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Silver Jubilee Publication-II

Special Issue on Application of Remote Sensing, GIS & Mathematical Modeling in Ground Water

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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 groundwater.

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Silver Jubilee Publication-II

Special Issue on

Application of Remote Sensing, GIS & Mathematical Modelling in Ground Water

Profile

Sushil Gupta, Chairman, CGWB

Sri Sushil Gupta completed his Masters in Applied Geology with Honors as Gold Medalist from University of Roorkee in the year 1974 and joined Central Ground Water Board in the year 1977. Shri Gupta has served CGWB in various capacities as Scientist, Regional Director, Member Secretary (CGWA), Member (SAM) & Member(SML). After completing 35 years of service he took over as Chairman, Central Ground Water Board in October 2012.

Sri Gupta has vast experience of working on diverse aspects of ground water development and management including in Hydrogeological surveys, Aquifer Mapping and Management, Exploratory drilling for ground water, detailed ground water budgeting, isotope applications, pollution aspects, Conservation and Artificial Recharge to Ground Water, Data Base Management, Regulation and Control of Ground Water Development, and management of Trans-Boundary (National) aquifers etc.

He has more than 50 technical reports to his credit as an author and has supervised innumerable scientific activities throughout his career and has also contributed several scientific papers in various National and International seminars. He is chairing several scientific and technical committees and is member of various inter-ministerial committees as an expert in ground water domain.

Sri Gupta is a widely travelled ground water scientist with various accolades. He lead the Indian delegation to the Executive Meeting on “Application of Isotope Techniques in Geogenic Contamination” held in Vietnam, in 2006. He was invited by UNESCO to present a paper on “Trans-boundary Aquifers in Punjab, India” during ISARM conference held in Paris in December 2010. Under the World Bank aided Hydrology Project, he has visited South Africa and Denmark in the year 2010 to study the “Development of Decision Support System (Planning)” in these countries. Sri Gupta participated in the World Water week 2012 held at Stockholm, Sweden. Very recently in January, 2013 he was invited by International Atomic Energy Agency (IAEA) for a meeting at Vienna (Austria) on application of isotope techniques in aquifer mapping.

Profile

Dr N.Varadaraj, Member(SAM), CGWB

Dr N.Varadaraj has completed his M.Tech in Applied Geology from University of Roorkee in the year 1976, PG(Dip Hon's) from IPI(NRSA) Dehradun in 1981 and Ph.D from University of Madras, Chennai in 2007. He has joined Central Ground Water Board in the year 1977. Dr Varadaraj has served CGWB in various capacities as Scientist, Technical Secretary to Chairman, Regional Director in Andhra Pradesh & Tamil Nadu, and Director(RGI),Raipur. Since October 2012, he is holding the post of Member(SAM) with additional charge of Director(RGI), CGWB.

He has vast experience of more than 35 years of service in field of Hydrogeological Investigations, Groundwater modeling, Hydrochemical studies and Aquifer Mapping. He has research experience in field of Hydrogeology with specialization in ground water contamination. He has completed the Remote Sensing studies in SIDA assisted ground water Project in Kerala, Source finding under Rajiv Gandhi National Drinking Water Mission in Tamil Nadu and R&D study under Hydrology Project in Kuttanad alluvium, Kerala, which are highly acclaimed.

Dr Varadaraj has undergone number of ground water professional trainings including Ground Water Modelling at IHE, The Netherlands for 12 weeks during the year 1990. He has number of National & International publications and scientific reports to his credit. He has participated and presented paper in World Water Week, Stockholm in 2010. He has also headed various departmental committees and associated with inter-departmental committees related to Ground Water issues.

Profile

D.S.C.Thambi, Member(TT&WQ), CGWB

Shri D.S.C.Thambi has completed his post-graduate degree in Geology from University of Kerala in the year 1974. He joined Central Ground Water Board in 1977. Shri Thambi has served CGWB in various capacities as Scientist, Regional Director, before becoming Member of the Board in 2012. He has worked in Kerala state unit, Trivandrum, SIDA Assisted Coastal Kerala Ground Water Project, Trivandrum, North Central Chhattisgarh Region, Raipur and South Eastern Coastal Region, Chennai. Presently He is holding the post of Member(TT&WQ), CGWB.

During the professional service of more than 35 years, he was associated with Ground Water studies, exploration, Planning, Management in various terrains of India. He has vast experience in Coastal hydrogeology, Hard rock hydroegeology and Water Conservation in Kerala, Tamil Nadu. Under his leadership SECR, Chennai got 1st prize for participation of maximum number of school children in 1st & 2nd National Painting competition on water conservation in the consecutive year of 2011 & 2012. His work towards Costal Hydrogeology has been widely acclaimed.

Shri Thambi has headed various departmental committee for making National report, Vision Mission document of CGWB Guidelines for hydrogeological surveys etc. He was also associated with number of inter-departmental committees related to Ground Water, including Indo-China Water issues. He has number of National and International publications and scientific reports to his credit. He has undergone international training on Data Storage Retrieval in Sweden in 1985, besides number of other ground water professional training.

Editorial

Remote Sensing & Geographical Information System (GIS) play a very important role in deciphering ground water resources. The advance Remote Sensing Techniques using Satellite Imageries and Digital Image Processing have capabilities to delineate lineaments and other structural features for ground water prospecting. Ground Water Modeling is also one of the useful tools which can be used in formulation of strategies for sustainable management of ground water resources.

*Keeping the above in view, a special issue has been prepared on **Application of Remote Sensing, GIS & Mathematical Modelling in Ground Water** as Silver Jubilee Publication-II of Bhujal News. In this issue, ten scientific papers have been included. Dr Sarkar, in his paper, emphasized the role of GIS in morphometry analysis and ground water potentiality mapping in Jharia Coal field. S.K.Sinha elaborated on role of ground water modelling in ground water management. An overview on Application of Remote Sensing in water quality and water resources management is presented by D.Bagchi & R.Busa. Various Case Studies have been given by K.Babu Govindha Raj etal and D.P.Reddy on application of Remote Sensing & GIS in Groundwater Resource Management. In their papers, Rajesh Chandra, etal and Dr Shashank Shekhar, Case Studies on Numerical Modelling for ground water management have been suggested. Various applications of Remote Sensing & GIS in ground water are presented in the papers by Dr.Mukherjee, etal ,V.Nair etal and V.S.Arya etal*

Sincere efforts have been made to make this issue more informative and useful. It is hoped that the papers in this issue will benefit our readers.

Dr. S.K.Jain
Editor

A GIS Approach to Morphometric Analysis of Damodar River Basin and Groundwater Potentiality Mapping in Jharia Coalfield

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ABSTRACT

Geographic Information System (GIS) techniques are being increasingly and effectively used in morphometric analysis and groundwater potentiality mapping of drainage basin owing to its capabilities of manipulation, analysis, flexibility of experimentation and ability to extract topological attributes from various thematic maps, and to work as a unique tool for geospatial modelling. An attempt to establish morphometric parameters of Damodar river basin and suitable delineation of groundwater potential zones in Jharia coalfield has been made following a multi-criteria evaluation GIS approach using Geomatica and SPANS software tools. The morphometric analysis of the basin reveals that the basin has low to moderate relief, elongated shape and consists of fractured and permeable resistant rocks. For delineation of groundwater potential zones, various data layers such as, litho-stratigraphy, drainage, lineaments (faults), water table elevation, and slope have been emphasized because of their relative importance in holding capacity of groundwater amongst other parameters. A multi-criteria evaluation following a Bayesian probability weighted approach has been employed for map overlay analysis that allows a linear combination of weights of each thematic map. The resultant map indicates that the buried river channels in the southwestern part of the coalfield and flood plains and river channels near Damodar river are groundwater potential zones.

Keywords: Morphometric analysis; Geographical information system; Jharia coalfield; Multi-criteria evaluation, Groundwater potentiality.

INTRODUCTION

Jharia coalfield, the study area lies between 23°39′ N to 23°48′ N latitude and 86°11′ E to 86°27′ E longitude and is located in the eastern part of Dhanbad district, Jharkhand with an area of about 456 sq. km. It falls within the Survey of India (SOI) Topographic maps 73 I/1, 73 I/2, 73 I/5 and 73 I/6. The area is characterized by the gently undulating to a rolling topography with an overall slope towards east-southeast. The average topographic slope varies from 0.01% to 2.18 % and above. The ground elevation of the area generally varies from 240 m in the western part to 140 m in the southeastern part near the Damodar river (NRIMS, 1995). The entire area is subjected to denudational process. Different physiographic units include hillocks and escarpments, pediplains, monadnocks, valley side slopes and valley flats. Vegetation cover is mainly sparse and degraded in general. Important rock types exposed in the area include sandstone and shale of Gondwana age and Precambrian metamorphics. The Gondwana sediments lie unconformably over the Precambrian metamorphics. The groundwater level is dependent mainly upon the presently existing topography, geomorphic features such as, abandoned channels, etc. and human-induced recharge condition. Due to scarcity of drinking water and unhygienic condition around Jharia coal belt, the active population of the Jharia coalfield faces acute shortage of drinking water, which becomes even worse in the summer months. Some part of the coalfield faces water crisis so much so that the habitants use mine water discharge as potable water. In this context, an attempt has been made to evaluate different morphometric parameters of the Damodar river basin and to delineate suitable groundwater potential zones in around Jharia coalfield.

METHODOLOGY AND DATABASE

Various thematic maps, viz., litho-stratigraphy, slope, drainage and lineament have been generated using SOI Topography map Nos. 73 I/1, 73 I/2, 73 I/5, 73 I/6 in1: 50,000 scale and Geological Survey of India’s (GSI) map of Jharia coalfield in 1:63,360 scale. Ground truth has been collected on the litho-stratigraphic units through various field traverses. Dug well data have been collected at different locations in and around the Jharia coalfield. Digital Elevation Model (DEM) of the area has been generated from the topographic contours and spot heights. Elevation contour map has been prepared from the DEM. Generation of these layers have followed a step-approach, *i.e.* digitization, editing, building topological structure and finally, polygonization for GIS overlay analysis. A flow diagram for different thematic layer generation and GIS-based multi-criteria evaluation network is given in Fig. 1.

The database used for generation of different thematic layers includes, (i) contour and spot height data collected from Survey of India’s Topographic maps *viz.* 73 I/1, 73 I/2, 73 I/5, and 73 I/6 in 1:50,000 scale; (ii) litho-stratigraphic data collected from Geological Survey of India’s (GSI) map of Jharia coalfield (Fox, 1930; Mehta and Murthy, 1957) in 1:63,360 scale; (iii) lineament data collected from GSI map of Jharia coalfield (Fox, 1930; Mehta and Murthy, 1957) in 1:63,360 scale and CMPDI map of Jharia coalfield in 1: 25,000 scale (Verma *et al.*1989) and; (iv) dug well data collected from different networking stations in Jharia coalfield.

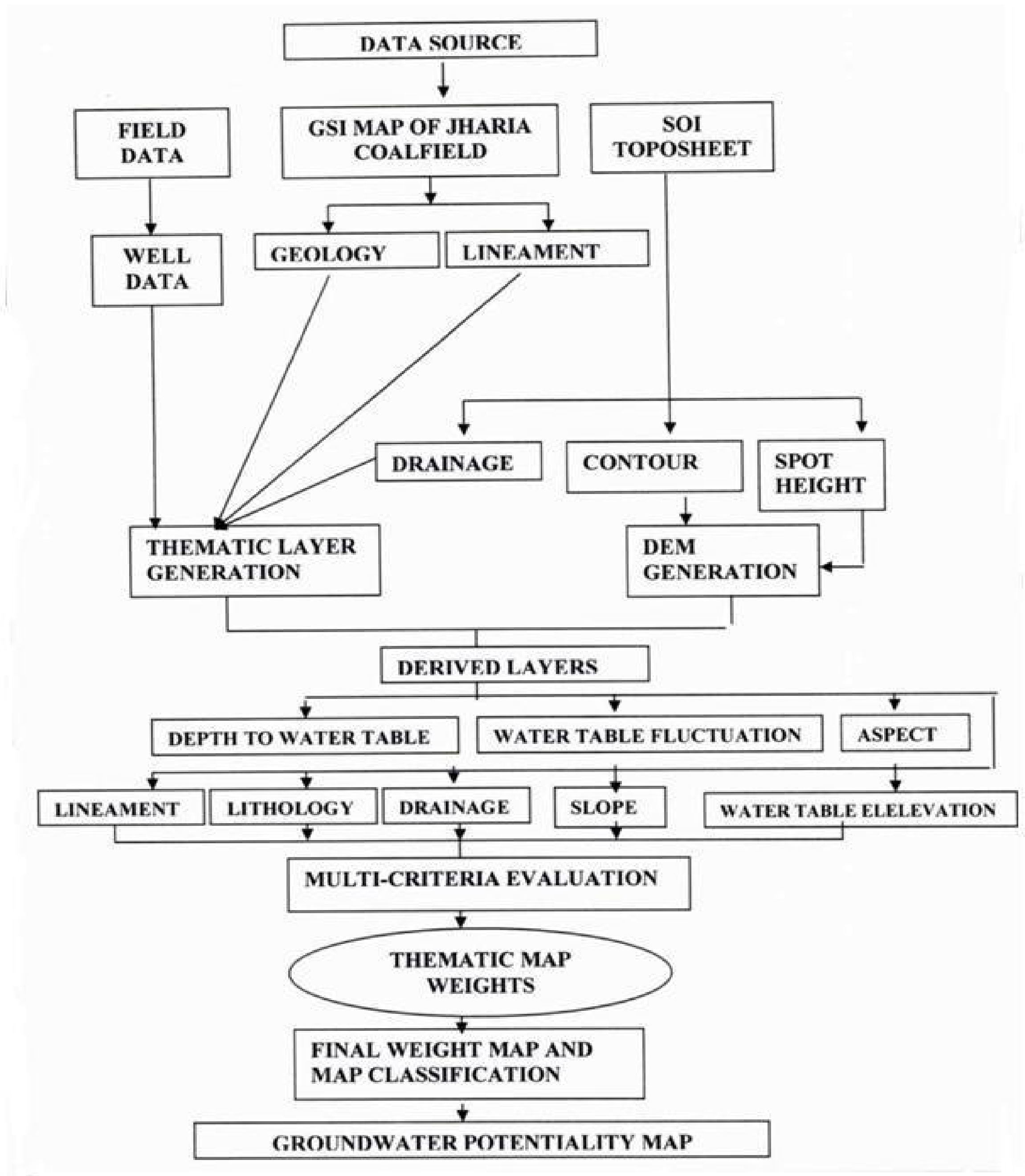


Fig. 1 Flow diagram of groundwater potentiality mapping scheme**.**

GEOLOGICAL SETTING

Jharia coalfield with its sickle shape has its longer axis running northwest-southeast. The coal basin extends for about 38 km along east-west direction and for a maximum of 18 km in north-south direction covering an area of about 456 sq. km. The basement metamorphic rocks are overlain by Talchir formation, which is followed upward in succession by Barakar formation (main coal-bearing horizon), Barren Measures, Raniganj formation (the second coal bearing horizon). The litho-stratigraphic map of the area with lineaments (fault system) is given in Fig. 2. Various structures of the coal basin as deciphered from a large volume of surface and subsurface data have been compiled by Verma *et al.* (1989) and Chandra (1992). Gondwana sediments of Jharia basin are largely disturbed by a large number of various types of fault system. In the southern part of the basin, Southern Boundary fault exists with a trend approximately along WNW- ESE and has a stratigraphic throw of 1800 m towards north. The fault system dips 53° to 60°. A number of interbasinal faults also exist in the southern part. The fault angle varies from 45° to 65° with normal throw in all cases.

MORPHOMETRIC ANALYSIS

Quantitative morphometric analysis of river basin has been carried out in GIS environment for an understanding of the relationship among the different aspects of drainage parameters. Drainage channels have been classified into different orders as per Strahler's scheme (1964). Hierarchy of stream segments has been established according to stream ordering classification scheme. Individual channel segments have been assigned a first order, joining of two such first order segments resulting to a stream of second order, two second order streams join to form a third order stream and so on. The morphometric parameters established are given in Table 1 and include bifurcation ratio, stream length, form factor, circulatory ratio, elongation ratio, drainage density and stream frequency.

Table 1 Morphometric parameters

Bifurcation ratio (1^{st} /2^{nd} order)	3.89
Bifurcation ratio (2^{nd} /3^{rd} order)	4.50
Bifurcation ratio (3^{rd} / 4^{th} order)	4.00
Average Bifurcation ratio	4.13
Area of the basin (sq. km)	456.56
Length of the basin (sq. km)	32.78
Average width of the basin (km)	10.32
Maximum width of the basin (km)	17.74
Perimeter of the basin (km)	107.73
Form factor	0.42
Circulatory ratio	0.49
Elongation ratio	0.74
Drainage density (km/sq. km)	0.57
Stream frequency (no. of streams /sq. km)	0.20

Stream orders

Stream order analysis based on the Strahler's method shows that the main basin is of the fourth order to which a number of third, second and first order streams join. When the number of streams is plotted against the stream order, the drainage network exhibits a linear relationship and the plot on a semi-logarithm scale (number of streams on the logarithm scale and the order on the linear scale) approximates to a straight line. The first order streams have higher frequency than the streams of other orders.

Bifurcation Ratio (R_b)

The term bifurcation ratio (Rb) is used to express the ratio of the number of the streams of any given order to the number of streams in the next higher order (Rb = N_u / N_u+ 1), where N_u is the total number of streams of Nth order and N_u+ 1 is the total number of streams in the next higher order. Average value of the bifurcation ratio has been calculated by determining the slope of the regression line of logarithm of stream number (ordinate) and stream order (abscissa). The values of the bifurcation ratio in the study area indicate that the drainage basin has been affected by structural disturbances. Moderately high values of bifurcation ratio of the study area indicate that the basin is moderately elongated in nature.

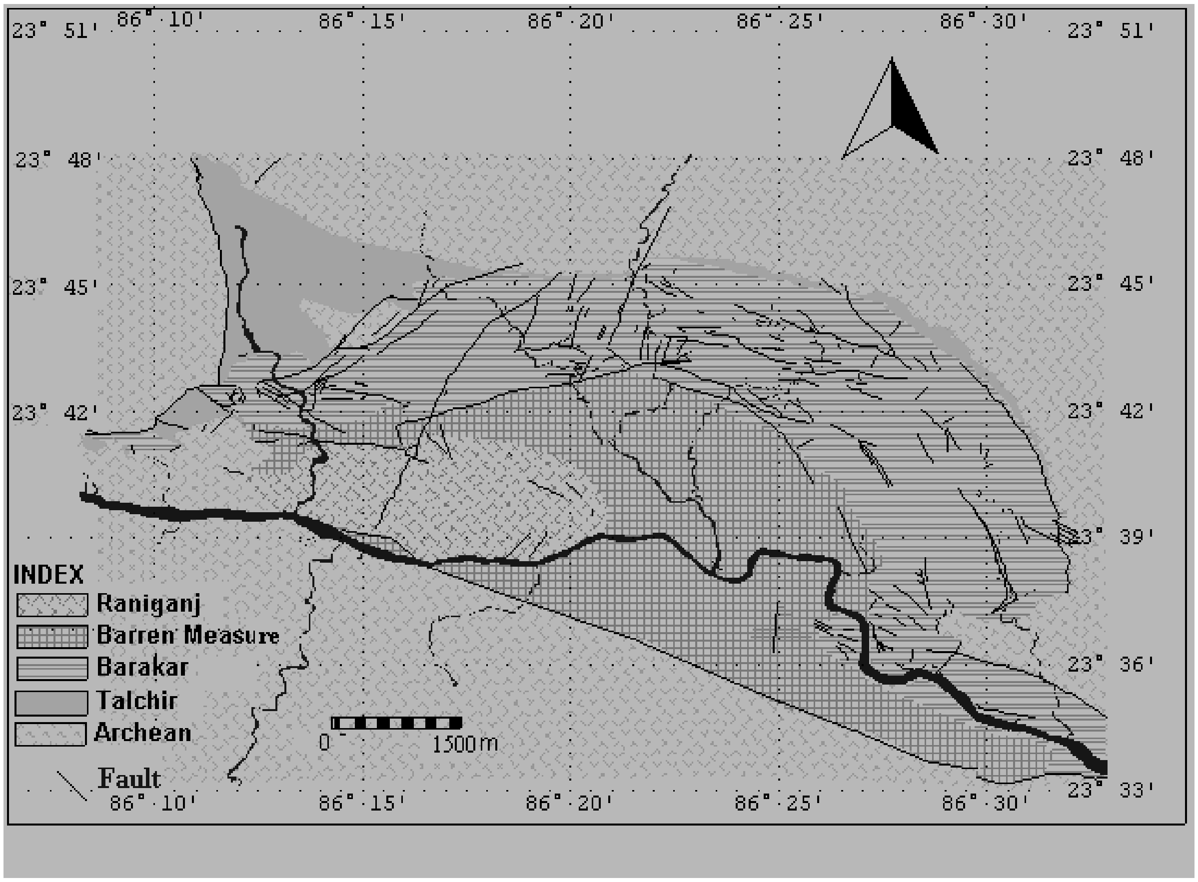


Fig. 2 Litho-Stratigraphic and lineaments (faults) map of Jharia coalfield.

Stream length

Order-wise stream length, cumulative stream length, number of streams, and mean stream lengths are given in Table 2. The plot of the logarithm of the cumulative stream length, mean stream length and total stream length along ordinate and stream order along abscissa for the present study basin reveals a near straight line fit. The straight line fit indicates that the ratio between the mean stream lengths and the stream order is consistent throughout the successive order of a basin and suggests that the geometrical similarity is preserved within the basin with increasing order.

Drainage density (D_d)

Drainage density is the measure of the length of the stream segment per unit area ($D_d = L/A$). In the present study area, a calculated low value of drainage density (0.57) indicates the presence of fractured, resistance permeable rocks and a low relief.

Table 2 Stream analysis

Stream characteristics	1st order	2nd order	3rd order	4th order
Stream length (km)	92.18	68.46	54.18	45.82
Cumulative stream length (km)	92.18	160.64	214.76	260.86
Number of streams	70	18	4	1
Mean stream length (km)	1.32	4.28	14.55	45.82

Form factor (R_f)

It is defined as the ratio of the area of the basin to the square of the length of the basin ($R_f = A/ (L_b)^2$). Smaller the value of form factor, more elongated is the basin. Basins with high form factors have high peak flows for shorter duration, where as elongated basin with low form factor will have a flatter peak of flow longer duration. The value of the form factor in Jharia basin is 0.42, which indicate that the basin is elongated.

Circulatory ratio (R_c)

It is ratio of the area of the basin to the area of the circle having the same perimeter that of the basin. If circulatory ratio value approaches unity, it indicates that the basin shape is circular. The Jharia basin has a lower circulatory ratio of 0.49, which again indicates its elongated nature.

Elongation ratio (R_e)

It is the ratio of diameter of the circle having the same area as that of the basin to the maximum length of the basin. A higher elongation ratio value indicates high infiltration capacity and low runoff conditions. The calculated value of the elongation ratio for Damodar river basin is 0.74, which indicate that the basin is of low to moderate relief, the drainage is structurally controlled and the basin is moderately elongated.

GIS APPROACH

GIS is a special case of information system where the database consists of observations on spatially distributed features, activities or events that are definable in space. It has made tremendous impact owing to its capabilities of manipulation and analysis of individual layers of spatial data and of providing tools to analyse and model the interrelationships among different layers. It is used to provide support for making a wide variety of decisions based on data that are in the form of maps, images, reports, tables and field observations.

Data layer generation

Various thematic layers have been generated from the SOI Topographic maps, GSI map of Jharia coalfield and from field data. DEM generated exhibits spatial distribution of elevation continuously over a region in digital format (Fig. 3). The contours at 20m intervals have been traced from the topographic maps and digitized, edited and rasterised in the Geomatica software. The thematic layers are then generated through data input as point data with their respective ground elevation (Z-value) and then analysed through nonlinear interpolation. The contour layer has been generated through a Triangular Irregular Network (TIN) of the points. The X and Y values are the two dimensional locational values of the points. The Z-value is an attribute for point data, e.g. elevation, dug well data, etc.

Litho-stratigraphy

The litho-stratigraphic map of the area has been generated from GSI map of Jharia Coalfield. The different lithologies have been traced from the geological map and digitized as an area layer and then edited resulting to a thematic map in SPANS Topographer software. The dominant lithologies include sandstone, shale and granite gneiss (basement rock). The litho-stratigraphic map of the study area is shown in Fig. 2.

Slope

Slope is the change of elevation of a surface and it is expressed as a percentage of rise over run. A value of 0% represents a slope of 0° while a value of 100% represents a slope of 45°. The relationship between percentage and degrees as represented on this case is non-linear. In the present study, slope map has been generated from the DEM. Slope plays a very significant role in determining infiltration vs. runoff. Infiltration is inversely related to slope The slope map of the study area is presented in the Fig. 4, which shows an overall gentle slope towards east-southeast.

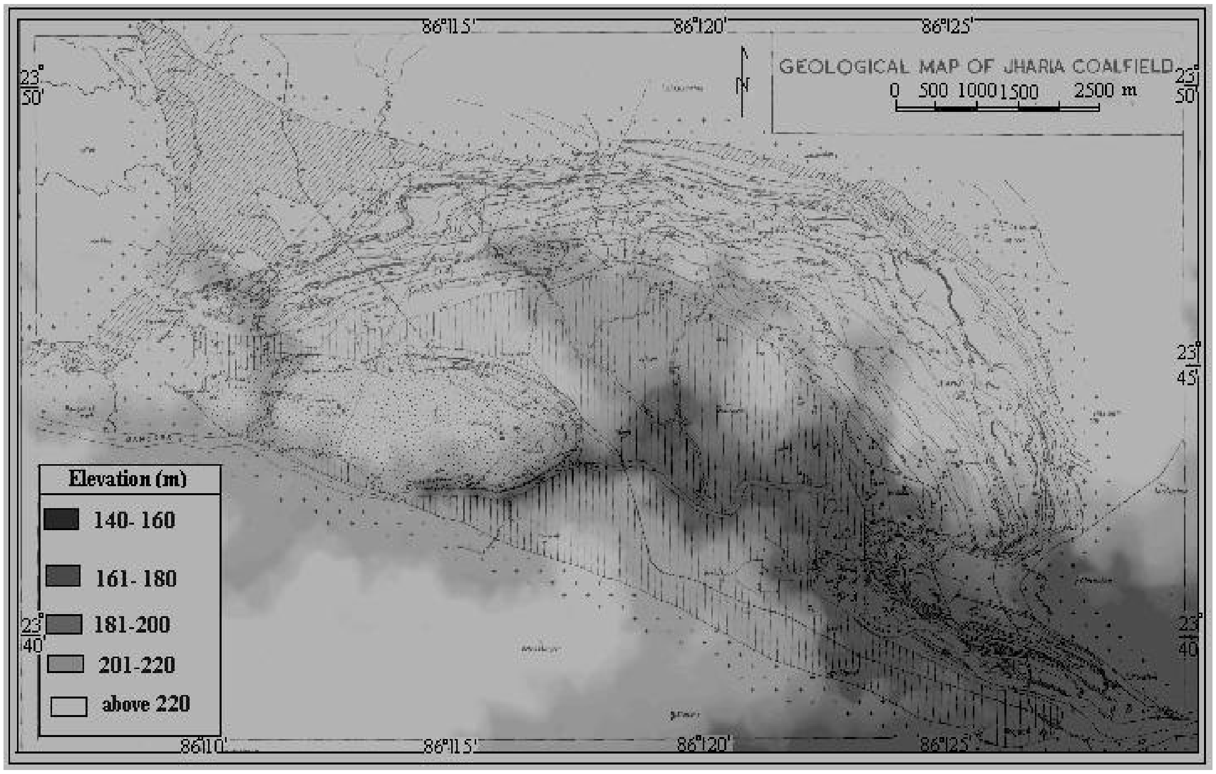


Fig. 3 Digital Elevation Model (DEM) of Jharia coalfield**.**

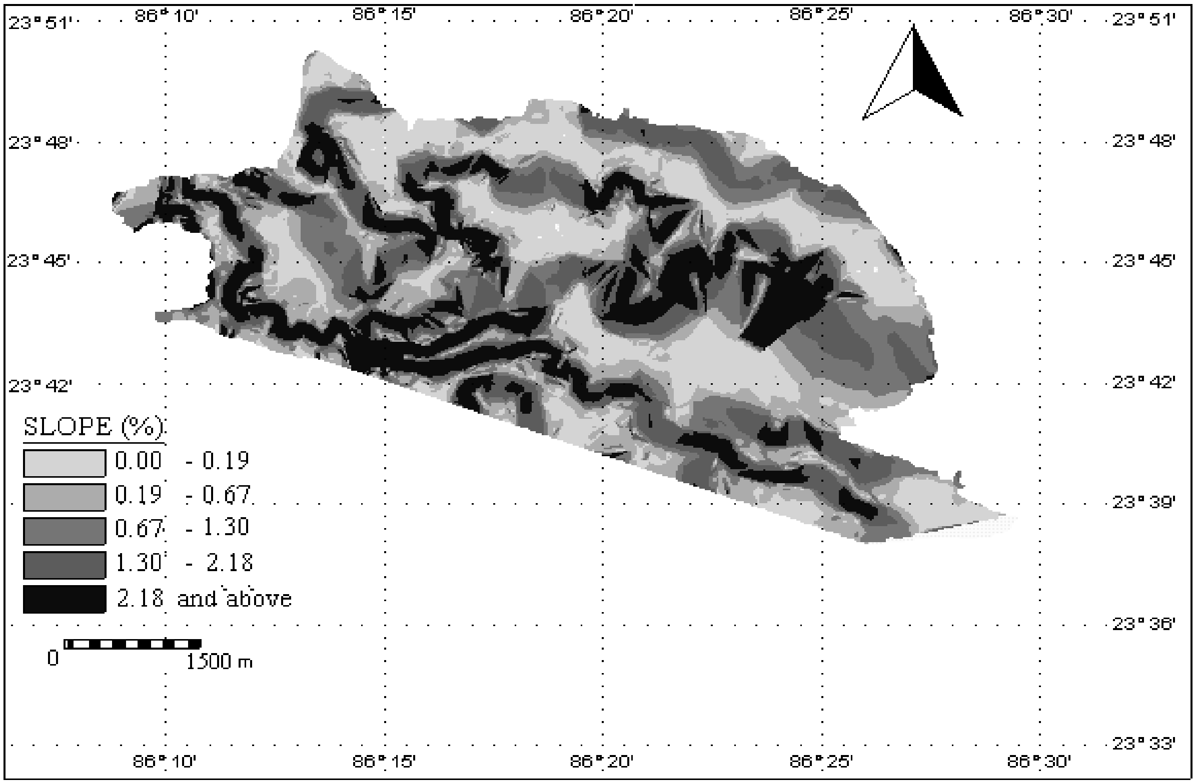
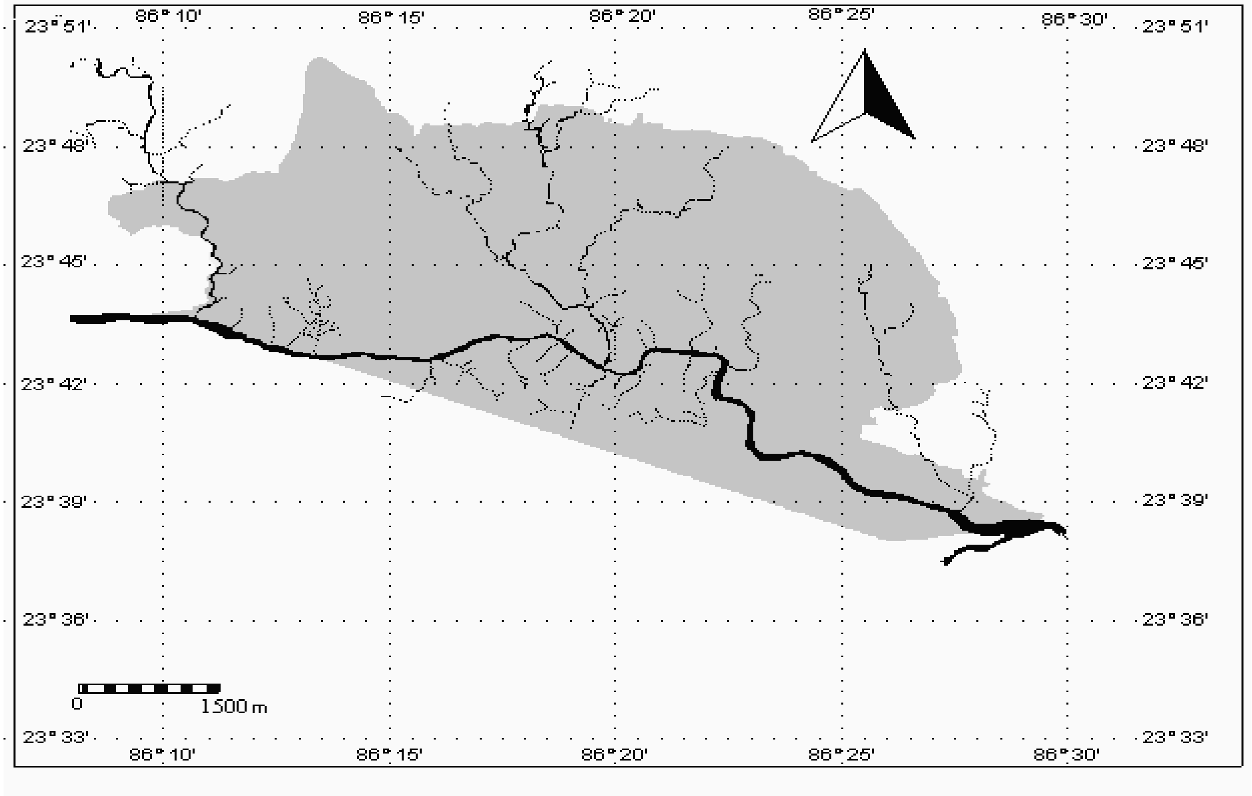


Fig. 4 Slope map of Jharia coalfield.

