Groundwater Pricing in Over-exploited Torehalla Watershed (4B4B2), Hassan District, Karnataka — A Scientific Approach

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Abstract: Ground water is the most reliable resource to meet domestic and agricultural water needs and for agricultural demands where the surface water is scarce. As a consequence of increased groundwater reliance, the stage of groundwater development in many watersheds in Karnataka state is semi-critical to over-exploited. The cost of ground water extraction in over-exploited areas is high due to the increased cost of drilling and electricity charges. In order to reduce the groundwater extraction, pricing in over-exploited watershed and conservation of watershed should be taken up. The groundwater pricing should be in tandem with the cost involved for construction of Artificial Recharge Structures (ARS). Based on the groundwater resources estimation, in Torehalla watershed covering total geographical area of about 455 sq.km., the net annual groundwater availability is 6277 ha.m., which is 764 ha.m. less than the gross groundwater draft for all uses. An attempt has been made to balance the groundwater availability and draft for all uses in a watershed. Geomorphological, geology and lineament have been interpreted using IRS-ID satellite data and aero-magnetic breaks map prepared based on aero-magnetic contour map. Based on the drainage map of the watershed, sub-watershed has been demarcated and the drainage morphometric characteristic of micro-watershed has been analysed. Geomorphology, geology, lineament, aero-magnetic breaks, landuse/landcover, soil layers and morphometric characteristic have been generated in GIS and integrated using weighted index overlay model to derive feasible artificial recharge structures in micro-watershed. Based on the number of ARS to be constructed in the watershed, groundwater pricing is proposed for future planned development of the watershed.

INTRODUCTION

Preventing the excess surface runoff in the watershed, by constructing recharge structures, can reduce the burden of aquifer systems. Identification of suitable sites for constructing recharge structures is essential to extract benefit efficiently. Integration of information derived from the satellite data interpretation coupled with Geographical Information System (GIS) makes it possible to identify the suitable structures for construction. Singh et al. (1996) and Behera and Mohapatra (1996) have carried out studies on the application of remote sensing techniques for suggesting suitable sites for soil and water conservation measures in various watersheds of the country. Chandar Shekhar and Rao (1999) suggested suitable sites for various water harvesting structures like farm ponds, check dams, bunds for watershed of Song river in the Doon valley of Uttaranchal.

Quantitative measurements of the drainage basin and its parameters are also essential to understand the nature of the drainage basin. Morphometric analysis could be used for prioritisation of watersheds by studying different linear and aerial parameters of the watershed (Biswas et al., 1999). GIS overlay technique has been used to locate the potential zones of ground water (Murthy, 2000).

The present study aims at identification of suitable zones for constructing recharge structures by integrating multiple thematic layers generated from satellite data using GIS spatial logical modelling and also through morphometric studies of the drainage basin. Number of recharge structures suggested and their cost for construction were estimated. Based on the construction cost, the groundwater pricing can be estimated. This attempt can help in augmenting the groundwater resources and recharge the ground water in proper way.

SPATIAL DATA USED FOR INTEGRATION

Thematic maps containing details from aero-magnetic breaks, geomorphology, geology and lineament, landuse/landcover and soil maps have been prepared. These have been subsequently digitized through MapInfo GIS. Using high altitude aero-magnetic map obtained from GSI, aero-magnetic breaks layer was generated. Other maps have been prepared through IRS-ID, LISS-III + PAN merged remote sensing data. All the layers were integrated in Arc-view GIS. Three sub-watersheds and drainage have been delineated with help of Survey of India (SOI) toposheets and updated with help of real time satellite data in order to compute the morphometric parameters of the sub-watershed.

Spatial Analysis of Thematic Maps

The thematic maps were assigned theme weight and class weight based on the groundwater infiltration capacity. Index Overlay Model (IOM) was adopted to evaluate the maps. The resultant map was re-classified into three zones according to higher values to lower values of map integration. The zones are unsuitable, suitable for farm ponds/nalla bunds and suitable for percolation tank/check dam. The zone map was again overlaid with drainage map to assure the sources for recharge structures. In the study area, four suitable sites were located based on the zones, drainage catchments area which will recharge the secondary porosity and structural features of the watershed.

