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A Proposed New Approach for Groundwater Resources Assessment in India

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Abstract: Assessment of groundwater resources in India is guided by National Water Policy (1987, 2002) which states that groundwater resources can be exploited only up to its recharge limit. The methodology for groundwater resources assessment in India is broadly based on Ground Water Resources Estimation Methodology, 1997 and it involves assessment of annual replenishable groundwater resources (recharge), annual groundwater draft (utilization) and the percentage of utilization with respect to recharge (stage of development). The assessment units (blocks/watersheds) are categorized based on stage of groundwater development (utilization) and the long term water level trend. The present methodology though useful in identification and prioritization of areas for groundwater management, falls short of addressing several critical issues like spatial and temporal variation of groundwater availability within the aquifer, accessibility of groundwater resources and quality of groundwater. This paper introduces a new categorisation scheme considering the above issues. The proposed scheme takes into account four criteria, viz. (i) stage of exploitation, (ii) extractability factor, (iii) temporal availability factor and (iv) quality factor. In comparison to the existing method used for categorisation, the proposed approach is more inclusive. The methodology is also equally suitable for both alluvial and hard rock terrain since it takes into consideration the variable characteristics of different types of aquifers and convergence of quantitative and qualitative assessment. The categorisation proposed here involves GIS based integration of different parameters/ themes. This allows better representation of spatial variability. The proposed methodology is demonstrated in this paper taking a case study from a hard rock terrain in central India.

Keywords: Groundwater Resources Assessment, GEC’97, Stage of Exploitation, Extractability Factor, Temporal Availability, Groundwater Quality, Categorization

INTRODUCTION

India with the geographical area of around 3.2 million Km^2 and population of more than one billion, is heavily dependent on groundwater. There are nearly 20 million groundwater abstraction structures in India as per the estimates of Minor Irrigation Census, 2006-07 (Ministry of Water Resources, 2007). The figure has been further revised to about 30 million by the Planning Commission Working Group on “Sustainable Ground Water Management” (Planning Commission, 2011). More than 70% area of the country is occupied by hard rock aquifers. Rainfall, which is the main source of groundwater recharge varies widely from negligible in the deserts of western India to as high as 11000 mm in the north-eastern part of the country. Groundwater resource availabilities within the country therefore show wide variation. Hence country level assessment of groundwater resource in India is a necessity and a challenge.

Assessment of groundwater resources has been undertaken in various parts of the world including India, since it is the basic pre-requisite for planned groundwater resources management. Assessment of groundwater resources is usually done periodically and the methodologies for assessment are also revised periodically (Chatterjee & Ray, 2014). The first attempt to assess groundwater resources in India was made in 1972. India has since moved to a more systematic assessment based on the groundwater estimation methodology, which is popularly known as GEC’97 (Ministry of Water Resources, 1997). This methodology has attained its present form after several revisions (Sharma, 2006). So far three assessments of groundwater resources have been completed in India using GEC’97 for the years – 2004, 2009, and 2011. The resource assessments were carried out jointly by the Central Ground Water Board and the State Ground Water Departments. The assessments take into account annual recharge from rainfall, and other sources, as also groundwater withdrawal for various purposes. The assessments also involve categorisation of the assessment units, based on the status of exploitation which forms the basis for various management interventions and regulatory measures.

The categorisation done by this method broadly matches the ground situation. However, with increasing dependency on groundwater resources to meet demands from various sectors, further precision in categorization is required for formulation of more pragmatic groundwater management programme.

The objective of this paper is to suggest a new approach for groundwater resources assessment in India which is more realistic and proactive in identification and demarcation of groundwater potential and vulnerable zones, the two key issues of groundwater management.