Drainage

Drainage pattern of an area is very important in terms of its groundwater potentiality. It is the source of surface water and is affected by structural, lithological and geomorphological control of an area. The drainage pattern in the present study area is dendritic. This may be due to more or less homogeneous lithology and structural controls. Damodar river is the main control of drainage system along the Jharia coalfield. It is a fourth order stream to which a number of third to first order streams, *viz.* Jamunia, Khudia, Katri, Ekra, Tisra, Chatkari etc. join. Damodar river flows along the southern periphery of the coalfield. The main flow direction is from west to east. The drainage map of the study area is presented in Fig. 5.

Fig. 5 Drainage network of Jharia coalfield



Lineament

In Jharia coalfield, faults are the dominant linear feature. The Gondwana sediments of Jharia basin are largely disturbed by a large number of various types of fault system. In the southern part of the basin, Southern Boundary Fault is present with a trend approximately along WNW- ESE. A number of interbasinal faults also exist. The lineament data have been prepared by tracing various lineaments from the geological map of Jharia coalfield that have been digitized as a line layer. The fault frequency indicates the infiltration of water into the sub-surface. A high fault frequency provides an indication of higher infiltration and vice versa. The lineament map along with the litho-stratigraphic map is shown in the Fig. 2.

GIS MODELLING

Groundwater condition in various litho-units can be described under three broad divisions, *viz*. (i) weathered formation; (ii) fractured formation; and (iii) abandoned water logged area. To determine the status of the groundwater table, water level data have been collected from different dug wells at 46 locations of Jharia Coalfield during pre-monsoon and post-monsoon periods. The pre-monsoon and post-monsoon depth to water table map, water table elevation map, and water table fluctuation map have been generated from the water level data

Overlay analysis

In the present study, the choice among a set of zones for evaluation of groundwater potentiality has been based upon multiple criteria such as drainage pattern, control of lithological units, steepness of slope, lineament frequency and water table elevation. The process is known as Multi-Criteria Evaluation (MCE). For a Multi-Criteria Modelling, firstly a template has been created by identifying the quadtrees used in the analysis. The number of input quadtrees that can be selected is reduced to one less than the total number. A default weight is calculated by dividing 100 by the number of quadtrees used in the overlay and is assigned to each quadtree in the analysis. A default of 0 for each class score is assigned to each quadtree class. Each class is labelled with the short legend title taken from the input quadtree. Different categories of derived thematic maps have been assigned scores in a numerical scale of 0 to 5 depending upon their suitability to holding capacity of groundwater. A summation of these product values led to the generation of final weight map.

Mathematically, this can be defined as:

$G_W = f\ (Dr, Lin, Lith, Sl, WTE)$

where, G_W is groundwater, Dr is drainage, Lin is lineament, Lith is lithology, Sl is slope and WTE is water table elevation.

The groundwater potential map value, thus derived is given by the equation:

$GWP = \sum W_i CV_i$; with $\sum W_i = 1$;

where, GWP is the groundwater potential map value, W_i is the probability value of each thematic map, and CV_i is the individual capability value to hold groundwater.

Hence, the GWP estimated is given as summation of:

$(0.294 * CV_{Lin}) + (0.118 * CV_{Lith}) + (0.235 * CV_{Dr}) + (0.235 * CV_{WTE}) + (0.118 * CV_{Sl})$.

The resultant final weight map indicates the potentiality of groundwater occurrence in the Jharia Coalfield (Fig. 6).To derive the final weighted map, a probability weighted approach (Sarkar *et al*., 2001) has been employed that allows a linear combination of probability weight of each thematic map (W) with the individual capability value (CV).

Using Baysian statistics, the capability values have been estimated from their assigned scores in a numeric scale. These capability values have then been multiplied with respective weight of each thematic map (Table 3) to lead to generation of groundwater potentiality map. The map has been classified into five categories of potentiality, namely, Excellent, Very Good, Good, Poor and Very Poor.

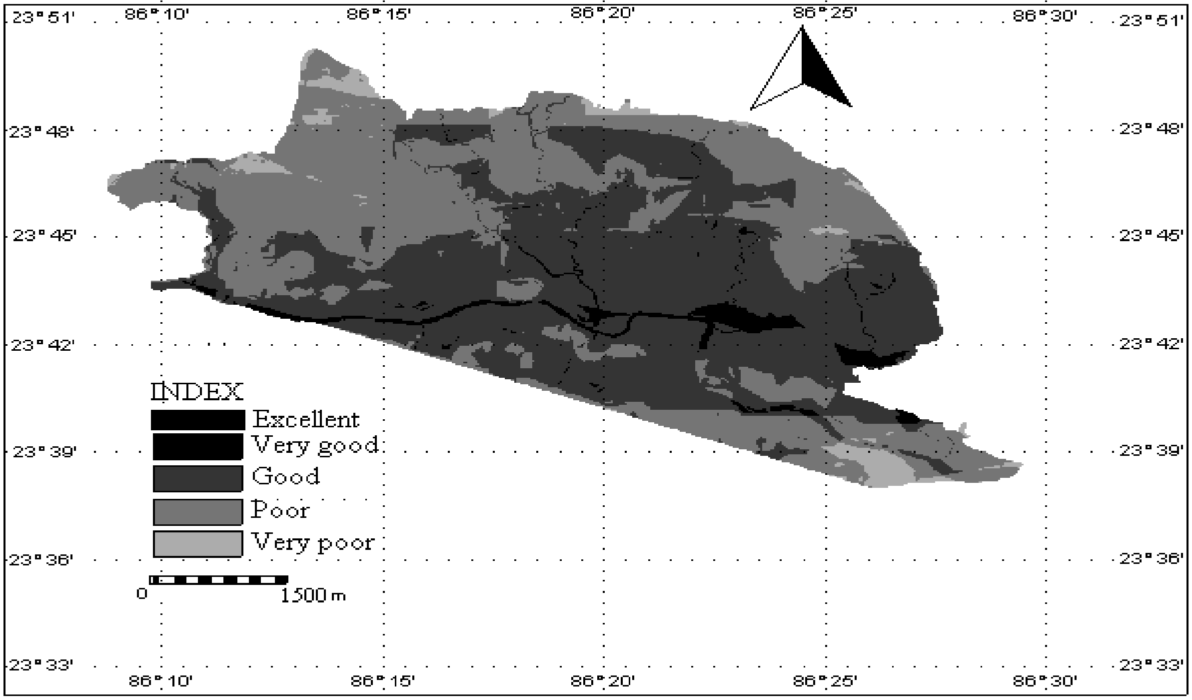


Fig. 6 Groundwater potentiality map of Jharia coalfield.

Table 3 Thematic map weights and capability values

Thematic layers	Map weights (W_i)	Categories	Capability values (CV_i)
Lineament	0.294	Very high frequency	0.40
		High frequency	0.30
		Moderate frequency	0.20
		Low frequency	0.10
		No frequency	0.00
Lithological units	0.118	Raniganj formation	0.40
		Barakar formation	0.30
		Barren Measures	0.20
		Archean Meatmorphics	0.10
		Talchir formation	0.00
Drainage	0.235	Damodar river	1.00
Water table elevation	0.235	High	0.40
		Moderate	0.30
		Low	0.20
		Very low	0.10
Slope (%)	0.118	0.00 – 0.19	0.40
		0.19 – 0.67	0.30
		0.67 – 1.30	0.20
		1.30 – 2.18	0.10
		2.18 and above	0.00

RESULTS AND DISCUSSION

In weathered and fractured zones, groundwater occurs at shallow depths. The Archean metasedimentary formations, the granites and intrusive metabasics and lower Gondwana sedimentary formations constitute the productive aquifers. Groundwater occurring in the interconnected joints and fractures at shallow depths are under unconfined condition. They are connected with the overlying saturated weathered residuum. In the Archean metamorphics of the Jharia coalfield, groundwater occurs in semi-confined to confined aquifer condition. Groundwater occurs under unconfined condition in the top weathered mantle of the variegated Barren Measures and the Barakar and Raniganj sandstones except for Talchir shales. This is because the original rocks being nonporous and nonpermeable, even weathering of top layer does not become conducive to groundwater movement. It is under semi-confined condition in the deeper fractures zones that have imparted secondary porosity and permeability in these rocks. The Gondwana sandstone, in general, is known to constitute good aquifers at many places.

The groundwater potentiality map derived employing multi-criteria evaluation technique reveals distribution of various potential zones of groundwater in and around Jharia coalfield. The northwestern and southwestern part of the basin shows poor to very poor groundwater potentiality while along the flood plain and river terraces, it shows good to excellent groundwater potentiality. In the southeastern part of the coalfield, groundwater potentiality is good though in reality many areas in the southeastern part show poor groundwater reserve. This may be due to the active mining activities in that part which have disturbed the groundwater reserve in that area. Areas in the north-eastern part of the coalfield show good to poor groundwater potentiality. In the eastern side, some areas near the river shows excellent groundwater potentiality. More than century old coal mining activity in Jharia coalfield has substantially modified the groundwater level, movement and flow direction. Following are the observations of resultant effect of the present day set-up of ground water regime:

a) General lowering of ground water level of about 30 m depth in the undisturbed zone in colliery area in comparison with the disturbed zone, because of underground mining activity up to an average depth of 150 to 200 m.

b) Re-circulation of pumped out groundwater from mines and discharging to surface drainage system, followed by percolation through fracture system and again recharging to neighbouring mines as well as in the periphery of the same mine.
c) Main flow of the groundwater in Jharia coalfield is through a networking of existing fault system with 275 nos. of such faults of varying throw.

CONCLUSION

Following concluding remarks can be made from the morphometric analysis and the groundwater potentiality mapping study:

a) Morphometric analysis of Jharia coalfield reveals a drainage basin with low to moderate relief, dendritic pattern, structural control, and being mainly composed of fractured and permeable resistant rocks;
b) Flood plains, abandoned river channels, valley flats provide potential groundwater zones;
c) Generally, 60 to 70 years old goaf filled with water has become part of the present day groundwater regime resulting in high potential source of groundwater that can be exploited for the use of the society.
d) Quality of water, in general, in the very old goaf is potable but it may be analysed and subject to water treatment for use of the society wherever necessary.

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Ground Water Management – Role of Ground Water Modelling

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INTRODUCTION

The ubiquous availability of ground water, coupled with technological advancements in its extraction and its deemed ownership as easement to land, has led to a quantum leap in development of this resource during the last five decades. The unscientific development of ground water contributes to its increasing scarcity, reflected in steep decline of water level and under certain situations, sharp deterioration in quality of water. A continuous declining trend in ground water levels has been observed in localized pockets through out the country. As per the latest ground water estimation of dynamic resources , out of 5723 assessment units nearly 1615 units recorded significant decline in ground water level in either pre or post monsoon period on long term basis and have been categorized as overexploited / critical or semi critical. The phenomenal increase in the overexploited areas are reported globally and India is not an exception. Surprisingly, water is the largest exported commodity in the world, in terms of virtual water. Ground water management on scientific lines is the key for sustainability of this vital resource.

GROUND WATER MANAGEMENT : An Urgent Need

In view of the increasing thrust on groundwater resources and the present scenario of availability vis-a vis demand there is a need to re-orient our approach to ground water management. It is very important that the management of ground water in the country is taken up with a proper planning keeping in mind various social obligations and its requirement for various purposes. Further, emphasis should be given for purpose driven studies involving research and development for scientific development of this precious natural resource.

Aquifer management which deals with a complex interaction between human society and physical environment, presents an extremely difficult problem of policy design. Aquifers are exploited by human decisions and over-exploitation can't be always defined in technical terms, but as a failure to design and implement adequate institutional arrangements to manage people who exploit the groundwater resources. ' Common pool ' resources such as ground water have been typically utilized in an ' open access ' framework , within which, resource ownership is according to a rule of capture. When no one owns the resources, users have no incentive to conserve for the future, and self interest of individual users leads them to overexploitation.

The various management options available for ameliorating or solving problems related to ground water quantity and quality can be broadly grouped under two major categories. The first category relates to supply side management and are referred as " Structural techniques" which usually involve some form of water supply augmentation and artificial recharge. For an effective supply side management it is essential to have full knowledge of hydrogeological controls which govern the yield and behaviour of groundwater levels under abstraction stress, the interaction of surface and groundwater in respect of river base flow and changes in flow and recharge rates due to their exploitation. The effects of groundwater development can be short term and reversible or long term and quasi-reversible which require a strong monitoring mechanism for scientific management. The other category encompasses Demand side management which is user targeted and are referred as " Non – structural techniques". In demand side management the socio-economic dimension plays an important role involving managing the users of water and land. Mere regulatory interventions like water rights and permits and economic tools of water pricing etc. cannot be successful unless the different user groups are fully involved to get their cooperation and participation. For effective management of groundwater resources there is a need to create awareness amongst the different water user groups and workout area specific plans for sustainable development. Thus, groundwater management not only requires proper assessment of available resource and understanding of interconnection between surface and groundwater system but also actions required for proper resource allocation and prevention of the likely adverse effects of uncontrolled development of groundwater resources. In a nut shell the first category of management options targets policies for 'managing the water' and the second category calls for 'coordinating the people'.

GROUNDWATER MODELS – AS MANAGEMENT TOOL

With the invent of high speed computers and advancement in mathematical techniques, groundwater models have become the most sophisticated tool for the decision makers in planning and management of ground water . Whether, the management options are structural or non structural, ground water models have become inevitable. At the same time , while using the models as a management aid, we must keep in mind that models are not an end in itself, they are just one piece of a larger puzzle when we are looking at real-world problems from a systems approach angle. Hence, in true sense Systems analysis is a philosophy of problem solving, most often used with large, complex problems where decision makers collects information and uses everything available to decide what to do. Under the systems analytical approach the groundwater models can be formulated and solved in two frame work, which are well tested in solving real world problems.

A. **SIMULATION**
B. **OPTIMIZATION**

A. GROUNDWATER SIMULATION MODELS

Groundwater simulation models provide a platform to study the problems in broader perspective and resolve solutions for the optimal benefit taking into considerations the simplest and complex aspects along with economic, social and environmental aspects. A model is any device that represents an approximation of a field situation. Physical models such as laboratory sand tanks and R-C analog models simulate groundwater flow directly. A mathematical model simulates groundwater flow indirectly by means of governing equations. In the present scenario we shall be discussing mainly the mathematical models which are conceptual descriptions or approximations that describe physical systems using mathematical equations—they are not exact descriptions of physical systems or processes. The applicability or usefulness of a model depends on how closely the mathematical equations approximate the physical system being modelled. In order to evaluate the applicability or usefulness of a model, it is necessary to have a thorough understanding of the physical system and the assumptions embedded in the derivation of the mathematical equations. These equations are based on certain simplifying assumptions which typically involve: the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms, and chemical reactions. It is because of these assumptions, and the many uncertainties in the values of data required by the model, that a model must be viewed as an approximation and not an exact duplication of field conditions. The equations that describe the groundwater flow and fate of transport processes may be solved using different techniques.

Before one decides to construct a ground water model and use it as a tool for management it is always better to give an eye on the saying of Sherlock Holmes, the great philosopher that “It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts’.

Groundwater simulation models can be of different type based on the criteria adopted for classification. Based on the objectives and application of model it can of three types. Most common groundwater modeling efforts are aimed at predicting the consequences of a proposed action and are called Predictive models, which essentially requires calibration. There are, however, two other important types of applications. Models can be used in an interpretative sense to gain insight into the controlling parameters and used as a framework for studying system dynamics and or organizing field data called Interpretative Models, does not necessarily involve calibration. The RASA (Regional aquifer System Analysis) programme of USGS is the ideal example of such models. The third type is the Generic Models , used to study and analyze hypothetical hydrogeological systems, may help in formulating regional regulatory guidelines for a specific region, does not necessarily require calibration.

As we have seen that groundwater models are basically an approximation of field conditions in the form of mathematical equations, hence based upon the approach for solving these equations, it can be classified into three broad categories. The first category includes the Deterministic models (e.g. analytical models and numerical models) which are strictly based on physical laws controlling the flow or transport processes such as conservation of mass, Darcy’s law, Fick’s law etc. Deterministic models describe cause and effect relationship and generally requires solution of partial differential equations , no chance factor is involved in this. Depending upon the treatment of various aquifer parameters it could be a Lumped parameter model , which precludes the heterogeneous hydraulic properties in the model or a Distributed parameter model which allows the representation of variable system parameters.

Under the Deterministic models , the simplest is Analytical models, attempts exact solutions to equations which describe very simple flow or transport conditions and others (such as numerical models) may be approximations of equations which describe very complex conditions. Because of the simplifications inherent with analytical models, it is not possible to account for field conditions that change with time or space. This includes variations in groundwater flow rate or direction, variations in hydraulic or chemical reaction properties, changing hydraulic stresses, or complex hydrogeologic or chemical boundary conditions.

The analytical models are best used for:-

- Initial assessments where a high degree of accuracy is not needed,
- Prior to beginning field activities to aid in designing data collection,
- To check results of numerical model simulations, or
- Where field conditions support the simplifying assumptions embedded in analytical models.

The Theiss , Theims , Jacobs , Boultons method for analysis of pumping test data are good examples of analytical solutions of the radial flow equations. Similar analytical solutions are also available for different aquifers in Cartesian coordinates which provides closed form solutions between excitation and response. Under simplifying assumptions these analytical solutions are very useful tool to determine permissible level of pumpage to maintain certain minimum water level / piezometric heads and assist in decision making or to test various other management options .

When the system is complex, anisotropy is to be considered, the only choice left is to go for Numerical Models. Numerical models are capable of solving the more complex equations that describe groundwater flow and solute transport. These equations generally describe multi-dimensional groundwater flow, solute transport, and chemical reactions. In Numerical models we don't get closed form solutions, here the response is estimated at pre-selected space and time, encompasses large computational burden and numerical errors are inevitable. The commonly used numerical approaches used in practice today for solving ground water flow equations are Finite Difference Method (FDM) and Finite Element Method (FEM) , other than that some latest models also uses Method of Characteristics (MOC) as well. Each model, whether it is a simple analytical model or a complex numerical model, has applicability and usefulness in hydrogeological and remedial investigations, in spite of the simplifications inherent in the model equations. However, the selection and proper use of a model must be based on a thorough understanding of the importance of relevant flow or solute transport processes at a site, this requires proper site characterization. Proper site characterization involves the collection of site-specific data that accurately describe the movement of groundwater and disposition of solutes at the site. Without proper site characterization, it is not possible to determine whether the model equations are appropriate or to develop a reliably calibrated model. Groundwater flow and transport models are used to predict the migration pathway and concentrations of contaminants in groundwater. The accuracy of model predictions depends upon the degree of successful calibration and verification of the model simulations. Errors in the model used for predictive simulations, even though small, can result in gross errors in solutions projected forward in time. Monitoring of hydraulic heads and groundwater chemistry (performance monitoring) will be required to assess the accuracy of predictive simulations. Numerical modeling requires a complete protocol to be followed starting from establishing the purpose or objectives of modeling to conceptualization to model design to calibration, validation, predictions , sensitivity analysis and finally the post audit. One of the important aspect is the selection of proper code (modeling software) Depending upon the aquifer to be modeled and objective of the study the model can be two dimensional , fully three dimensional or quasi three dimensional. Availability of data pertaining to geometry of the aquifer, hydraulic parameters as well as prevailing boundary conditions need to be ascertained before a model is conceptualized.

Recent studies have indicated that the variables which are commonly being dealt in ground water hydrology such as hydraulic heads , transmissivity and various other aquifer parameters related in space do not behave truly in deterministic way and many a times it is very difficult to model these parameters strictly within the deterministic framework. There is a gradual shift from deterministic approach to stochastic approach which takes into account the chance factor as well as time dependency and work under probabilistic framework. Statistical or stochastic models are more commonly used in time series analysis in which the deterministic and stochastic components are treated separately. Analysis of deterministic component of time series includes

Trend , periodicities, randomness etc. Common questions related to time series are whether the time series is random or not, whether the time series is having a trend, if at all there is a trend whether it is significant or not. To answer some of these questions there are well established techniques which can be applied in the ground water as well. Some of the commonly applied techniques are listed below

- Turning point test for Randomness
- Kedall's Rank Correlation test for trend
- Linear Regression test for quantification of trend as well as for significance test.
- Harmonic analysis for periodicities.

In addition, there are established techniques used for analysis of the stochastic components of time series, which includes

- Correlogram analysis
- Spectral analysis
- Monte Carlo Simulation
- Auto Regressive (AR)Models, (Markov Chain)
- Moving Average (MA)Models
- Autoregressive Moving Average (ARMA) Models
- Autoregressive Integrated Moving Average (ARIMA) Models, etc.

The high frequency data available from the digital water level recorders may be put for time series analysis with an objective to simulate the series and as per the requirement alternate sequence may be generated as well as it can be used for forecasting purposes. It can also be used for data gap filling and record extrapolation.

Hence, we can use ground water simulation models to study the consequences of a proposed action , for predictions / and or management of ground water , we can even have the quantitative aspects of groundwater flow, changes in hydraulic head with respect to time and space, river / canal interactions and impact of various stresses on the ground water regime.

B. OPTIMIZATION MODELS

Though simulation models are very robust mathematical tool , it has certain limitations in the sense that it can basically checks for feasibility of a management strategy , it can not provide the optimal management strategy. However , an optimization model identifies an optimal management strategy from a set of feasible alternative strategies. In order to ensure that the optimal strategy is physically / hydraulically feasible , a simulation model is necessary to simulate the system behaviour. Because of mathematical complexities of involving the non linearity the present approach in ground water domain is to have separate optimization model, and testing the optimal strategy through simulation models. The same has been adopted in all the Conjunctive use projects completed by CGWB , in which the optimal conjunctive use plan was derived from Linear Programming (an optimization model) by way of optimizing the benefits or minimizing the cost. In this approach generally we get two to three cost effective scenarios , which are then tested through simulation model to arrive at the decision which scenario is most viable or optimal. Hence only simulation model do not provide sufficient alternatives for the decision makers to arrive at best solution.

In the water resources sector various optimization models are used very frequently to solve the water allocation problems. Some of the important optimization techniques used are as below

- Linear Programming
- Dynamic programming
- Integer Programming
- Non Linear programming etc.

The above models are commonly used in surface water domain, the use of optimization models alone in ground water domain is limited. In coming years, we have marched a step ahead and the combined use of simulation and optimization techniques have been demonstrated to be most powerful and useful method in determining and planning management strategies for optimal development and operation of ground water system. Simulation models can answer the question " What if " and it can simulate the responses of the system to a specified management strategy. However, an optimization model identifies an optimal management strategy from a set of feasible alternative strategies. In order to ensure that the optimal strategy is physically acceptable, a simulation model is necessary to simulate the system behaviour. The best option is to go for a combined Simulation / Optimization approach, where simulation models can be combined with the management model either by using the governing differential equations as binding constraints in the optimization model or by using a response matrix (Gorelick, 1983) or an external simulation model. In the following paragraph an attempt has been made to explain various techniques.

The goal of a formal mathematical optimization-based groundwater management model is to achieve a specified objective in the best possible manner within the various limiting restrictions. The limiting restrictions are derived from managerial considerations and physical behaviour of the system. In order to ensure that the final solution does not violate the physical laws of the system, a model simulating the behaviour and response of the system is incorporated within the management model. Once the optimization model is formulated, a suitable mathematical programming technique is applied to obtain the solution. Some of the important optimization techniques for the solution of groundwater quantity and quality management problems are discussed in the following paragraphs.

Embedding technique and response matrix approach are the two methods generally used to incorporate the simulation model within a management model (Gorelick 1983). In embedding technique, the finite difference or finite element form of the governing groundwater flow and solute transport equations are directly incorporated as part of the constraint set in a formal mathematical programming-based management model. Other physical and managerial constraints on heads, gradients, velocities or pumping/injection rates can be incorporated easily. Some of the unknown groundwater variables, i.e. hydraulic heads, source/sink rates, existing solute concentrations, solute concentrations of the source/sink at each node may become decision variables in the optimization problem. When large numbers of pumping cells are used and steady state management policies are desired, the embedding technique requires less computer memory and processing time than the response matrix approach (Peralta & Datta 1990). This conclusion may not be valid for transient cases. For nonlinear systems, the response matrix approach is not applicable and use of embedding technique becomes necessary. However, the time step used in the embedding approach for transient problems may require a larger number of variables and constraints for accuracy of the solution. In the response matrix approach, the time step used may not be an important consideration except from the management view point. In highly nonlinear problems such as those involving density dependent transport models, where the response matrix approach is not strictly applicable, a management model even for a small study area may become dimensionally large. Solving such management models using nonlinear optimization techniques, therefore, becomes difficult. Computational difficulties in using standard optimization packages for large scale problems are reported by Elango & Rouve (1980), Gorelick (1983), Tung & Koltermann (1985), Yazicigil & Rasheeduddin (1987).

The response matrix approach (Gorelick 1983) uses an external groundwater simulation model to develop unit responses. The unit response describes the influence of a unit change in an independent decision variable/design variable (such as sink/source rates) at pre-selected well locations, upon a variety of dependent variables/other design variables (such as hydraulic head, velocity, solute concentration) at specified observation points. The assembled unit responses are used to construct the response matrix, which is included in the management model. In order to generate the unit response matrix, a simulation model is solved several times each with a unit stress (pumping/recharge) or concentration loads at a single node. The response matrix approach works on the principles of superposition. It is applicable when the system is linear or approximately linear and the boundary conditions are homogeneous. For highly nonlinear systems, the performance of response matrix Optimization techniques in groundwater management approach is reported to be unsatisfactory (Rosenwald & Green 1974). Any change in boundary condition, location of the source/sink, and observation wells requires several simulations to generate the responses and also requires recalculation of the response matrix. Many researchers have reported the use of embedding technique and/or response matrix approach in conjunction with mathematical programming methods to find a solution of the groundwater management model. Application of some of the optimization models alone as well as coupled Simulation / optimization models in the ground water domain has been discussed in following paragraphs.

Application of linear programming

Linear programming (LP) techniques can be utilised for solving groundwater quantity and quality management problems when the imposed physical and managerial constraints and the objective function are linear. The capability of LP techniques to solve large-scale problems and to guarantee global optimal solutions has attracted the widespread attention of many researchers in the groundwater management field. Some of the aquifer management problems formulated and solved by using LP technique are discussed here. Alley *et al* (1976) applied LP formulation to two-dimensional transient situations in a confined heterogeneous anisotropic aquifer. In the governing differential equation, the source/sink term was expressed as the sum of specified net source/sink and unknown source/sink terms. Their objective was to maximise the hydraulic heads for a portion of the management period such that a fixed total pumping was maintained with a certain minimum pumping from a specified location, while maintaining a certain minimum head during the specified period. For the remaining portion of the management period the objective was to maximise the pumping subject to maintaining of some lower limits for the heads at the interior nodes, with restrictions on pumping at some fixed nodes. This as a different objective and thus could not be formulated as a single problem with the previous one, though these two objectives were applicable to constituent parts in the total management period. The management period was divided into small periods of intervals and solved for each of these small periods separately by using LP. The solution from the previous LP formulation was used as initial condition for the next period. Further they extended the methodology for steady state cases to study the feasibility of disposing of waste water by injection into an aquifer system. The objective was to minimise total pumping from two lines of wells subject to: (i) a reversal of hydraulic gradient towards the pumping well, (ii) maintenance of monotonicity of head values to prevent the recharged waste product from reaching a particular area, and (iii) to meet certain water demands for irrigation.

For optimal management of a coastal aquifer in southern Turkey, Hallaji & Yazicigil (1996) used LP technique. They proposed six LP models for steady state and transient state, and one quadratic optimization model for steady state management of the aquifer system. The general constraints were (i) water demand constraints, (ii) drawdown limitations, (iii) maximum pumping rate constraints, and (iv) minimum pumping rate constraints. The response matrix approach was used to obtain the drawdown limitations. However, the hydraulics of saltwater intrusion was not considered in the response matrix. The objectives considered for the steady state management were (i) maximisation of steady state water withdrawals from the existing wells, (ii) maximisation of withdrawals without any maximum limit on withdrawals from the wells, (iii) minimisation of the sum of drawdowns at pumping wells and saltwater-control nodes, and (iv) minimisation of the sum of the drawdowns at the saltwater-control nodes along the coast. The objectives for transient state management were (i) maximisation of the sum of monthly withdrawals, and (ii) minimisation of the sum of drawdowns at the pumping wells and saltwater-control nodes for all pumping periods.

