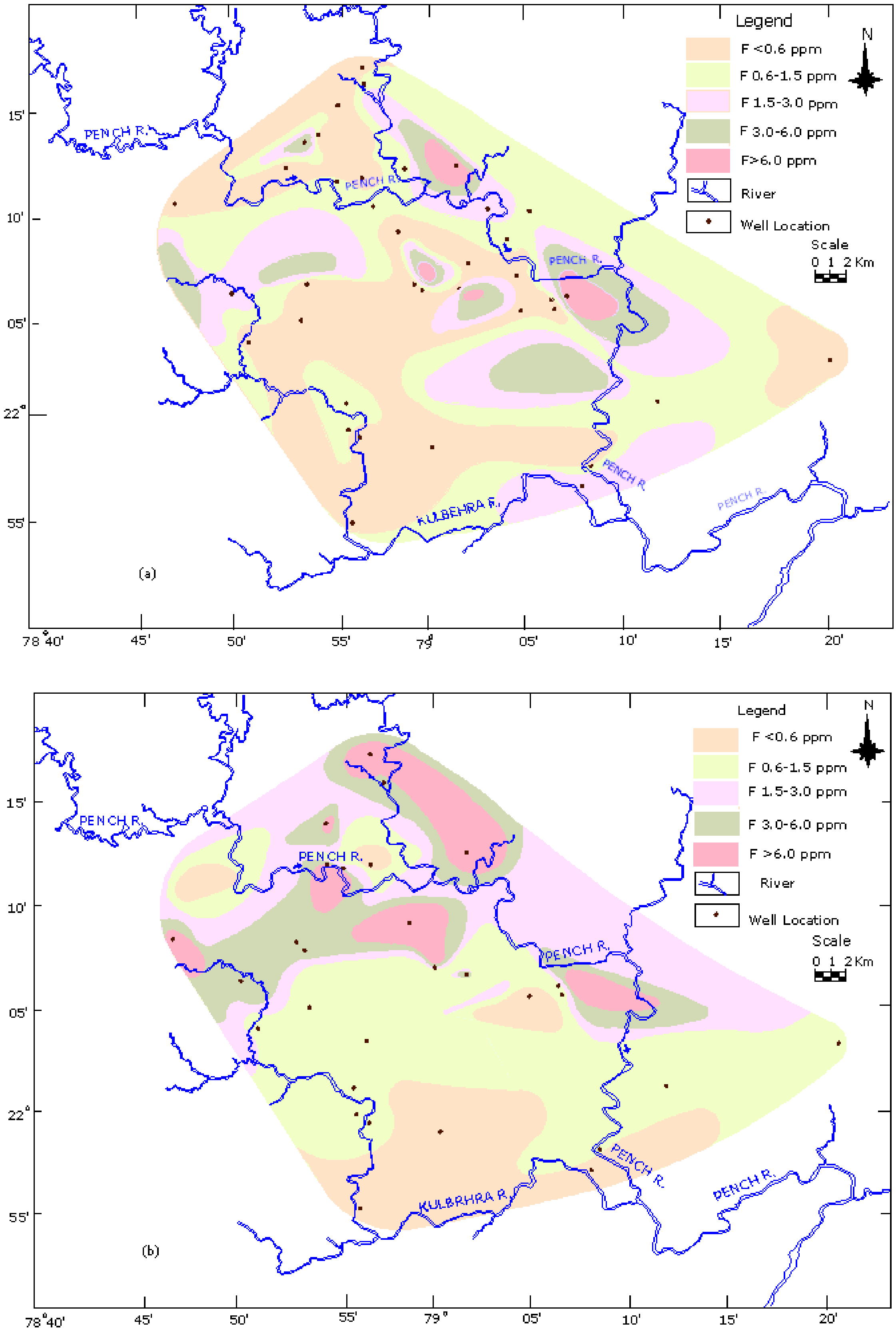


Fig.4. Spatial distribution of fluoride in ground water during (a) pre-monsoon period and (b) Post-monsoon period

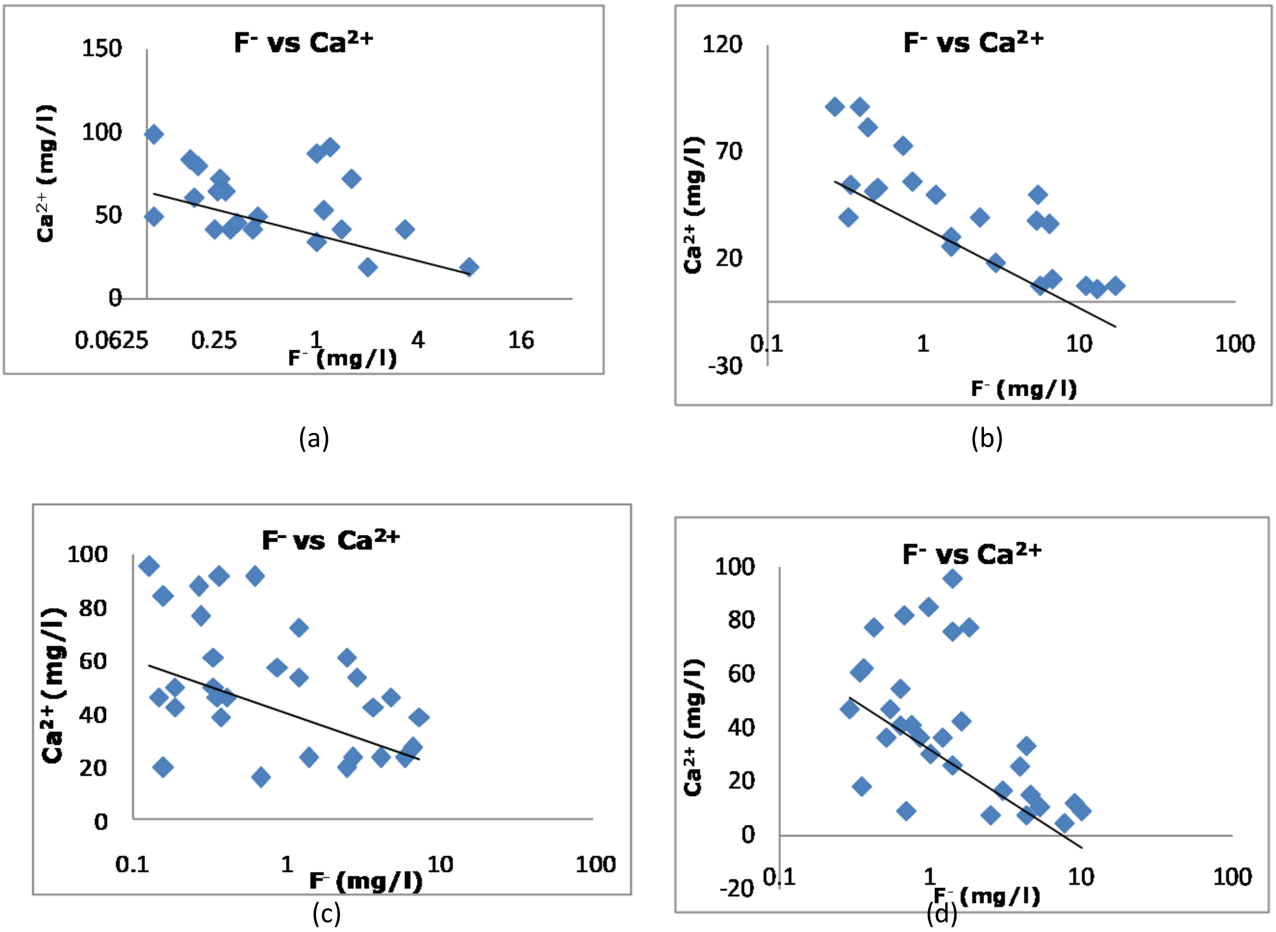


Fig.5. Relationship of fluoride and Ca $^{2+}$**: a & b** in granitoids in the pre- and post-monsoon period, **c & d** in basalts in both the period