STUDY AREA

Identification of suitable sites for constructing the recharge structures, which will help in estimating groundwater pricing, were carried out in over-exploited Torehalla watershed. This watershed falls in Cauvery basin and tributaries of Hemavathi river, which is flowing in the southern part of the watershed. The study area lies between 76° 05' 10" E and 76° 18' E longitude and 12° 49' 19" N and 13° 11' 02"N latitude, covering total geographical area of 455 sq.km. (Fig. 1). The major part of the study area lies in the Hassan taluk except the southern-most part, which falls in Hole Narisipur taluk of Hassan district. The study area receives annual rainfall of 733 mm to 790 mm.

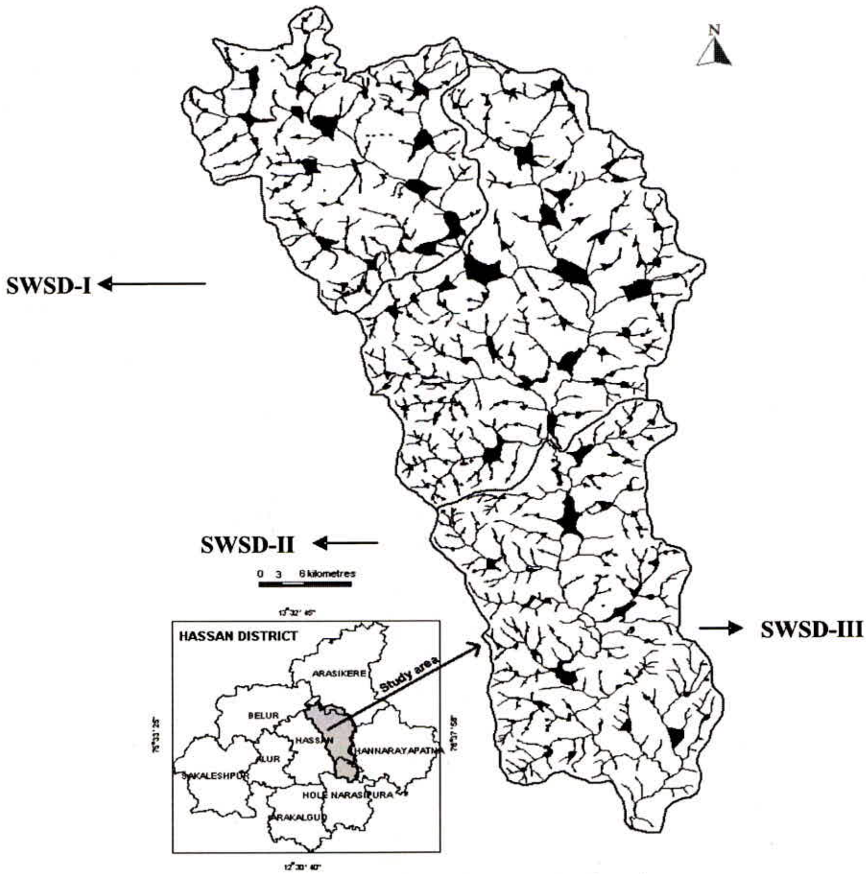

Fig. 1. Drainage map with sub-watershed of study area.

Geology

The area comprises litho units of Archaean to Lower Protrozoic age. The major litho-units exposed in the area are gneiss, ultramafics, schists, meta-ultramafites, silicate rocks, meta basalt and tuff, phyllites, and quartz chlorite schists. The general strike of rock formation varies from NNW-SSE to NW-SE with steep dip on either direction.

Lineament

Lineament has control over the drainage system and plays a dominant role in the movement and occurrence of ground water. Tectonic lineament and its intersection points are very useful for groundwater exploration, since the cross-points are characteristic of extreme yield conditions. The lineaments interpreted in the study area include tectonic lineaments viz, fracture aligned streams, linear litho contacts and faults/shears (Fig. 2). Three sets of lineaments trending in NW-SE, WNW-ESE and NNE-SSW were identified. The NW-SE set of lineament is very prominent and all the lineaments are mainly controlled by the drainage/streams of the area. These lineaments are very important for recharging the ground water.

Aeromagnetic Breaks: High altitude aero-magnetic data has been found useful in tracing lithological contacts and in recognizing major tectonic structures like fold, faults, shears and igneous intrusion dyke, kimberlitic pipes and layered complex. As tectonic fracturing and surface weathering are primary factors that control ground water in the hard rock terrain (Clarke and Lewis, 1985), the study of magnetic breaks would be beneficial in locating the potential groundwater zones in hard rock area. Using the Astier and Peterson (1985) criteria, a number of magnetic breaks have been marked which could be indicative of faults/joints/fracture zones and lithological contacts.