Application of mixed-integer programming

Mixed-integer programming (MIP) can be used to solve optimization problems with linear objective function and linear constraints in which some of the variables can take only integer values. These types of requirements arise when dealing with groundwater management problems in which decision variables seek answers of the type yes or no, or the decision variables decide the number of installations, locations etc. In special cases all the variable may take only integer values, where the problem reduces to one of integer programming. Some example applications of MIP in groundwater management are presented in Rosenwald & Green (1974), Willis (1976). MIP has also been applied successfully in developing optimal monitoring network for groundwater quality by Meyer & Brill (1988), Datta & Dhiman (1995), Loaiciga *et al* (1992). Some of these applications of MIP for general management of groundwater quality and quantity are presented here. Rosenwald & Green (1974) developed a methodology to find the best locations for a specified number of wells. They used the branch and bound method to solve the mixed-integer programming problem and utilised a transient response matrix. Willis (1976) presented a planning model for the optimal conjunctive use of groundwater and surface water resources. As the pumping, recharges and boundary conditions were known *a priori*, the flow equations did not need to appear in the constraints. However, the flow equations needed to be solved externally to supply the velocities as fixed coefficients in the transport equation. The steady state solute transport simulation model was first formulated as a finite difference coefficient matrix. The inverse of this matrix was then computed and relevant portions were then included in the management model as constraints. The management model optimised the assimilative waste capacity of the aquifer in waste water treatment. The sum of annual cost of removal and the cost of incorporation of dilution water for all constituents were minimised. The conjunctive use model minimised the costs associated with (i) surface waste water treatment, (ii) dilution water, and (iii) waste water treatment plant. The model considered several unit processes for the waste treatment plant that involved primary, secondary, and various forms of advanced waste treatment. The solution determined the optimal unit treatment process and the most cost effective volume of imported dilution water. The resultant mixed integer programming problem was solved readily by decomposing the overall problem into individual sub-problems involving decisions on the amount of dilution water and each unit process combination. Each sub-problem minimised a concave objective function subject to a convex linear constraint set.

Recently the MIP has been successfully used in the joint study of CGWB and NIH to develop an operational model based on Simulation – Optimization model for Palla well field in the Yamuna flood plain area of , Delhi.

Application of nonlinear programming

Many groundwater planning and management models involve nonlinearities in the objective function and constraints. These nonlinearities may arise due to various causes such as (i) nonlinear cost functions, (ii) nonlinear equations governing the flow particularly for unconfined aquifers, (iii) nonlinearities in the governing equations for solute transport in groundwater, (iv) other types of nonlinear physical and managerial objective functions and constraints. These nonlinear management problems can be solved using nonlinear programming (NLP) algorithms.

Maddock(1972b) used quadratic programming with nonlinear objective function and linear constraints for managing an unconfined aquifer. He developed a nonlinear technological function for the unconfined aquifer which was used in the management model. He used mixed-integer quadratic programming to minimise the pumping costs plus fixed costs for well and pipeline construction. The quadratic portion of the objective function was made separable by a suitable transformation that facilitates the solution by a combination of mixed-integer and separable programming. Further, postoptimality sensitivity and error analysis was performed to evaluate the effects of uncertainties in economic and hydrologic factors, on the planning activities.

Gorelick *et al* (1984) presented a general modelling approach to determine the optimal design of reclamation schemes for contaminated groundwater systems. The planning model combined a nonlinear, distributed parameter groundwater flow and solute transport simulation model (SUTRA) with a nonlinear optimisation method (MINOS). They used the embedding technique. The planning model was applied for two systems. The first system involved steady-state aquifer reclamation. Contaminant withdrawal, in-ground dilution, and combined pumping/recharge strategies were considered. The second system involved transient flow and transport. Capturing a migrating contaminant plume and *in situ* dilution were the two management strategies considered.

Willis & Finney (1988) presented the planning and management model for the control of seawater intrusion in the Yun Lin regional groundwater basin. The aquifer was unconfined. The management model was formulated as a problem in optimal control. The optimal control problem was solved using (i) the influence coefficient method and quadratic programming, and (ii) the reduced gradient methods in conjunction with a quasi-Newton algorithm (MINOS). The simulation model developed by Mercer *et al* (1980a, b) was used to simulate the response of the aquifer system within the planning model. The simulation model was based on the assumptions that a sharp interface separates freshwater from seawater. Also, Dupuit's approximations were assumed to be valid. The control variables of the optimization model were the locations and magnitude of groundwater pumping/recharge. The state variables of the aquifer system were the freshwater head, saltwater head and the location of the interface toe, at the end of the planning period. The objective function minimised a weighted cost function of saltwater intrusion, water supply and recharge volume.

Finney *et al* (1992) presented the development and application of a quasi three-dimensional optimal control model for groundwater management in the Jakarta coastal aquifer basin. The movement of the freshwater–seawater interface was again based on the sharp interface assumption. The finite difference simulation model of Essaid (1990) was used to simulate the aquifer system response within the control model. The objective function of the model was a function of freshwater and seawater heads, and locations and magnitudes of groundwater pumping, or artificial recharge. The management problem was mathematically a nonlinear nonconvex programming problem with a flat response surface. They reported that MINOS was unable to differentiate between stationary points and local solutions and thus terminated with unusually large reduced gradients. Box's algorithm which is a sequential search algorithm, improved the solution generated by MINOS by approximately20%.

Application of combinatorial search algorithms

In the category of combinatorial search algorithms, two algorithms, viz. the genetic algorithm (GA) and simulated annealing (SA), have been used for groundwater management. Some recent works report the application of GA and SA for solving groundwater management problems. The genetic algorithm imitates some of the salient features of natural selection and natural genetics in order to find near-optimal solutions in a search space. The genetic algorithm operates on a population of decision variable sets. Three genetic operations, namely selection, cross over, and mutation, are applied on the initialised population to obtain an optimal solution. Simulated annealing uses the analogy between (i) the cooling and annealing process of solids, and (ii) optimisation of a multivariable function. However, this is an imperfect analogy. The five major steps of simulated annealing are: (1) representation of the possible system configuration in a concise form, (2) specification of the penalty type objective function, (3) rearrangement of the system, (4) control parameter and annealing schedule and (5) criteria for terminating the algorithm. More details on genetic algorithm and simulated annealing can be found in Goldberg (1989), Holland (1975), Kirkpatrick *et al* (1983), Press *et al* (1986), Van Laarhoven & Aarts (1987), and Aarts & Korst (1989).

Application of the Artificial Neural Networks technique

Artificial neural networks (ANN) are intended for modelling the organisational principles of the central nervous system in the hope that the biologically inspired computing capabilities of ANN will allow the cognitive and sensory tasks to be performed more easily and more satisfactorily than with conventional methods. The network architecture has three basic components, namely: (i) a weighted summer which accumulates the weighted sum of the incoming signals to a neuron from other interconnected neurons; (ii) a linear dynamic system; and a (iii) a non-dynamic nonlinear function i.e. the transfer function defining the output responses of a neuron for a given input signal. Formulation of the network is the crux in the ANN technique. Training of the network is the Next phase in the ANN technology. For training of a network in a groundwater system, several groundwater responses corresponding to the aquifer stress scenarios are used. Once an ANN is trained to imitate a particular aquifer system, it can be suitably applied for further use in optimal management of the system also. Rogers & Dowla (1994) report the use of the ANN technique for optimal groundwater remediation design.

In the joint study of CGWB with NIH which has been recently completed with an objective to develop an operational management model to optimize the pumping at Palla well field to exclude the possibility of any upcoming of brackish water underlying the fresh water aquifer in the area a Simulation / optimization (S / O) approach has been adopted. In the present approach the nonlinear , non –convex problem involving discrete (pumping locations) and continuous decision variables (pumpage) has been solved within S/O framework. It provides an accurate representation of the aquifer responses but involve high computational burden. Therefore, in the present study Artificial Neural Network (ANN) is used as a virtual simulator of a variable density driven numerical flow model aquifer simulation. Simulated Annealing , non gradient based algorithm has been used as an optimizer in this study.

DECISION SUPPORT SYSTEM (DSS) FOR PLANNING AND MANAGEMENT OF GROUND WATER RESOURCES

Decision Support Systems (DSS) are most advanced technical tool to support information needs of ground water resources management processes. DSS application may pertain to groundwater resources planning or management depending on the scope of the decisions they intend to support.

Adopting a systems approach it is always advisable to go for an integration of all relevant data and knowledge under one platform which may include an open relational databases, an interactive tool to administrate and display geographical data, an interactive graphically supported user interface and a reliable knowledge base including, for instance, different groundwater models, statistical data about recent water utilization and long term trends in the region, area wise maximum acceptable groundwater levels, etc. Such integrated system should provide tools :

- For two or three dimensional grid design
- For establishing links between the data base and the specific grid and ground water model
- To analyze model simulations,
- To display the results in comprehensive form and ,

- To control the logical sequence in ground water modeling and optimization.

Such systems which should be implemented on a graphical work station are summarized by terms such as :

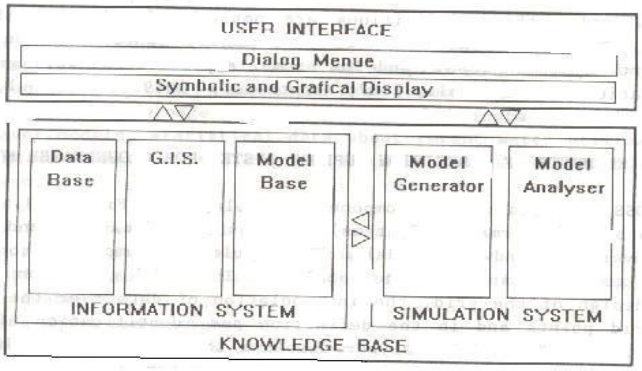
- Decision Support System
- Knowledge Based System
- Expert System

Expert system has been defined as an intelligent computer programme that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. That is, an expert system is a computer system which emulates the decision making ability of human expert. The term ‘ emulate’ means that the expert system is intended to act in all respects like a human expert. The terms expert system and knowledge based system are often used synonymously.

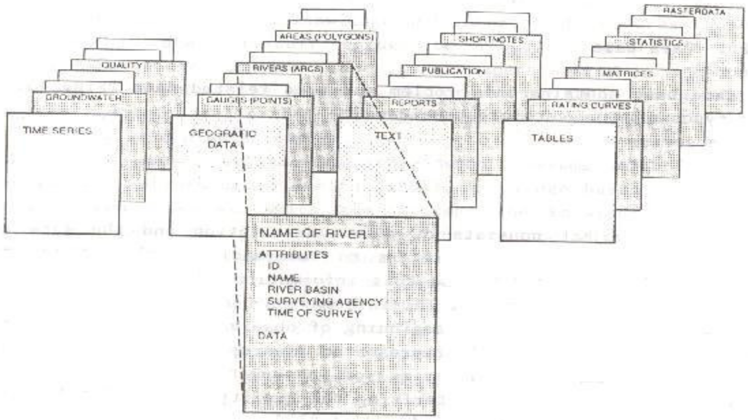
Decision Support System (DSS) support the decision making process in a complex environment by providing flexible models which can be interactively adapted to a specific problem and by providing a reliable data base which should be user friendly combined with the models. A typical DSS includes five main components: data acquisition system, user-data model interface, databases, data analysis tools, and a set of inter-linked models. The components of a typical DSS is shown in figure below.

Case Study :

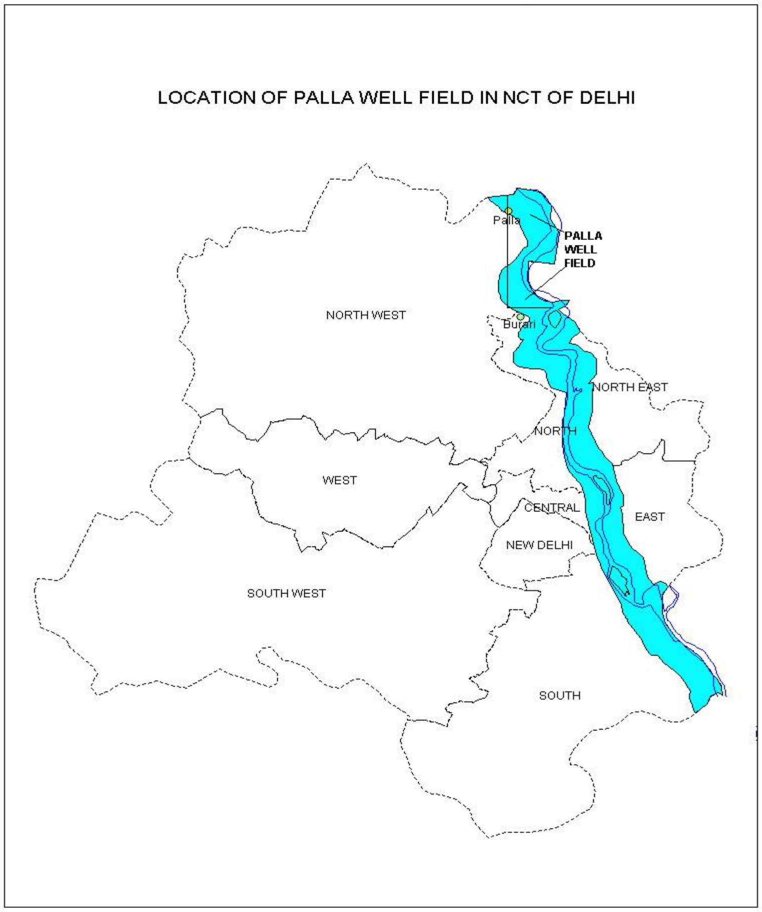
A ground water Operational Management Model was developed for the northern part of Yamuna flood plain area in Delhi (Fig.1). The area is underlain by alluvial formation, in order to augment the water supply in Delhi area , to Central Ground Water Board constructed 95 tube wells in Palla Sector in the depth range of 38-50 m for Delhi Jal Board, which is the domestic water supply agency of the Delhi area. The ground water pumping in the Pall well field offer a complex situation as the area is underlain by geologically occurring saline ground water. The amount of pumping in this case is mostly guided from water quality considerations rather than water quantity. Though the flood plain area offers good alternative for ground water development but because of underlying saline water , any over withdrawl or excess pumping may result in upconing of saline water leading to deterioration of water quality especially for drinking water needs. This may further complicate the overall saline –fresh water interface down below and cautious development of such aquifers are recommended.



Schematic diagram of the system components



Elements in the data base



Fig, 1. Location of the Palla well field in the NCT of Delhi

Keeping this in view, an attempt has been made to address the problem and develop an operational ground water management model so that optimal ground water development plan along with withdrawl schedule in space and time may be recommended to user agency. The work has been taken up jointly by CGWB and NIH. The nonlinear, non-convex problem involving discrete (pumping locations) and continuous decision variables (pumpage) has been solved within the Simulation – Optimization (S/O) framework. S/O approach provides an accurate representation of the aquifer responses but involve high computational burden. Therefore in the present study Artificial Neural Network (ANN) is used as virtual simulator of a variable density driven numerical flow model for aquifer simulation. Simulated Annealing (SA) a non – gradient based algorithm is used as an optimizer in this study.

On the basis of a Simulation Optimization model developed during the study it was concluded that nearly 30 MGD of water can be safely drawn from these tube wells during monsoon and non-monsoon seasons to augment the water supply to meet the ever increasing drinking water requirements of National Capital Territory, Delhi. The Palla well field is situated in the Yamuna river bank and during simulation, the river Yamuna has been considered as constant head boundary. After calibration of the model, the volumetric budget indicates that out of the total ground water withdrawl a part of flood water (rejected recharge) is utilized to augment sub-surface storage during monsoon. This also provides the scope for induced recharge from the river Yamuna. Hence, the storage space created during the non monsoon pumpage gets replenished during the flood season and hence the overall ground water regime situation remains under control and provides sustainability.

The experience of Yamuna flood plains in Delhi has shown the scope of enhancing ground water recharge by pumping to lower the water table ahead of the rainy season and thus creating more space for the flood water to percolate. The concept can be implemented in similar situations in different parts of the country after carrying out detailed study on the hydrodynamics of the flood plain zones involving stream-aquifer interaction.

ACKNOWLEDGMENT

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Application of Remote Sensing and Geographic Information System in Groundwater Resource Management: A Case Study from Ladakh, Jammu & Kashmir.

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INTRODUCTION

Proper management of groundwater is essential for the development of any country. Ground water is a major source of drinking water to the rural population in India. There are still, a large number of habitations in the country which are either non-covered (NC) or partially-covered (PC) due to the non availability of suitable drinking water sources. The spatio-temporal variations in rainfall and regional / local differences in geology and geomorphology have led to uneven distribution of groundwater in different regions across the country. Systematic estimation and budgeting of groundwater resource based on its spatio-temporal distribution & its allocation are required for meeting the competing demands for irrigation, industrial and domestic usage.

Groundwater study involves analysis and integration of large volume of data from various sources. Remote Sensing and GIS technology offers effective and meaningful solutions to the problem. NRSC has taken up a project to create a scientific database on ground water in the form of ground water prospects maps based on the interpretation of Indian Remote Sensing (IRS) Linear Imaging Self Scanning (LISS) III data having spatial resolution 23.5 meter with limited ground checks, in GIS environment. The database facilitates scientific source finding of ground water for all the habitations in the country besides providing necessary information for selection of sites for construction of recharge structures to improve the sustainability of drinking water sources.

The groundwater prospects hitherto are evaluated considering only the rock type, i.e., the primary porosity and permeability of the rock formations. Hence in most of the groundwater maps, rock type forms the basic unit. However, the secondary porosity and permeability contributed by fracture network and geomorphological setup also significantly controls the occurrence and movement of groundwater particularly in hard rock area. Geomorphology in terms of its topographic variations plays an important role in understanding the surface runoff and infiltration. It also influences the groundwater flow and quality to a certain extent. Then, it percolates into the ground, comprising of different rock formations having different hydrogeological properties (Sankar, 2002 and Bahuguna 2003; Rao, etal, 2001). Satellite data in conjunction with limited ground truth data provides cost & time effective accurate data on all these parameters. Similarly, GIS forms an effective tool for integration and analysis of the data on groundwater controlling parameters. Taking the advantage of the availability of satellite data and GIS technology, an innovative methodology has been developed for assessment of groundwater prospects more effectively.

ADVANTAGE OF SATELLITE DATA IN GROUNDWATER STUDY

The satellite images acquired using Remote Sensing technology provides diagnostic signatures on the parameters i.e rock types, geomorphology, geological structures and recharge conditions which control the occurrence and distribution of groundwater. Using these signatures, all these parameters can be studied and mapped accurately avoiding detailed field survey which is time taking, particularly in hilly terrains where the area is inaccessible, the satellite data is highly useful (Mather, 1987; Lillesand and Kiefer, 2004). The study of ground water demands a systematic inventory of all the details of the parameters for drawing meaningful conclusions. It is time taking to bring out all the details pertaining to the parameters by field work using conventional methods. Further, the occurrence and distribution of groundwater at a given location cannot be assessed just based on the consideration of parameters only at that location. They have to be considered in their totality.

The synoptic view of the image derived due to large area coverage, provides information about the parameters on regional scale thereby facilitating the understanding of the ground water regime as a whole. The groundwater regime is a dynamic system governed by the combination of several parameters. For the proper understanding of the system, the role of each parameter in forming the aquifer and the degree of its influence on the groundwater prospects need to be evaluated. The satellite data provides information about the parameters in an integrated form, so that, the role and influence of each parameter can be studied with respect to the other parameters there by a quick evaluation of groundwater conditions can be made. The three dimensional view provided by the satellite data facilitates to study of the terrain conditions and geomorphology more effectively.

STUDY AREA

Leh district is situated at 32° 20′ to 35° 15′ North latitude and 76° 20′ to 79° 40′ East Longitude (Figure 1). It has an area of 45100 sq. km, major part of which is rugged hilly terrain occupied by glaciers and snowfields. The elevation varies from 5900 m to 8500 m above mean sea level. Regionally, the study area forms part of a major Himalayan mountain belt comprising Proterozoic to Recent formations. The soil type is characterised by sandy soil and hilly soils.

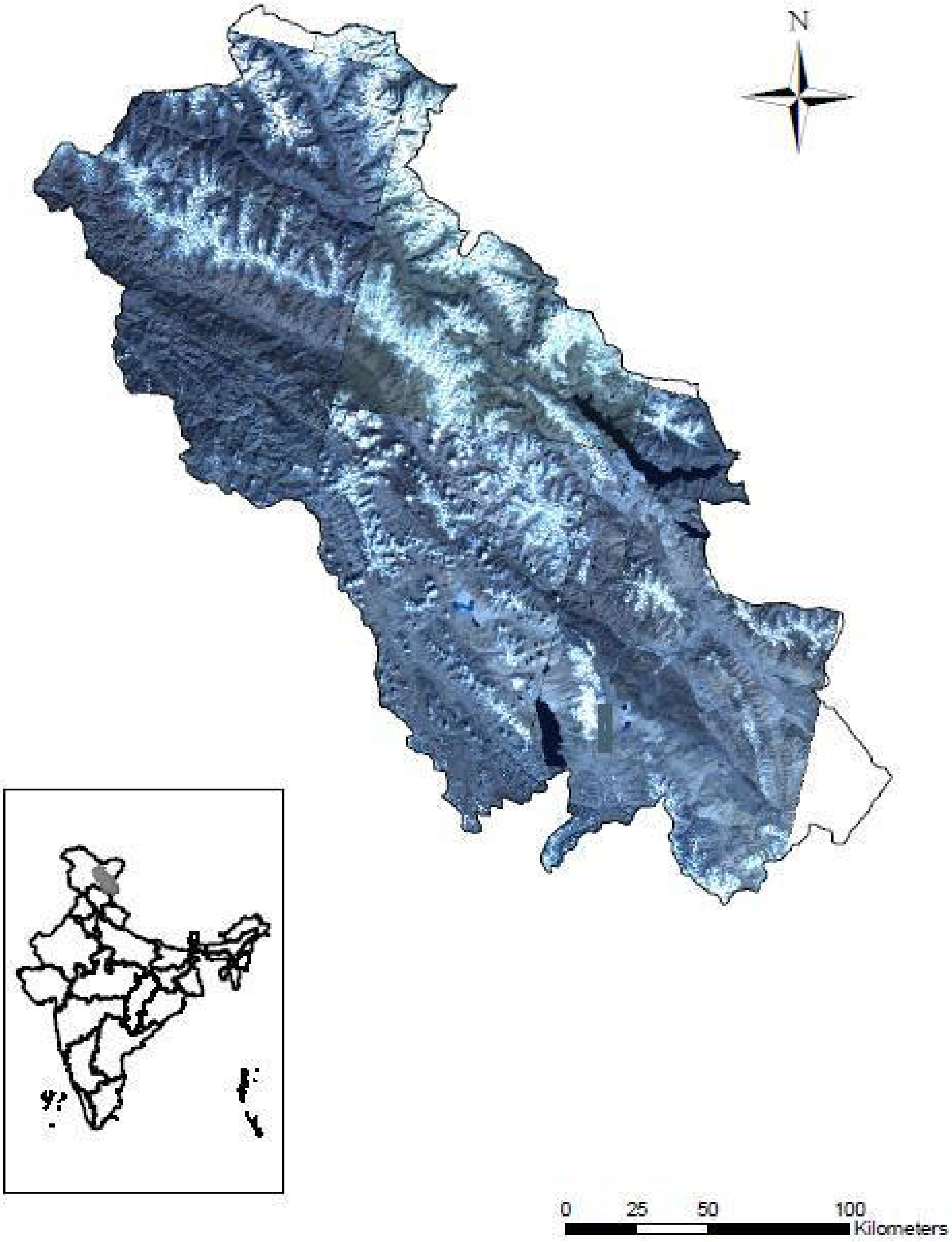

Figure 1. Location map of the study area

GEOLOGY

Geologically the area covers formations from igneous, sedimentary and metamorphic rocks of sub-recent to Proterozoic age in nature. Important among area –Nidar Ophiolites, Shyok formation,Shergol Ophiolite melange, Khardung volcanics, Ladakh Plutonic complex, Indus formation etc. The lithological map of Leh district is shown in Figure 2.

Sl No	STRATIGRAPHY	ROCK_GROUP	LITH_UNIT	ROCK_TYPE
1.	Cretaceous to Lower Eocene	Consolidated Sediments	Shale with LST/ SSt	Shale with LST/ SSt
2.	Diong Formation	Consolidated Sediments	Thick Bedded Quartzite	Thick Bedded Quartzite
3.	Dras Volcanics Nindam	Other Volcanics & Metavolcanics	Massive Basalt	Dras Volcanics
4.	Falcan,K2 Gneiss,Tangse Migmatite	Gneiss- Granitoid Complex/ Migmatite Complex	Gneiss and Migmatites	Falcan,K2 Gneiss,Tangse Migmatite
5.	Granite 500 Ma	Gneiss- Granitoid Complex	Granite	Granite 550 Ma
6.	Hundri Formation	Metamorphic Rocks	Slate	Slate
7.	Indus Formation	Consolidated Sediments	Shale with LSt	Indus Formation
8.	Jutogh Almora	Metamorphic Rocks	Undifferentiated Metasediments	Metasediments
9.	Kargil, Liyan, Kailas	Unconsolidated Sediments	Mollasses	Sst/Lst/Congl
10.	Khardung Volcanics	Volcanics & metavolcanics	Acidic Volcanics	Acidic Volcanics
11.	Ladakh Plutonic Complex	Plutonic Rocks	Basic & Ultrabasics	Ladakh plutonics
12.	Lamayuru	Semi-Consolidated Sediments	Shale with SSt	Shale with SSt
13.	Nidar Ophiolite	Other Volcanics & Metavolcanics	Ophiolite	Ophiolite
14.	Puga, Gurla Mandhata	Metamorphic Rocks	Undifferentiated Metasediments	Undifferentiated Metasediments
15	Saltoro Molasse	Semi-Consolidated Sediments	Mollasses	SSt/Lst/Conglomerate
16	Shakasgam,Gircha,Pasu (Upper Palaeozoic)	Metamorphic Rocks	Quartzite	Quartzite
17.	Shergol Ophiolitic Melange	Other Volcanics & Metavolcanics	Ophiolite	Ophiolite
18.	Shillakong	Semi-Consolidated Sediments	Limestone	Limestone
19.	Shyok Formation / Rakaposhi	Other Volcanics & Metavolcanics	Ophiolites	Ophiolites
20	Taglang La, Low grade Mansarover met	metamorphic Rocks	Low grade Metasediemts	Low grade Metasediemts
21	Triassic -Jurassic Limestone	Consolidated Sediments	Limestone	Limestone
22	Ultrabasics (Ultrabasic, Gabbro)	Plutonic Rocks	Gabbro	Gabbro

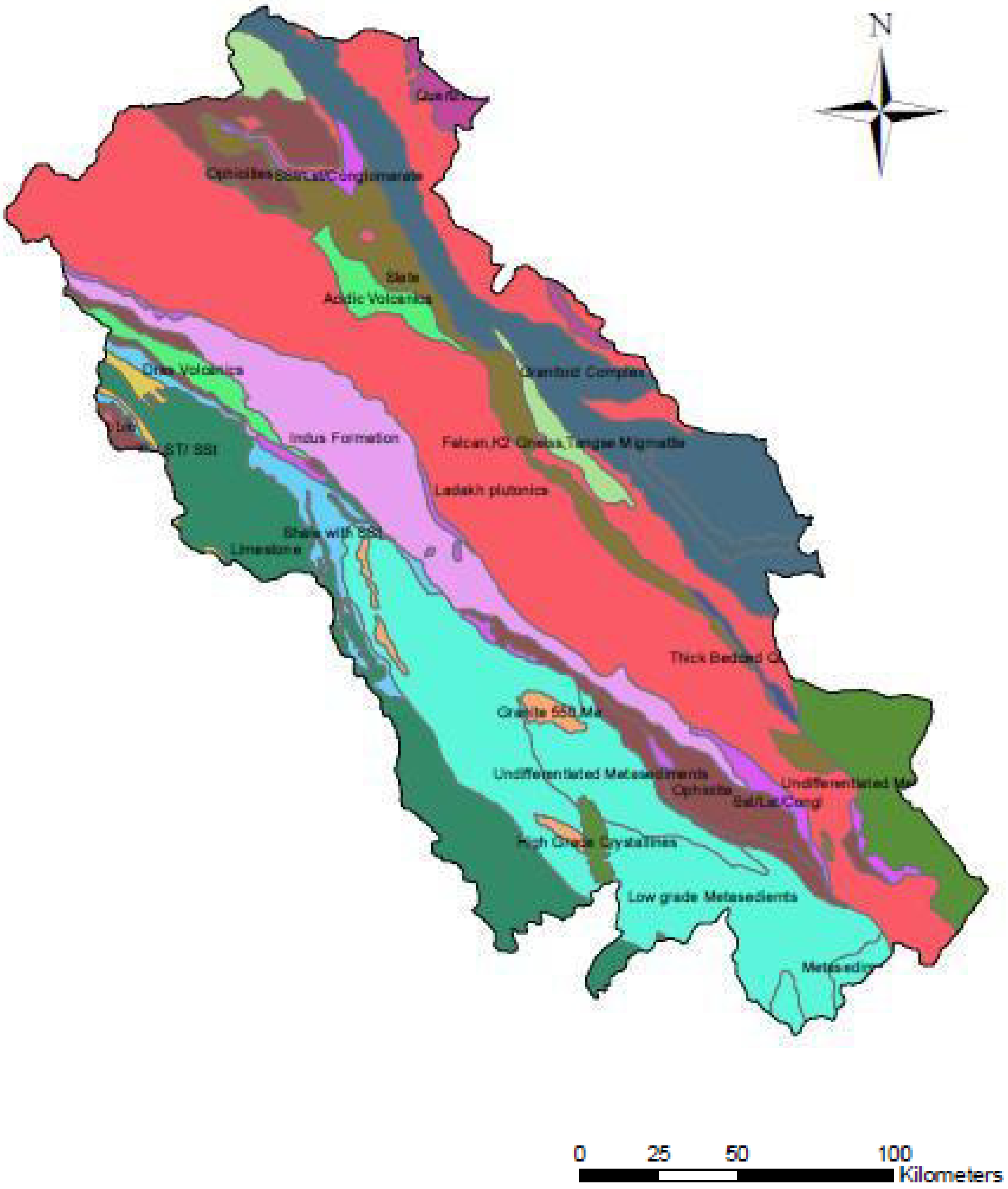

Figure 2. Lithology map of the study area

GEOMORPHOLOGY & LANDFORM

The area is very rugged and mountainous terrain with little or no vegetation. The area is occupied by glaciers and snow fields. Siachen glacier, Shyok glaciers are some of the major glaciers present in this region. Main geomorphology is the large 'U' shaped glacial valleys developed by glacial erosion and moraine deposits. Glacial outwash plains, Linear Ridges, Eolian Plain, Talus cones, Intermontane Valleys ,Valley Fills and Denudations Hills are the other landforms types in the region. Figure 3 depicts the geomorphology map of the region.