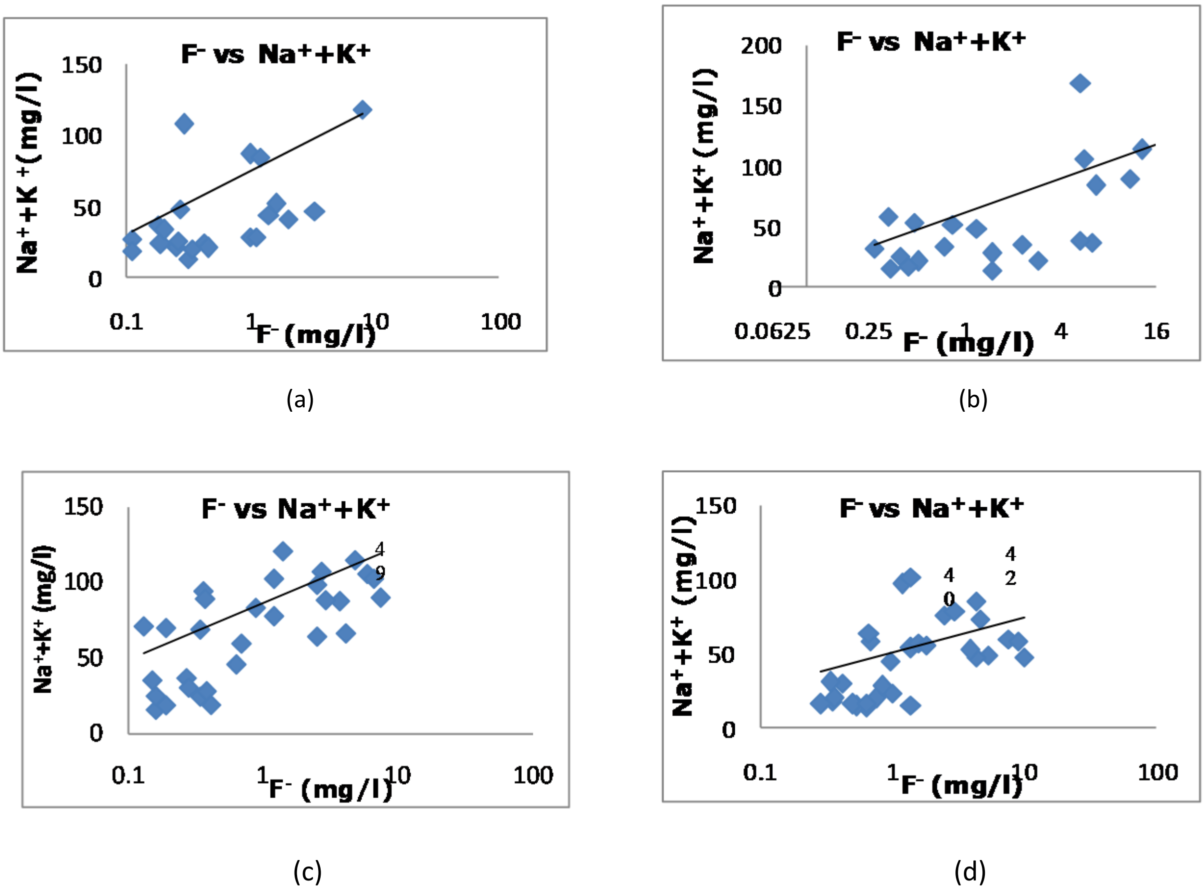
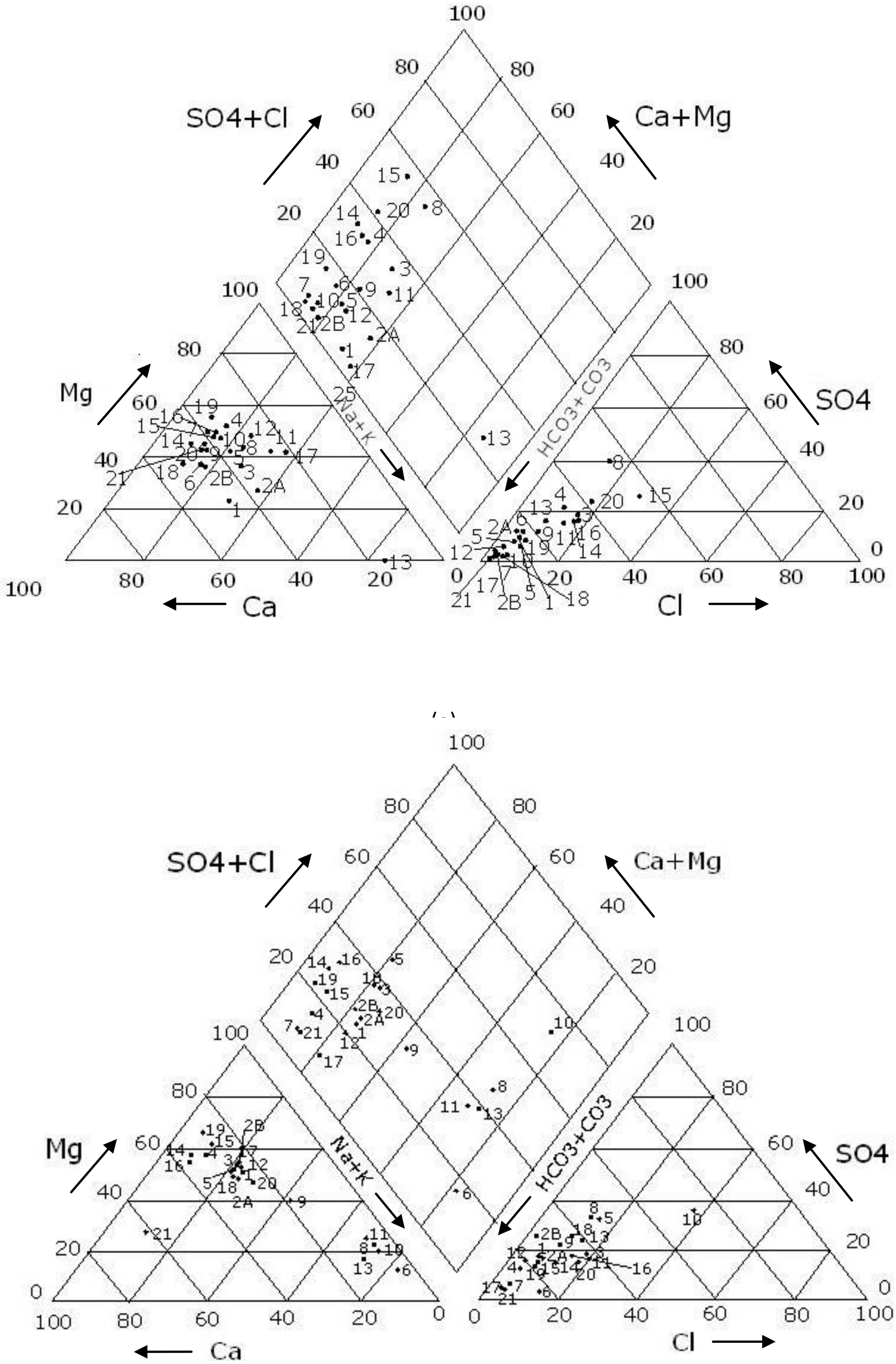
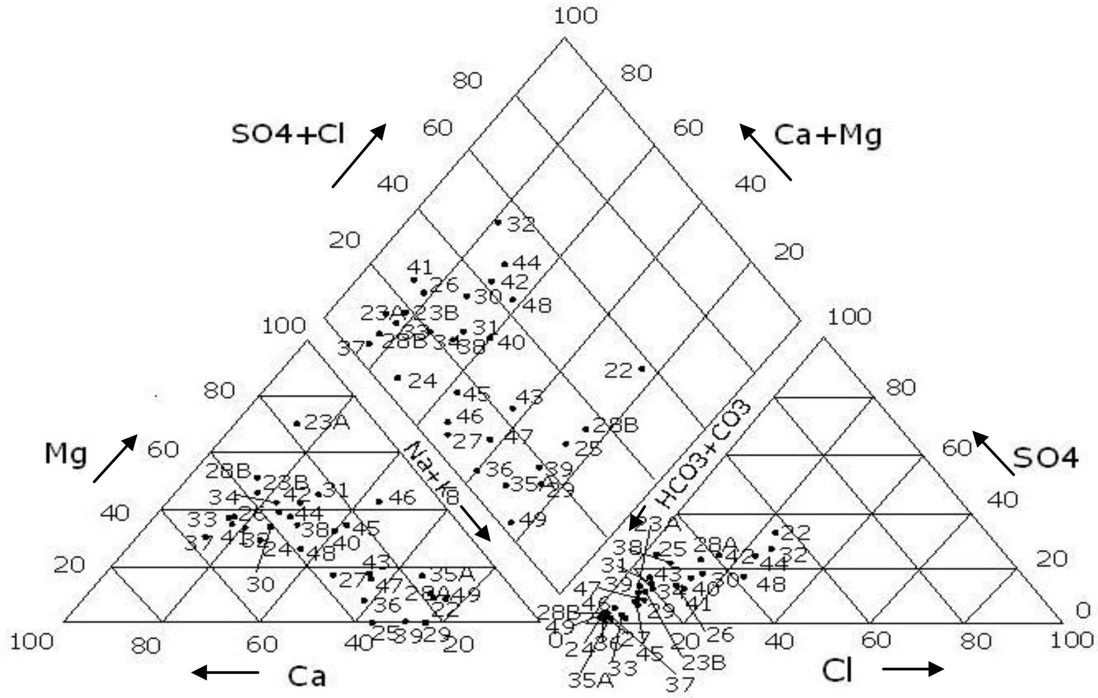