GROUNDWATER RESOURCES ASSESSMENT METHODOLOGY IN INDIA – STRENGTHS AND LIMITATIONS

National Water Policy (1987, and revised in 2002), enunciates that, 'exploitation of groundwater resources should be so regulated as not to exceed the recharging possibilities…'(Ministry of Water Resources,2002). Therefore, the 'Exploitable Groundwater Resources' is limited to the annual groundwater recharge. A methodology for assessment of groundwater resources has therefore been formulated to estimate the 'annual recharge', 'annual utilization' and 'percentage of utilization'. The assessment methodology is known as Ground Water Resource Estimation Methodology -1997 or more commonly in short form as - GEC'97 (Ministry of Water Resources, 1997). GEC'97 is based on the premise of lumped water balance. The geographical unit of assessment is a block (an administrative unit) in the states predominantly occupied by alluvium and watershed in the areas occupied predominantly by hard rocks. The detailed guidelines for estimation of groundwater resources using the methodology of GEC'97 is available on the public domain (Central Ground Water Board, 1998). The major steps of the methodology are depicted in Fig.1 (Chatterjee and Purohit, 2009). The assessment involves estimation of 'annual replenishable ground water resource', which is the sum-total of monsoon and non-monsoon recharge. Keeping an allocation for natural discharge, 'net annual ground water availability' is arrived at. 'Annual ground water draft' is estimated based on groundwater withdrawal for irrigation, domestic and industrial purposes. The percentage of 'annual ground water draft' with respect to 'net annual

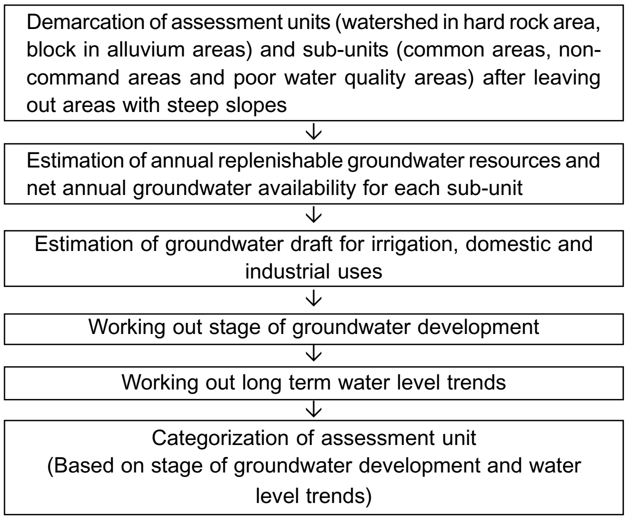

Fig.1. A broad outline of the groundwater resource estimation methodology (GEC'97) followed in India. (Chatterjee and Purohit, 2009).

ground water availability' is computed to find out the 'stage of ground water development'. The assessments are also linked to the groundwater management as they provide a categorisation scheme for prioritisation of areas for groundwater management. Assessment units are categorized as 'safe', 'semi-critical', 'critical' and 'over-exploited' based on the stage of ground water development and long term water level trend (Table 1).

Considering the constraints posed by the availability of groundwater budget related data in India, GEC'97 has some advantages: (a) The method is a lumped approach and, therefore, relatively simple to use; (b) It is suitable with regard to the data normally available from groundwater-level monitoring programmes of the state and central agencies; (c) Application of water-level fluctuation (WLF) method is suitable for recharge assessment at regional scale and at periodical intervals (Scanlon et al. 2002); (d) intrinsic

Table 1 Categorisation scheme as per existing methodology - GEC'97 (Chatterjee & Purohit, 2009)

Sl. No.	Stage of Ground Water Development	Significant Long term Decline		Categorization
		Pre-monsoon	Post-monsoon	
1	≤70%	No	No	Safe
2	>70% and ≤90%	No	No	Safe
3		Yes/No	No/Yes	Semi- Critical
4	> 90% and ≤100%	Yes/No	No/Yes	Semi-Critical
5		Yes	Yes	Critical
6	> 100%	Yes/No	No/Yes	Over- Exploited
7		Yes	Yes	Over- Exploited

process of validation exists within the methodology. Since monsoon rainfall is the most significant contributor to groundwater recharge in India, the rainfall recharge during the monsoon season estimated by WLF method is validated with norms of rainfall infiltration factor (RIF) as suggested in GEC'97. Further, the stage of ground water development is validated with long term water level trend (Chatterjee and Purohit, 2009).