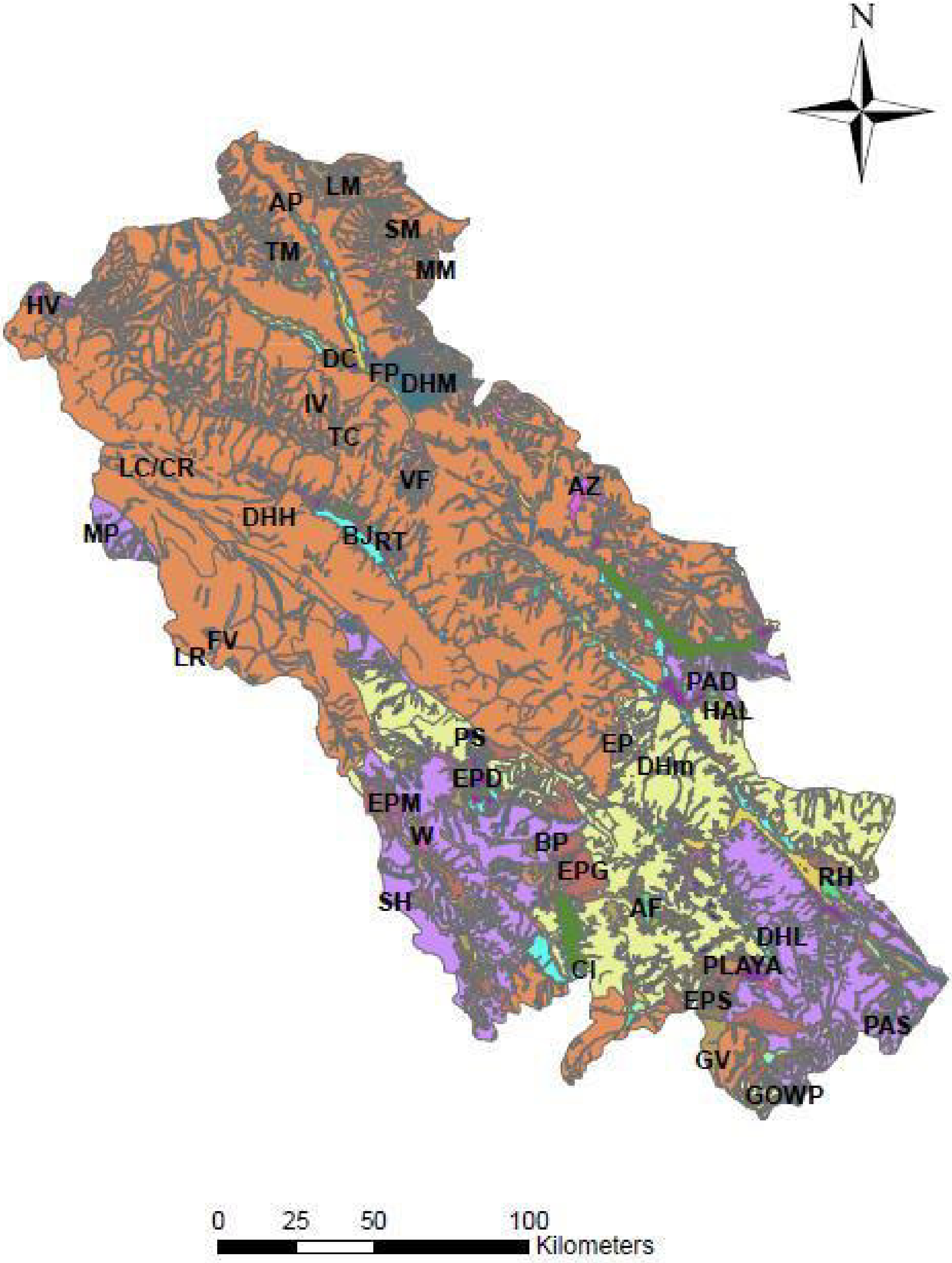

Figure 3. Geomorphology map of the study area

GEOLOGICAL STRUCTURES

The area is characterised by various major thrust systems like Indo-Tsango Suture zone. Besides these thrusts there are various lineaments and fractures present in the region. Many of the springs are located in the fault/ fracture zones. Figure 4 shows the geological structure map of the region.

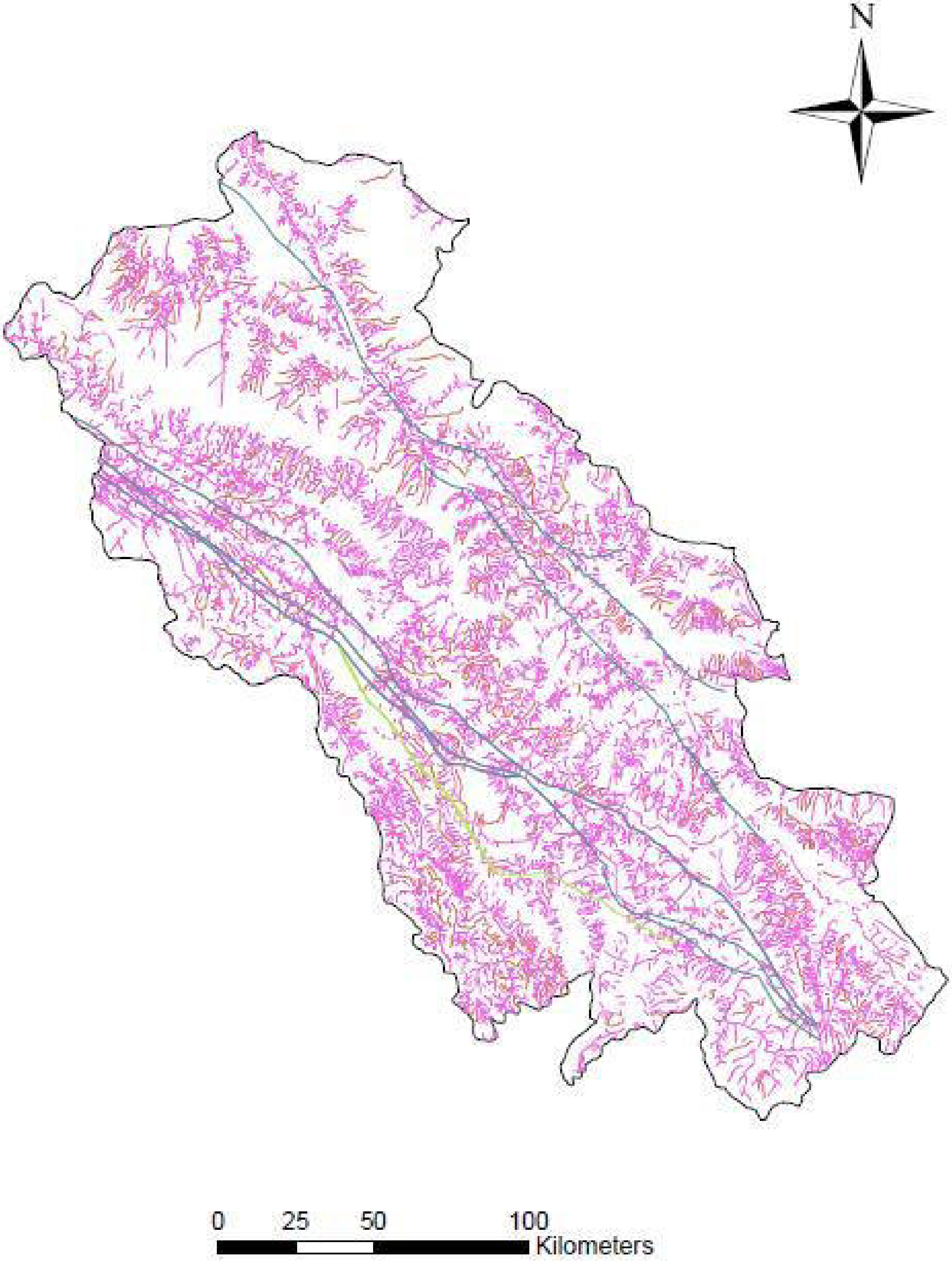

Figure 4. Geological structure map of the study area

HYDROLOGY

The region is well drained by water from snow-melt runoff and perennial rivers such as Indus,Shyok, Nubra rivers. The main source of irrigation is through canals and an area of nearly 10,000 hectares is drained through canal irrigation. Groundwater irrigation is nil in the district. The major crops are wheat, barley, pulses and fruits and all these crops are irrigated by canals. Figure 5 showing the hydrology map of the district.

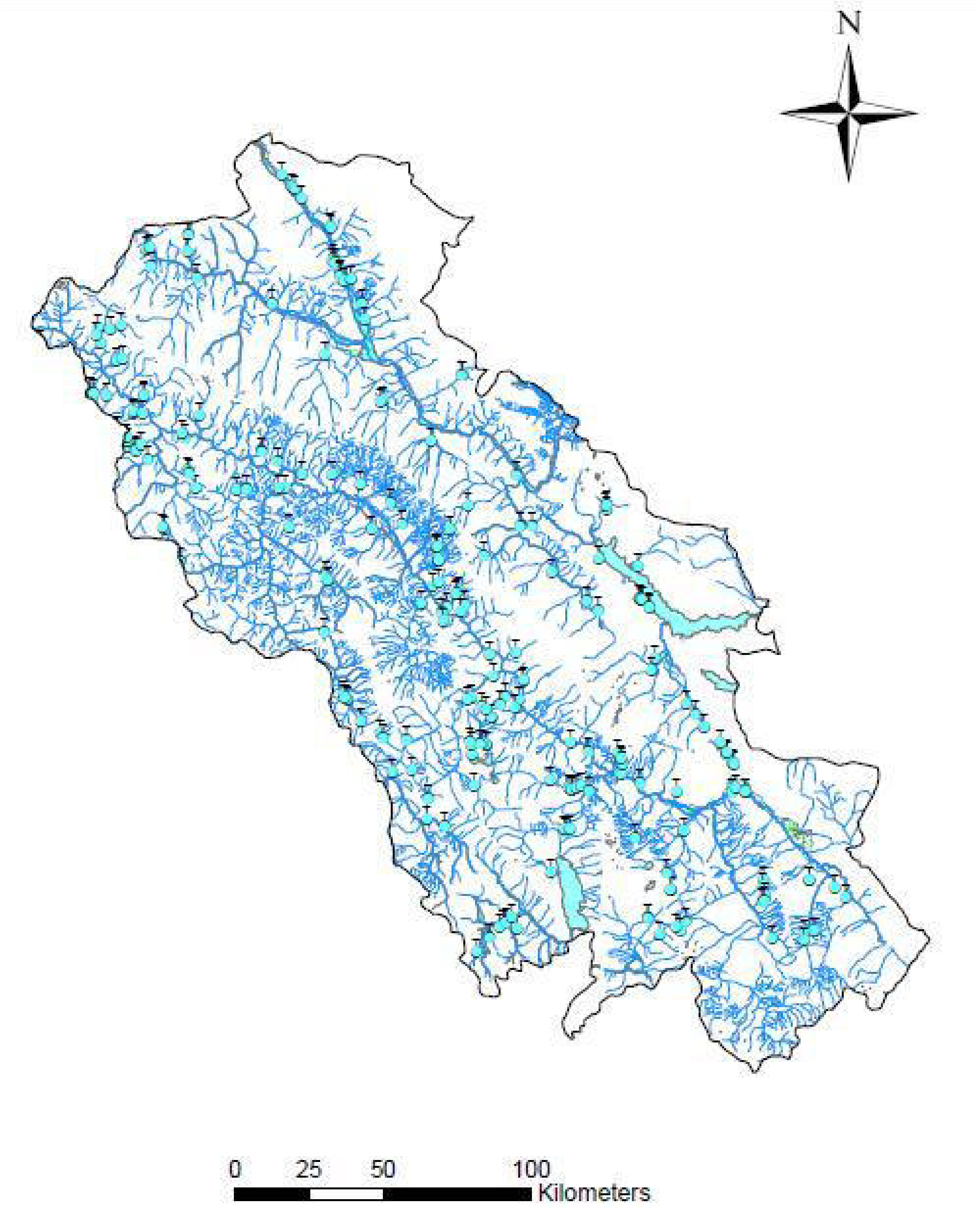

Figure 5. Hydrology map of the study area

METHODOLOGY & RESULTS

In the first step, all the above maps /layers on groundwater controlling parameters have been mapped based on the onscreen interpretation of satellite data with limited ground checks. In the second step, the data on the parameters have been integrated in GIS environment to delineate homogenous hydrogeomorphic units having unique combination of lithology, geomorphology, structure and recharge conditions. The hydrogeomorphic units are considered as aquifers for all practical purposes. Based on the weighted index overlay method considering the Hydrogeological characteristics of the parameters, the groundwater prospects are evaluated and drawn meaningful conclusions on the occurrence and distribution of groundwater. Figure 6 shows the groundwater potential map of Leh district.

Major aquifer systems in the district are consolidated sediments / hard rocks, unconsolidated sediments and recent alluvium deposits. The denudational hills with consolidated sediments having very less potential of groundwater. Many cases ground water occurs in the fractures / lineaments in the hilly terrains. The yield varies from 50 – 100 litre per minute (LPM).

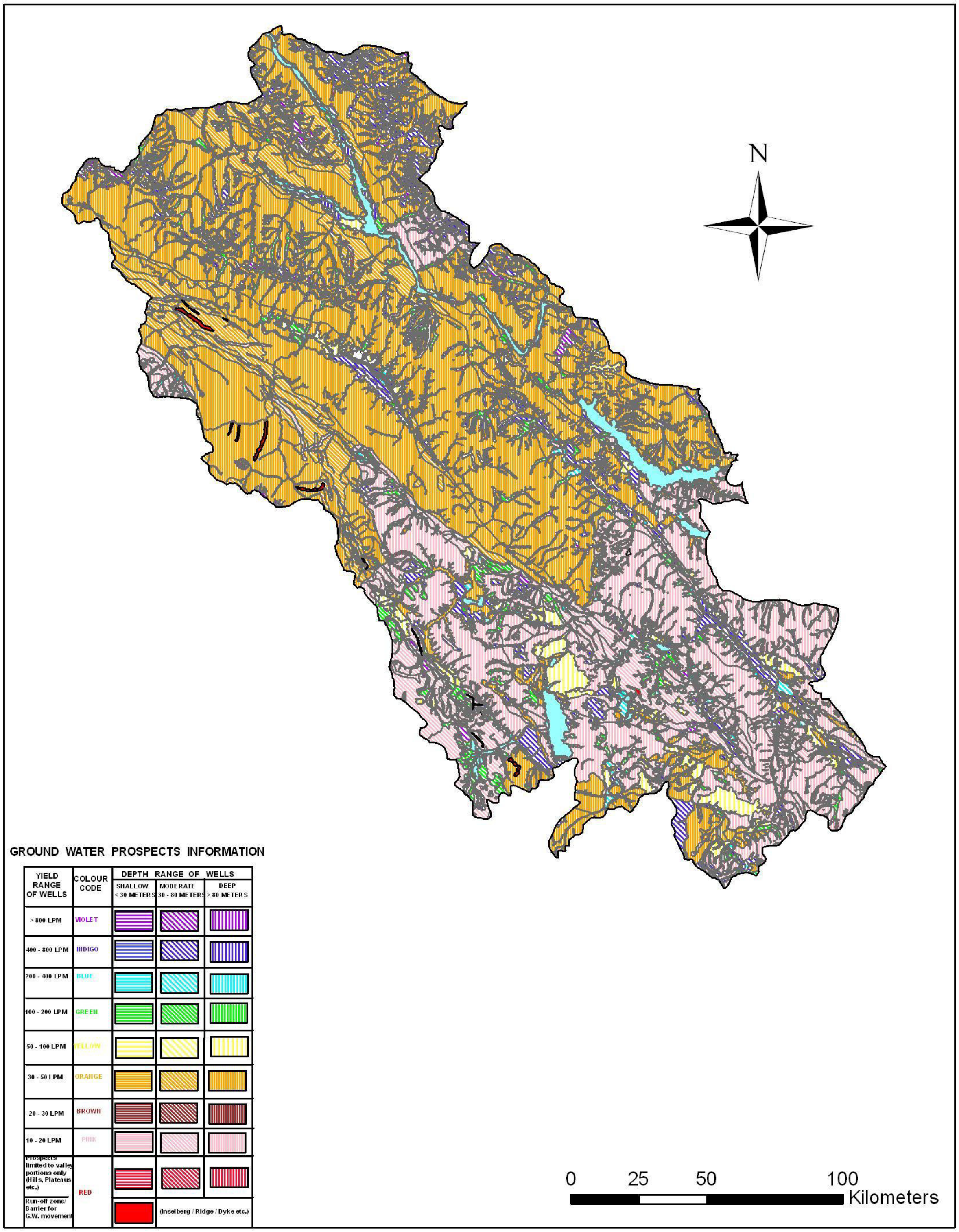

Figure 6. Groundwater potential map of the study area

Valley Fill Shallow(VFS), Talus, Glacial Valley (GV), Glacial outwash plains (GOWP) and moraine deposits constituted by unconsolidated sediments forms aquifers having moderated yield (200-400 LPM). The maximum yield of >600 LPM of groundwater is expected from the unconsolidated alluvium of river / drainage channels. Most of the habitations are located along the alluvial plains near to river channels.

Groundwater development in the district is in moderate scale and restricted to valley portions only. Many of the drinking water sources depend on the natural springs, rivers and nalas. As Leh is part of the Ladakh Cold

Desert', freezing of water is a major concern during winter season. Snow water harvesting is also an artificial recharge technique which can be adopted in the district for augmenting the water. Spring development along major fracture zones can provide more groundwater in many hilly terrains. Check dam type recharge structures are suggested along the foot hill zones for recharging the groundwater. Valley fill deposits, river terraces and moraine deposits are the highly productive zones for construction of tube wells for water supply. Due to the high elevation and snow-melt runoff hydropower generating sites can be constructed at appropriate locations and the arrested water can be used for irrigation.

RECOMMENDATIONS

- Natural springs data has to be collected and necessary spring development activities needs to be carried out.
- Snow water harvesting practices must be adopted in many areas.
- Drilling of suitable wells in moraine deposits needs to be carried out.

ACKNOWLEDGEMENTS

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Application of Remote sensing and GIS Techniques for Hydrogeological Investigations in Amarja Nala Watershed, Gulbarga District, Karnataka State, India

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ABSTRACT

Remote sensing and GIS techniques were used in hydrogeological investigations to interpret physiography, drainage, geomorphology, geology, structural pattern and land use and land cover in Amarja Nala Watershed. It is quite helpful in ground water exploration as the remotely sensed data provides a large area synoptic view with high observational density. Using geomorphological features, areas with high, medium and low potential of aquifers have been delineated. The experience shows that that the percentage of success for locating ground water using satellite imageries increased to almost 90%. As remote-sensing data provides multi-spectral, multi-resolution images with synoptic view, its use has been increasing for geology and structural mapping and other fields. The different properties of terrain features and their reflectance characteristics produce tonal expressions coupled with interpretative elements, such as tone, shape, size, drainage, texture, pattern, association and shadow etc., when used in conjunction with the existing geological maps and limited field checks. The satellite imageries help us to delineate various litho-logical units and structural features. Hence, geological, geomorphological, land use/ land cover and structural features of the area have been prepared on maps using the remotely sensed data.

INTRODUCTION

The Amarja nala is a tributary to the Bhima River of Krishna river basin, lies in between North latitudes 17° 43' 20'' - 17 ° 09' 25'' and East longitudes 76 ° 22' 00'' - 76 ° 42' 25'' falling in Survey of India toposhets nos. 56 C/6,7,8,10,11and12. It covers an area of 1508.40 sq.kms, of which 1423.40 sq.kms is within Gulbarga district of Karnataka and the rest 85.00 sq.kms, falls in the Osmanabad district of Maharastra state. The area under investigation forms a part of the semi-arid tract Climate is fair and dry. Summer begins from the end of February and ends in the month of June. Temperature ranges from 20^0C to 47^0C. The monsoon commences in June and continues till the end of October month. The area receives an average annual rainfall of 650 mm. Cold weather prevails during December and January months. The study area experiences one or other type of drought. Rainfall is erratic and wide variation in space and time is observed and The intensity of rainfall is high in the southwestern and northeastern part. The Amarja nala basin, comprised of Deccan basalts, is located between the Karanja and the Bhima rivers.

SPECTRAL SIGNATURE

Remote sensing, encompassing the study of satellite data, is a powerful technique for exploration, mapping and management of earth's' resources. The basic principle involved in remote sensing is that each object depending upon its physical characters reflects, emits and absorbs varying intensities of radiation at different EM wavelength ranges. Using information from one or more wavelength ranges it is possible to discriminate between types of ground objects (e.g. water, dry soil, wet soil, vegetation, rocks, etc.) and map their distribution on the ground. One of the important remote sensing techniques is areal photography. Aerial photography has essentially remained to be the visible part of Electro Magnetic spectrum, where it is only a very small fraction of the EM spectrum. The values of spectral characteristics over different well-defined wavelength intervals are called 'Spectral signature' of the objects by which they can be uniquely distinguished.

COMPONENTS OF REMOTE SENSING

Remote sensing involves three components viz., source of energy (transmitter), target (object of the earth) and the sensor (sensing device). Remote sensing involves transmission of Electro Magnetic Emission from source of the earth surface and its interaction with intervening atmosphere, interaction of energy with the earth's surface, transmission of reflected energy to the sensor spaced at a suitable platform, detection of energy by the sensor, converting into photographic maps, Transmission of sensor output data to recording station, processing and generation of data products, collection of ground truth and collateral data analysis and interpretation. The information obtained through remote sensing is usually represented as image either in the form of photograph (analog) or digital format. A photograph is an image formed by electromagnetic radiation detected by photo generative chemical on film.

SENSOR CHARACTERISTICS

The IRS (Indian Remote Sensing) satellites are important elements of National Resources Management System (NNRMS) and serve national goal in terms of providing continues and operational remote sensing data service for effective management of India's natural resources (NRSA, 1989). The successful launch of IRS-P2 in 1994 and IRS-1C in 1995 heralded the era of spectral remote sensing programs in our country. In the present studies IRS 1B, IRS 1C's False Color Composite (FCC), geo-coded products are used. The different spectral ranges that are applicable for identification of different natural resources are presented in Table.1.

Table.1.Different spectral range & application areas of Indian Remote Sensing satellites

Band	Spectral Range	Application areas
1	0.45 – 0.52	Coastal environmental studies (Coastal morphology and sedimentation studies) Soil vegetation differentiation Coniferous \ deciduous vegetation differentiation
2	0.52 – 0.59	Vegetation Rock\soil differentiation Turbidity and bathymetry in shallow waters
3	0.62 – 0.68	Strong charcophyll absorption leading to differentiation of plant species
4	0.77 – 0.86	Delineation of water features Landform \ geomorphic studies

VISUAL INTERPRETATION

IRS-1B satellite image on 1:50,000 scale has been subjected to visual interpretation using certain fundamental photo elements viz., color, tone, shape, texture, pattern, location and association, shadow aspects and resolution. The base map has been prepared on 1:50,000 scale, using Survey of India topo-sheets of the study area, overlaying on satellite image, using the image characteristics, the information relating to drainage, geology and structure, hydro-geomorphology, land use/land cover, have been derived. Various thematic maps are prepared by combining the natural resource information together with ground truth information and existing collected data. The maps are digitized using MAP INFO GIS, software. Conventionally, groundwater maps are prepared by manually interpolating the ground water levels. Presently, the maps are also prepared using GIS and other interpolation. In GIS and interpolation software's, the krigging is often used in interpolation method. The satellite data products used in the present study are given in the Table.2.

Table: 2 Details of Satellite products used in the present study.

Sl. No	Satellite	Path & Row	Date of pass	Product	Scale
1	Landsat	P145 R49	11.10.1989	FCC,	1:50,000
		P145 R49	10.01.1989	Geo-coded	
		P145 R49	24.10.1988	56C/6,7,8,	
		P145 R49	28.01.1988	10,11&12	-do-
2	IRS	P27 R25	25.12.1988	-do-	
	LISS 1	P27 R25	15.01.1989	-do-	
3	IRS 1A LISS II	P27 R56	3.02.1991	FCC	-do-
	IRS 1B	P27 R56			
	IRS 1C	P27 R56			

Digital Image Processing (DIP): The image processing software in remote sensing applications can be broadly grouped into as data input routines, pre-processing routines, image display routines, image enhancement and filtering routines, classification routines and out put routines. An idealized sequence for digital analysis can be broken up in to 4 specific groups- Pre-processing preparation operations- preparing satellite data for subsequent analysis. Enhancement- the enhancement operations are normally prepared on image data prior to visual interpretation effects and Data presentation.

The geographic data may be visualized map or value map (two-dimensional or three-dimensional). In the visualized map, the geographic data may be displayed in color, gray tone, as shades or as symbols. The area or raster data can be displayed in color and gray tones. Different classes or values can be assigned different colors or gray shades. For value maps e.g. elevation, soil, pH, groundwater depths etc., and the color may be assigned automatically. In the standard color schemes, the colors are assigned from blue to red and the intensity in each color changes from low to high as the values in the geographic data increase. In other schemes, the colors are assigned among violet, indigo, blue, green, yellow, orange, and red. The intensity in each color is increased with increase in the geographic data values. In the present study some of these techniques have been employed.

REMOTE SENSING IN GEOLOGY AND STRUCTURAL STUDIES.

Remote sensing studies have emerged as powerful and useful tools in geological and structural studies. Aerial photos and satellite imageries are excellent products used extensively for geology and structural mapping. Geological Survey of India has been using aerial photographs since 1967, for geological studies. National Remote Sensing Agency has started using False Color Composites (FCC) since 1973 for various natural resources applications including geology, structural mapping and hydro-geomorphological mapping.

Lithology is an important determinant in ground water potential mapping. The maps are prepared using remotely sensed data. Various rock types are very well visible on the data. It is possible to observe them due to difference in spectral signature in vegetation, erosion and pattern etc., after litho logical units are differentiated, the structural mapping is done. In the structural mapping dips, fractures and joints are mapped. Lineaments are linear features, clearly visible on the remotely sensed data. These are visible due to sudden changes in the vegetation, spectral signatures and drainage etc., It is evident that, remote sensing and GIS techniques have limited but decisive role to play in groundwater investigations since sub-surface features are manifested on the surface in a synoptic view more information is revealed. The visible and infrared techniques are more in use presently.

The details of satellite products used in the preparation of geological and structural interpretation maps of the study region are presented in the Table.2. The F.C.C products are subjected to visual interpretation techniques. The various geological and structural units are delineated and digitized using MAP INFO GIS software.

Joints are the important structural features, normally well developed in systems or groups, which are essentially linear features, which can be discernible from the satellite imageries. The strike direction of joints in the region varies between N50^{0}W to S50^{0}E. The major trend directions of joints and fractures are N45^0 W – N45^0 E, N50^{0}E-S50^{0}W and E-W directions.

Lineaments are relatively large linear features, which can be identified from remote sensing data, aerial photos, and geological and geophysical maps. Lineament studies are useful in groundwater exploration and engineering applications (Bonham & Graeme 1994). It is also defined as a large-scale linear feature, which expresses itself in terms of topography and an expression of under lying structural features like faulting, jointing, displacement and abrupt truncation of rocks. Pradeep. K.T (1998), have stated that the lineaments delineated from the remote sensing data provides important information and sub-surface features that may control the movement and storage of groundwater. Sharma (1979) is of the opinion that sub-surface permeability is a function of density of fractures and lineaments. Therefore, delineation of lineaments and their analysis especially in hard rock areas is of great importance in hydrogeological studies.

Satellite imageries are being extensively used to delineate fractures/lineaments, and their analysis for groundwater studies. The identification of dense areas of neo-tectonic lineaments and their intersections from satellite imageries are useful in exploration of fresh water zones (Bakliwal and Ramaswamy 1987). In the present study, lineaments have been delineated through visual interpretation of geo-coded FCC of IRS 1B &1C satellite imageries. The lineaments are represented in the form of strike frequency diagrams, having different trend directions and varying dimensions.

Higher lineament density lies in the area where secondary porosities like joints and fracture are mapped. In the present region of study higher density of lineaments are observed in the south and middle portion of the basin, suggesting good groundwater potential. From the lineament density map it is inferred that the area having higher density in terms of length and number of lineaments, which are associated with higher secondary porosity and are likely to yield high discharge of ground water. Thus, these maps will help to narrow down the areas for taking up geophysical investigations at micro-level.

REMOTE SENSING IN GEOMORPHOLOGICAL STUDIES

Based on geology and groundwater conditions the geomorphologic units are divided into valley fills, floodplains, moderately and shallow weathered pedeplains and denudation hills. Among these hydro-geomorphic units valley fills, floodplain units form good ground water prospect zones followed by moderately shallow weathered peneplains. Certain geomorphological features e.g. flood plains; paleochannels are very good ground water reservoirs. They are also very good locations for induced recharge. The geomorphological features can be mapped from remotely sensed data. Water is seen as blue to black in color on the FCC. The aquifers are formed in weathered and fractured zones. The fractures and faults are manifested in terms of linear features on the satellite images. River channels are oriented along these features. There may be a tonal difference in soil, vegetation/slopes/topography across which are manifested on the satellite data.

Geomorphological mapping e.g. mapping of pediments, buried pediments, valley fills and their characterization is very useful in ground water investigation. Ground truth is needed for mapping pediments. The above features have increasing order of ground water potential. The areas having ground water potential may have anomalous exuberant vegetation. Thus the study of the hydrogeomorphology using remote sensing technique has much utility in ground water studies. Hence, it has been used in the present study and it is briefly described below(Fig.1)

Residual hills are the end products of the process of pediplanation, which reduces the original mountain masses into series of scattered knolls on the pediplains (Thornbury, 1955). They occur as isolated hills with considerably small areal extent formed at lower altitudes as compared to the denudational hills. The image characteristic feature of these landforms is darker in tone, coarse in texture, mostly circular in shape, devoid of any vegetation. Due to steep slopes, most of the rainwater escapes as runoff immediately without much infiltration and hence the ground water prospects are poor in these units. Residual hills are observed in the Amarja nala watershed around Kadaganchi, Revur, Yelsngi, Nirgudi, and Allapur villages.

Pediments: Pediment is the transition zone between the hills and adjoining plains. They are better developed in semi-arid climate. The slope varies from 1 to 7^0. The pediments are shaped by erosion and transportation affected by sheet floods. The dissected pediments are subsequently smoothened by weathering and sheet floods. It is a gently sloping smooth surface of erosional bedrock with or without thin cover of detrital materials. In the present study area, pediments are developed over the basaltic terrain. On the satellite imagery these are observed with light photo tones, coarser texture, devoid of any vegetation. These are well seen around Chincholi, Kerur, Allapur, Mogha’K’ and Kadaganchi villages. In the pediment regions of the area, a yield of groundwater structures is moderate.

Pediplains: Bryon (1950) proposed the concept of pedeplanation. The pediplain is most generally used to describe a series of coalescing pediments (Thornbury, 1955). Pediplains are the products of pedeplanation. The individual landforms developed differ considerably depending upon insitu conditions such as bedrock, topography, geological structure and geomorphic process acted upon them.

In the present study area pediplains are identified based on image characteristics, like tone, texture, vegetation etc., using FCC images. Moderately weathered peneplain is a flat to gently undulating plain terrain with 5 to 10 m weathered material are covered with mixed soils. These hydro-geomorphic units are spread over most of the area. These are traversed by fractures and lineaments. In general ground water prospects are moderate to good. Good yields are expected along the fracture/ lineaments and their interconnections. Large numbers of dug-cum-bore wells are located in these units. The yields of bore wells vary from 75 to 150 lpm. Large variation in yields can be attributed to the proximity to the fracture and their interconnections. The slopes of streams vary from o to 2%.

Shallow weathered pediplains are gently sloping surface of weathered peneplain with 0 to 10 m thickness; weathered materials are covered with mixed soils. They give rise to medium to coarse texture on the satellite image. These landforms are spread over the entire basin and occupy large part of the basin. Vast area of these landforms is found to occur on either side of stream courses. Fractures and lineaments at many places truncate them. The ground water prospects are poor to moderate. Groundwater yield is in the range of 50 to 100 lpm (i.e moderately good).

Moderately weathered pediplain is a flat to gently plain terrain with 5 to 10 m-weathered zone covered with mixed soils. These hydrogeomorphic units are observed to occupy most of the area. These are traversed by fractures and lineaments. In general groundwater prospects are moderate. Good yields are expected along the fracture/lineaments and close to their inter sections. Large numbers of dug-cum-bore wells are located in these units. The yields of bore wells vary from 75 to 150 lpm. Large variation in yields can be attributed to the proximity to the fracture and their interconnections. The slopes of streams vary from 0 to 2%. Majority of the dug wells are found dry during the summer period. In general ground water quality is suitable for domestic and irrigation purposes.