The breaks interpreted in the area include tectonic lineaments, shears and litho-contacts. Three sets of lineament trending NW-SE, WNW-ESE and NNE-SSW have been identified. The NW-SE and NE-SW lineaments are very prominent in the study area, which will play major role in groundwater recharge (Fig. 2).

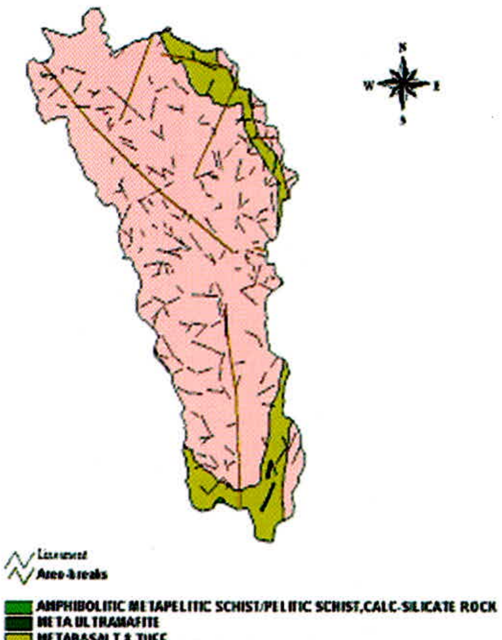

Fig. 2. Geological map.

Geomorphology

The different landforms, discernable on the imagery, have been broadly classified into denudation and fluvial landforms. The landforms delineated are pediment, pediplain and valley fills (Fig. 3).

Pediment: Pediment is gently undulating rock surface and wears a thin cover of weathered materials. It has been carved over melt basalt and tuff formation exposed in the northern part of the watershed.

Pediment zones permit poor infiltration and act as run-off zones. However, the fractures, which traverse these zones, could act as good recharge zones.

Pediplain: This landform is covered by thick veneer of soil ranging in thickness from 1 to 5 m (pediplain-shallow) and occurs over the entire terrain. The development of soils is mainly due to disintegration of county rock of tonalitic gneiss. The thickness of weathering zones ranges from 10 to 15 m (pediplain-moderate) and this zone act as good infiltration zone.

Valley fill shallow: Valley fill has been developed mainly in the valley portions over gneiss due to deposition of unconsolidated materials by fluvial agencies. The materials are silt, fine sand and at places pebbly. The thickness of fill and weathered zones range from 1 to 15 m and act as good recharge zone.

Structural Hill: The structural hills occur in the southern and northern parts of the area and formed by meta-basalt. It forms linear stretch trending NW-SE and NE-SW direction. Pediment Inselberg complex and Inselberg are formed in the gneiss formation covering very small area in the watershed.

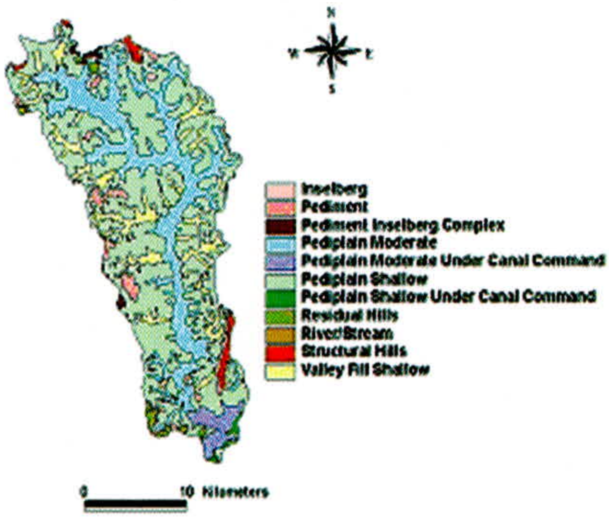

Fig. 3. Geomorphological map.

LANDUSE/LANDCOVER

Landuse/landcover of the watershed was prepared based on the visual interpretation of satellite data with the help of photo-interpretation keys. In the study area, twelve landuse/landcover classes were classified (Fig. 4). The major landuse classes occupied in the study area are kharif, double crops, forest plantation and other plantation. These classes are distributed in the plain land, valley area and along the drainage areas. The landcover classes are land with scrub, land without scrub, scrub forest and barren rock/stony waste. These classes are occupied in the upland and hilltop. Water features are classified into tanks and rivers in the area. The class and theme weight were assigned based on the influences to recharge the ground water.