However, GEC'97 has some major limitations, like (a) in this approach, a block or watershed is categorized (safe, semi-critical, critical or over exploited) as a whole. Thus variations in hydrogeological conditions within the assessment unit cannot be brought out, (b) similarly, temporal variations in groundwater availability particularly in hard rock terrain are not reflected in GEC'97. In the present assessment there are instances, when a unit has been categorised as safe, yet the area faces acute shortage of groundwater during the summer, (c) the methodology primarily deals with the storage property of the rock formation (specific yield). The transmission property of the rock formations is ignored. Thus there are instances in hard rock terrain, where the assessment unit has been categorized as 'safe' while there is no worthwhile groundwater development prospect in the area. This mismatch between category and ground situation often confuses managers and planners of groundwater, (d) GEC'97 recommends assessment of groundwater resources of poor groundwater quality areas separately. However, different levels of groundwater contamination are not properly reflected in the categorisation. As pointed out in the Planning Commission Report of the Working Group on Sustainable Groundwater Management, 'there must be a convergence of assessment of groundwater in terms of quantity and quality for accurate estimation' (Planning Commission, 2011).

In the following paragraphs, a new methodology for categorisation is proposed which while retaining the basic approach of the existing methodology, addresses the issues that hitherto remained untouched. The proposed categorisation scheme primarily aims at presenting the holistic information on groundwater regime of an area to a groundwater manager.

PROPOSED APPROACH FOR CATEGORISATION

The Concept

The proposed concept suggested in this paper is inspired by the approach adopted for ground water resources assessment in South Africa (DWAF, 2006 A, B, C). The basic attribute of the assessment methodology as enumerated in the DWAF reports include the determination of harvest potential which is mainly an estimation of recharge and storage. Harvest Potential is then used for estimation of ground water resources potential. Ground water resource potential is further converted into groundwater exploitation potential, potable groundwater exploitable potential and utilizable groundwater exploitation potential. Exploitation potential takes into consideration the yield of borewells, potable exploitable potential accounts for quality aspect and finally, utilizable potential takes into consideration the ecological factors and other management related issues.

In line of the above, the integrated categorisation scheme proposed in this paper provides a single prioritisation index incorporating all the major groundwater related components that impact decisions in groundwater management. The categorisation scheme proposed incorporates the following criteria: (i) groundwater recharge, (ii) groundwater extraction, (iii) long term groundwater level trend, (iv) temporal variability in availability of groundwater resources, (v) groundwater accessibility and extractability and (vi) groundwater quality. The category would be determined considering the following four parameters – (i) stage of exploitation (SOE), (ii) extractability factor (EF) (iii) quality factor (QF), (iv) temporal availability (T_{avail}). Each mapped factor is classified into ranges and each range was assigned a rank (Table 2). All the parameters were assigned equal weight.

Stage of exploitation (SOE) as adopted in this paper can be defined as the ratio of annual ground water draft (extraction) and net annual ground water availability (net recharge) expressed as percentage.

$$\text{SOE} = \frac{\text{Annual Ground Water Draft} \times 100}{\text{Net Annual Ground Water Availability}} \qquad (1)$$

This term is synonymous with the stage of ground water development as in GEC'97. SOE is validated with long term groundwater level trend (Table 1). The ranges as adopted here are according to the classifications recommended by GEC'97.

As discussed earlier, it has been observed that many of the 'safe' category assessment units particularly in hard rock areas, do not have good ground water potential, since categorization is based on ratio of water recharged vs. water extracted. It is quite natural that in areas where ground water availability is less due to poor recharge, ground water extraction would also be less. Thus such areas would fall in 'safe' category because of meagre extraction rather than being under-exploited as reflected in the category nomenclature. It is, therefore, proposed that in hard rock areas, along with delineation of hilly and forested areas, the unweathered massive zones should also be delineated