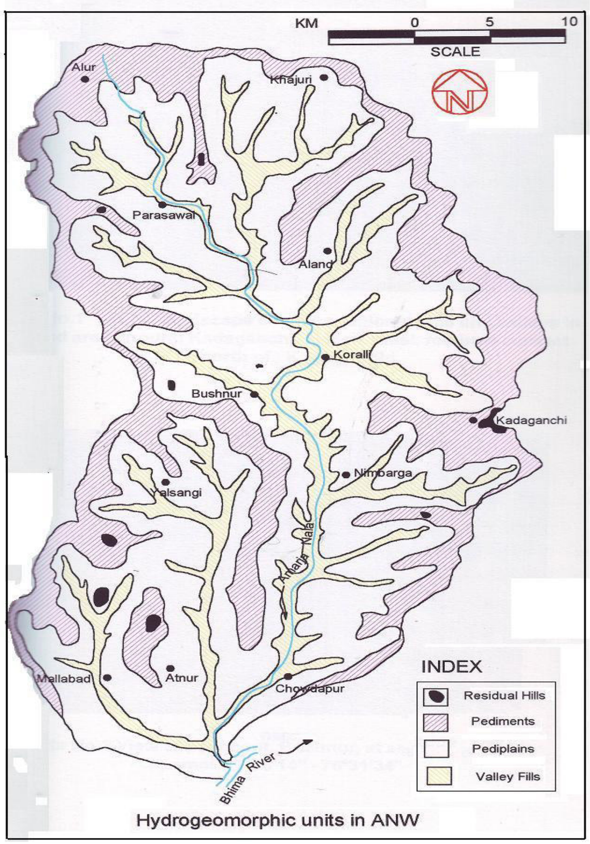

Fig.1

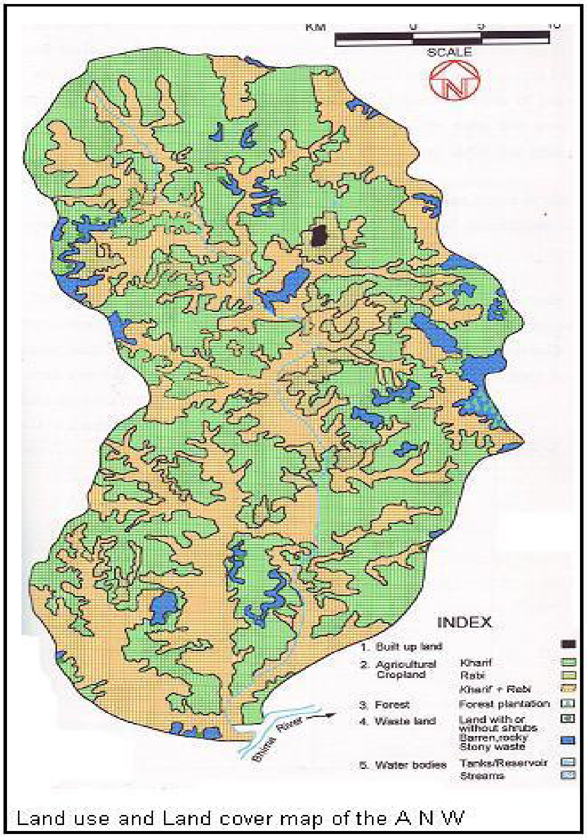

Fig.2

Deep weathered buried pediplains are flat and smooth surface of weathered pediplain, with 10 to 20 m thick weathered zone covered with black cotton soils. These units are often traversed by fracture and lineaments at many places. Ground water prospects are moderate to good. Groundwater yields are in the range of 50 to 150 lpm. These landforms are observed in the vicinity of Bhosga, Koralli, Dicksangi, Dhotargaon and Lad-Chincholi villages.

Valley Fills (VF): These landforms are observed in the fluvial domain of geomorphological set up of the area. These are mostly controlled by fractures/lineaments. They are narrow valley fill with fluvial sediments, composed of pebbles, sand, silt and clay. The thickness of valley fills range from 5 to 15 m and is predominantly observed south of Koralli. Ground water prospects are good to very good. The yields depend on the thickness of the fill and structure, fanged from 100 to 250 lpm. A large number dug wells, dug-cum-bore wells and bore wells are constructed in these areas. These areas are observed to be potential zones. Valley fills in the region are highly suitable for construction of water harvesting structures.

LAND USE \ LAND COVER

Remote sensing technology has made most significant contribution in the area of land use mapping. Data collected by different sensors over various regions of electromagnetic spectrum help in differentiating one feature from the other. Land use feature can be identified, mapped and studied on the basis of their spectral characteristics. Healthy green vegetation has considerably different characteristics in visual and near infrared regions of spectrum, whereas dry bare soil has a relatively stable reflectance in both the regions of spectrum. Thus, by using multi-spectral data different ground features can be differentiated from each other and thematic map depicting land use can be prepared with the satellite data. Land use classification not only involves mapping of the areas of a given crops or cover but also requires identification of specific crops or forest species. Higher resolution multi-temporal and multi-spectral data are ideal for this purpose.

Land use \ land cover investigations are needed for the optimal utilization and management of land resources of the region. Land use controls many hydrological processes in the water cycle e.g. infiltration, evaporation, surface runoff etc. Surface cover provides roughness to the surface. It reduces the discharge, thereby increasing the infiltration. Many classification systems have been proposed for land use classification. These maps are useful in water resources inventory, hydrological modeling and water management aspects. Thus, they are very good and cost effective source for land use mapping. These maps were prepared using remotely sensed data in the present study (Fig.2)

The characteristics of the land surface- artificial and natural soil cover are differentiated based on tone, texture, pattern, shape, and size, shadow and association. The land use classification system based on understanding the remote sensing techniques can be effectively used to complement traditional surveys for an accurate inventory of land use / land cover and has been developed under NRSA, Dept. of Space. The system is fairly compatible and has been followed by most other government departments in the country. Remote sensing can play a useful complimentary role in managing the land and water resources especially of command area to maximize the production. Multi-spectral satellite imagery in near infrared bands particularly 0.75-1.0 um range is ideal for inventorying of surface water bodies like ponds, tanks and reservoirs. Land use/land cover mapping is one of the important applications of remote sensing. Remote sensing provides excellent information with regard to spatial distribution of vegetation type and land use in less time at low cost in comparison to conventional data (Roy et al., 1973).

Land use classification: Land is one of the important natural resources and is precious asset. Many of the actions related to land and water management focus on influencing the vegetation, land use land cover. Land use refers to man’s activities and various uses, which are carried on land (Clawson & Stewart, 1965). The land use pattern depends upon the geomorphic set up of the area. The cultivable land includes the parts of ridges, slopes, and valleys. The standard classification of land includes, the net area sown, cultivable wastes, forest, current fallow land, pastures and others included under non-agricultural lands. The net area sown is important from the agricultural point of view. Agricultural land is the major economic resource has been providing sustenance to the people. It also governs the population distribution and density of the area. Though agriculture is the backbone of the economy suffers from many set backs like floods and droughts.

The Directorate of Land Records (Statistical abstract. 2001-02) has classified the State broadly in to following 5 categories viz., forests, land not available for cultivation, and other uncultivated land excluding fallow land, fallow land and net area sown. **Forests** of the land covered under forests include the natural forests of the forest area along roadside, railway tract and canal. **Land not available for cultivation:** This includes land put to non-agricultural uses, barren, and uncultivable land. **Other uncultivable land:** This excludes the fallow land and includes permanent pastures, and other grazing land, land under miscellaneous tree crops and groves not included in the net sown area and culturable waste. **Fallow land** includes fallow other than current fallow. Culturable land, which remains uncultivated during the current year are to be, termed as current fallow. **Net area sown** is the total area sown in the watershed.

The land use and land cover map of the Amarja nala watershed has been prepared using the FCC images through visual interpretation based on the classification decoded by NRSA (1989). The moderately undulating to gently sloping lands, which are chiefly used for cultivation and areas with badland topography are mostly unfit for cultivation. The study area falls in rain fed crop condition and the changes in the amount and intensity of rainfall received in a year brings considerable variation in land use. Water availability forms the chief criterion in the land use. This can be divided into seasonal surface sources and groundwater sources. Based on the availability of water, the cultivable area may be classified into monsoon cropping rain fed areas of seasonal surface sources and multi cropping cultivable areas of permanent surface water sources and ground water sources. The soils are one of the important factors in determination of land use. The nature of vegetation as well as crops grown varies.

The areas of different land use and land cover classes/types in the region are computed and presented in the Table.3 and a brief description is given below. The **built up land** under this category is not meant for agricultural purposes. Land used for human habitation covers building, transport, communication and utilities associated with water, vegetation and vacant lands. Major settlements in the study area are Aland City and other village habitations are delineated and they constitute an area of 3.08 sq.km of the total area of the watershed.

Table.3. Land use \ Land cover in Amarja Nala Watershed.

S. No	Land use/ Land cover	Area (Sq. kms)	% of the area
1	Built up land	46.37	3.08
2	Agricultural land		
	a. Kharif	1440.63	95.51
	b. Rabi		
	c. Kharif & Rabi		
3	Forest	4.10	0.27
4	Waste lands		
	a. Land with or without scrub	7.40	0.49
	b. Barren rocky lands		
5	Water bodies	9.83	0.65
	Tanks\reservoirs		
		------------------	------------------
	Total	1508.33	100

The agricultural land primarily used for farming and for production of food and other commercial and horticultural crops. It includes irrigated and non-irrigated cropland, fallow and plantations. It covers an area of 1440.63 sq.km and constitutes 95.51% of the study area, which includes the following. **Kharif non-irrigated** croplands are associated with rainfed crops under dry land farming with limited irrigational facilities. Crops like bajra, jawar, grams, groundnut, and cotton are grown. This is the major land use in the area**. Double-cropped** areas are the lands with assured irrigation facilities in the form of surface and groundwater. It covers an area of 780 sq.km of the watershed and accounts for 53%. They spread over the entire area mostly along the stream courses and fracture zones valley fills and flood plain areas. Major part of the double/ cropped area are irrigated by the ground water through dug wells, dug cum bore wells and bore well and mostly confined to valley fills, flood plains and along the stream courses, which have less than 2% slope.

Forests covers negligible areal extent, constitute an area of 4.10 sq.km. The **wasteland includes** land with or without scrub, covers an area of 7.4 sq.km. These are mostly confined to foothills and upland areas. They are usually associated with steep slops. These lands often support grasses and scrub and account for 0.49 % i.e. about 7.4 sq.km. A number of **water bodies** (tanks) with varying sizes and are present in the study occupy 9.83 sq.km. Most of the tanks rarely get filled up and are dry during summer seasons. They are mostly minor irrigation tanks; contribute to subsurface water in the form of recharge. A good number of dug wells, dug-cum-bore wells and bore wells are located on the down streamside of tank bunds.

YIELD OF ABSTRACTION STRUCTURES

The success rate of wells located in valley fills and floodplains is promising. The percentage of success is also high in areas falling in moderately weathered zones. The success rate of wells located in the pediment zones is very less and yields are relatively low. In the moderately weathered pediplain, the yield variation is quite significant. Only those bore wells, which are associated with lineaments, are more successful. The relation of well yields with lineaments, drainage and slope were studied

Yield and lineaments: It is interesting to compare well yields with the presence of lineaments. The distribution of wells with respect to lineaments (intersection on the lineament, near the lineament, away\ absence of lineament) studied. The bore wells associated with lineaments and intersections are successful with high yields of 200 to 400 lpm. Bore wells that are not associated with any lineaments (in recharge areas) are dry or yield is less than 75 lpm.

Drainage and yield: Amarja nala watershed is the 6^{th} order river micro basin. The distribution of wells with respect to stream orders and well yields are studied. Wells, which are associated with Ist order streams show low yields in the range of 5 to 20 lpm. It is seen that wells located near higher order streams are more successful due to their large catchments.

Yield and slope: The basin has been classified into 7 classes and their areal extent as well as well yields has been studied. First category of 0 to 1 % slope accounts for 65% of the total basin area, followed by very gently sloped class. It is clear from the figure the steep slope areas are associated with low yields. However, it is a fact that in various geomorphic units' presence of lineaments is the major controlling factors for variation in the yields of wells observed. Well yield is good in the valley areas.

Well yield and Electrical resistivity: Well yields were compared with vertical resistivity sounding data. Higher resistivities of more than 100 ohm/m are a characteristic feature of hard and massive rocks. The top layer is a soil cover with resistivity between 10 - 30 ohm\m. This is followed by a weathered layer having resistivity ranging between 20 - 80 ohm\m. Water saturated fractured\weathered zones are found to have resistivity varying between 20 - 80 ohm/m. Red-bole beds are characterized by varying resistivity. Resistivity range between 30 - 50 ohm\m are found to be associated with productive zones. Remarkable decrease in water yield is observed with increase in resistivity of fractured zones.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

The demarcation of potential zones using Remote Sensing data and GIS, gives valuable results (Krishna Murthy & Sreenivasa,1995). The manual on GIS for the planners and decision-makers explains that GIS allows the handling and manipulation of data in both spatial and non-spatial format. The power of GIS is in organization of spatial data information system and orients them towards decision-making or resource management. All of these are based on the concept of an emerging discipline, "spatial science". GIS is used as a tool for integrating large and different data types and it is enhancing our capability to manipulate and analyze this information for planning and decision-making. Ground water occurrence in any region mainly depends on litho logy, structure, topography and precipitation. Because of complex nature of groundwater occurrence and movement, it needs an integrated approach (Krishna Murthy & Sreenivasa,1995).

GIS has been one of the powerful techniques in assessing the suitability of land. Remote sensing and Geographical Information System could be effectively used in mapping, monitoring and management of natural resources (Ramachandran, et.al. 1998). In the present study, GIS technique has been utilized for the delineation of ground water potential zones by integrating thematic layers.

CONCLUSIONS

1. Landfills are quite narrow, mostly observed south of Koralli and cover negligible areal extent.
2. Forest covers just 4% of the geographical area, represents far below the national average of 21%.
3. Higher density of lineaments are observed in south and middle portion of the basin, suggesting good groundwater potential around these regions.
4. The strike direction of joints in the region varies between $N45^0W-S45^0E$, $N50^0E-S50^0W$ and E-W directions.
5. Four major geomorphic units are identified viz., Residual hills, Pediments, Pediplains and Valley fills, of which pediments and pediplains occupy 80% of the total geographical area and have yield range of 50 to 100 lpm.
6. Valley fills are structurally controlled geomorphic units and are composed of pebbles, sand, silt and clay are mostly suitable for large dia wells.
7. Double cropped area covers 53% of total geographical area of the watershed, mostly irrigated by dug wells, bore wells and dug-cum-bore wells.
8. Surface water bodies cover less than 1% of total geographical area. Thus recharge from these water bodies are limited.
9. Residual hills \ resistant ridges are low groundwater potential zones, because in these regions runoff is more when compared to infiltration.
10. Agriculture land covers 95.5%, where as built up land covers only 3.08% of total geographical area.
11. Thus the satellite data used in the study is to be of useful in delineating hydrogeomorphic units and lineaments and to demarcate groundwater potential zones.

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Application of Remote Sensing in Water Quality and Water Resources Management – An Overview

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ABSTRACT

Remote Sensing, coupled with Geographic Information System (GIS), is a powerful tool for monitoring of water quality and water pollution. Satellite imageries have been used successfully in determination of various water quality parameters like Total Suspended Solids, turbidity, chlorophyll content, colour, temperature etc. by using the Visible, Reflected Infrared and occasionally Thermal Infrared bands of the Electro Magnetic Spectrum. Remote Sensing techniques have been used in sustainable management of water resources, which include runoff and hydrological modeling, flood management, watershed management, drought management and management of Irrigation Command Areas. Satellite imageries obtained from Landsat Thematic Mapper (TM), Linear Imaging and Self Scanning (LISS) and Wide Field Sensor (WiFS) have been used extensively by various workers for calculation of drainage basin area, drainage density, Normalized Difference Vegetation Index (NDVI) and Leaf Water Content Index (LWCI). Application of Remote Sensing in flood management, drought management and Irrigation Command Area management were demonstrated in India by a number of researchers from time to time. Typical applications include mapping of active flood plains, long-range weather forecasting, estimation of crop acreage and crop production and preparation of “irrigability maps” through land use planning.

Keywords: Water Quality, Runoff and Hydrological Modelling, Watershed Management, Flood Management, Drought Management, Irrigation Command Area Management

INTRODUCTION

Sustainable management of the available water resource is a challenging task for the new millennium. As stated by the World Water Council, “There is a water crisis today. But the crisis is not having too little water to satisfy our needs. It is crisis of managing water so badly that billions of people and the environment – suffer badly” (World Water Council, 2000). Remote Sensing techniques have been used effectively in integrated development and management of water resources of India (Balakrishnan, 1986).

Water has very low spectral reflectance in the visible part of the Electro Magnetic Region (EMR) whereas snow or ice has very high spectral reflectance in visible and near infrared (NIR) part of the EMR. Pure water absorbs nearly all incident energy in both the near infrared and middle infrared (MIR) wavelengths. The low reflectance of water in visible and NIR band has advantage in Remote Sensing as water becomes clearly distinguishable from either vegetation or soil cover throughout the reflective infrared portion.

Total Radiance (R_t) recorded by a Remote Sensing system over a water body is a function of the electromagnetic energy and is given by the equation:

$$R_t = R_p + R_s + R_v + R_b$$

where, R_p = Atmospheric Path Radiance
R_s = Free-surface Layer Reflectance
R_v = Subsurface Volumetric Reflectance
R_b = Bottom Reflectance

In situ Spectroradiometer measurement of clear water with various levels of clayey and silty soil as suspended sediment shows that the reflectance peak shifts towards longer wavelengths as more suspended sediment is added to the water. Strong *chlorophyll a* absorption of blue light is observed between wavelengths of 400 and 500 nm and strong *chlorophyll a* absorption of red light is observed at approximately 675 nm (Lillesand and Kiefer, 2000).

Application of visual and digital Remote Sensing techniques and integration of the remotely sensed data in specific layers through the Geographic Information System (GIS) are used by scientists in management of water resources and prediction of natural water related hazards like flood and drought. Visual Remote Sensing has been extensively used in detection of water pollution, lake eutrophication assessment and estimation of flood damage. The technique of visual image interpretation can be used in variety of ways to help monitor water quantity, quality and geographic distribution of water resources (Lillesand and Kiefer, 2000). In the present paper, various methods of application of Remote Sensing in water quality and water resources management are discussed.

WATER QUALITY

The term water quality is generally used to describe whether or not water is suitable for a specific use and whether or not the surrounding environment is endangered by pollutants in the water. Till the middle of the twentieth century, modern economic development largely ignored considerations of water quality, with the result that an inverse relationship has been created between development and water quality. Water quality that is unacceptable to the biota is usually designated as polluted water. Water pollution can be categorized into (a) point source pollution in which effluents discharge through pipes and open channels from industrial and human habitat and (b) non-point source pollution (or diffuse pollution) which normally occurs from storm water runoff. Urban, industrial and rural areas are also part of the non-point source pollution in addition to open areas.

The sources of pollution are varied and are often unpredictable, both in time and in magnitude. Remote Sensing has an important role in water quality evaluation and formulation of management strategies, particularly in the case of non-point source pollution. The advantages of Remote Sensing like synoptic coverage, near real time data base generation and availability of multispectral, hyper spectral and multi temporal data, can be used effectively for water quality assessment and monitoring. Nevertheless, the use of Remote Sensing is limited to surface measurements of turbidity, suspended sediment, chlorophyll, eutrophication and temperature, although experiments to determine various other water quality parameters have been carried out in the past.

REMOTE SENSING AND WATER QUALITY

Spectral properties of water vary with wavelength of incident radiation not only due to the molecular structure, but also due to impurities present in the water body. Hence, Remote Sensing for mapping or monitoring water quality becomes quite complex. The water surface behaves as a partially diffused and partially specular reflector. Specular reflection is uniform at all wavelengths, but absorption and back scatter produce distinctive spectral signature or spectral response pattern. Solar energy that is not specularly reflected is reflected downward into the water body. This refracted energy is either absorbed or get scattered. The remaining signal is indicative of water quality, which is volumetric reflectance or back scattered energy caused by the material in water. In case of deep water, where the bottom reflectance is negligible, the reflectance comes from the surface of water body. However, for shallow water, the total reflectance is a function of both surface and bottom reflectance.

Spectral signature (or Spectral Response Pattern) of water is dependent on a number of factors viz. time of the year, sun elevation angle, aerosol and molecular content of atmosphere, water vapour content of the atmosphere, specular reflection of skylight from water surface, roughness of water surface, water colour and content of dissolved coloured material in water, characteristics of water surface (film, foam, debris or floating plant), reflectance and absorbance characteristics of suspended particles, multiple reflections and scattering of solar energy in water, depth of water and reflectance of bottom sediment, submerged or emerged vegetation and turbidity of water.

Physical characteristics of water quality can be ascertained thorough satellite imagery (Moore, 1977). Visible and infrared (reflected) parts of the EMR are most favourable for monitoring of water quality. Thermal Infrared (TIR) is also used occasionally for measuring water quality parameters but the method uses a direct measurement of emitted energy. Microwave region of the EMR is not very useful for water quality assessment due to its limited penetration depth. However, it is useful for detecting oil slicks, oil spills or other surface contamination.

In order to monitor water quality through Remote Sensing, the relationship between water quality parameters and spectral reflectance must be determined. As the reflectance changes with the modified value of water quality parameters, an empirical formula may be used. However, the formula may not be valid in multi temporal domain as the type of constituents in water may not remain constant. Sun elevation angle and atmospheric composition change with time and will affect the relationship between water quality parameter and spectral reflectance.

Multispectral mapping of seagrass has been done where bottom details in clear, calm ocean water have been mapped with penetration of about 20 m between the wavelengths of 0.48 to 0.60 µm using Landsat TM data (Smith and Jensen, 1998). A limitation of this method is that although blue wavelengths have the maximum penetration, extensive scattering occurs resulting in an "underwater haze". Penetration of only a few metres was obtained using the red wavelength.

Application of Remote Sensing, in most cases, is limited to determination of only a few water quality indicators (Engman et al., 1991). A summary of water quality parameters and the type of Remote Sensing technique useful for water quality monitoring is given in *Table 1.*

Table 1. Remote Sensing Techniques in Water Quality Monitoring

Sl. No.	Water Quality/Water Pollution Parameter	Remote Sensing Technique Employed	Remarks
1.	Total Suspended Solids (TSS)	Visible spectral region of EMR	Reflectance increases with the increase in sediment concentration, empirical relationships could be established for TSS estimation.
2.	Temperature	Thermal Infrared and Passive Microwave regions of the EMR	Infrared radiometers (in 8-14 µm region) based on Aircraft/Satellite can be used to estimate temperature of water body; the characteristics of temperature change depends upon nature of pollutants and effluents.
3.	Agricultural Runoff	B&W and Colour Infrared (CIR) photography	Change in vegetation can be identified and monitored through CIR; B&W IR imagery can also be used to identify the source of agricultural pollution.
4.	Eutrophication of Lakes	Colour Infrared (CIR) photography	Monitoring of floating algae identification and delineation of potential areas of algal blooms are possible with CIR image. Water transparency, colour, chlorophyll, algal blooms and aquatic vegetation of lake eutrophication can be monitored.
5.	Oil Pollution	Ultraviolet (UV) photography Thermal Infrared (TIR) Scanners Passive Microwave Sensors	Good weather condition and low altitude aerial survey is required to monitor oil pollution, limited to day time monitoring. All weather, day and night capability. All weather, day and night capability.
6.	Water Depth	Blue/Green portion of visible spectrum Aerial photogrammetric methods LASER Profile technique (LIDAR)	In clear water, blue light penetrates up to 15-20 m and green light penetrates up to 1-2 m Measures of parallax in stereopair photographs with at least three reference targets LIDAR systems can be used to measure accurate profile of water depths.
7.	Municipal and Industrial Discharge (Effluents)	Satellite/Airborne TIR imagery	Temperature difference between the effluents and the water (in which the effluent is discharged) can be identified and monitored as dispersal pattern of Effluent Plumes.
8.	Colour/Material Insolation	LASER Spectrometers	May not be possible to detect through satellite imagery; ground based LASER Spectrometers can be used for identification of chemical composition of the solution/water.

REMOTE SENSING IN WATER RESOURCES MANAGEMENT

Remote Sensing techniques have been used extensively in the past for various applications in the management of global water resource. A summary of such applications in various scientific investigations is given below:

Runoff and Hydrological Modelling

Although it is not possible to directly measure surface runoff by Remote Sensing techniques, they can be used in research areas like (a) determining watershed geometry, drainage network and other map-type information for distributed hydrologic models and for determining empirical flood peak, annual runoff or low flow equations and (b) providing input data like soil moisture or delineated land use classes, which are used for determining runoff co-efficient.

Remotely sensed data, particularly Landsat, Thematic Mapper (TM), Système Pour l'Observation de la Terre (SPOT), MLA data and Indian Remote Sensing Satellite (IRS) data has been used for calculation of drainage basin area and stream network density. Quantitative geomorphic information has been extracted from analysis of Landsat imagery (Haralick et al., 1985).

Remote Sensing can provide attribute data of suitable spatial resolution, which is extremely valuable as model inputs. Panchromatic stereo imagery from IRS-1C and IRS-1D can be used to develop a Digital Elevation Model (DEM) with horizontal resolution of 5.8 m whereas Cartosat-1 panchromatic data can be used with horizontal resolution of 2.5 m. A new technology, known as Interferometric Synthetic Aperture Radar (InSAR) has been used to demonstrate similar horizontal resolution and about 2 m of vertical resolution (Zebker et al., 1992).

Distributed hydrologic models require information on spatial land use. Most of the research on hydrological modeling using Remote Sensing has involved the Soil Conservation Service (SCS) Runoff Curve Number Model (USDA, 1972). Hydrologic Engineering Center (HEC-1) model was used to demonstrate the efficacy of using Remote Sensing for re-computation of hydrologic variables. HEC-1 model was used in integrating detailed land use data from Landsat TM, which resulted in 90% cost cuts in upgrading dams and spillways constructed on Sable River, Australia (Mettel et al., 1994). Distributed Hydrologic Modeling was done in the USA where a Group Response Unit based on interpretation of satellite data was evoked (Kouwen et al., 1993). Hydrological modeling and GIS has been used in similar studies in small watersheds in India (Hari Prasad et al., 1997).

GIS techniques can be used to integrate spatial data forms like topography and soil maps with hydrologic variables like rainfall distribution or soil moisture. The impact of land use change on Mosel River Basin, USA was quantified by using hydrologically similar units by DEM data, soil maps and satellite based land use data. The satellite data was also used to determine Normalized Difference Vegetation Index (NDVI) and Leaf Water Content Index (LWCI), which were combined to delineate areas where a subsurface supply of water is available to vegetation (Ott et al., 1991, Schultz, 1993, Schultz et al., 2000).

Flood Management

India is one of the most disaster prone geographical zones in the world. It has been estimated that a loss worth more than $300 million (about Rupees 1500 Crore) was incurred annually as a result of damage caused by flood and cyclone in India. In the list of worst flood affected countries, India stands second after Bangladesh (Agarwal and Narain, 1991) and accounts for one fifth of global death count due to floods. It has been estimated that about 40 million hectare (Mha) or nearly one eighth of India’s geographical area is flood prone.

In every aspect of flood management like preparedness, prevention and relief, space technology has made substantial contribution. Information acquired through Remote Sensing covers wide area, periodicity and spectral characteristics and is especially useful in comparing data before and after the flood. The utility of satellite Remote Sensing has been demonstrated operationally for mapping flood inundated areas. Major floods and cyclones that occurred in India were mapped in near real time and information was provided to concerned agencies. Partially cloud free data was acquired, analysed and interpreted in near real time by IRS series satellites. IRS-1C, IRS-1D, IRS-P6, Cartosat-1, Cartosat-2, Radarsat and Earth Resource Satellite (ERS) were used and are being used for flood inundation mapping, estimation of flood damage and infrastructure loss.

Watershed Management

Watershed management is an integral part of any water resources project. The prioritization of a watershed is based on calculation of sediment yield potential so that treatment of the watershed would result in minimizing sediment load into the river or a reservoir. Remote Sensing techniques have been used in a distributed parameter watershed model (Leavesley et al., 1990). Satellite data has been used extensively in many watersheds in India like Jurala (Krishna River Basin), Asan (Yamuna River Basin), Ukai (Tapi River Basin) etc. for deriving the parameters of the Sediment Yield Index (SYI) Model to provide quantitative silt load estimates in watersheds developed by the All India Soil and Land Use Survey, Ministry of Agriculture, Government of India.

Space borne multi spectral data has been used to generate baseline information on various natural resources like soil, forest cover, surface water, groundwater and land use/land cover. Subsequent integration of such information with slope and socio-economic data in a GIS has resulted in generation of location specific management plan for sustainable development of land and water resources within a watershed. A national level project entitled Integrated Mission for Sustainable Development (IMSD) was undertaken by the Department of Space, Government of India, which has covered an area of about 84 Mha spread over 175 districts in India. Implementation of rain water harvesting in selected watersheds under the project has demonstrated the benefits by way of increased recharge to groundwater and agricultural development of once barren areas.

Drought Management

The socio-economic life of millions of people is being affected every year by drought, which is one of the worst natural disasters. Due to the highly non uniform distribution of monsoon showers in both space and time, drought has become a menace over many parts of India. It has been estimated that out of the net sown area of 140 Mha, 68% is vulnerable to drought conditions and about 50% of the drought prone area is classified as “Severe” where frequency of drought is bi-annual or less (Rao, 1999).

Timely and reliable information about the onset of drought, its extent, intensity, duration and impact can limit drought related loss of life, minimize human suffering and reduce damage to the economy and environment. Remote Sensing data from geostationary and polar orbiting weather satellites like Indian National Satellite (INSAT), National Oceanic and Atmospheric Administration (NOAA) and other global data are used as major inputs in rainfall predictions ranging from long-term seasonal predictions through medium range predictions to short-term predictions. Vegetation Index derived from satellite imageries are now being used continuously to monitor drought conditions on near real time basis.

National Remote Sensing Centre, Department of Space has introduced a National Agricultural Drought Assessment and Monitoring System (NADAMS), through which early warning is provided on expected yield from major crops at district level by the end of August. The information is updated by the end of September and October with improved accuracy based on the relationship between total crop growth profile and crop yield. The NADAMS uses daily data from NOAA Advanced Very High Resolution Radiometer having 1.1 km horizontal resolution and IRS Wide Field Scanner having 188 m horizontal resolution. The high resolution data of bi-weekly or monthly Vegetation Index is used by NADAMS, which provides periodic bulletins and detailed reports to the user agencies. Crop Acreage and Production Estimate (CAPE) programme is operational at district level for providing production forecast before harvest from major crops in winter season. IRS-1D data having high spatial resolution and ground based meteorological data are used for forecasting of winter crop production under the CAPE programme.

Irrigation Command Area Management

A major factor in increasing agricultural production is development of irrigation practices, which in turn is essential for economic development of the country. In most of the Irrigation Command Areas (ICA) in India, the present scenario demands a more efficient water management programme. The ICAs in India suffer from problems of inadequate and unreliable water supply, wide gap between created and utilized irrigation potential, temporal imbalances of water demand and supply, excessive seepage loss and rise of groundwater table leading to water logging and salinity problems.

Remote Sensing techniques can be immensely helpful in inventory of irrigated land, identification of crop types, crop extent, crop condition and estimation of crop yield, as demonstrated in various investigations in India and in other countries. Periodic satellite monitoring of Irrigation Command Areas has helped in evaluating increase in irrigation utilization and improvement in agricultural productivity over a period of time. Remote Sensing methods have been successfully applied in delineating saline and alkaline soils and detecting areas having ineffective water management practices leading to decrease in crop yield. Remote Sensing techniques are now increasingly applied in land use planning and in identifying areas suitable for sustained irrigated cropping with the help of "irrigability maps" prepared from satellite data. Vegetation Indices and demand-supply analysis is used in many Irrigation Command Areas in India to evaluate irrigation potential.