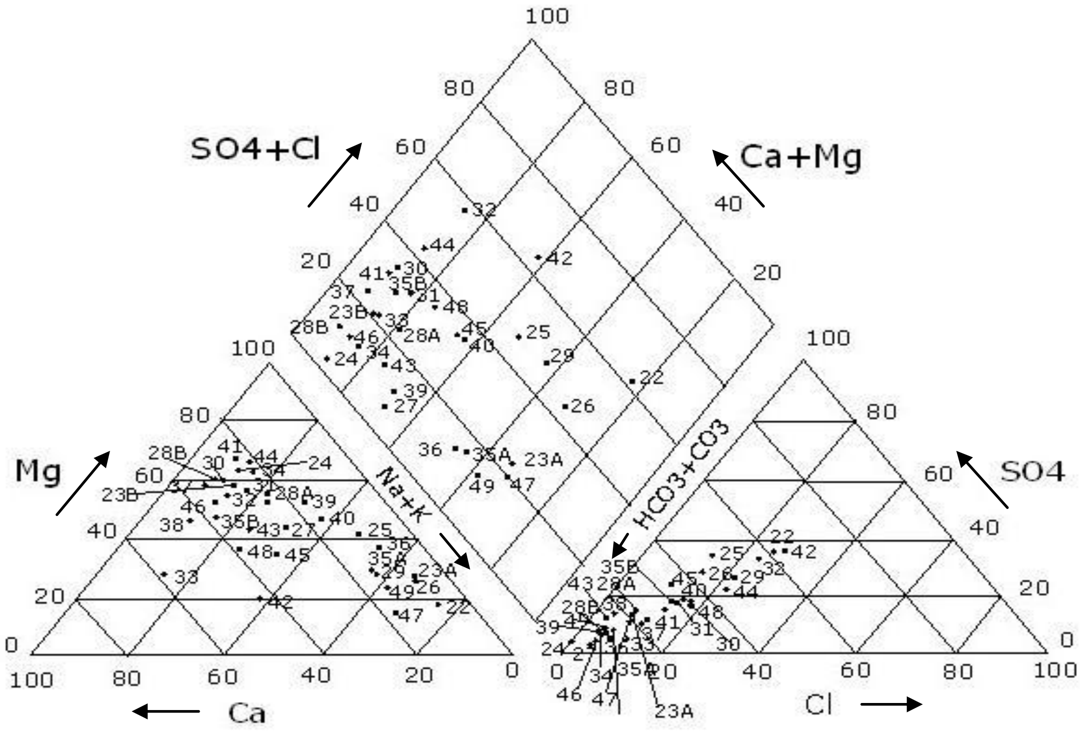
Fig.6. Relationship of fluoride and Na^{+}+K^{+}**: a & b** in granitoids in the pre- and post-monsoon periods, **c & d** in basalts in both the periods



(b)

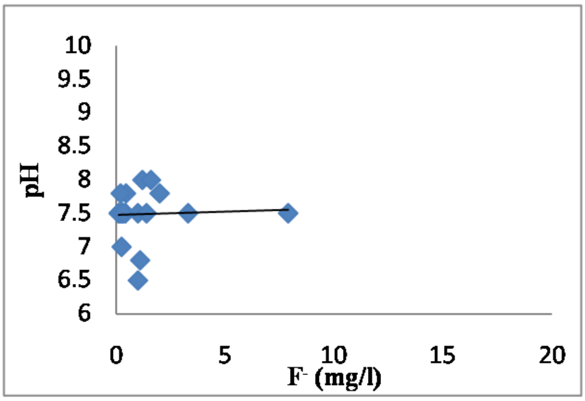
Fig.7. Piper-diagrams (1944) in the granitoids: (a) pre-monsoon and (b) post-monsoon periods