Table 2. Indices of Parameters recommended for Categorization

Parameter	Range/criteria	Index
Stage of Exploitation(SOE)	Range of Stage of development	
	Safe (Stage of development less than or equal to 70)	1
	Safe (Stage of development more than 70 but less than 90)	0.7
	Semi-critical	0.5
	Critical	0.1
	Over-Exploited	0
Extractability Factor (EF)	Ranges of Well Yield	
	>25 litres per second	1
	6 to 25 litres per second	0.7
	3 to 5 litres per second	0.5
	< 2 litres per second	0.1
Quality Factor (QF)	Prevailing water quality situation	
	Unmodified, pristine conditions – Natural groundwater quality conditions prevail OR*Localised, low levels of contamination, but no negative impacts apparent* – Largely natural groundwater quality conditions prevail	1
	Moderate levels of localised contamination, but little or no negative impacts apparent– Some localised contamination detected; may impact the purpose for which groundwater is used. Example: Localised occurrence of high hardness or Iron in ground water.	0.7
	Moderate levels of widespread contamination, which limit the use or potential use of the aquifer – Groundwater contamination is quite widespread but levels are relatively low; may impact the purpose for which groundwater is used. Example: Mappable areas with salinity, Fuoride, Arsenic, Industrial pollution etc.	0.5
	High levels of local contamination, which render parts of the aquifer unusable – High levels of contamination detected in places; use of groundwater from impacted area to be restricted or prohibited. Example: widespread occurrence of Arsenic, Fluoride etc.	0.1
	High levels of widespread contamination which render the aquifer unusable – Very high levels of contamination widespread throughout the aquifer. Groundwater use to be restricted or prohibited. Example: Saline aquifers	0
Temporal availability (T_{avail})	Groundwater Resources in the lean period (summer) as compared to the resources in the *rabi* (winter) period	
	$\Delta S_{lean\ period} \geq 50\%$ of ΔS_{Rabi}	1
	$\Delta S_{lean\ period} \geq 33\%$ & $< 50\%$ of ΔS_{Rabi}	0.7
	$\Delta S_{lean\ period} \geq 10\%$ & $< 33\%$ of ΔS_{Rabi}	0.5
	$\Delta S_{lean\ period} < 10\%$ of ΔS_{Rabi}	0.1

from the total area of the assessment unit for correct recharge estimation. In addition, an extractability factor is introduced to address the issue of the development potential of the aquifer.

Extractability factor (EF) is based on the fact that the groundwater recharge estimates do not give an indication of what can practically be pumped out of an aquifer unit. The extraction of groundwater resources depends on the rate at which groundwater is transmitted within the aquifer material i.e. the hydraulic conductivity or transmissivity of the aquifer systems. However, good information on distributions of hydraulic parameters is often unavailable. Since there is a good correlation between well yield and transmissivity, the degree of groundwater extractability (accessibility) is reflected in borehole yield distributions. Therefore 'well yield' can be used as an index of ground-water extractability (accessibility), which is termed as extractability factor (EF) (DWAF, 2006a). Kaehler and Hseih (1994) have used 'well yields' as a tool for comparison of yield characteristics of different hydrostratigraphic units. The well yield data is proposed to be adopted from the hydrogeological map/ ground water potential zone maps prepared by Central Ground Water Board/ State Ground Water Departments. The recommended EF indices are given in Table 2.

Quality factor (QF) is the rating of groundwater quality, which is an important consideration in groundwater management. In India, pollution of groundwater has been reported from isolated pockets of several districts (Central Ground Water Board, 2014). A rating of groundwater quality and its numerically equivalent quality factor (QF) as included in the proposed scheme of categorisation (Table 2) takes into account degree and extent of groundwater pollution. Quality consideration includes all types of contamination which may render groundwater unfit for use in any of the three sectors viz. Irrigation, domestic and/or industry. While detailed techniques like tracing pollution plumes or solute transport modelling could provide much realistic assessment of groundwater quality in an area, a simplified approach is proposed here considering the existing availability of data and country wide applicability of the categorisation scheme.

Availability of groundwater resources (recharge) particularly in hard rock terrain is not uniform throughout the groundwater year. The monsoon recharge in hard rock terrain often dissipates at a faster rate resulting in lesser availability of the resource on field during the lean (non-monsoon) period than projected based on monsoon recharge estimation. Therefore a factor called temporal availability factor (T_{avail}) is introduced (Table 2).