Remote Sensing techniques have been successfully applied for performance evaluation of Mahi Right Bank Canal command with an area of 212,000 ha in Gujarat State (Ray et al., 2002). During this study, IRS-1C Linear Imaging and Self Scanning-III (LISS-III) and Wide Field Sensor (WiFS) data were used for calculation of Adequacy Index, Equity Index and Water Use Efficiency (WUE) for characterization of the Irrigation Command Area. The multi-temporal Remote Sensing data was finally used for crop inventory, generation of vegetation spectral index profiles and estimation of crop evapotranspiration.

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Groundwater management in Palla well field of Delhi using numerical modelling technique - a case study.

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ABSTRACT

The Palla well field of Delhi is a model of sustainable groundwater development and management practices. A battery of ninety tubewells extracts around 25-30 MGD (41-49 million m^3/day) of groundwater to augment drinking water needs of Delhi. The groundwater management policy for groundwater abstraction from the well field was based on a numerical modeling study. The paper explains details of numerical modeling study and critically examines the model. It suggests for updating of the numerical model used for formulating groundwater management policy in the Palla well field of Delhi.

INTRODUCTION

The NCT of Delhi has perennial deficit of drinking water, mainly attributed to the ever increasing population of Delhi. The drinking water deficit in Delhi can be partially augmented by developing the potential aquifers. The aquifers in Yamuna flood plain of NCT Delhi is most promising aquifer for development of the groundwater resources. Palla area (Fig.1) lies in the part of the flood plain of river Yamuna and nearly ninety tubewells were constructed there for augmenting drinking water supply to NCT Delhi. The Yamuna flood plain aquifers in Palla area has considerable freshwater thickness in range of 35 to more than 65 meters. The Yamuna river in this stretch has no visible major drains joining it as such it is pollution free, or else there are nearly 19 drains joining river Yamuna downstream. The active flood plain in the area is totally agricultural land and it gets flooded during post monsoon inundation by river Yamuna leading to natural recharge to subsurface aquifers by surface spreading methods during peak post monsoon floods.

HYDROGEOLOGY

The Yamuna flood plain of Palla area has younger alluvium overlying older alluvium. The younger alluvium comprises of medium to coarse sand admixed with silt, clay and heterogeneously coloured gravels (Fig.2 and Fig.3). They have been classified as unconfined aquifers (Shekhar and Prasad 2009; Shekhar 2006; Rao et al 2007). While the older alluvium is composed of finer sediments having clay admixed with silt and kankar (calcareous concretions). The saline water is mostly restricted to older alluvium. The depth to water level in the area is found in the range of 5 m below ground level. The transmissivity of the younger alluvium is in the range of 600-2000 m^2/day, while transmissivity of the older alluvium is in the range of 130-403 m^2/day (Shekhar et al 2009, Chatterjee et al 2009). The Specific yield of the aquifer is in the range of 0.2. The average discharge from individual tubewells in the Palla area was in the range of 0.5 MGD (0.82 million m^3/day) and as such it was expected to have around 45 MGD (74 million m^3/day) of groundwater discharge from a battery of 90 tubewells in Palla area. The quality of groundwater from the battery of tubewells was well within the desirable limit set for drinking water.

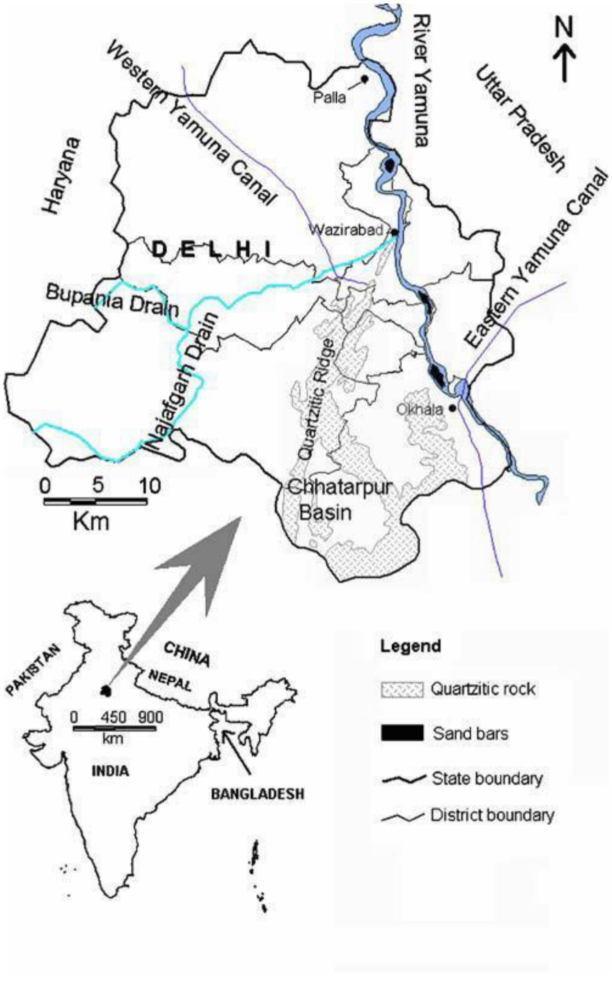

Fig.1 Location of the Palla area

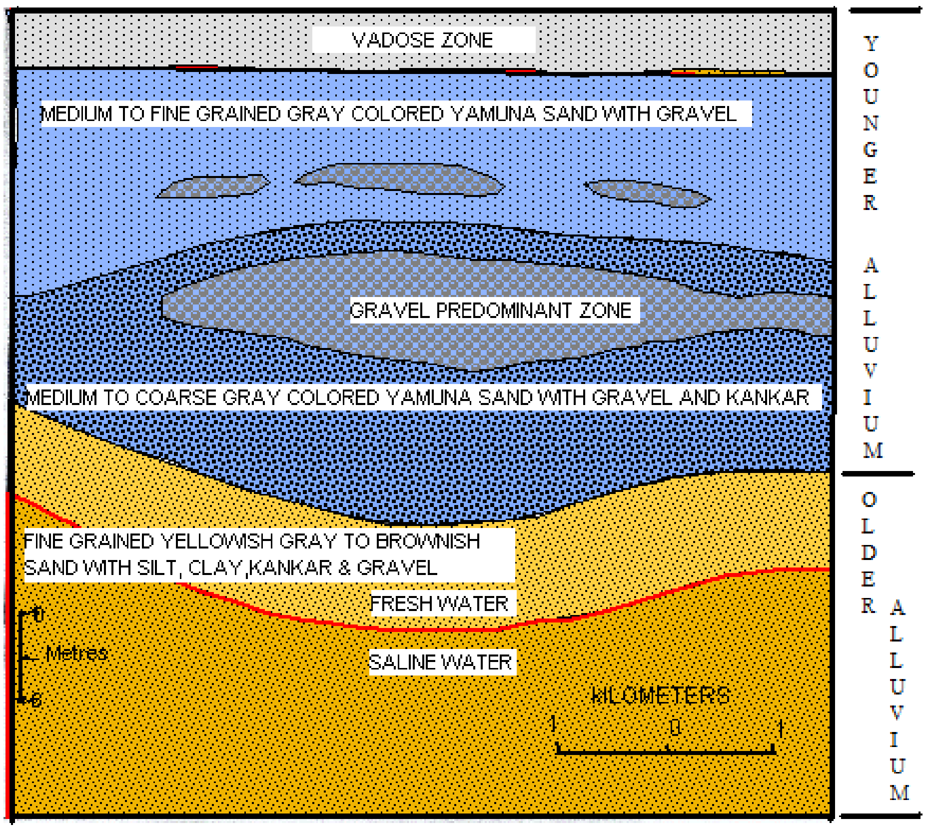

Fig.2 Transverse subsurface cross section of the Palla area near southern end (Shekhar and Prasad (2009).

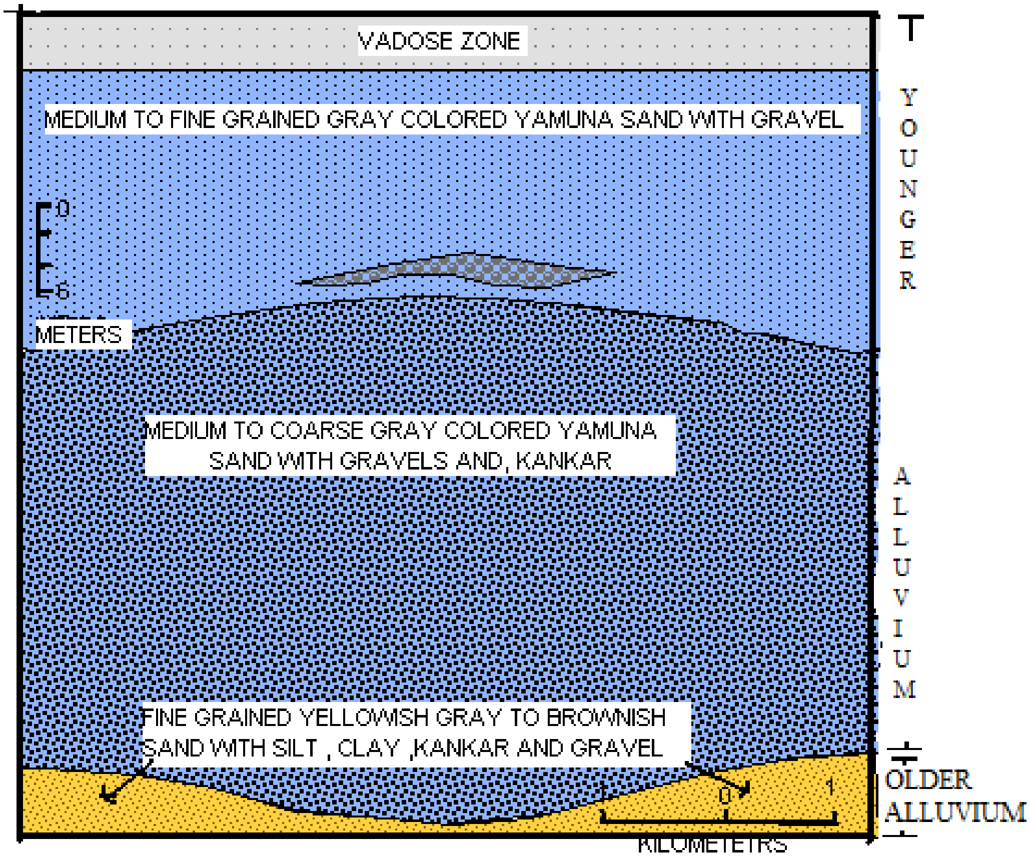

Fig.3 Transverse subsurface cross section of the Palla area near northern end.

THE GROUNDWATER MODELING IN THE PALLA AREA

The production from the Palla well field tubewells raised many issues which needed to be addressed scientifically. Some of the issues raised by different stake holders are listed below:

1. Such high density of tubwells will lead to very high discharge from a very small area, which may lead to saline water up coning from the lower saline aquifers.
2. The shallow tubewells of the farmers in the area will become non functional by lowering of the water table during peak discharge period
3. The heavy withdrawal of groundwater from close vicinity of the river will alter the river flow, which may be in contradiction to the river water sharing agreement between the riparian states.

The above raised issues could not be addressed by analytical solutions or numerical techniques. It required that a system simulation and numerical modeling study be done and the issues addressed in right perspective. In this perspective a collaborative project between NIH Roorkee and Central Ground Water Board was formulated. The project had time span of one year to finish the work on priority basis. It was decided by the project investigators that the first model of the area should address the issue of saline water up coning and suggest optimal pumping schedule to control saline water up coning and see that water level lowering during peak demand period does not affects the shallow tubewells of the farmers. The issue of stream aquifer interaction was not the main objective in the model, though a subjective quantification on stream aquifer interaction would always be a product of any such modeling exercise. This was decided primarily because the rivers cross sections, time series river gauge and discharge data and other hydrological data related to the river Yamuna was not available. In order to overcome the data limitation, the Yamuna stretch in the model area was surveyed locally to provide the minimum necessary data for the numerical modeling exercise. Thus it was agreed that the stream aquifer interaction produced by such models will not be very accurate but a subjective figure. In the context of very short duration of time available for the study, the project investigators agreed that only spatial model calibration will be done and temporal calibration of the model with water level hydrograph at the groundwater monitoring stations in the model area will be taken up later, during subsequent study on the issue.

The model area:

The area of interest was only a small area in the flood plain where these battery of tubewells were installed, but due to unavailability of suitable boundary conditions, the model area was extended further in west to coincide with the western Yamuna canal which in turn coincided with hydraulic boundary (Fig.3 and Fig.4). It was decided that a telescopic mess refinement will be done for the area of interest and thus regional to local approach of numerical modeling was adopted.

The model structure:

A seven layer model was designed with 53 rows and 99 columns with grid spacing in X and Y direction as 250 meter for the regional model. The surface topography was superimposed on the top layer. The spacing in the z direction varied from 10-25 meters. A no flow boundary was set at around 85-100 meter below ground level in the seventh layer.

The input and output stresses:

The input stress was uniform rainfall recharge of 0.1 meter per monsoon season and recharge of 0.3 to 0.5 meters from the flood water during the floods (Rao et al 2007) and the output stress was the groundwater discharge figures extrapolated from CGWB report Chatterjee et al (2006) subsequently published in paper Chatterjee et al (2009), the groundwater extraction figures in the area of interest was further verified by well inventory in field.

The aquifer parameters in the model:

The modeling exercise was started with the aquifer parameters established by aquifer performance tests in field, and the concept paper of the study Rao et al (2006a) had taken the hydraulic conductivity of the formation in X and Y direction as 45 m/day and in Z direction as 4.5 m/day. It was felt during the course of modeling exercise that the aquifer parameters were not giving realistic results; hence inverse modeling approach was used to derive the appropriate aquifer parameter values. The aquifer parameters ultimately used in the model (Rao et 2007) considered the aquifer heterogeneity and assumed hydraulic conductivity of

20 m/day in the first layer of the model, and hydraulic conductivity of 9.8 m/day in x and y direction and 1 m/day in Z direction in the remaining layers of the model. The specific yield was assumed as 0.2.

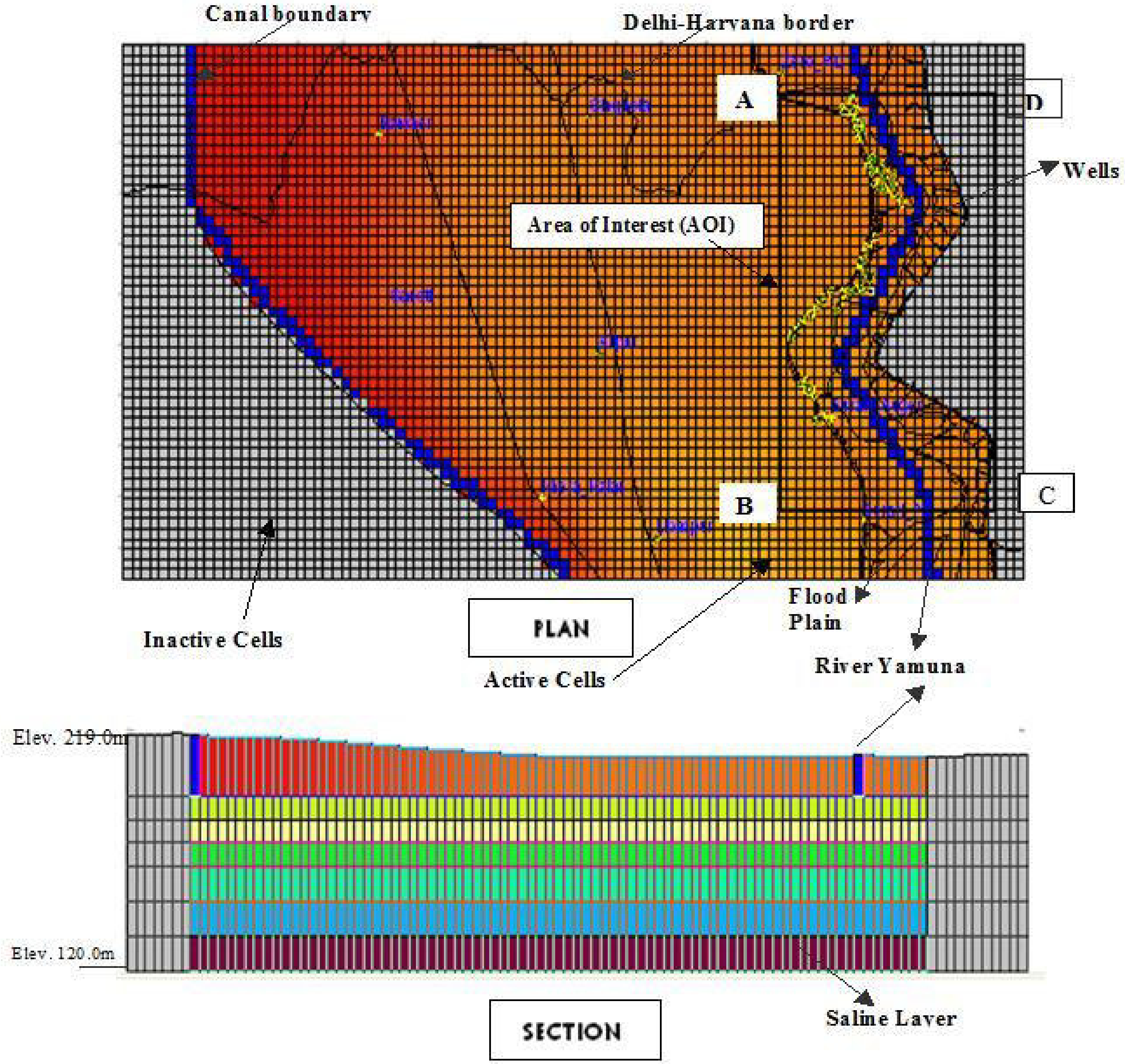

Fig.3 Plan and cross section of seven layer Palla Regional Model and area of interest (Rao et al 2006b)

The Model outputs:

The model generated heads were contoured and matched with contour of the water table heads observed on regional scale and then different scenarios were created (Fig.4). The model output was optimized to see the relationship between salinity and total groundwater draft from the well field (Fig.5).

The model suggested optimum pumping schedule from the Palla group of tubewells to control the possibility of saline water up coning. It was suggested that the Palla well field can sustainably supply 25-30 MGD (41-49 million m^3/day) of drinking water by staggering pumping in space and time. This meets 20% of Delhi's drinking water deficit. It was also established that the Palla well field seeks to pump groundwater that is seasonally recharged by floodwaters in the flood plains and from the river boundary. The water quantity pumped through the Palla well field has approximately 40% contribution from rainfall and induced flood recharge, 38%

contribution from river boundary recharge and 22% contribution from aquifer storage. It can be said that the Palla well field pumping creates additional subsurface storage space. If the abstraction does not create a space for absorbing the flood recharge, the flood recharge water would invariably join the river boundary or can create water logging conditions. Thus the Palla Well field helps in utilizing flood recharge more efficiently.

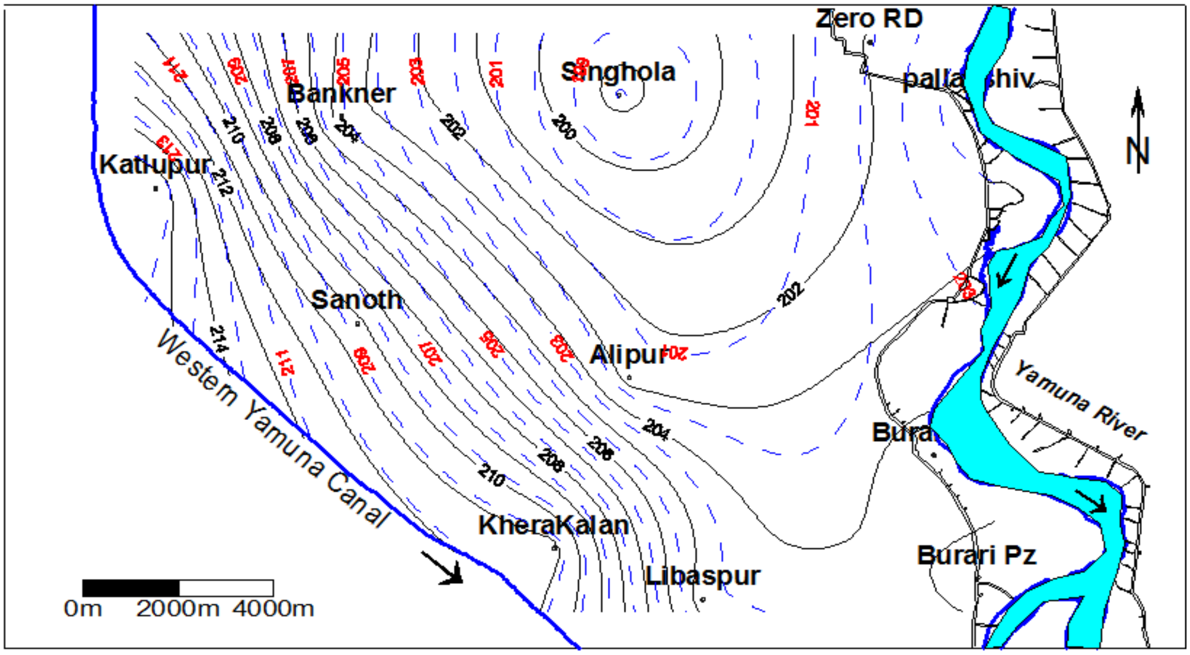

Fig.4 Observed (continuous line) and Simulated (dashed line) contours of groundwater levels in first layer beginning monsoon season, year 2004 (Rao et al. 2006b).

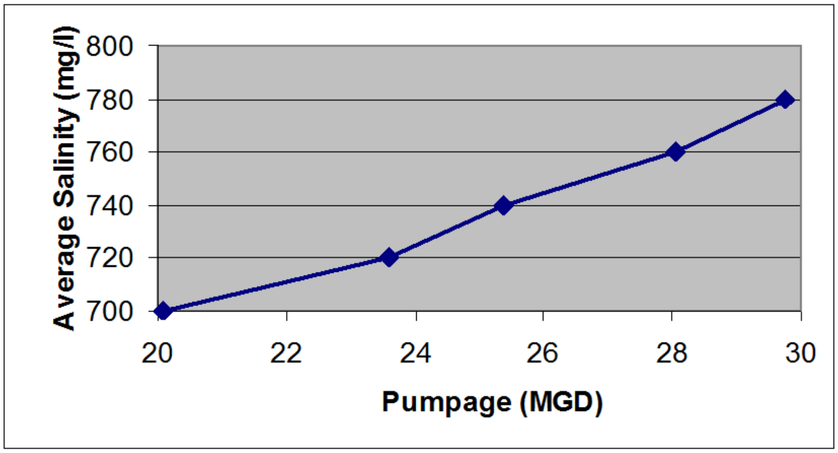

Fig.5 Relationship between total groundwater withdrawal and salinity (Rao et al 2006b)

DISCUSSIONS

The groundwater model produced by the collaboration between NIH Roorkee and CGWB published in Rao et al 2007 needs to be updated. As mentioned earlier, the model had only spatial calibration, thus it is required to have temporal calibration with water level hydrographs over a period of time. The model also needs to be updated by incorporating time series hydrological data related to river Yamuna and western Yamuna Canal. It is suggested to incorporate salinity gradient data collected from the aquifers in the area in to the model to the extent possible. The input stress in the Palla model published in Rao et al 2007 included recharge by flood waters during the flood. It is suggested to have an assessment of surface spreading of the flood waters (inundation pattern) in the model area at the different stages of water flow in the river Yamuna and incorporate that as input in the revised model. The aquifer parameters inferred in the model using inverse modeling approach also needs to be re assessed vis-à-vis aquifer geometry and if required then some suitably designed aquifer performance test can be done. The lateral and vertical aquifer heterogeneity needs to be refined in the model with respect to hydraulic conductivity and storage coefficient. The revised Palla model then can be run to give maximum possible sustainable groundwater extraction from the area with various permutation and combination of tubewell spacing and tubewell locations. The groundwater recharge variations in wet and draught years must also be taken in to consideration. To sum up it is suggested to have the revised model peer reviewed by active workers in the field and the model parameters, input and output stresses etc. agreed upon by all the concerned stake holders.

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Identification of Suitable Area Using GIS Techniques for Artificial Recharge of Ground Water in Chhattisgarh State

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Central Ground Water Board

ABSTRACT

Agricultural sector is the prime consumer of ground water resources in the state and country. The rapid increase in ground water irrigated area in last few years, in Chhattisgarh state has brought 0.41 Mha of land under ground water irrigation. The increased ground water draft sharply leading to sectoral decline in ground water level .The decline ground level has threaten the sustainability of hand pumps, the principal source of drinking water and life line of rural water supply system. Artificial recharge to ground water is the best possible solution to the above problem. Central Ground Water Board through its network monitoring stations all over the state, ground water sampling, exploration, detailed hydrogeological studies in specific areas has generated large data base on hydrogeological condition of the state.

In the present paper an attempt has been made to incorporate the available data base to demarcate the suitable area for Artificial Recharge in the state applying the GIS technique. A total of 7049 sq.km area in 23 isolated pocket spread in 49 blocks of 15 districts has been identified using six thematic layers by GIS technique. The artificial recharge can provide additional secured irrigation to 87320 ha land on expenditure of nearly Rs 5140 million and improve the sustainability of ground water abstraction structures. Since in Durg district the stage of ground water development is highest within the state and seven out of 12 block of Durg district and three out of four block of Dhamtari district are categorized under “Semi Critical” hence special emphasis has been given to deal with Durg and Dhamtari district.

INTRODUCTION

The increase in ground water utilization in the last decade for agricultural activities through adoption of bore wells has resulted in a six-fold increase in ground water draft in the last 20 years in Chhattisgarh. During the year 1990 the ground water draft was 60830 ham, it has increased to 359772 ham in 2009, resulting in an overall increase in stage of ground water development from 3.31% to 31%. The present stage of development of ground water in the state varies from 2% in Bijapur to 69% in Durg district. The ground water irrigated area has increased more than 6 times in last decade from 0.087 Mha to 0.41 Mha. Overall increase in the irrigated area of State during last decade has mostly been contributed through ground water. The development has not been uniform and steady in the State. Due to multifarious reasons the development has been slow in certain area but it has galloped in other places. Out of 146 blocks of Chhattisgarh, the stage of ground water development is still less than 30% in 104 blocks, between 30-50% in 19 blocks and more than 50% only in 23 blocks. However there are only 14 ‘semi-critical’ blocks (Balod, Bemetra, Baramkela, Rajnandgaon, Gurur, Durg, Dhamtari, Dhamdha, Kurud, Patan, Pandaria, Nagri, Saja and Belha) and no ‘critical’ or ‘over exploited’ blocks as per the latest (2009) resource estimation in the State. During 1990 stage of ground water development was lower than 33% in all the blocks. When compared with earlier resource estimation of 1990’s it shows two to nine fold increase in the stage of ground water development among those 74 blocks where presently the ground water development is more than 30%. (State report 2009)

Chhattisgarh State requires assured irrigation for sustainable agricultural productivity and to mitigate the effect of incessant drought condition. This is possible by adopting ground water development in 104 blocks where the stage of ground water development is still below 50%. Adopting rainwater harvesting and artificial recharge practice, simultaneously in those blocks where ground water development is presently above 50% and in those blocks where the sustainability of the abstraction structures is under threat in lean period, can enhance the sustainability.

Durg district having the highest ground water development within the state, where seven out of tewlve blocks fall under semi-critical areas, need special emphasis to mitigate the emerging challenge of development with scientific ground water management practice. Durg is located on Mahanadi plains where the population density is high. Being plain land and scanty forest cover the availability of agricultural land is higher. The districts occupied with rocks of Chhattisgarh Supergroup, mainly karstic limestone, gypsiferous and calcareous shale, which are potential aquifer. Simultaneously Durg is socio-economically advance district of the state. All these above conditions are conducive for rapid growth of ground water recourses in the district. Three out of four block of Dhamtari district are also categorised as semi critical required attention. Nagri block of Dhamtari district situated on granitic terrain and having largely unconfined aquifer where rainwater harvesting can be very useful for managed aquifer storage.

Application of modern technique like GIS can help to identify the pockets of areas where immediate attention has to be given for proper ground water resource management to mitigate the emerging ground water problems.

METHODOLOGY

To demarcate suitable sites of Artificial Recharge in Chhattisgarh six different thematic layers were prepared from the available and field data generated by monitoring through well-established network of 381 monitoring stations all over the state (Year book 2005) and other hydrogeological sdudies.

a) Post monsoon depth to water level (DTW) map was prepared using Mapinfo 6.5 with vertical mapper keeping 3 m interval. The grid map was generated using Natural Neighborhood statistical package from table extracted from Oracle database. Vadose zone available for recharge is calculated based on decadal post monsoon depth to water level data (November) separately for every 3 m interval. Vadose zone available below 3 m ground level has been considered suitable for recharge
b) The decadal ground water trend of post monsoon level is generated using November (1995-2004) ground water level data through Mapinfo 6.5. with vertical mapper. Areas showing fall in ground water level @ > 10 cm/year has been considered for artificial recharge.
c) The stage of ground water development was calculated for all the 146 blocks using GEC 1997 norms.(CGWB, 2005)
d) The geological map prepared by GSI (and modified by various works) on 1:250000 scale has been used for identification of aquifer along with the back ground hydrogeologic information available for all the major rock type with CGWB including specific yield for various rock type.
e) All the above hydrogeological layers were superimposed on administrative map of Chhattisgarh State along with water shed map, using Mapinfo 6.5.
f) Using the GIS facility, the areas were demarcated having more than 3m post monsoon ground water level with a falling trend in post monsoon period @ > 10 cm/year or having stage of ground water development as semi critical. Logical and scientific discrimination is applied with the marked area keeping the land use and population density criteria in mind to restrict the earmarked area.
g) Finally the marked areas were superimposed on geological and geomorphological map to propose suitable method of Artificial Recharge.
h) Based on the volume of Vadose zone calculated separately for each watershed (AISLS1990), and availability of surplus subsurface runoff in that particular watershed, the number of Artificial Recharge structure were finalized.
i) Budgetary requirement for construction of Artificial Recharge structure were calculated based on guideline provided by CGWB New Delhi.(CGWB, 2002)
j) The work presented here is a team effort of all the scientific officers of CGWB, NCCR, Raipur.

DISCUSSIONS

Identification of area

Over the years, traditional rainwater harvesting through structures like tanks and village ponds has been practiced. In order to cope with recurrence of drought and water depletion, a massive “Watershed Development Programme” was launched by Government of India in 1975 in drought prone areas, focus was laid on sustainable effort to harmonize the use of water, soil, forest resources, with the emphasis on holistic planning on basin/ sub basin level.

Based on data of National Hydrograph Stations established by CGWB to monitor the fluctuation of ground water levels in different hydrogeological situations, a trend analysis was carried out for the decade between 1995 and 2004. A total area of 7049 sq.km. in Chhattisgarh shows declining trend in ground water levels. 23 major watersheds have been identified in Chhattisgarh in which declining trend of more than 0.1 m/yr was recorded. (**Fig 1**) These watersheds have been identified for construction of suitable artificial recharge structures to augment the available ground water resources.