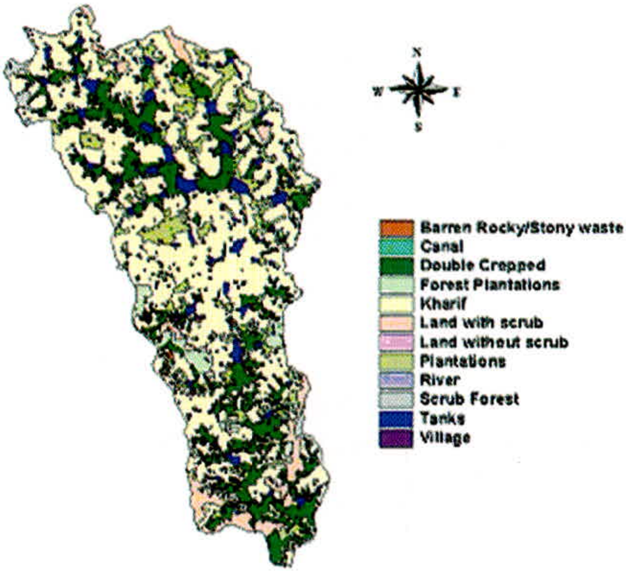

Fig. 4. Landuse/landcover map.

Soil

Soil map of the watershed was prepared on the basis of visual interpretation of satellite data and classified into two family textures, which are clayey and clayey skeletal. Based on the nature of materials, run-off and thickness, the soils were further classified into seven classes (Fig. 5). Deep, moderately well drained clayey soil of valley occupies along the drainage and deep well-drained clayey soil of clayey skeletal with severe erosion area occupies the uplands of the watershed. Moderately deep and very deep, well-drained clayey soils on undulating interfluves occupy the southern part of the study area.

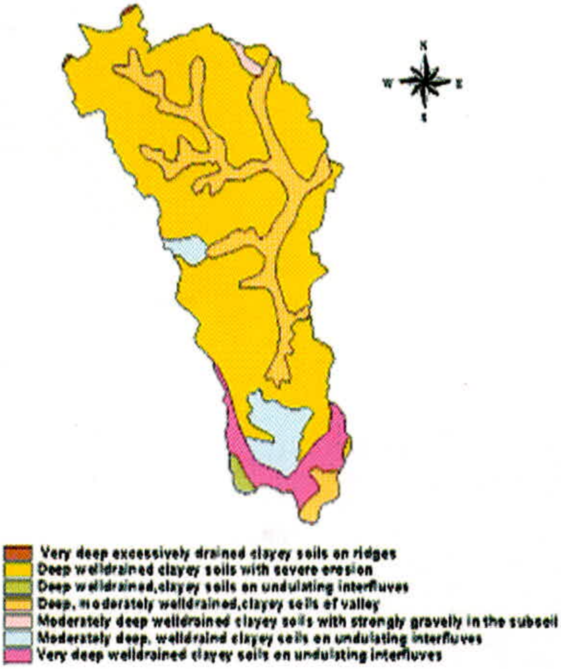

Fig. 5. Soil Map.

Theme Weight and Class Weight

Theme weight and Class weight were assigned for geological, geomorphological, lineament, aero-magnetic, landuse/landcover and soil maps (Table 1) according to the theme and classes that play major role in the groundwater recharge of the watershed.

Table 1. Details of theme weight and class weight assigned for map calculation

S. No.	*Theme*	*Theme weight*	*Class*	*Class weight*
1	Geomorphology	30	Valley fill shallow	8
			Pediplain shallow	6
			Pediplain shallow, moderate under command and River/stream	0
			Pediplain moderate	7
			Pediment	5
			Structural hill	3
			Inselberg, Residual hill and PIC	2
2	Soil	19	Vd.excessively drained CS on ridge and u.interfluves.	2
			D.well drained CS with severe erosion	6
			D.well drained CS on u.interfluves	4
			D.moderately well drained CS of valley	8
			M.well drained CS with gravely in the subsoil.	5
			M.d.well drained on u.interfuves.	3
3	Lineament	15	100 m buffer	9
4	Aeromagnetic map	13	1000 m buffer	8
5	Geology	12	Silicate rock and greywacke	2
			Metaultramafic	3
			Ultramafics schist	4
			Matabasalt and tuff	6
			Tonalitic gneiss	8
			Dyke	2
6	Landuse/landcover	11	Canal,river and village	0
			Barran rock/stony waste and land without scrub	2
			Land with scrub	4
			Kharif	6
			Plantaion, forest plantation, scrub forest	8
			Double crops	9

Suitable Zones for Constructing Recharge Structures

Based on the integration of multiple thematic maps, using weighted average index overlay method with the help of GIS, three zones were demarcated in the watershed. The zones are unsuitable, suitable for farm ponds/nallah bunds and suitable for percolation tank/check dam. The details of the each zone are discussed below.