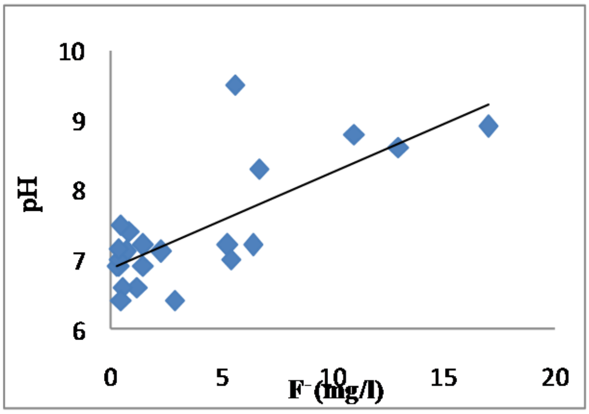


(b)

Fig.8. Piper-diagrams (1944) in the basalts; (a) pre-monsoon and (b) post-monsoon periods



(a)



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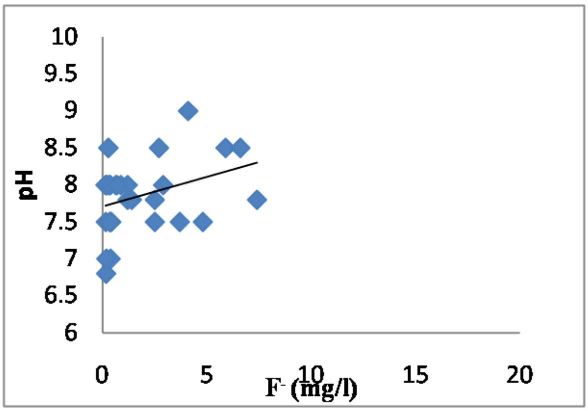
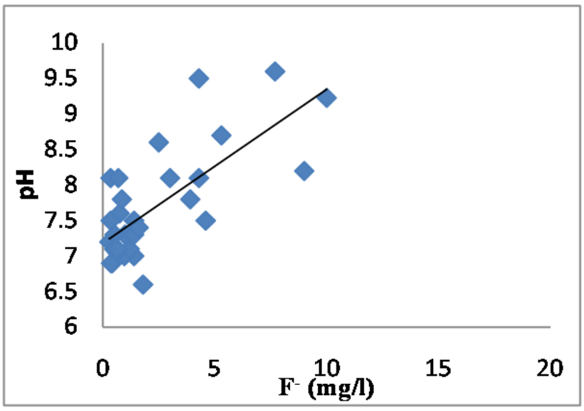
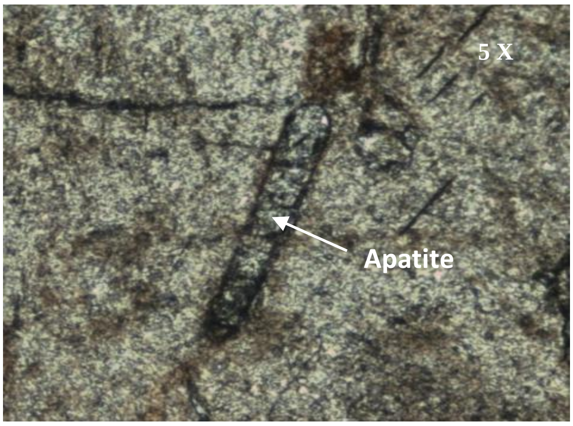


(c)

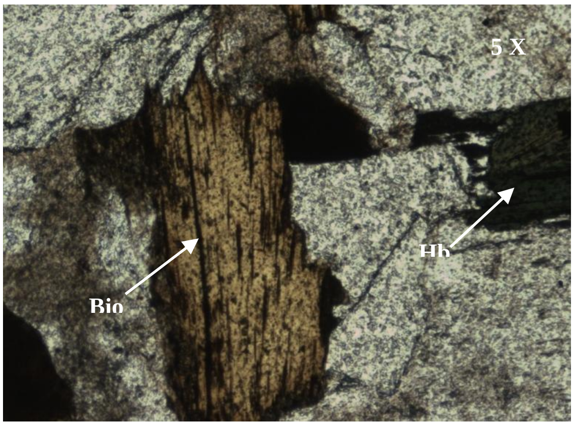


(d)

Fig.9. Relationship of fluoride and pH in the granitoids; (a) pre-monsoon and (b) post-monsoon periods and basalts; (c) pre-monsoon and (d) post-monsoon periods



(a)



(b)

Fig.10. a & b: A plane-polarized light micrograph of granite of the thin-section from the study area; Bio (Biotite), Hb (Hornblende) and Apatite present

CONCLUSION

Generally most ground water-samples from tube/bore-wells have higher F^- contamination/pollution. However, in the studied area the prevalence of F^- is found to be directly related to the distribution of F^- bearing minerals mainly in granitoids and partly in the basalts. The most stable F^--bearing component is apatite apart from hornblende and biotite in the granites/granitoids in the area (Fig. 10 a & b). Besides, leaching of fluorine from micas in granitoids during weathering has also contributed F^- in aquifers to some extent. The degree of weathering and the leachable F^- in a terrain is more important in deciding F^- content in the water rather than the mere presence of F^--bearing minerals in the bulk rock/soils. The samples from granitoids show F^- as high as 7.9 ppm in pre-monsoon and 17 ppm in post-monsoon periods.

Basalts are releasing F^- in small quantities are another dominating lithology in the area and no mineral-bearing high F^- could be traced, excepting amphibole, biotite and fluorapatite. The source of F^- in the ground water of this area appears to be these OH^- minerals. Its shows F^- values raging from 7-10 ppm, in both the periods. Figure 4 a, and b show the F^- concentration extends in the post-monsoon period owing to a long span of contact-time of F^- minerals with fluids.

The study finds that high-alkalinity of water is responsible for higher concentration of F^- in ground water in granitoids and basalts.

The study also shows that the 'high concentration belt' of F^- extends in NNW-SSE and calls for more studies in adjoining north-west and south-east areas when the high-fluoride belt seems to extend (Fig. 4 a, and b).

The tube-wells with high/low F^- may be marked and prohibiting for drinking purposes. The study also shows that there is a need of a proper health-survey in the tribal belts of Chhindwara and surrounding districts located in the granitoids/basalts.

