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Approach to Groundwater Management towards Sustainable Development in India

Approccio alla gestione delle acque sotterranee verso uno sviluppo sostenibile in India

Y.D. Khare, A.M. Varade

Riassunto: La gestione delle risorse idriche sotterranee per uno sviluppo sostenibile è un tema molto discusso in India, per via della vasta estensione geografica del Paese (3287000 km^2), in cui vivono circa 1250 milioni di persone. Il Paese affronta molto spesso periodi di scarsità di acqua potabile. Questa situazione costringe ad adottare delle pratiche di gestione per lo sviluppo sostenibile delle risorse idriche sotterranee. L'obiettivo di questo contributo è focalizzato sulla necessità di adottare delle appropriate strategie di gestione per lo sviluppo sostenibile delle risorse idriche sotterranee. In quest'ottica viene discusso lo stato delle risorse idriche sotterranee in India, in base a quanto trattato in letteratura, dove vengono discussi i motivi della scarsità idrica e lo stato delle acque sotterranee in India. In base a questa analisi viene proposto un approccio per la futura gestione delle acque sotterranee per raggiungere l'obiettivo di uno sviluppo sostenibile. Questo contributo fornisce un'analisi di tutti i fattori che influenzano lo stato delle risorse idriche sotterranee in India. Sulla base di questo vengono anche discusse possibili soluzioni per la futura implementazione di programmi di conservazione dell'acqua. Questo studio mostra che, nonostante l'ampia disponibilità di risorse idriche sotterranee, il Paese si trova spesso ad affrontare situazioni di scarsità di acqua potabile. Ciò necessita di un'ulteriore analisi per fornire una soluzione definitiva a questo problema.

Keywords: *Sustainable development, groundwater management, controlling factors, India.*

Parole chiave: sviluppo sostenibile, gestione delle risorse idriche sotterranee, fattori di controllo, India.

ABHAY M. VARADE ✉
Department of Geology, RTM Nagpur University
Nagpur-440001, Maharashtra, India
varade2010@gmail.com

Y. D. KHARE
Retd. Scientist, Maharashtra Remote Sensing Application Centre
Nagpur-440002, Maharashtra, India

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Abstract: *The management of groundwater resources for sustainable development is a challenging task in India because of its vast geographical extent (3287000 km^2), where about 1250 million people live. As a result, the Country is facing scarcity of drinking water quite often. This situation compels to adopt management practices for the development of sustainable groundwater resources. The objective of the paper is to focus on need of adoption of appropriate management strategies for sustainable development of groundwater resources. In view of this the groundwater situation in India as reflected through published literature has been discussed, in which the causes of scarcity, aquifer situation, and groundwater assessment in India have been explained. Based on this study the future approach for groundwater management to achieve the objective of sustainable development has been suggested. This paper provides insight to all the controlling factors affecting groundwater resources in India. Based on this, suggestions for future implementation of water conservation programmes have also been discussed. The present study shows that despite availability of ample groundwater resources the country faces drinking water scarcity quite often. This fact needs further analysis of scarcity situation to provide everlasting solution of problems related to groundwater.*

Introduction

India is a vast Country in terms of geographical area (3287000 km^2), being the fifth largest Country of the world (Fig. 1). The Country is bestowed with rich natural resources pertaining to physiography, geology, minerals, climate and solar energy. The rich heritage and culture of the Country has led to exploitation of natural resources for human development since ages. Among these, groundwater is the most significant natural resource for human development, and being used for irrigation, drinking, industrial supply and domestic purposes (Siebert et al. 2010; Kulkarni et al. 2015; Zaveri et al. 2016; Selvakumar et al. 2017). Since the Country has a vast human population (about 1250 million inhabitants), the use of groundwater has increased manifold in the past four decades, resulting in situations of scarcity (Srinivasan et al. 2013; McDonald et al. 2014) to which attention should be paid on priority.

The current population of India is almost 1250 millions. In order to achieve the food security of such large population, it is imperative to harness surface water as well as groundwater resources. Over the years, the Government of India has constructed large, medium and minor dam projects across the rivers at suitable locations to boost the irrigation.