1. Unsuitable: Unsuitable zone is influenced by pediplain shallow landform with moderate to deep well drained clayey soil of severe erosion. This zone is occupied in the kharif and plantation landuse and occupies major part of the study area. Weathered thickness and structural disturbances are very low in this zone, which indicates that this may not be suitable for constructing any major recharge structures.

2. Suitable for farm ponds/nallah bunds: This zone is generally occupied in the pediplain moderate, valley fill shallow landforms with deep moderately well-drained clayey soil of the valley. First to third order streams are generally draining in this zone and traversed by the aero-magnetic breaks and minor lineament of the watershed. Double crop and plantation are the main landuse classes in this zone. Farm pond and nalla bund may be constructed in this zone.

3. Suitable for check dam and percolation tank: Based on the integration, this zone has higher values and falls in the pediplain moderate and valley fill shallow landform of the watershed. This zone is highly influenced by the lineament and aero-magnetic breaks. The area is composed of highly weathered mantle and interconnected with secondary porosity. In this zone, check dams and percolation tanks may be constructed and groundwater recharge through these structures will have direct impact on the groundwater regime.

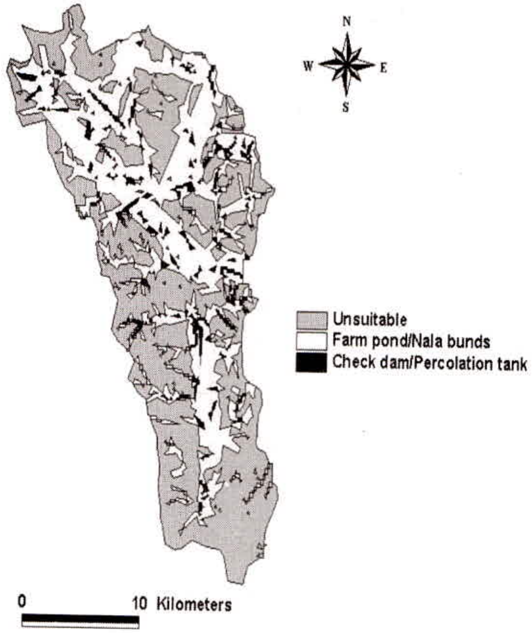

Fig. 6. Suitable zones for constructing recharge structures.

MORPHOMETRIC ANALYSIS

Three sub-watersheds are delineated in the watershed with the help of drainage map generated from SOI toposheet and digitized using MAP/INFO GIS (Fig. 1). Stream orders were calculated using Strahler's (1964) method. The methodologies adopted for the computation of morphometric parameters are given in Table 2 and the results are summarised in Table 3.

Linear parameters: Linear parameters of sub-watersheds were analysed, which include stream order, stream length (Lu), mean stream length (Lsm) and mean bifurcation ratio (Rbm). The number of streams in various orders was counted and total length of each stream was calculated with the help

Table 2. Methodology adopted for computation of morphometric parameters

Morphometric Parameters	*Methodology*
Stream order	Hierarchical order
Stream length (Lu)	Length of stream (km)
Mean stream length (Lsm)	Lsm = Lu/Nu
Mean bifurcation ratio (Rbm)	Rbm = Av. Rb (Rb = Nu/Nu + 1)
Drainage density (Dd)	D = L/A
Stream frequency (Fs)	Fs = N/A
Texture ratio (T)	T = N1/P
Form factor (Rf)	Rf = A/Lb2
Circularity ratio (Rc)	Rc = 4 × π × A/P2
Constant channel maintenance (C)	Inverse of drainage density

where:
Lu = Total stream length of order 'u'.
Nu = Total number of stream segment of order 'u'.
Nu+1= number of segment of next higher order.
L = Total length of streams.
A = Area of watershed in sq.km.
P = Perimeter of watershed in km.
Lb = Basin length in km.
π = 3.14

Table 3. Result of morphometric analysis of sub-watershed

Sub-watershed Name	*A*	*P*	*Basin order*	*Lu*	*Lsm*	*Rbm*	*Dd*	*Fs*	*T*	*Rf*	*Rc*	*C*
SWSD-I	114.2	55.14		168.39	1.16	3.37	1.47	1.26	2.61	0.41	0.47	0.68
SWSD-II	187.1	67.13	V	272.95	1.11	3.70	1.45	1.31	3.64	0.31	0.52	0.68
SWSD-III	153.8	60.98		270.4	0.99	4.06	1.32	1.76	4.44	0.14	0.52	0.75

of GIS software. In the study area, Lsm is varying from 0.99 to 1.16 and this may be due to topography and lithology. The reverse of stream joining is bifurcation and this varies in each order of streams. In the study area, Rbm is calculated by averaging Rb of all orders. The Rbm is varying from 3.37 to 4.06, which falls under normal basin category. However, SWSD-III is geologically more complex than other two sub-watersheds.