ΔS_{Rabi} and $\Delta S_{lean\ period}$ can be estimated using eq. 2 and eq. 3.

$$\Delta S_{Rabi} = \Delta h_{May–Nov} \times Area \times Sy \quad (2)$$

$$\Delta S_{lean\ period} = \Delta h_{May\ (prev.\ year)\ –\ Jan.} \times Area \times Sy \quad (3)$$

where ΔS_{Rabi} = available groundwater resources during rabi (winter) period. $\Delta S_{Lean\ period}$ = available groundwater resources during lean (summer) period; $\Delta h_{May\text{-}Nov}$ = fluctuation in water table from May to November in the year of assessment; $\Delta h_{May(prev.yr.)\text{-}jan}$ = fluctuation in water table from May (previous calendar year) to January; Area = area of the assessment unit; Sy = specific yield.

As adopted in the proposed categorisation (Table 2), T_{avail} indices are assigned based on the ratio of $\Delta S_{Lean\ period}$ to ΔS_{Rabi}. Since for any particular area Sy can be considered constant, the ΔS ratio is equivalent to the Δh ratio for all applications in the proposed scheme of classification. Δh ratios can be used to represent ΔS ratios in assigning indices (Table 2).

The category index (CI) proposed here is defined as

$$CI = SOE \times EF \times QF \times T_{avail} \quad [\text{for } SOE/T_{avail}/EF/QF > 0.1] \quad (4)$$

$$CI = 0.01 \ [\text{for } SOE/T_{avail}/EF/QF = 0.1] \quad (5)$$

$$CI = 0 \ [\text{for } SOE/T_{avail}/EF/QF = 0] \quad (6)$$

where, *CI* = category index; *SOE* = stage of exploitation; T_{avail} = temporal availability; EF = extractability factor; QF = quality factor.

GIS Application for Categorization

The methodology proposed here involves GIS based integration of different types of spatial variables using index overlay method (Bonham-Carter, 1994). Index overlay is a technique, which is widely used to assemble mutually related information on a GIS platform to generate integrated maps. In the present example, the map manipulations were carried out using MapInfo 6.5 (with vertical mapper). The map integration can be done using any software that supports map based calculations like ArcGIS, MapInfo, Surfer etc. These integrated maps are interpreted by scoring, integrating or classifying the information to produce indices, ranks, classes etc. The scoring, ranking and integration methods are user defined. For map based calculations, four separate maps as per the parameters/themes defined above are generated. The maps are then rasterised, reclassified and indices are assigned as given in Table 2. These four maps are then multiplied using a GIS based tool to generate the resultant map. This resultant map, in turn, is reclassified to generate the final map of the category index. A colour scheme is proposed for various Index components viz. SOE, EF, QF, T_{avail} and CI (Table 3).

Categorisation of Assessment Units and Groundwater Management

Guidelines given in Table 4 are recommended as groundwater management option in the areas with specific category indices. While devising detailed management plans, all the attributes like recharge, exploitable resources, groundwater resource availability in rabi and lean periods, groundwater draft for different purposes, stage of exploitation, extractability of aquifer, quality of groundwater etc. are to be considered. As regards the colour codes (Table 3), various shades of blue indicate places where groundwater exploitation is feasible. Yellow colour indicates that the conditions are alarming and red colour denotes extreme condition. If any of the index component is of yellow or red colour, the same will prevail upon the region, rendering it unsuitable for groundwater exploitation. Necessary groundwater management interventions need to be adopted based on the type of the component which has poor index rating. The colour coding scheme proposed here is a generalized scheme. The colour scheme can be modified depending on the local hydrogeological conditions and scale of study.