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Table 1 Analysis of ground water in granitoids in the pre- and the post-monsoon periods

S. No.	**Sample No.**	**Location**	**Periods**	**pH**	**EC µS/cm**	**Major ions in ppm**												**Depth (m)**	**Types of water**
						TDS	**TH**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Fe**	**HCO_3^-**	**SO_4^{2-}**	**Cl^-**	**F^-**	**NO_3^-**		
1	**1**	Sonapipri	Pre	6.5	268	171.52	123.5	34.2	9.12	27.22	1.29	**4.625**	366	5.0	5.54	1.0	62.40	-	Ca-Mg-HCO_3
			Post	6.4	348	222.72	144.4	18.24	23.71	21.44	0.53	1.518	97.6	18.6	5.54	2.9	26.60		Ca-Mg-HCO_3
2	**2A**	Patha A	Pre	7.5	353	225.92	171.5	41.8	16.08	45.37	1.47	0.107	366	35.5	13.66	3.3	45.98	120	Ca-Mg-HCO_3
			Post	7.2	635	406.4	258.4	36.48	40.13	35.70	1.13	0.512	158.6	28.0	11.08	6.4	31.85		Ca-Mg-HCO_3
3	**2B**	Patha B	Pre	6.8	392	250.88	237.5	53.2	25.08	18.06	10.06	0.493	594.75	2.0	10.15	1.1	24.63	120	Ca-Mg-HCO_3
			Post	7.2	642	410.88	307.8	38	51.07	36.16	2.12	0.257	207.4	52.8	7.38	5.3	0.0		Ca-Mg-HCO_3
4	**3**	Kundalikalan	Pre	7.5	889	568.96	437	87.4	52.44	74.71	11.90	0.072	411.7	95.6	59.81	1.0	147.78	91.44	Ca-Mg-HCO_3
			Post	6.6	835	534.4	364.8	50.16	57.46	45.42	2.70	0.219	128.1	29.8	24.0	1.2	43.68		Ca-Mg-HCO_3
5	**4**	Babai	Pre	7.5	427	273.28	275.5	41.8	41.04	23.07	0.91	0.204	381.2	20.5	15.14	0.42	52.54	85.34	Ca-Mg-HCO_3
			Post	6.6	697	446.08	372.4	53.2	57.46	20.15	0.79	0.094	250.1	25.6	11.08	0.51	20.36		Ca-Mg-HCO_3
6	**5**	Khirsadoh	Pre	7.5	569	364.16	380	72.2	47.68	38.86	8.91	0.317	350.7	84.3	34.15	0.27	31.53	76.2	Ca-Mg-HCO_3
			Post	6.4	826	528.64	372.4	51.68	58.37	39.69	13.55	0.326	134.2	**62**	25.84	0.47	39.08		Ca-Mg-HCO_3
7	**6**	Urdhan	Pre	7.5	508	325.12	266	60.8	27.36	22.50	0.91	0.062	366	35.4	17.34	0.19	114.94	135	Ca-Mg-HCO_3
			Post	8.8	555	355.2	49.4	6.08	8.21	**112.0**	1.32	0.119	170.8	2.9	16.61	13	0.0		Na-HCO_3
8	**7**	Haranbhata	Pre	7.8	307	196.48	285	49.4	38.76	17.6	2.81	0.384	411.7	6.1	11.26	0.45	29.88	121.9	Ca-Mg-HCO_3
			Post	7.2	414	264.96	243.2	30.4	40.13	11.83	1.77	**1.835**	347.7	10	14.77	1.5	0.0		Ca-Mg-HCO_3
9	**8**	Palatwara	Pre	**8.0**	**1031**	**659.84**	**522.5**	91.2	70.68	72.32	12.40	0.035	305	210	55.01	1.2	9.85	60.96	Cl-Mg-K-HCO_3
			Post	8.9	438	280.32	76	7.6	13.68	89.11	0.45	0.264	91.5	43.5	11.08	11	0.49		Cl-Mg-K-HCO_3
10	**9**	Munga	Pre	8.0	591	378.24	313.5	72.2	31.92	41.05	10.23	0.148	381.2	39.1	29.35	1.6	124.79	76.2	Ca-Mg-HCO_3
			Post	7.0	1093	699.52	395.2	50.16	64.75	69.26	**99.4**	0.100	237.9	59.7	20.31	5.4	44.33		Ca-Mg-HCO_3
11	**10**	Panjra	Pre	7.0	433	277.12	237.5	41.8	31.92	20.08	0.95	0.752	**488**	16.7	16.61	0.25	68.96	-	Ca-Mg-HCO_3
			Post	**9.3**	613	392.32	83.6	7.6	15.50	104.9	0.68	0.153	36.6	37.8	**31.4**	5.6	0.0		Na-Cl
12	**11**	Seonimegha	Pre	7.5	928	593.92	418	64.6	61.56	85.30	**22.15**	0.122	472.7	80.6	51.69	0.29	144.5	-	Ca-Mg-HCO_3
			Post	8.9	457	292.48	79.8	7.6	14.59	79.54	0.55	0.096	97.6	24.5	16.61	**17**	0.0		Cl-Mg-K-HCO_3

Table 1 Contd…..

S. No.	Sample No.	Locations	periods	pH	EC µS/cm	Major ions in ppm												Depth (m)	Types of water
						TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	F^-	NO_3^-		
13	**12**	Kaparwari	Pre	7.5	428	273.92	294.5	41.8	45.6	42.22	1.66	0.166	411.7	28.8	14.21	1.4	25.61	120	Ca-Mg-HCO_3
			Post	6.9	431	275.84	205.2	25.84	33.74	25.18	1.86	0.180	152.5	22.2	5.54	1.5	2.63		Ca-Mg-HCO_3
14	**13**	Bangaon	Pre	7.5	479	306.56	*28.5*	19	*0.0*	**116.7**	1.73	0.368	350.7	55.5	26.21	**7.9**	12.15	54.8	Na-HCO_3
			post	8.3	573	366.72	72.2	10.64	10.94	81.83	1.43	0.288	91.5	27.2	14.77	6.7	2.63		Cl-Mg-K-HCO_3
15	**14**	Ner	Pre	7.5	807	516.48	494	**98.8**	59.28	25.13	1.44	0.126	427	64.6	62.58	0.11	108.37	165	Ca-Mg-HCO_3
			post	6.9	1205	771.2	**604.2**	**91.2**	90.29	23.46	0.95	0.079	305	50	**31.38**	0.39	42.69		Ca-Mg-HCO_3
16	**15**	Khajri	Pre	7.5	983	629.12	484.5	83.6	**66.12**	33.23	3.09	*0.0*	228.7	**94.2**	**85.28**	0.18	**190.47**	42.6	Cl -Mg-K-HCO_3
			post	7.1	1063	680.32	570	72.96	**93.02**	24.44	8.82	0.201	**384.3**	50.8	24	0.74	43.02		Ca-Mg-HCO_3
17	**16**	Sarna	Pre	7.8	820	524.8	456	79.8	61.56	26.74	6.10	0.836	427	73.8	53.90	0.2	131.36	130	Ca-Mg-HCO_3
			post	6.9	**1236**	**791.04**	577.6	**91.2**	83.90	25.16	6.02	0.077	225.7	42	29.54	0.27	44.33		Ca-Mg-HCO_3
18	**17**	Rajakhoh	Pre	7.8	316	202.24	142.5	19	22.8	38.76	2.31	0.509	442.7	6.9	6.46	2.0	31.86	170	Ca-Mg-HCO_3
			post	7.1	552	353.28	285	39.52	44.69	32.63	1.84	0.099	219.6	8.9	*5.54*	2.3	**44.99**		Ca-Mg-HCO_3
19	**18**	Chhindwara	Pre	7.5	201	128.64	180.5	41.8	18.24	8.1	4.13	2.363	396.5	1.8	8.49	0.31	15.44	90	Ca-Mg-HCO_3
			post	7.4	876	560.64	387.6	56.24	59.28	48.57	2.25	0.229	183	59.3	20.31	0.85	42.69		Ca-Mg-HCO_3
20	**19**	Deverdhatolla	Pre	7.5	516	330.24	323	49.4	47.88	16.97	0.9`1	0.112	427	32.8	22.1	0.11	91.95	140	Ca-Mg-HCO_3
			post	7.0	780	499.2	444.6	54.72	73.87	13.91	0.74	0.118	219.6	27.3	14.76	0.34	43.67		Ca-Mg-HCO_3
21	**20**	Karaghat	Pre	7.5	668	427.52	342	64.6	43.32	24.33	0.76	0.049	244	73.9	43.32	0.26	91.95	150	Ca-Mg-HCO_3
			post	7.15	811	519.04	296.4	39.52	47.42	56.88	1.31	0.195	170	35	27.69	0.33	26.27		Ca-Mg-HCO_3
22	**21**	Khairibhutai	Pre	7.5	371	237.44	228	45.6	27.6	19.39	0.34	0.030	411.7	4.2	12.55	0.34	62.40	120	Ca-Mg-HCO_3
			post	7.3	581	371.84	300.2	81.6	23.09	16.08	0.15	0.123	170.8	6.3	5.54	0.44	36.12		Ca-Mg-HCO_3