Sub-surface storage space and water requirement

To estimate the sub surface storage and space available, a map was prepared on the basis of average post monsoon depth to water level for the period 1995-2004. The decadal post monsoon average depth to water level is predominantly in the range of 3 to 6 m below ground level. Based on this map the volume of unsaturated zone available for recharge (Vadose zone to 3 m below ground level) was calculated for each of the 23 identified watersheds. A total 456mcm volume of vodose zone was calculated based on the specific yield of the rock types in the watersheds of Chhattishgarh state (CGWB 1984).The requirement of water to fully saturate the vadose zone upto 3 m below ground level was worked out for each watershed at 75% efficiency considered for recharge structures. The total requirement of water to saturate the sub-surface storage space worked out to be 606 mcm for the entire State **(Table 1).**

Fig 1. Area identified for artificial recharge to ground water in Chhattisgarh

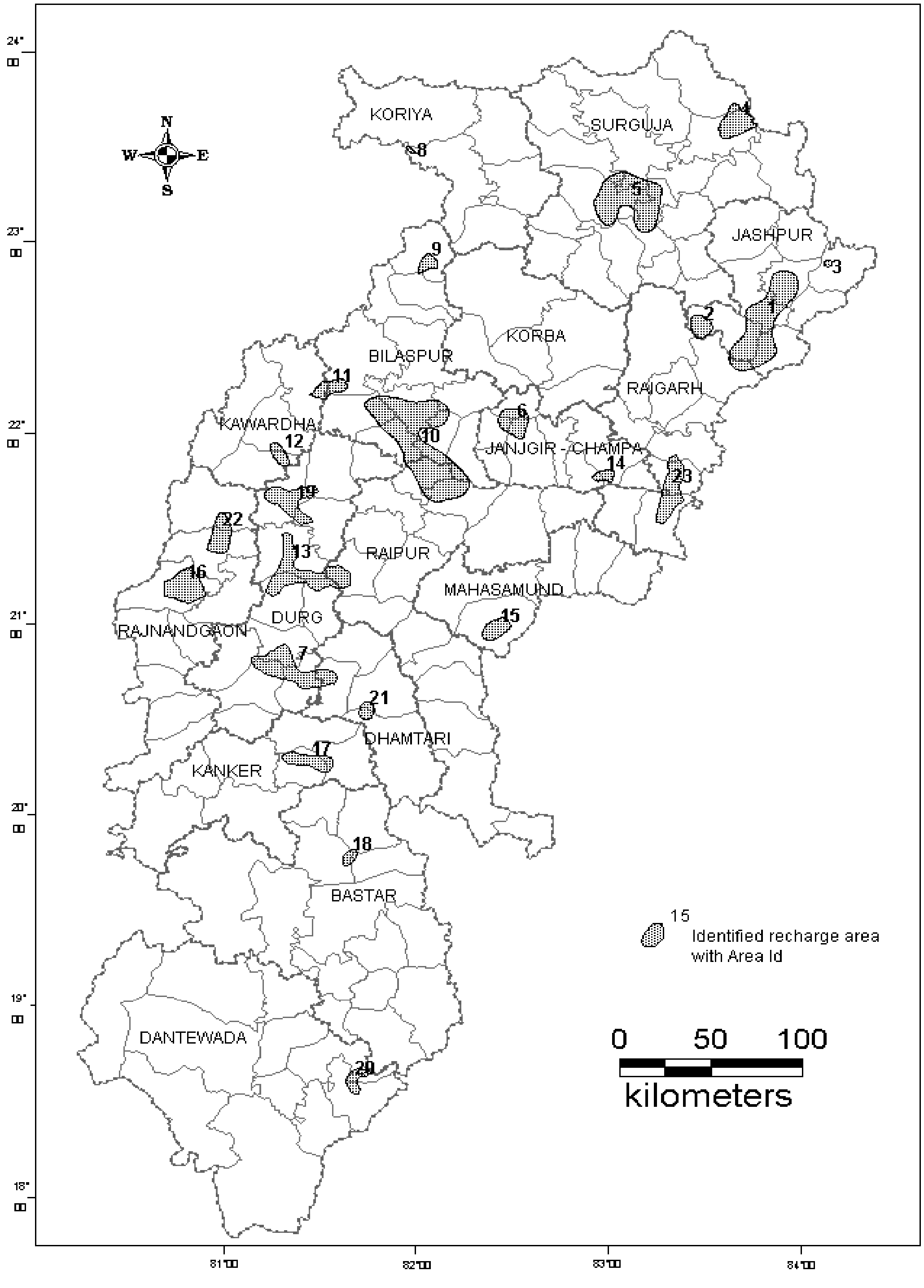

Table 1 Silent features of area identified for artificial recharge of ground water in Chhattisgarh

Area Id	Basin/ Sub basin	Water shed code	District	Block	Identified area in sq.km	DTW in mbgl	Trend Falling in m/Year	Stage of ground water development in %	Vadose zone in mcm	Geology of the area	Sp. Yield in %	Geomorphology of the area
1	Mahanadi/ Mahanadi	4G2B	Jashpur	Kunkuri, Kansabel, Pathalgaon, Tapkara	957	3 to 6	0.1-0.5	18.5	43.07	Granite	0.030	Pediment/ Pediplain
2	Mahanadi/ Mahanadi	4C2C	Jashpur	Pathalgaon	120	3 to 6, 6 to 9	0.1-0.5	27.3	9.90	Granite	0.030	Pediment/ Pediplain
3	Brahmani	4H1D	Jashpur	Jashpur	12	3 to 6	0.1-0.2	37.9	0.54	Granite	0.030	Pediment/ Pediplain
4	Ganga/ Son	2A6C	Sarguja	Balrampur	237	3 to 6, 6 to 9, 9 to 12	0.2-0.5	10.98	25.60	Granite	0.030	Pediment/ Pediplain
5	Ganga/ Son	2A6E	Sarguja	Surajpur, Ambikipaur, Pratapur	825	3 to 6	0.2-0.5	21	31.50	Barakar sst.	0.040	Pediplain/ Structrual plain
6	Mahanadi/ Mahanadi	4G2D	Janjgir Champa	Baloda, Akaltara,	210	3 to 6	0.1-0.2	13.75 18.73	11.02	Raigarh shale	0.035	Pediplan
7	Mahanadi/ Seonath	4G3B, 4G3D	Durg, Dhamtari	Gunderdehi, Balod, Gurur, Dhamtari	506	3 to 6	0.1-0.2	60.86, 72.75,95.3 ,79.46	26.72	Limestone	0.035	Pediplain
8	Ganga/ Son	2A6H	Koriya	Manendragarh	10	3 to 6	0.2-0.5	16.55	0.60	Barakar sst.	0.040	Structrual plain
9	Ganga/ Son	2A6H	Bilaspur	Marwahi	71	6 to 9, 9 to 12	0.1-0.5	14.41	9.81	Talchir sst	0.020	Pediplain/ Structrual plain
10	Mahanadi/ Seonath	4G3A & 4G3B	Bilaspur	Takhatpur, Mungeli, Patharia & Belha	1085	3 to 6, 6 to 9, 9 to 12	0.1-0.5	34.19, 50.5, 39.64, 70.59	141.42	Limestone	0.040	Alluviam plain/ Pediplain
			Raipur	Bhatapara, Balodabazar	492	3 to 6	0.1-0.5	26.91, 23.73	22.14	Limestone	0.030	Alluviam plain/ Pedi plain
11	Mahanadi/ Seonath	4G3A	Kawardha, Bilaspur	Pandaria, Lormi	131	3 to 6	0.1-0.2	63.34, 15.37	6.88	Limestone	0.035	Pediplain
12	Mahanadi/ Seonath	4G3C	Kawardha	Kawardha, Lohara	82	3 to 6	0.1-0.2	25.88, 17.13	4.31	Limestone	0.035	Pediplain
13	Mahanadi/ Seonath	4G3C, 4G3B, 4G3D	Durg, Raipur	Dhamdha, Durg, Patan, Dharsiwa	577	Not representative	0.1-0.2	75.65, 84.02,72.0 , 37.37	30.29	Limestone	0.035	Pediplain
14	Mahanadi/ Mahanadi	4G2C	Janjgir Champa	Malkharoda, Jaijaipur	59	3 to 6	0.1-0.2	68.93 ,54.71	3.10	Limestone	0.035	Pediplain
15	Mahanadi/ Mahanadi	4G2E	Mahasamund	Baghbahra	134	3 to 6	0.1-0.7	18.15	6.03	Granite	0.030	Pediplain
16	Mahanadi/ Seonath	4G3D	Rajnandgaon	Dongargarh	309	3 to 6	0.1-0.5	29.01	9.27	Volcanic	0.020	Structrual plain/ pediplain
17	Mahanadi/ Mahanadi	4G2G	Kanker	Kanker & Narharpur	189	3 to 6, 6 to 9	0.1-0.2	25.48, 27.87	10.48	Granite		Denundation slope
18	Godavari/ Indravati	4E2E	Bastar	Pharasgaon, Makri	52	3 to 6	0.1-0.2	4.84, 10.89	1.56	Granite/ Granulite	0.020	Denundation slope
19	Mahanadi/ Seonath	4G3C	Durg	Saja & Berla	305	3 to 6	-	72.01 ,62.71	13.73	Limestone Gys.shale	0.035	Pediplain
20	Godavari/ Sabri	4E1C	Dantewada	Katekalyan & Chhindgarh	96	3 to 6	0.1-0.2	1.24, 1.89	4.32	Granite, Limestone	0.030	Structrual Hill/ Structural plain
21	Mahanadi/ Mahanadi	4G2G	Dhamtari	Magarlod, Nagri	63	3 to 6	0.1-0.2	27.08, 25.64	2.36	Granite, sandstone	0.025	Structrual plain/ pediplain
22	Mahanadi/ Seonath	4G3C	Rajnandgaon	Chhuikhadan, Khairagarh	201	3 to 6	0.1-0.2	16.96 ,33.74	6.03	Rhyolite	0.020	Pediplain
23	Mahanadi/ Mahanadi	4G2C & 4G2E	Raigarh	Phusour & Baramkela	326	3 to 6	0.1-0.2	62.21 ,64.96	17.12	Limestone	0.035	Pediplain

Source water availability

The availability of surplus monsoon runoff was estimated for 23 identified watersheds mainly on the basis of data from State Irrigation Department. The total availability of source water for recharge worked out to be 16658 mcm, which is much more than the total requirement to create the sub-surface storage. However, for each watershed the requirement vis-à-vis the availability was seen and the least of the two was considered as available source water for harnessing artificial recharge structures. The total quantum of source water, which can be utilized for creation of sub-surface storage worked out to be 601 mcm for all the 23 identified watersheds

Recharge structures

The suitable artificial recharge structures in the State are gully plugs, gabion structures, contour bunds in the upper reaches of the watersheds, percolation tanks, nala bunds in the runoff zones and recharge shafts, gravity head wells in down stream areas. The main artificial recharge structures are given below and estimated number of feasible structures and their cost are described in **Table 2.**

Percolation Tanks

Percolation tank is the main artificial recharge structure proposed for effective utilisation of the surplus monsoon runoff. In hard rock areas only 50% of the total estimated surplus surface water resources have been considered for storage in the percolation tanks. As per the hydrogeological conditions in Chhattisgarh an average percolation tank has filling capacity of 0.1 mcm. It can actually store 200% of the capacity due to multiple filling during the monsoon. Unit average gross storage capacity of 0.2 mcm has been considered for the percolation tank . The average cost of such structure has been considered as Rs.20 Lakh. The number of feasible percolation tank in each identified watershed is presented in Table 2. The total percolation tanks feasible in Chhattisgarh are 1470 costing Rs. 2940 million

Nala Bunds

There is a large scope for constructing Nala bunds/Cement plugs in various second order streams in State. About 25 % of surplus monsoon runoff can be utilized by recharging through these structures. The average capacity of Nala bunds/Cement plugs has been considered as 0.03 mcm. The average cost of each structure has been taken as Rs.1.0 lakh. It is estimated that 5050 Nala bund/Cement plugs can be constructed in the State at the cost of Rs 505 million.

Table 2 Feasibility of Artificial recharge structures and cost estimation in Chattisgarh

Area Id	Identified area for Artificial recharge in sq.km	Vadose zone in mcm	Requirement of water for storage @ 75% efficiency	Availability of non committed surface water in watershed in mcm	Proposed no. of artificial recharge structures				Estimated cost			
					Percolation tank	Nala bunding cement plug/ check dam	Gravity head Dug well/ tube well/ recharge shaft	Gully plugs Gabion structure	Percolation tank @ Rs.20 Lacks	Nala bunding cement plug/ check dam @ Rs.1.0 Lacks	Gravity head Dug well/ tube well/ recharge shaft @ Rs.2.5 Lacks	Gully plugs Gabion structure @ Rs.0.1 Lacks
1	957	43.07	57.28	370.05	143	477	573	1718	2860	477	1432.5	171.8
2	120	9.9	13.17	476.85	33	110	132	395	660	110	330	39.5
3	12	0.54	0.72	286	2	6	7	22	40	6	17.5	2.2
4	237	25.6	34.05	315	85	284	340	1021	1700	284	850	102.1
5	825	49.5	65.84	1983	124	549	658	1975	2480	549	1645	197.5
6	210	11.02	14.66	327.33	37	122	147	440	740	122	367.5	44
7	506	26.565	35.33	1410	83	294	353	1060	1660	294	882.5	106
8	10	0.6	0.80	297.38	2	7	8	24	40	7	20	2.4
9	71	9.81	13.05	297.38	33	109	130	391	660	109	325	39.1
10	1085	141.42	188.09	941.53	470	1567	1881	5643	9400	1567	4702.5	564.3
	492	22.14	29.45	628.47	74	245	294	883	1480	245	735	88.3
11	131	6.88	9.15	941.53	23	76	92	275	460	76	230	27.5
12	82	4.31	5.73	406.52	14	48	57	172	280	48	142.5	17.2
13	577	30.29	40.29	1816	101	336	403	1209	2020	336	1007.5	120.9
14	59	3.1	4.12	476.85	10	34	41	124	200	34	102.5	12.4
15	134	6.03	8.02	483.37	20	67	80	241	400	67	200	24.1
16	309	9.27	12.33	782.67	31	103	123	370	620	103	307.5	37
17	189	10.48	13.94	635.97	35	116	139	418	700	116	347.5	41.8
18	52	1.56	2.07	414.97	5	17	21	62	100	17	52.5	6.2
19	305	13.73	18.26	406.52	46	152	183	548	920	152	457.5	54.8
20	96	4.32	5.75	1442	14	48	57	172	280	48	142.5	17.2
21	63	2.36	3.14	635.97	8	26	31	94	160	26	77.5	9.4
22	201	6.03	8.02	406.52	20	67	80	241	400	67	200	24.1
23	326	17.12	22.77	476.85	57	190	228	683	1140	190	570	68.3
Total	**7049**	**455.645**	**606.01**	**16658.73**	**1470**	**5050**	**6060**	**18180**	**29400**	**5050**	**15150**	**1818**
Additional Secured Irrigation in 87320 ha									Cost Rs 514Cror			

Recharge Shafts & Gravity Head Recharge Wells

These structures are feasible in villages and urban pockets. About 10% of the surplus monsoon runoff can be utilized through these structures. The average recharge capacity through recharges shafts, gravity head recharge through dug wells during an operational period of 60 days in monsoon and post monsoon period is considered as 0.01 mcm. The average cost of structure may be taken as Rs.2.5 Lacs. The number of structures and their cost for each identified watershed is calculated and presented in Table 2. For the entire State the feasible structures are 6060 costing Rs.1515 million.

Gully Plugs, Contour Bunds, Gabion Structures

These are mainly soil conserving structures help to increase the soil moisture with limited recharge to ground water. It is estimated that 15% of total water available for recharge can be utilized through these structures, which have an average storage capacity of 0.005 mcm. The average cost of each structure is taken as Rs.10,000/-. The structures feasible in each identified watershed has been estimated and presented in Table 2. For the entire State feasible structures total up to 18180 costing Rs 182 million.

Cost estimates and benefits

The main artificial recharge structure in the 23 identified watershed are percolation tanks, Nala bund/ Cement plugs, Recharge shaft/Gravity head recharge wells and water conservation structures like gully plug, contour bund and gabion structures. The total cost of these artificial recharge structures works out to Rs 5142 million. The benefit from the proposed plan would be in terms of creation of additional irrigation potential in rural areas and supplementing drinking water needs in urban areas.An additional irrigation potential of 873 Sq km would be created.

RESULTS AND CONCLUSIONS

Application of GIS technique to demarcate suitable areas for artificial recharge of ground water in Chhattisgarh by using six thematic layers namely i) decadal post monsoon depth to water level ii) decadal post monsoon water level trend iii) stage of ground water development iv) watershed v) geology and vi) geomorphology has brought out nearly 7049 sq.km area in 15 district in 23 isolated pockets. Total 456 mcm vadose zone is available for artificial recharge of ground water. These 23 identified areas were spread over 49 blocks and 15 watersheds. Out of these 15 watersheds 9 were from Mahanadi basin, where ground water development is maximum. The identified area needs 606 mcm of water to saturation, which is only3.6% of the available surplus runoff. For these 23 pockets, the total structure recommended are 1470 percolation tanks, 5050 cement plugs, 6060 gravity head recharge structures and 18180 rainwater harvesting structures. The construction of these structures required nearly 514crors of rupees and will generate peoples participation and rural employment. This also brings additional 87320 ha of land under assured irrigation and will enhance sustainability of ground water structures, particularly of hand pumps for drinking water supply.

In Durg district three areas have been identified in 8 out of 12 blocks for artificial recharge covering nearly 1188 sq.km area. Based on the aquifer character of karstified limestone and gypsiferous shale gravity head recharge wells are assume to be the best effective artificial recharge structure for Durg district. It is suggested that gravity head recharge wells may be constructed in existing irrigation tanks or in combination with stop dam/check dam so that the deeper aquifer are recharged properly during the lean period for more effective results. Site selection for these gravity head recharge wells must be done in a scientific manner for success of the project. Artificial Recharge in gypsiferous aquifers of Saja and Bemetra block will also improve the quality of ground water making it soft by dilution .

The area identified for artificial recharge in the present paper is based on the regional level studies. Before implementation of above recommendations in the selected 23 areas micro level field investigations are to be carried out.

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Numerical modelling of contaminant migration from Najafgarh Drain, South West District of Delhi

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ABSTRACT

Najafgarh Drain (NGD) is the largest surface drains joining the Yamuna river in *National Capital Territory.* Its catchment area is around 374 sq.km. Because of severe constraints in the sewerage system in its drainage basin, NGD carries a very large quantity of urban waste water. In addition, it receives treated effluent from various STPs and freshwater from Western Yamuna Canal. NGD is one of the major source of pollution. NGD is the perennial drain and high level of flow in NGD makes this channel as a typical polluted river. In view of the magnitude of the inorganic and organic load carried by NGD and the path traversed by it through a major part of the city, it gains tremendous significance in the overall strategy for control of pollution in river Yamuna. This study aims to evaluate probable groundwater vulnerability due to emerging pollutants in Najafgarh drain, South West Delhi using solute transport modelling. Groundwater flow modelling shows that NGD is hydraulically connected with groundwater. In South West District NGD is recharging water to groundwater and due to this groundwater is shallow along the NGD..

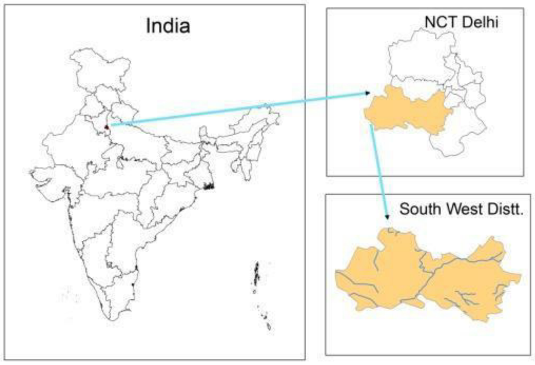
Keyword: *Najafgarh Drain, urban waste water, groundwater vulnerability, emerging pollutants.*

INTRODUCTION

Najafgarh Drain (NGD) is the largest among all the surface drains joining the river in NCT. Its sewered catchment area is around 374 sq.km. Because of severe constraints in the sewerage system in its drainage basin, NGD carries a very large quantity of urban waste water. The combined discharge is over 2000 MLD, while the BOD load varies between 80 t/d to 195 t/d and; this alone represents 50% of hydraulic load and over 25% of organic load from NCT Delhi in to the river Yamuna. The urban waste water gets polluted in many ways. Runoff from streets carries oil, rubber, heavy metals, and other contaminants from automobiles. Untreated or poorly treated sewage can be low in dissolved oxygen and high in pollutants such as fecal coliform bacteria, nitrates, phosphorus, chemicals, and other bacteria. Treated sewage can still be high in nitrates. Groundwater and surface water can be contaminated from many sources such as domestic waste, garbage dumps, toxic waste and chemical storage and use areas, leaking fuel storage tanks, and intentional dumping of hazardous substances. The presence of a wide variety of pharmaceutical and personal care products in water and wastewater has been frequently reported after the early findings of Ternes (1998) and Daughton and Ternes (1999). These compounds are a source of concern because they are used and released in large quantities and their physical and chemical properties contribute to their widespread distribution into the environment. The consequences are particularly worrying in aquatic organisms as they are subjected to multigenerational exposure (Halling-Sörensen et al., 1998). The presence of micropollutants also endangers the reuse of treated wastewater, a generally proposed solution to achieve a sustainable water cycle management. Pharmaceutical and personal care products represent a rising part of the trace organic micropollutants found in urban and domestic wastewaters that reach sewage treatment plants (STP), either metabolised or not. Many of these substances escape to conventional activated sludge wastewater treatments allowing them to reach surface water streams and distribute in the environment (Tauxe-Wuersch et al., 2005).

So far no study has been carried out to evaluate the extent of vulnerability of groundwater pollution in NGD. A maiden attempt has been made to delineate vulnerability of groundwater along Najafgarh Drain using numerical simulation technique to comprehend the present and future migration of emerging pollutants. Due to paucity of specific data for the NGD, average pollutants carried out by any urban waste water drain reported in published literature is considered here.

The study area is situated in south west part of Delhi (Figure 1) and it lies between 28° 30'-28°40' N lat. and 76°50' -77° 12' E long. It is spread over an area of about 420 km^2 and is characterized by undulating topography with hills located in the southern parts, sloping towards north and northwest. The highest elevation (altitude) in the south east part of the district is of the order of 290 m amsl, whereas in the plains it ranges from 190 m amsl in the western part of the area. NGD flows south to north. The average annual rainfall is of the order of 750 mm for the period 1971–2001. Geologically, the area is occupied with Alwar quartzites in the east and fluvio-aeolian deposits in the rest of the district(Fig.2). The borehole data of Central ground Water Board (CGWB) shows alternation of fluvial bands with Aeolian bands in sporadic manner. The sediments are mostly silt with medium to find sand, clay and Kankar. The depth to bedrock data indicates towards steep subsurface escarpment on western side of the Delhi ridge (Alwar Quartzites) exposed in the district (Shashank, etal, 2006). The general trend of groundwater flow direction of shallow aquifer is in the north and northeast directions (Figure 3).



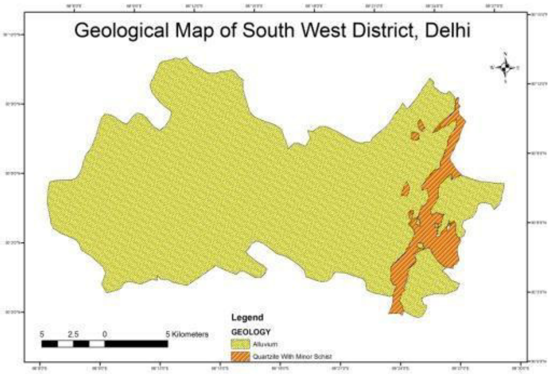


Fig.1 Index map of study area

Fig. 2 Geological Map of South-West Distt

METHODOLOGY

Ground water flow model is the pre-requisite for solute transport modelling. A steady state groundwater flow model is developed . In order to set up ground water flow model in the MODFLOW set of codes, the area of interest needs to be discritized into in the e form of grids. This grid has to be block-centred, i.e. the groundwater heads will be computed at the centre of each grid block. The areal extent of the basin in about 420 km2, a grid size of 500x500 m was decided (Figure 4). The cell size was further refined along NGD to meet the peclet and courant criterion. The actual values of the ground surface elevation and bottom elevation of the bedrock were entered in the model. In the present case, the boundary conditions had been determined based on the hydraulic condition and flow net analysis of water table contour map. No-flow boundary has been set in the eastern and north-eastern south-western part of the study area because Alwar Quartzites has been characterized as practically impermeable in the conceptual model and flow lines are parallel to boundary.

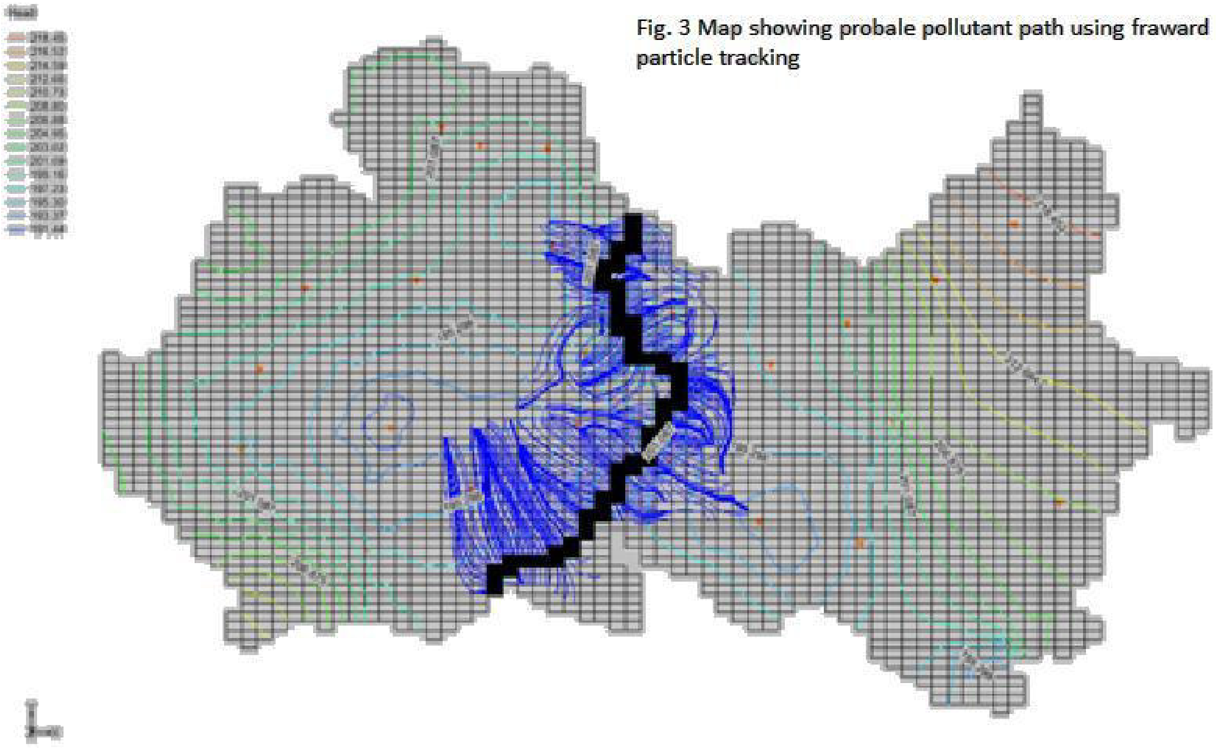


Fig. 3 Map showing probale pollutant path using fraward particle tracking

Specified flow (Neumann conditions) were assigned at remaining places . Inflow and out flow were calculated based on Darcy flux. Initially hydraulic conductivity and recharge were assigned based field data collected by CGWB in previous studies. Water balance technique was used to make initial estimates to Recharge rates. Based on remote sensing study it was observed that study area comprises two distinct landuse/landcover pattern that is urban area and rural area. Recharge rates for urban area was assigned as 10% of the mean annual rainfall and 30% for agricultural activity dominated rural area. These input parameters were further refined using inverse modelling .The data for groundwater draft from irrigation, industries and domestic was taken from published literature (CGWB, 2004). Model calibration was done by modifying hydraulic conductivity and recharge rates. Final figures were arrived after inverse modelling.

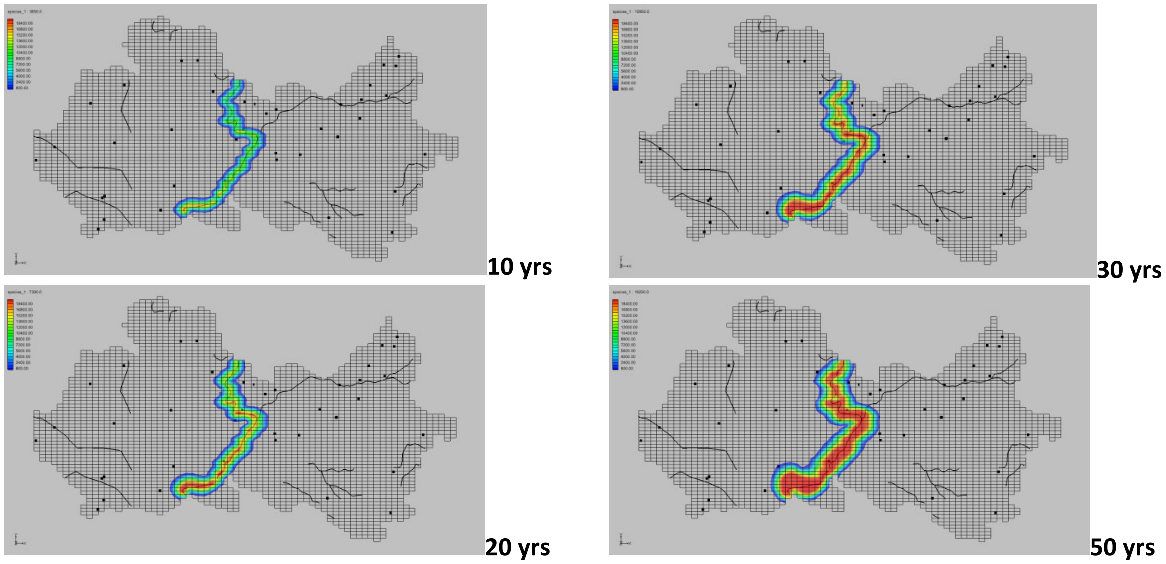

10 yrs 30 yrs 20 yrs 50 yrs

Fig. 4 Plume migration along NGD, South west distt. , NCT Delhi.

Solute Transport Modeling

MT3DMS software developed by USGS (Zheng and Wang,1999) was used to simulate changes in concentrations of miscible contaminants in groundwater considering advection, dispersion, diffusion, and some basic chemical reactions, with various types of boundary conditions and external sources or sinks. The concentration of pollutant(TDS) in the NGD was assumed to be more than 20000 mg/l. It was assumed that 30% of the sewerage flow seeps into the groundwater system. After natural attenuation, retardation and sorption it was assumed that on a conservative basis the pollutants reaching the water table has a solute concentration, which is 30% of that present at the surface. An effective porosity of 0.25 for fluvioeolian deposits and 0.1 for Alwar quartzites were uniformly assumed for the entire area. Longitudinal dispersitivity was taken as 10m to generate different scenarios for migration emerging pollutants. Since migration of pollutants depends on various factors like octanal water partition coefficient, organic carbon partition coefficient, Henry law coefficient, hydrolysis and biotransformation. The transport model was run until the contaminant plume has reached steady state conditions. Assuming the source of the contaminant flux remains near constant.

RESULTS AND DISCUSSION

The model calculated TDS concentration for 20 years shows that the pollutant could migrate only to about 1000 m all around from the NGD. During next 50 years the pollutant migrated to about 2500 m around the NGD. After delineating groundwater vulnerable area along NGD it is estimated that about 73 sq. km. area is vulnerable to groundwater pollution (Fig. 5). To arrest this contaminant migration in situ remediation technology like permeable reactive barrier(PRB) option is need to be explored. A PRB is a passive in situ treatment zone of reactive material that degrades or immobilizes contaminants as ground water flows through it. PRBs are installed as permanent, semi-permanent, or replaceable units across the flow path of a contaminant plume. Natural gradients transport contaminants through strategically placed treatment media. The media degrade, sorb, precipitate, or remove chlorinated solvents, metals, radionuclides, and other pollutants. These barriers may contain reactants for degrading volatile organics, chelators for immobilizing metals, nutrients and oxygen to enhance bioremediation, or other agents. It is to be mentioned that this model shows only potential vulnerable area and before making final conclusion detail water quality data is need to be analysed.