GIS BASED APPROACH FOR ASSESSMENT OF CATEGORY INDEX - A CASE STUDY FROM CENTRAL INDIA

GIS based procedure recommended for calculation of the category indices is demonstrated here with a sample area

Table 3 Colour scheme for various Category Indices in GIS platform

Colour Scheme (Rating)	Classification	Groundwater Potentiality
SOE		
1	Very Low	Highly Feasible
0.7	Low	Feasible
0.5	Moderate	Moderate Feasibility
0.1	Very High	Alarming
0	Over-exploited	Not Recommended
EF		
1	Very High	Highly Feasible
0.7	High	Feasible
0.5	Moderate	Moderate Feasibility
0.1	Low	Poor yielding Aquifer
QF		
1	Very Low	Highly Feasible
0.7	Low	Feasible
0.5	Moderate	Moderate Feasibility
0.1	High	Alarming
0	Very High	Not Recommended (Contaminated)
Tavail		
1	Very High	Highly Feasible
0.7	High	Feasible
0.5	Moderate	Moderate Feasibility
0.1	Low	Poor yielding Aquifer
0	Very Low	Not Recommended
CI		
>0.7	Very Low	Highly Feasible
0.24 - 0.7	Low	Feasible
0.06 - 0.23	Moderate	Moderate Feasibility
0.0 - 0.06	High	Alarming
	Very High	Not Recommended

of nearly 2000 km^2 from Seonath sub-basin covering three blocks (Durg, Patan and Gunderdehi) of Durg district in Chhattisgarh state, India (Fig.2). The area consists of Precambrian sedimentaries of Chhattisgarh Supergroup (Das et al., 1992, Mukherjee et al., 2014). Southern part is

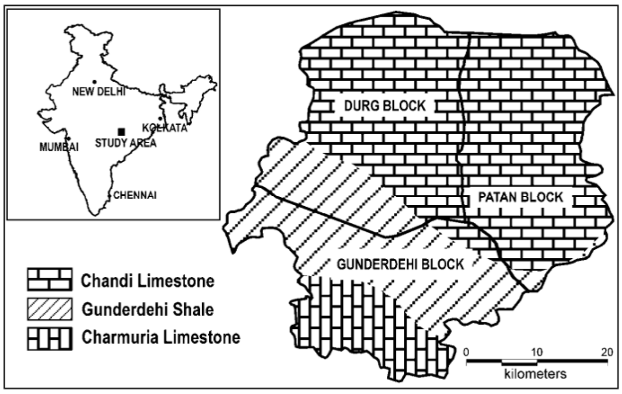

Fig.2. The case-study area (parts of Durg District, Chhattisgarh State) with the major hydrostratigraphic units.

Table 4 Category Indices and recommended ground water management options

Category Index (CI)	Management Option
Between 0.06 and 1.00	Areas suitable for ground water development. More the CI, higher is the feasibility for ground water development.
Greater than 0 but less than 0.06	Areas for implementation of artificial recharge and rainwater harvesting, quality remediation depending on the prevailing hydrogeological conditions. Lower the CI, higher is the priority of the area for management interventions
CI=0	Areas to be considered for regulation, resource augmentation and quality remediation depending on the prevailing hydrogeological conditions

occupied by Charmuria Formation which comprises karstified limestone. Gunderdehi shale, which has a gradational contact with the underlying Charmuria Formation and occupies nearly 30% area in the central part. The northern part is covered by Chandi Formation, which is mostly limestone. Both Charmuria and Chandi formations (limestones) make potential aquifers in the area. Gunderdehi shale, on the other hand, has very limited groundwater potential. There is significant variations in groundwater potential and quality in the area. Monthly water levels were recorded from a network of 49 monitoring wells (Fig.3) in the study area as part of another study carried out by Central Ground Water Board (CGWB), North Central Chhattisgarh Region, Raipur. All these wells are dugwells