Pre = Pre-monsoon (2010), post = Post-monsoon periods (2011) (- = not available)

(Highest-values = **bold** and lowest-values = underlined),

Table 2 Analysis of ground water in basalts in the pre- and the post-monsoon periods

S. No.	Sample No.	Location	periods	pH	EC µS/cm	Major ions in ppm												Depth (m)	Types of Water
						TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	F^-	NO_3^-		
1	**22**	Tumdi	Pre	8.5	523	334.72	28.5	22.8	6.84	106.6	0.74	0.027	137.25	83.17	42.64	2.7	10.18	106.7	Na-Cl
			Post	9.5	499	319.36	68.4	7.6	11.86	84.63	0.21	0.132	61	41.6	24	4.3	0.0		Na-Cl
2	**23A**	Jhurraimal A	Pre	6.8	361	231.04	237.5	19	45.6	14.59	1.57	0.208	396.5	30.9	16.61	0.16	28.24	91.44	Ca-Mg-HCO_3
			Post	8.6	377	241.28	87.4	7.6	16.42	74.69	1.08	0.120	122	14.9	9.23	2.5	0.98		Cl-Mg-K-HCO_3
3	**23B**	Jhurraimal B	Pre	8.0	382	244.48	275.5	49.4	36.48	24.03	0.75	0.631	366	40	16.43	0.34	42.69	80	Ca-Mg-HCO_3
			Post	7.6	572	366.08	307.8	41.08	49.25	19.45	0.22	0.152	201.3	29.7	11.08	0.75	35.14		Ca-Mg-HCO_3
4	**24**	Tendukhera	Pre	7.0	293	187.52	161.5	38	15.69	23.97	4.3	0.372	457.5	0.5	7.57	0.38	32.84	97.54	Ca-Mg-HCO_3
			Post	7.5	571	365.44	224.2	26.14	38.12	14.44	0.32	0.143	225.7	0.0	3.69	1.4	23.97		Ca-Mg-HCO_3
5	**25**	Mandla	Pre	7.5	365	233.6	28.5	41.8	0.0	87.46	0.37	0.070	259.25	60	18.09	3.7	9.85	106.7	Ca-Na-HCO_3-SO_4
			Post	8.7	450	288	117.8	10.64	21.89	48.13	0.48	0.126	73.2	37.14	11.08	5.3	7.22		Ca-Mg-HCO_3
6	**26**	Mandli	Pre	8.0	750	480	361	87.4	34.2	34.97	2.04	0.221	411.75	60.3	36.37	0.27	137.9	91.44	Ca-Mg-HCO_3
			Post	**9.7**	351	224.64	68.4	4.56	13.68	59.58	0.06	0.283	67.1	25	9.23	7.7	0.66		Cl-Mg-K-HCO_3
7	**27**	Mothar	Pre	8.0	495	316.8	199.5	53.2	15.96	84.46	4.13	0.219	777.75	16.4	8.12	2.9	21.35	45.72	Ca-Mg-HCO_3
			Post	8.1	591	378.24	231.8	33.44	35.57	45.22	1.94	0.087	347.7	14.2	7.38	4.3	0.33		Ca-Mg-HCO_3
8	**28A**	Chanhiyakalan A	Pre	8.5	538	344.32	85.5	22.8	6.84	102.7	3.20	0.464	320.25	86.5	35.63	5.9	14.78	243.8	Ca-Na-HCO_3-SO_4
			Post	8.1	663	424.32	144.4	18.24	23.71	16.13	1.83	0.290	97.6	15.8	5.54	0.35	26.60		Ca-Mg-HCO_3
9	**28B**	Chanhiyakalan B	Pre	7.5	360	230.4	275.5	45.6	38.76	18.15	1.13	0.069	472.75	22.7	7.94	0.41	42.69	167.6	Ca-Na-HCO_3-SO_4
			Post	7.2	636	407.04	349.6	47.12	55.63	15.08	0.50	**2.017**	195.2	9.5	7.38	0.29	16.09		Ca-Mg-HCO_3
10	**29**	Jamhoripanda	Pre	8.5	294	188.16	28.5	26.6	0.0	102.2	0.55	0.063	335.5	25.6	14.21	6.6	13.79	-	Na-HCO_3
			post	9.2	311	199.04	76	9.12	12.77	47.55	0.0	0.163	54.9	22.2	12.92	**10**	2.63		Cl-Mg-K-HCO_3
11	**30**	Kotalbarri	Pre	8.0	964	616.96	**427.5**	**95**	46.8	69.48	1.79	0.046	381.25	83.2	64.43	0.13	**170.77**	76.20	Ca-Mg-HCO_3
			post	6.9	1162	743.68	589	77.52	94.85	29.69	0.49	0.045	207.4	47.4	33.23	0.42	44.66		Ca-Mg-HCO_3
12	**31**	Sarra	Pre	8.0	832	532.48	389.5	57	59.28	80.65	2.89	0.064	625.25	80.5	38.77	0.88	118.22	110	Ca-Mg-HCO_3
			post	7.0	1223	782.72	**630.8**	76	105.8	52.28	0.99	0.129	250.1	54.2	33.23	1.4	45.32		Ca-Mg-HCO_3
13	**32**	Imlikhera	Pre	8.0	893	571.52	399	91.2	41.04	45.23	0.78	0.174	213.5	96.0	67.93	0.63	72.25	121.9	Cl-Mg-K-HCO_3
			post	7.0	1300	832	596.6	85.12	92.11	43.66	1.13	0.110	140.3	86.8	48	0.97	42.03		Ca-Na-HCO_3-SO_4
14	**33**	Kakai	Pre	*7.0*	437	279.68	218.5	49.4	22.8	18.22	0.83	0.029	366	26.7	16.98	0.19	65.68	60.96	Ca-Mg-HCO_3
			post	7.0	722	462.08	205.2	54.72	16.42	13.49	0.27	0.133	189.1	19.5	14.77	0.63	26.60		Ca-Mg-HCO_3
15	**34**	Somadhana	Pre	7.5	428	273.92	237.5	45.6	29.64	33.48	2.10	0.210	350.75	39.5	21.97	0.15	65.68	155	Ca-Mg-HCO_3
			post	7.3	551	352.64	288.8	30.4	51.07	22.15	1.15	0.176	262.3	12.4	11.08	1.0	22.99		Ca-Mg-HCO_3
16	**35 A**	Chanhiyakhurd A	Pre	7.5	447	286.08	95	19	11.4	91.89	6.86	0.248	747.25	18	12.18	2.5	21.67	213.4	Na-HCO_3
			post	8.1	513	328.32	133	16.72	21.89	76.23	2.39	0.152	176.9	9.6	14.31	3.0	1.64		Cl-Mg-K-HCO_3