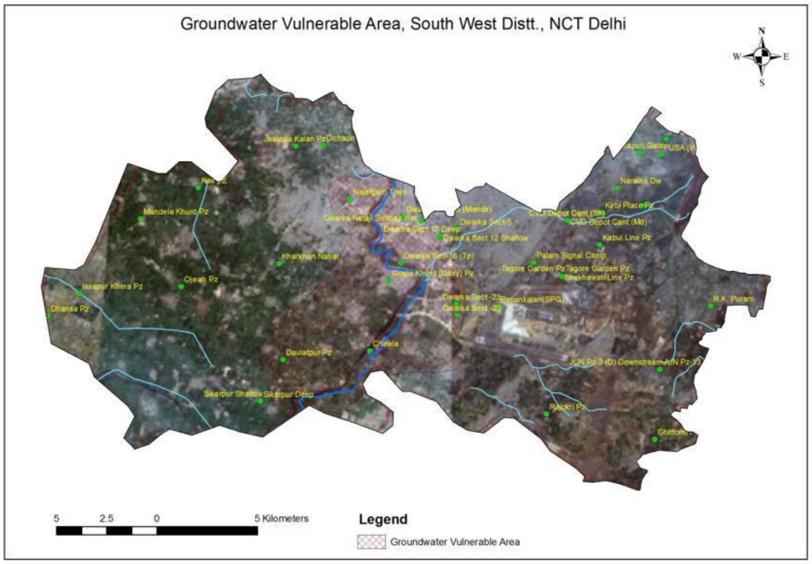


Fig. 5 Groundwater vulnerable area along NGD, South West District, NCT Delhi

CONCLUSIONS

It is recommended to periodically monitoring of the water level and water quality(including inorganic and organic compound) along NGD is required often to ascertain changing groundwater scenario. Well head protection measures need be taken up for all abstraction structures to avoid entering of pollutants. Other than rainfall NGD is the only source of recharge. In this regard it is to mention that high level of contamination in NGD may have adverse impact on groundwater quality. Therefore to control further advancement of contaminate migration installation of PRBs is recommended.

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Delineation of Groundwater Potential Zones in An Around Sinnar Area, Nasik District using Remote Sensing and GIS Techniques

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ABSTRACT

In the present study, the groundwater prospect of Sinnar area has been delineated using remotely sensing data, base map of Geological Survey of India(GSI), ground truth data, and geographic information system. Based on these integrated studies, it has been noticed that the lithology of the area mainly consist vesicular/weathered basalt, massive and hard compact basalt belonging to cretaceous to early Eocene period. Based on hydro-geomorphological, geological and lineament mapping the Sinnar area can be qualitatively categorized into three groundwater potential units, viz. good, moderate and poor . The high prospect zones are alluvial plains and valley fills mainly influenced by quaternary formations with yield expectation between 15 to 180 lpm. The moderate zone is mainly consisting of weathered and fractured aquifer material with expected yield of water between 30 to180 lpm. The low potential zones mainly comprises of massive and hard rocky surface with expected discharge below 50 lpm.

Keywords: Groundwater, Potential, Lineaments, Geology, Basalt.

INTRODUCTION

Groundwater is a precious gift of nature. Remote sensing tools and methods are increasingly becoming popular for mapping land features with the advent of improved satellites sensors; where images can be acquired with fine resolution and image interpretation is faster and less expensive than the ground survey. Remote sensing techniques provide us an opportunity to study the surface resources of the Earth in a systematic repetitive manner.

Remote sensing and geographical information system(GIS) is a most powerful tool of delineation of groundwater potential for occurrence and distribution of groundwater regime. Many authors has worked upon the application of Remote Sensing and GIS techniques in groundwater studies (Krishnamurthy and Srinivas 1995; Krishnamurhty et al. 1996; Saraf and Chaudhary 1998; Khan and Mohrana 2002; Pietronio & Prowse. 2002; Hoffmann, 2005; Jaiswal et al. 2005; Jha and Chaudhary 2007; Hoffmann and Sander 2007). It will support in the quantification of hydrologic parameter in data collection and transmission to facilitate rapid analysis of various facet of water resources.

LOCATION OF STUDY AREA

The Sinnar study area confined between Longitude 73°52'55"E to 74°12'54"E latitude 19°42'23"N to 19°56'30"N. The study area belongs to Nasik district, Maharashtra covered an about 566 Sq.km. area.

Geology of the Study Area

Geologically, the entire study area is covered by Deccan basalt formations(Fig-1) comprising nearly horizontal lava flows. These flows have been considered to be a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The types of basalt occurring in the area are vesicular/weathered basalt and massive basalt, in the present study geological mapping is done using **IRS-P6, LISS-IV** image with the help of image interpretation. Keys Basalts are showing bluish tone with coarse texture. Basalts occurring in and around the study area exhibit both vesicular and massive forms. The massive basalt units are fine grained, dense and compact, they are dark in colour. The vesicular type of basalts is highly weathered.

Geological Structure

The Sinnar area is traversed by various directional fractures / lineaments and most of them are in NW – SE, NE-SW, ENE – WSW and E – W directions(Fig-2). Lineaments look as narrow linear features with dark tone due to high moisture content and look red due to presence of vegetation. Presence of lineaments in a geomorphic unit increases the prospects of groundwater occurrence in Sinnar area Nasik district Maharashtra.

The micro-lineaments are found to be better conduits of groundwater. Presence of lineaments in a geomorphic unit increases the prospects of groundwater (Murthy and Jayram, 1996; Thorat and Sable, 1990, Muley *et.al, 2010*).

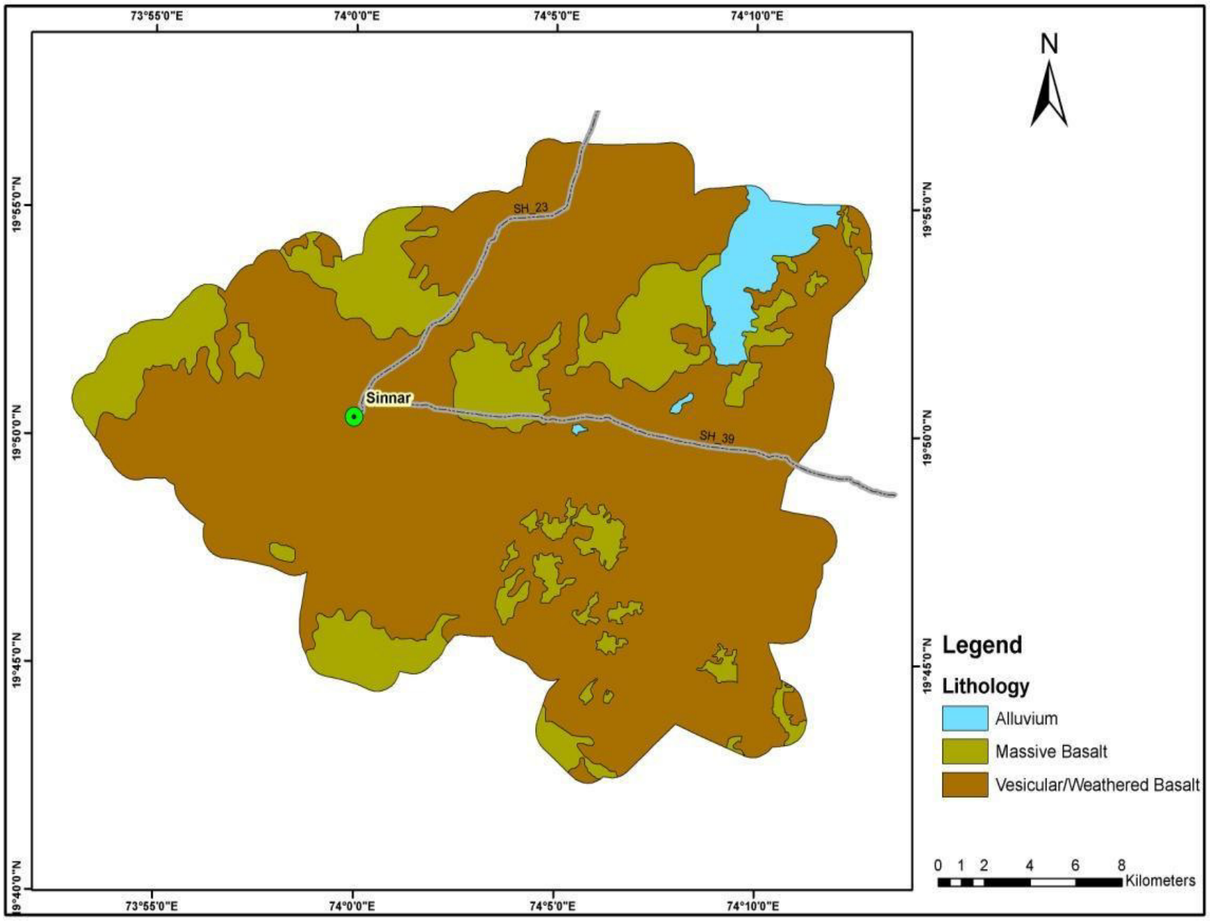

Figure:1. Geological map of the study area

Groundwater Potential Mapping

Geological and remote sensing data has been utilized for delineation of groundwater potential zones. A strong mutual correlation exists between geological variables and hydrological characteristics. Such relationship can be applied to both surface and groundwater regime. Thus the linking of geological parameters with hydrological characteristics of the area provides a simple way to understand the hydrogeological and groundwater potential behaviour of the area.

The groundwater potentiality of the area has been assessed through integration of the hydrogeology, lineament, slope and aquifer thickness. The groundwater potential zones map (Fig-3) generated through the base map and remote sensing was verified with the yield data to ascertain the validity of the potential zones. The verification showed that the groundwater potential zones demarcated through the map are in tune with the bore well yield data. Basically three groundwater potential units have been demarcated such as good, moderate and poor.

On the basis of hydrogeological and lithological characteristics, three categories of groundwater prospect zones: high, moderate and low are delineated. The high prospect zones are alluvial plains and valley fills mainly influenced by quaternary formations with yield expectation between 15 to 180 lpm. The moderate zone has vesicular/weathered covered in addition to weathered and fractured aquifer material with expected yield of water between 30 to 180lpm. The low potential zones mainly comprise massive and hard rocky surface with expected discharge below 50 lpm.

Thus, the above study has clearly demonstrated the capabilities of geological studies and remote sensing in demarcation of the different groundwater potential zones in the study areas.

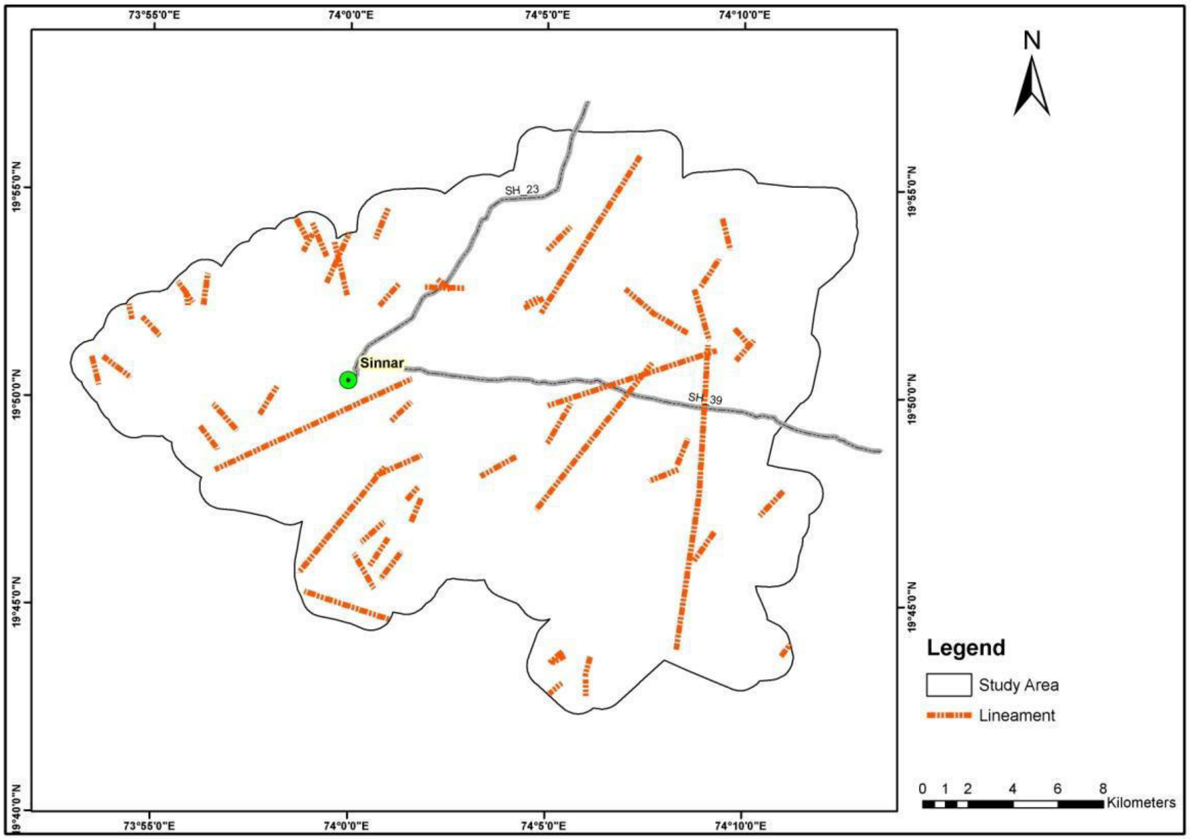

Figure:2 Lineament density map of Sinnar area

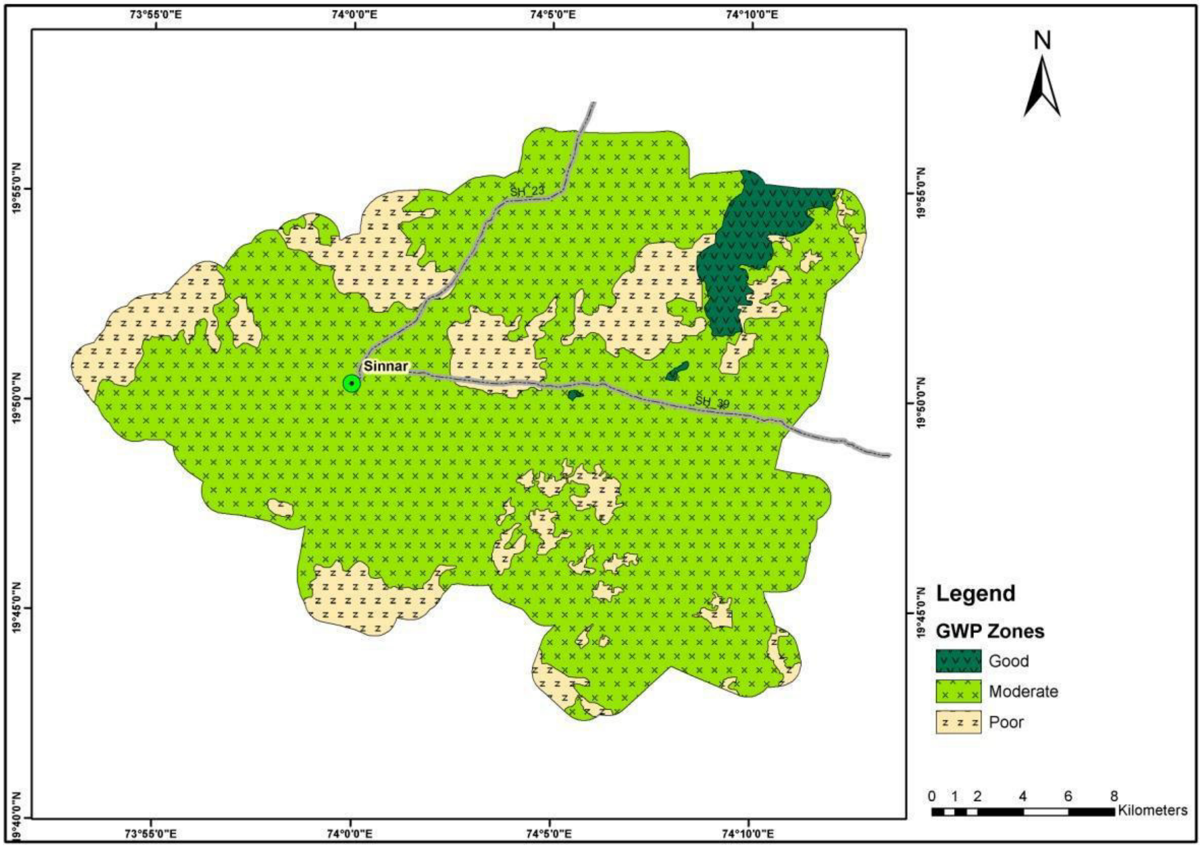

Figure:3. Delineation of groundwater potential zones in study area

CONCLUSION

The groundwater potential units revels and give an idea about development and management plan of groundwater recourses. The three type of groundwater potential units has been observed such that good, moderate and poor potential zones. These units have been demarcated by the different lithologic and geological conditions.

1. The good groundwater potential units consist of vally fills, flood plain and thick alluvium deposits geomorphological features. The lithology of this units are mainly alluvium and lineaments present in the area cut to each other.
2. In the case of moderate groundwater potential unit the geomorphological condition is buried pediment, older alluvium plains. The lithology is vesicular/weathered basalt having secondary porosity in rocks. Lineament having cut and parallel structured to each other .
3. Poor groundwater potential units carousing a lithology of massive compact basalt devoid of porosity, and absence of water conducting lineament.

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Watershed Based Ground Water Quality Studies using Geo-Informatics in Mahendergarh District, Haryana

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ABSTRACT

Water is a major input in agriculture and its relative availability in requisite quality in different agro climatic zones calls for efficient water resource development plans. Ground water constitutes the main source of irrigation in many parts of Haryana. The study was conducted in ten micro-watersheds falling under rainfed area in Mahendergarh District. Geo-informatics techniques in combination with ground data was used for identification, demarcation and preparation of ground water quality maps. Water samples were collected from the running tube wells of the study area and locations of sampling sites were recorded in the form of latitude &longitude using handheld Global Positioning System (GPS). These collected water samples were analyzed for their E.C., pH, Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-}. These waters were classified as per the established methodolgy. It was observed that good quality waters occupied an area of 60.81% of total geographical area of all the micro-watersheds. Sodic water mainly found in Khudana –V, or Adalpur micro-watershed.

INTRODUCTION

Water is conceived to be most precious natural resource on earth. It is directly linked with agricultural productivity and protection or development of human needs. The Sub-Surface water quantity and quality both are important for long time irrigation activities or for drinking purposes. This needs detailed information on land and water resources and agriculture in the region for meticulous planning of strategies and effective implementation. There is a close relationship between water scarcity and reduced food productivity, mainly applicable in rain fed areas of the country. So the management of water is essential for drinking as well as irrigation purpose (ENVIS Newsletter, 2008). The most common standards used to assess water quality relate to drinking water, safety of human contact and for health of ecosystems. Gayananath et. al. 2001 also assessed environmental parameters on groundwater quality. Remesan & Panda, 2008 prepared water quality and risk zone mapping using remote sensing and geographical information system (GIS). An understanding of the various factors influencing water quality is thus very important as human health is largely dependent on the quality of water available for use.

Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The terms basin, catchment, watershed etc. are widely used to denote hydrological units (Watershed Atlas of India, 1990). The watershed area is therefore an ideal water management unit. High resolution satellite data and GIS techniques were also used for sustainable development in semi-arid regions on micro-watershed basis (Arya et.al.2010). Hence the size of a watershed is governed by the size of the streams occupied by it.

Remote sensing, Geographical Information System (GIS) and Global Positioning System (GPS) techniques have capability to provide reliable information for spatial planning's. The synoptic large area repetitive Coverage provided by satellite sensors can provide appropriate data base for water and watershed management Practices.

STUDY AREA

The study area comprises of ten micro- watersheds of Mahendergarh district in Haryana viz. Nangal Mala, Usmanpur, Zerpur-I&II, Mandola-I&II, Adalpur, Dholi, Khudana-II, Khudana-V located between 28^0 18' 0" N to 28^0 25'30"N and 76^0 30' E to 76^0 9' 15"E covering an area of 5585.64 ha as shown in Figure-1.

Mahendergarh District is situated in south-western part of Haryana, has an area of 1899 sq.km. Geographically it is bordered by Bhiwani district in north, Rewari district in east, Alwar, Jaipur and Sikar in south and in west by Sikar and JhunJhunu district of Rajasthan State.

PHYSICAL DESCRIPTION

The district is dominated by dry lands with presence of inland streams, sandy plains, shifting sand dunes, stabilized sand dunes, dissected uplands tracks and often barren, denuded, rocky hill ranges and their outcrops, consequently, the overall relief are undulating with a regional slope from north to northeast. Area covered with sandy plains encloses western & eastern section of Aravalli ranges mostly in Mahendergarh tehsil. The area of shifting sand dunes is locally known as Bagar, Rocks outcrops traverse through most part of district in roughly southwest to northeast direction. The hills are linear, forming roughly parallel series of ridges.

The drainage of the district comprises seasonal streams Dohan & Krishnawati make irregular flood plains. These streams are active only during the rainy season. The seasonal flowing of Dohan & Krishnawati periodically raises the fresh quality water. It also helps base flow during early part of the dry season.

The climate conditions in the district vary from arid to semi-arid .The summer months are very hot whereas winter season is fairly cool & dry during the months of December & January. Occasionally, frost also occurs in winter. The average annual rainfall of the district is 499mm. About 75% of rainfall is received during the south-west monsoon months i.e. July to September. July & August are the rainiest months in the year.

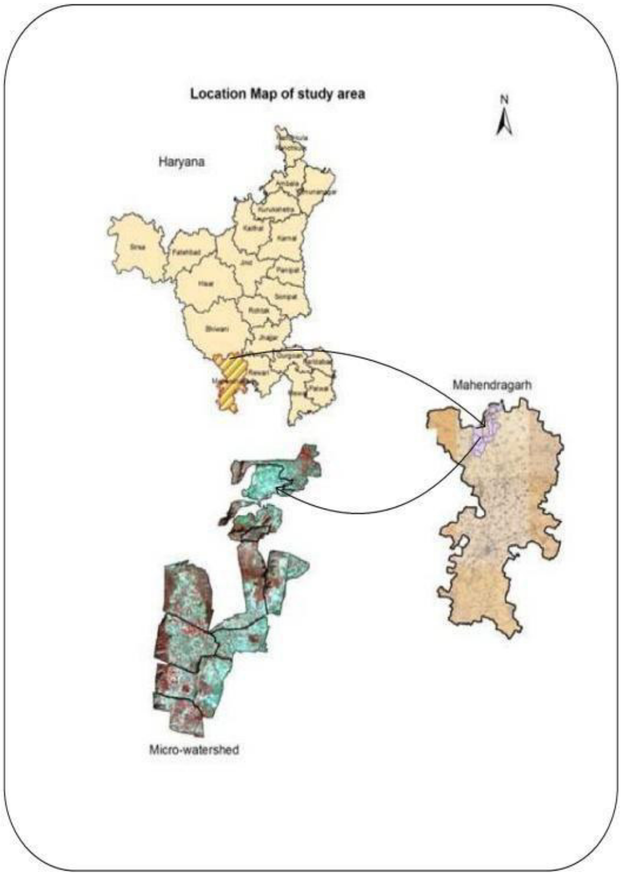

Fig-1: Location Map of Study Area

Temperature begins to rise from March to June. The mean daily maximum temperature is about 45^{0}C. This may go up to 48^{0}C. After October, there is decrease in both day & night temperature. January is the coldest month with daily mean temperature of 11^{0}C.

MATERIALS AND METHODOLOGY

The Indian Remote Sensing Satellite data (IRS-P6, LISS-IV) was used for the study. Satellite sensor or sensor specifications and acquisition dates for the data used during the analysis are given in table-1 and table- 2.

Table 1: Satellite Data Used.

Satellite	Sensor	Date of acquisition
IRS-P6	LISS-IV	Oct.29, 2007
IRS-P6	LISS-IV	Nov.17, 2007
IRS-P6	LISS-IV	Nov.17, 2007
IRS-P6	LISS-IV	Mar.22, 2007
IRS-P6	LISS-IV	Feb.22, 2007
IRS-P6	LISS-IV	Apr.15, 2007

Table -2: Satellite sensor Specifications.

Resolution	IRS-P6 LISS-IV
Spatial	5.8m
Spectral	B2 0.52-.59 µm (Green) B3 0.62-.68 µm (Red) B4 0.77-.86 µm(NIR)
Radiometric	7 bit
Temporal	24 days
Swath	23.9 km (multispectral mode) 70 km (Monomode)

Ancillary Data

Survey of India Topographical Sheets: 53D/3, 53D/4, 54 A/1 on 1:50,000 scale.

Microwatershed boundary maps were collected from Department of Agriculture, Haryana.

Software Used

ERDAS IMAGINE-9.3, ARC/MAP-9.3, and handheld GARMIN-72 GPS.

Satellite data used for the study was geo-referenced and the vector layers of micro-watersheds boundaries were overlaid on the satellite image. A detailed ground water quality survey was also conducted.

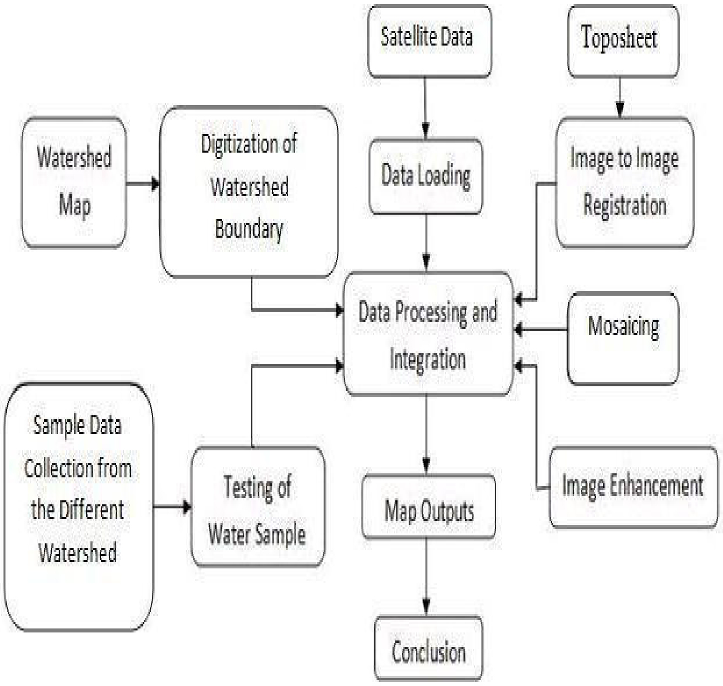

Fig-2: Methodology flow chart

Total 29 Ground water samples from operational tube wells representing different micro-watersheds were collected. GPS locations in the form of latitudes & longitudes were also taken and their locations were marked on the map. The collected water samples were analyzed for their chemical properties using following methods outlined by Richards (1954). The water quality was judged as per the criteria as shown in table-3.

Table-3: Water quality classification criteria.

Quality class	**EC (µS/m)**	**RSC (meL^{-1})**
Good	<2	Usually <2.5
Normal	2-4	<2.5
Marginal Saline	>4	absent
Sodic	<4	<>2.5

RESULTS AND DISCUSSION

The collected/tested water samples were classified after analyzing their chemical properties into different quality classes. The water quality classes along with their locations are given in table-4. Brief description of various classes is given below and their areal extent is shown in table-5.

Good: This quality of ground water was found in nine microwatersheds. It covered an area of 3396.67 ha and constitutes 60.81% of the total area of all the microwatersheds. These waters are fit for irrigating all agricultural crops as well as for drinking purposes for human and animals.

Table-5: Area Under Different water quality classes

Category	Area (ha).	% of Geographical area
Good	3396.67	60.81
Normal	40.339	0.72
Sodic	182.24	3.26
Marginal- Saline	1966.38	35.20

Normal: This class occupied an area of 40.34 ha in Khudana-IV, Khudana-V, Microwatersheds. It constitutes 0.72 % of the total study area. These waters can also be used for agriculture as well as drinking purposes. As the electrical conductivity is more than 2 so these waters can be harmful for the salt sensitive crops.

Sodic: Sodic water was found in khudana –V and Adalpur microwatersheds covering an area of 182.24ha which is 3.26 % of the study area. These waters are very harmful to crops as well as for soils. These are unfit for irrigation and should not be used for any purposes.

Marginal saline: This category occupied an area of 1966.38 ha and constitutes 35.20 % of the study area. It was mainly found in Mandola-I&II, Zerpur- I&II, Dholi, Adalpur or Kudana-II microwatersheds. These waters can be used after mixing with canal water and in sandy soils.

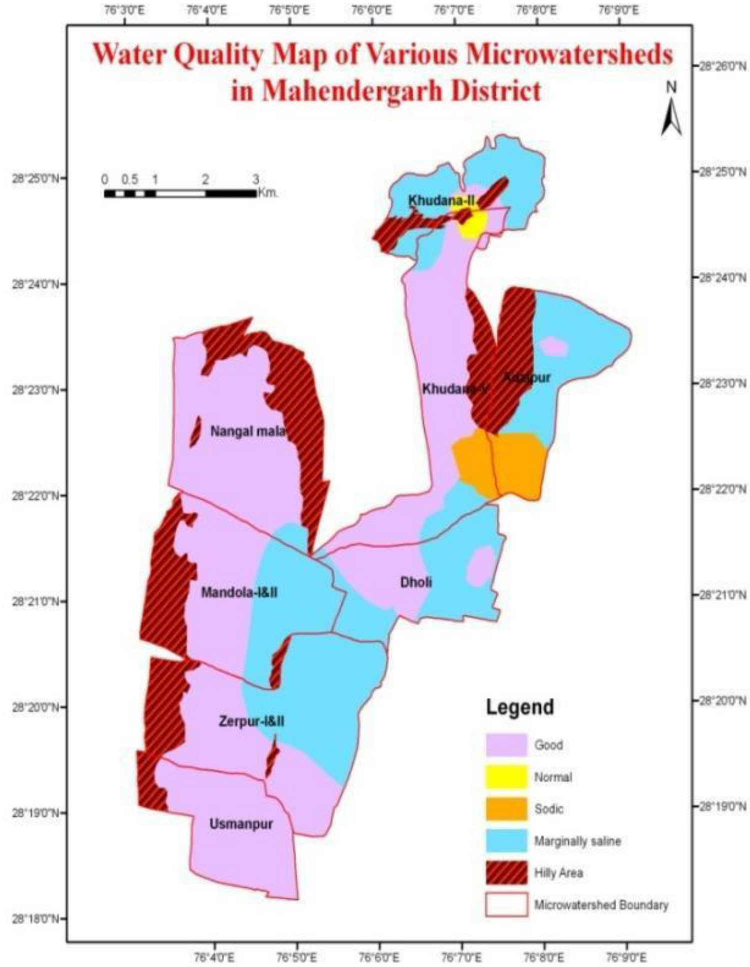

Fig-3: Water quality Map of Various Micro- watersheds.

CONCLUSIONS

The ground water quality maps of these microwatersheds can be very useful for micro-level planning. The saline and sodic waters should not be used for irrigation as they will degrade the soils of concerned microwatersheds. Based on the information generated along with the soil information, the crops can be suggested to the farmers of that area.

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