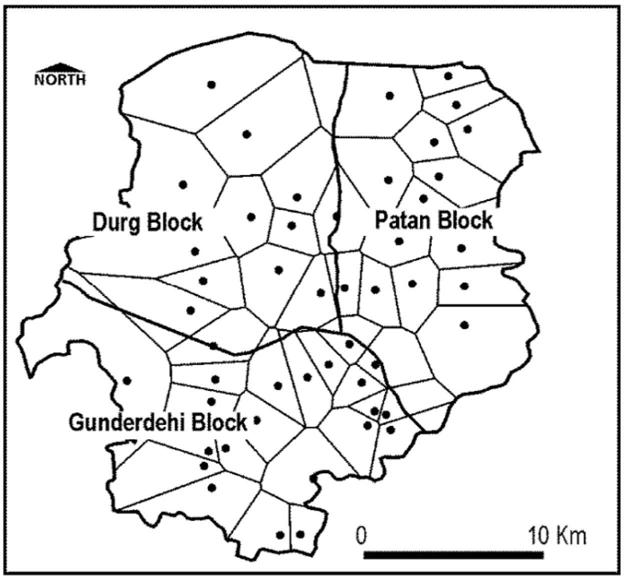

Fig.3. Location of water level monitoring wells (black dots) in the study area and the Vornoi diagram generated based on these monitoring wells. The Vornoi diagram was generated using MapInfo software.

with depth ranging from 6 to 18m. Water levels in these wells remain mostly within 10m during premosoon period and within 5m below ground level during the post monsoon period. The existing ground water resources categorisation based on blockwise stages of ground water development does not represent the on field variations in groundwater development potential. Calculation of category indices is shown here considering the existing basic data. The calculation is done in two broad steps. (i) preparation of input maps and (ii) calculation of category indices using these input maps.

Input Maps

The procedure requires four input maps (Fig.4a to d). Existing estimates of block wise stages of ground water development and long term water level trends were considered for assigning SOE indices (Fig.4a, Table 2). The study area comprises parts of three assessment units (blocks) Durg, Patan and Gunderdehi (Fig.2). As per the groundwater resource assessment for the year 2009 carried out based on GEC'97, the stages of ground water development in Durg, Patan and Gunderdehi blocks are 84%, 72% and 61% respectively. While Durg and Patan are categorised as 'semi-critical' (Table 1), Gunderdehi is categorised as 'safe'. Based on the stages of development, Durg and Patan blocks were assigned SOE index 0.5 and Gunderdehi block an SOE index of 1 (Fig.4a).

Central Ground Water Board (CGWB) as a part of its exploratory drilling programmes has constructed 20 water wells tapping the individual hydrosratigraphic units existing in the study area. The study has established that the aquifers are vertically connected and the potential zones are mostly restricted to 70m. Well yield determined in Gunderdehi shale remain mostly within 1 litres per second (lps). Chandi limestone and Charmuria limestone are much more productive than the Gunderdehi shale. Yields of borewells in Chandi Formation remain mostly around 4 litres per second (lps) in the study area while in Charmuria limestone well yield is upto 12 lps. As per the criteria given in Table 2 extractability factors (EF) were assigned to Charmuria limestone, Gunderdehi shale and Chandi limestone as 0.7, 0.1 and 0.5 respectively and plotted as three separate regions (polygons) on the map (Fig.4b).

Groundwater in the study area is mostly potable except a few instances of high sulphate (Ray and Mukherjee, 2008) in the two isolated patches in Durg and Gunderdehi blocks and high hardness reported from the northern and southern parts of the study area. High sulphate which is associated with gypsum veins renders groundwater unfit for drinking purposes in two isolated pockets. The issue of high hardness