Table 2 Contd……

S. No.	Sample No.	Locations	periods	pH	EC µS/cm	Major ions in ppm TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	F^-	NO_3^-	Depth (m)	Types of Water
17	**35 B**	Chanhiyakhurd B	Pre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			post	7.5	1531	979.84	753.4	60.8	48.34	26.87	3.45	0.120	311.1	55.7	36.92	0.34	**45.98**		Ca-Mg-HCO_3
18	**36**	Bilva	Pre	7.5	365	233.6	114	45.6	4.56	93.72	0.84	0.063	579.5	6.0	14.77	0.36	19.70	152.4	Na-HCO_3
			post	8.1	407	260.48	114	9.12	21.88	57.84	0.19	0.258	128.1	8.4	5.54	0.69	5.58		Cl-Mg-K-HCO_3
19	**37**	Bohnakheri	Pre	8.5	680	435.2	389.5	76	47.88	29.31	1.42	0.048	503.25	47	34.15	0.28	95.24	91.44	Ca-Mg-HCO_3
			Post	6.9	890	569.6	444.6	62.32	69.31	18.97	0.58	0.124	219.6	26.2	20.31	0.36	43.68		Ca-Mg-HCO_3
20	**38**	Bhandpipariya	Pre	7.8	567	362.88	304	60.8	36.48	61.09	3.39	0.094	549	**139.1**	12.18	2.5	13.14	10v6.7	Ca-Mg-HCO_3
			Post	7.3	761	487.04	247	47.12	31.01	13.25	1.10	0.113	207.4	24.4	7.38	0.54	42.03		Ca-Mg-HCO_3
21	**39**	Saliwara	Pre	**9.0**	252	161.28	9.5	22.8	0.0	64.93	1.70	4.145	289.75	33.3	11.26	4.1	21.67	115.8	Na-HCO_3
			Post	7.8	569	364.16	258.4	25.84	46.51	50.58	1.69	0.110	**317.2**	21.7	5.54	3.9	0.66		Ca-Mg-HCO_3
22	**40**	Sikarpur	Pre	8.0	555	355.2	218.5	41.8	27.36	64.04	6.2	0.128	366	67	41.9	0.19	24.30	76.20	Ca-Mg-HCO_3
			Post	7.1	945	604.8	361	36.48	64.75	93	3.53	0.362	195.2	44.9	27.69	1.2	19.05		Ca-Mg-HCO_3
23	**41**	Bisapurkalan	Pre	8.0	618	395.52	323	83.6	27.36	23.89	1.24	0.041	381.25	50.8	38.95	0.16	88.67	91.44	Ca-Mg-HCO_3
			Post	7.1	633	405.12	345.8	36.48	61.10	14.89	0.48	0.137	115.9	25.5	14.77	0.51	39.74		Ca-Mg-HCO_3
24	**42**	Samaswara	Pre	7.5	749	479.36	361	60.8	50.16	65.52	3.70	0.204	289.75	88	50.21	0.34	88.67	45.72	Ca-Mg-HCO_3
			Post	7.3	**1583**	**1013.1**	353.4	**95.76**	27.36	**98.56**	2.77	0.552	152.5	**118.6**	**66.46**	1.4	25.29		Ca-Na-HCO_3-SO_4
25	**43**	Jhilmili	Pre	7.5	559	357.76	190	45.6	18.24	106.9	8.13	0.160	503.25	74.6	24.18	4.8	12.48	144.8	Ca-Na-HCO_3-SO_4
			Post	7.8	706	451.84	201.4	36.48	26.45	25.93	2.01	0.050	219.6	22.3	7.38	0.85	21.6		Ca-Mg-HCO_3
26	**44**	Bariwara	Pre	8.0	**1173**	**750.72**	475	91.2	**59.28**	85.36	4.11	0.534	274.5	101.4	**74.68**	0.37	187.19	135	Ca-Mg-HCO_3
			Post	7.1	1356	867.84	364.8	82.08	**159.6**	61.32	2.03	0.062	189.1	59.2	46.15	0.67	45.65		Ca-Mg-HCO_3
27	**45**	Khutpipariya	Pre	8.0	694	444.16	323	53.2	45.6	100.5	2.2	0.180	**793**	62.2	26.39	1.2	65.68	-	Ca-Mg-HCO_3
			Post	7.4	840	537.6	220.4	42.56	27.36	47.45	**9.0**	0.189	195.2	59.4	46.15	1.6	26.60		Ca-Mg-HCO_3
28	**46**	Baregaon	Pre	8.0	327	209.28	161.5	15.2	29.64	58.32	1.57	0.073	472.75	10	9.78	0.69	18.39	150	Ca-Mg-HCO_3
			Post	7.1	489	312.96	258.4	41.04	37.39	16.21	0.44	0.108	195.2	9.9	6.46	0.63	11.16		Ca-Mg-HCO_3
29	**47**	Rajola	Pre	7.8	420	268.8	142.5	38	11.4	88.34	1.84	0.191	427	26.3	18.27	**7.4**	18.39	83.32	Ca-Na-HCO_3-SO_4
			Post	8.2	363	232.32	57	12.16	6.38	57.25	1.15	0.186	109.8	12.4	6.46	9.0	0.0		Na-HCO_3
30	**48**	Sihora	Pre	7.8	742	474.88	294.5	72.2	27.36	70.96	**6.94**	0.433	259.25	69.0	62.95	1.2	68.86	129.5	Ca-Mg-HCO_3
			Post	*6.6*	828	529.92	376.2	77.52	43.78	50.01	5.81	0.289	189.1	45.6	29.54	1.8	4.27		Ca-Mg-HCO_3
31	**49**	Mahendrawara	Pre	7.8	399	255.36	85.5	22.8	6.84	**119.7**	1.18	0.189	625.25	11.2	8.50	1.4	18.72	185.9	Na-HCO_3
			post	7.5	445	284.81	98.8	15.2	14.59	70.64	2.79	0.099	146.4	12.2	3.69	4.6	0.0		Cl-Mg-K-HCO_3