Aerial parameters: Aerial parameters of sub-watershed computed are drainage density (Dd), stream frequency (Fs), texture ratio (T), form factor (Rf), circulatory ratio (Rc) and constant channel maintenance (C). The Dd provides numerical measurements of landscape dissection and runoff potential. The study area exhibits low drainage density, which is varying from 1.32 to 1.47. It indicates that the sub-watersheds are composed of highly permeable subsurface materials and covered with dense vegetation. The Fs is related to permeability, infiltration capacity and relief of the sub-watersheds. The study area shows low Fs, which is indicative of low relief and high infiltration capacity of the bedrock. Texture ratio of watershed depend on the underlying lithology, infiltration capacity and relief aspect of the terrain. In the present study, T is varying from 2.61 to 4.44, which indicates that the SWSD-I and II are characterized by high infiltration capacity. Form factor of the watershed is having direct relation to stream flow and shape of watershed. Rf of the study area is varying from 0.14 to 0.41, which indicate that SWSD-III is elongated in nature with less stream flow for shorter duration and high main flow for longer duration. Circulatory ratio is influenced by the length and stream frequency, geological structures, landuse/landcover, climate, relief and slope of the basin. Here, all three sub-watersheds have low to high Rc values—0.47, 0.52 and 0.52 respectively. It is found that the SWSD-II and III are circular in nature and SWSD-I is elongated in nature. Constant channel maintenance is expressed by reverse of drainage density and depend on the rock type, permeability, climate regime, vegetation cover and duration of erosion. The C of sub-watersheds shows that all three sub-watersheds exhibit low structural disturbance, high permeability and low surface run-off.

Surface water potential: Surface water potential of sub-watersheds was estimated based on the Inglis formula and the results are presented in Table 4.

$$R = ((P-17.8)/254) \times P$$

where R and P are runoff and rainfall in cm.

Table 4. Surface water potential of the sub-watershed

Sub-watershed name	*Surface water potential (ha.m.)*
SWSD-I	2009.9
SWSD-II	3292.9
SWSD-III	2706.9
Total	8009.7

Average rainfalls of adjacent four stations of the study area have been considered for computing the rainfall of sub-watersheds. The total surface water potential of the watershed is 8009.7 ha.m. In the study area, a percolation tank having catchment area of 3 sq.km., if constructed based on this estimation, about 50 ha.m. water can be stored in the structure.

Groundwater Pricing

Groundwater pricing may be estimated based on the number of structures to be constructed in the suitable zones and amount of water recharged in this zone. Assessment of the water recharged through the structures in each zone and extracting by the users are essential to compute groundwater pricing.

CONCLUSION

Remote sensing and GIS are useful tools in demarcating suitable zones for construction of structures to recharge the groundwater. In the present study, three suitable zones were demarcated based on the Index Overlay Method using GIS. It is found that suitable zone for constructing check dam and percolation tank can have direct impact on the ground water recharge in the watershed. The watershed has been divided into three sub-watersheds and morphometric parameters of the sub-watershed were computed. It is found that the SWSD-I and II are more suitable for constructing recharge structures. Surface water potential of the sub-watershed has been estimated based on the Inglis formula which indicates that 8009.7 ha.m. water is available in the entire watershed for the recharge. Groundwater pricing of the subwatershed depends on the amount of water recharged through these structures and extracted by the users.

ACKNOWLEDGEMENT

The authors express their sincere thanks to the Chairman, Central Ground Water Board, Faridabad (Haryana) for permission to present this paper in the seminar. The authors also express their sincere thanks to Mr. T.M. Hunse, Regional Director, Mr. M.K.M. Rao, Scientist-D and Mr. K.M. Vishwanath

Scientist-D, CGWB, SWR, Bangalore for their valuable guidance in preparing this paper. Thanks to AMSE (GSI) Bangalore for giving valuable inputs for finalizing the paper.

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