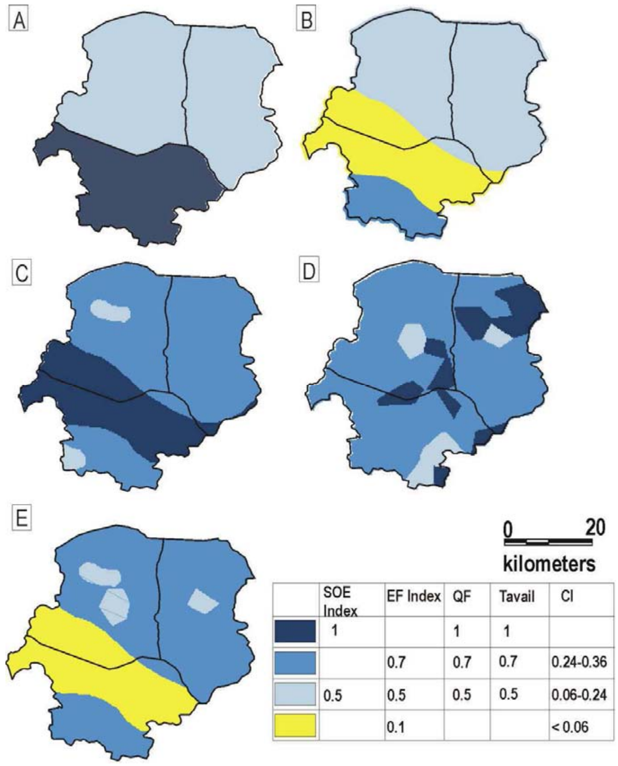

Fig.4: Input maps (**A** to **D**) for GIS based calculation and the resultant category indices (**E**) calculated for a case study area in parts of Durg, Patan and Gunderdehi blocks of Durg district, Chhattisgarh. **A**: Stages of Exploitation (SOE) and SOE indices **B**: Extractability Factors (EF), **C**: Quality Factor (QF), **D**: Temporal Availability Factor (T_{avail}), **E**. Category Indices (CI)

caused mostly by high concentrations of $CaHCO_3$ is diffused in nature and is less severe in comparison to pollution due to sulphate. The area with high sulphate in groundwater was assigned a QF of 0.5 and the area with high hardness was assigned a QF of 0.7 (Fig 4c).

Temporal availability factors (T_{avail}) were estimated based on monthly water levels. The location of 49 wells as described were plotted on a map and a Vornoi diagram was generated, the Vornoi polygons represent the area of influence of the respective monitoring wells (Fig.3). Water levels recorded from the monitoring wells were assigned to the respective polygons. As described above, the ratio of water available in the lean period to that in the rabi period (eq. 2 and eq.3) is equivalent to the ratio of the water level fluctuations in the respective periods. Such ratios were estimated for each polygon. Based on these ratios, the temporal availability factors (T_{avail}) were calculated for each polygon. The GIS based map, thus produced, has a set of polygons with the respective temporal availability factor included as attribute of the individual polygon (Fig 4d).

Map Integration

The four input maps have distinct regions with assigned indices. For GIS based processing for calculation of category indices (CI), the input maps were first rasterised. These four rasterised maps were then multiplied in a GIS platform. The product of these four maps is the resultant raster map with the category indices. The resultant raster map is then reclassified (Fig 4e). While reclassifying, the ranges of category indices were so chosen as to ignore outliers so as to demarcate only regional variations. This is done to demarcate the areas for implementation of various groundwater management interventions at a regional scale. Commensurate with the scale of the inputs, larger ranges were chosen for preparation of the final category index map. With more detailed information for the input maps, maps showing detailed variations in category indices can be prepared as an aid for village-level groundwater management.

CONCLUSIONS

A new categorisation scheme is introduced which integrates four aspects-stage of exploitation, extractability, groundwater quality and availability in lean period.

The advantage of the proposed approach is its flexibility. The methodology can be implemented on a detailed scale in case village-wise data are available and village-level management interventions are envisaged. On the other hand, at a larger scale, it can replace the existing approach of groundwater resources assessment by providing much more information on the groundwater regime of the area in a more user friendly manner. In the proposed methodology, administrators and water resources mangers have the choice of fixing the desirable limit of each category index. For example, in water scarce area, the desirable limit of various categories as suggested in the present paper can be retained but in areas where water resources are sufficiently available, more stringent limit for various category like quality (QF) etc. can be fixed. Thus, groundwater management practices would be more in accordance with the actual ground situations.

The methodology introduces a new guideline for linking groundwater assessment with management. More field tests are to be conducted and further deliberations are required to firm up the linkage between assessment and management in varied hydrogeological conditions across India. The bottom line of success of the assessment methodology remains on the quality of data used for the study and the logical application of the methodology keeping in mind the prevailing hydrogeological setup of the assessment area.

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