Pre = Pre-monsoon (2010), post = Post-monsoon periods (2011) (- = not available)

(Highest-values = **bold** and lowest-values = underlined),

Table 3 Fluoride values exceeding permissible limit (1.5 ppm) in different Blocks

S. No.	Name of the Block	Name of the village	F^- (ppm) in pre-monsoon period	pH	Name of the village	F^- (ppm) in post-monsoon period	pH
1	Chhindwara	Bangaon* Rajakhoh* Chanhiyakalan A** Bhandpipariya** Jamhoripanda** Chanhiyakhurd A** Saliwara**	7.9 2.0 5.9 2.5 6.6 2.5 4.1	7.5 7.8 8.5 7.8 8.5 7.5 9.0	Bangaon* Rajakhoh* Seonimegha* Panjra* Jamhoripanda** Chanhiyakhurd** Saliwara**	6.7 2.3 17.0 5.6 10.0 3.0 3.9	8.3 8.1 8.9 9.3 9.2 8.1 7.8
2	Parasia	Patha A* Tumdi** Mandla** Mothar**	3.3 2.7 3.7 2.9	7.5 8.5 7.5 8.0	Patha A* Patha B* Palatwara* Munga* Sonapipri*	6.4 5.3 11.0 5.4 2.9	7.2 7.2 8.9 7.0 6.4
					Urdhan* Tumdi** Jhurraimal** Mandla** Mandli** Mothar**	13.0 4.3 2.5 5.3 7.7 4.3	8.8 9.5 8.6 8.7 9.7 8.1
3	Amarwara	Rajola**	7.4	8.2	Rajola** Sihora** Mahendrawara**	9.0 1.8 4.6	8.2 6.6 7.5
4	Chourai	Jhilmili**	4.8	7.5	Khutpipariya**	1.6	7.4

*Granitoids, **Basalt

Table 4 Summary statistics of chemical parameters of ground water samples in pre-monsoon (2010) and post-monsoon (2011) periods in Chhindwara District

S. No.	Constituents (in ppm except pH & EC)	WHO (1984) Standard	BIS (2003) Standard	Pre-monsoon					Post-monsoon				
				Min.	Max.	Avg.	SD	CV	Min.	Max.	Avg.	SD	CV
1	pH	6.5-8.5	7.0-8.5	6.5	9.0	7.53	1.14	0.15	6.4	9.7	7.56	0.81	0.11
2	EC (µS/cm)	400-2000	-	201	1173	542.40	239.11	0.44	311	1583	726.40	312.38	0.43
3	TDS	500-1000	500-2000	128.6	750.7	347.13	153.02	0.44	199	1013	464.89	199.93	0.43
4	TH	-	200-600	9.5	522.5	254.36	137.72	0.54	57	630	276.68	159.86	0.58
5	Ca^{2+}	100-200	75-200	19	98.8	51.84	23.97	0.46	4.56	95.76	40.52	26.19	0.65
6	Mg^{2+}	30	30	0.0	70.68	31.12	19.39	0.62	6.38	159.6	44.38	30.01	0.68
7	Na^+	200	-	8.1	119.7	52.99	32.88	0.62	11.8	112.0	44.88	27.05	0.60
8	K^+	10-12	-	0.34	22.15	3.49	4.01	1.15	0.0	99.40	3.78	13.49	3.57
9	Fe^{2+}	0.3	0.3-1	0.0	4.62	0.40	0.86	2.13	0.05	2.02	0.27	0.39	1.46
10	HCO_3^-	-	300	137.2	793	407.44	143.71	0.35	36.6	384.3	181.96	77.59	0.43
11	SO_4^{2-}	25-250	200-400	0.5	139.1	49.49	39.95	0.81	0.0	118.6	32.28	22.26	0.69
12	Cl^-	250	250-1000	5.54	85.28	28.47	20.77	0.73	3.69	66.46	17.62	12.82	0.73
13	F^-	0.6-1.5	0.6-1.2	0.11	7.9	1.45	1.94	1.34	0.27	17	2.95	3.61	1.22
14	NO_3^-	45	45-100	9.85	190.5	60.92	50.24	0.82	0.0	45.98	21.96	17.95	0.82

Avg.- average, SD- standard deviation and CV- coefficient variation

Table 5 Classification of ground water samples according to the concentration of fluoride and associated risk in Chhindwara district

Classification	F^- Conc. Ranges (ppm)	Associated risk	Pre-monsoon period		Post-monsoon period	
			No. of samples	%	No. of samples	%
Low risk areas	0-0.6	Dental caries	27	51.0	13	26.41
Safe areas	0.6-1.5	Within permissible limits	12	22.64	17	32.07
Low risk areas	1.5-3.0	Dental fluorosis	5	9.43	6	11.32
High risk	3.0-6.0	Dental & mild skeletal fluorosis	5	9.43	8	15.09
Very high risk	> 6.0	Severe skeletal fluorosis	3	6	8	15.09

Profile of National Geoscience Awardee-2010 (Ground Water Exploration)
Dr Dipankar Saha

Dr Dipankar Saha, Regional Director, Central Ground Water Board was conferred the 'National Geosciences Awards-2010 in the field of Ground Water Exploration by Hon'ble Speaker of Lok Sabha Smt. Meira Kumar in a function held on 16th February 2012 at Vigyan Bhawan, New Delhi, in the presence of Shri Dinsha Patel, Hon'ble Minister of State (Independent Charge). The brief profile of Dr Saha is:-

Dr Dipankar Saha obtained his Graduation and Post-graduation in Geology from Presidency College, Calcutta and Calcutta University. He obtained Doctorate Degree from ISM, Dhanbad. Dr Saha has versatile experience of working for more than 28 years on various aspects of ground water in different hydrogeological terrains in India and abroad. He has received training on various facets of Ground water and Integrated Water Management from IIRS Dehradun, Asian Institute of Technology Bangkok, RGI CGWB and JICA Tokyo.

Dr Saha joined Central Ground Water Board in the year 1985 and served under various capacities in different parts of India and is presently posted as Regional Director at Mid-Eastern Region, Patna. He has authored number of departmental reports including State Hydrogeological Reports of Bihar and Jharkhand and has number of technical papers to his credit published in internationally acclaimed journals on water and environment. He has worked extensively for development and management of ground water in arsenic affected areas of Bihar and also presented a paper in World Water Week-2010 at Stockholm. He has been associated with several collaborative studies with BARC Mumbai, NGRI Hyderabad and BIT Mesra. Dr Saha is a member of several State level committees of Bihar and Jharkhand for planning and implementation of a various schemes on ground water.