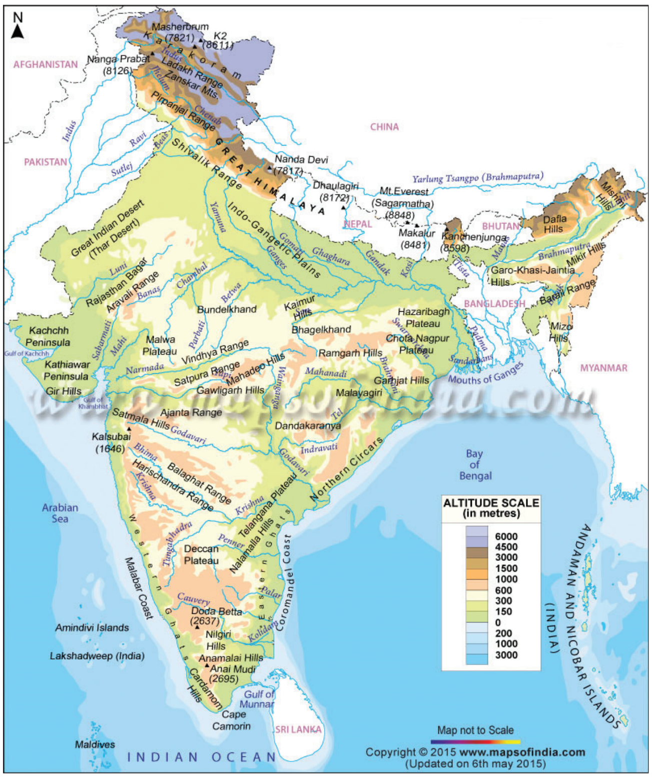

Fig. 1 -Topography map of India (www.mapsofindia.com)

Fig. 1 - Carta topografica dell'India (www.mapsofindia.com).

However, the present utilization of stored water is only 396 billion cubic meters (bcm) out of the available storage of 690 bcm. This has resulted in irrigation potential of 25.8 Mha, whereas the current irrigation based on groundwater is 35.4 Mha. Thus the total area under irrigation is 61.2 Mha which shows that the contribution of groundwater for irrigation is 58 %. Looking at the vast population, it becomes necessary to exploit all the available resources (Vora 1975; Rodell et al. 2009; Imam and Banerjee 2016). Hence, this calls for implementation of appropriate groundwater as well as surface water management techniques.

The objective of sustainable management can only be achieved with proper understanding on the controlling factors affecting groundwater resources. These factors (e.g., physiography, rainfall and geology), pertaining to India, have been discussed below.

Setup of natural resources in India

Physiography

India has a very typical physiography, being characterized by the Himalayan mountain ranges at the northern border, flanked by hilly ranges such as Western Ghats, Satpudas, Vindhyans, Aravalli etc. This hilly topography almost occupies 25 % of the geographical area of the Country, whereas the southern part of the Country, i.e., the peninsular region, is surrounded by the Arabian Sea to the west, the Great Indian Ocean to the south and the Bay of Bengal to the east. The scarcity of drinking water is a regular feature in the Country which needs special attention for providing sustainable drinking water supply.

The Country is crossed by large rivers, the Ganga in the northern part, the Brahmaputra and Mahanadi covering the eastern part, the Narmada in central India, and the Godavari, Krishna and Cauvery in the southern peninsula. The Indus river originates in India, flows through Pakistan, and ultimately meets the Arabian Sea. Except for the Narmada, which flow westerly, all other rivers flow easterly. All these rivers have huge networks of tributaries. These rivers cater the need of surface water for human purposes (Fig. 1). The rivers originating in the Northern Himalayan region are perennial, due to the presence of the snow-covered mountain peaks, while the remaining rivers, although perennial, they carry base flow and are perennial only in the lower reaches.

Rainfall

Rainfall is among the main source of fresh water on the surface of the Earth. In India, rainfall occurs in monsoon period only, from June to October. Data on rainfall indicates that there is a wide variation in its distribution. At the extreme eastern (i.e. Assam, Tripura, Meghalya, West Bengal etc.) parts of the Country, rainfall is very intense (i.e., more than 4000 mm/year). On the other hand, there are regions where rainfall is scanty (i.e., less than 400 mm/year) (Fig. 2) (IWR 2011). However, a very large part of the Country receives rainfall of the order of 600-2000 mm/year (IMD 2017; Duriaswami et al. 2016).

The overall rainfall is about 1123 bcm/year, out of which 433 bcm/year contribute to groundwater recharge (IWR 2011). Contribution of groundwater for irrigation is nearly 58 %. This is mainly because of its in situ availability with minimum efforts unlike irrigation projects which involves huge cost. The current irrigation scenario in India as mentioned in IWR (2011) shows that out of 155. 56 Mha cultivable land only 35.4 Mha is irrigated on groundwater (IWR 2011). Similarly, an area of 25.2 Mha is irrigated on surface water. This shows that out of the total cultivable land of 155. 56 Mha only 22.75 % of land is irrigated on groundwater which clearly highlights the need to adopt management strategies for the optimized use of groundwater. Furthermore, since the rainfall period is limited to the monsoon season, additional sources of surface water / groundwater are required for crop growth for the entire year. The rainfall patterns are erratic and not uniform, as a result, the country experience vagaries of monsoon almost every year (Sudarshan and Sooryanarayana 2016). The annual rainfall is not consistent and has a year to year variation. There are events of heavy floods in eastern and northern parts, whereas, events of drought are frequent in western and southern parts of the Country. Nearly 25 % of Country is drought prone. This situation is not very conducive for the development of groundwater resource as a whole. (Manual for Drought Management 2016).

Also, the Country experiences heavy summer, between March and June, in which the temperature rises to above 45°C. As a result, the rate of evapotranspiration is very high,

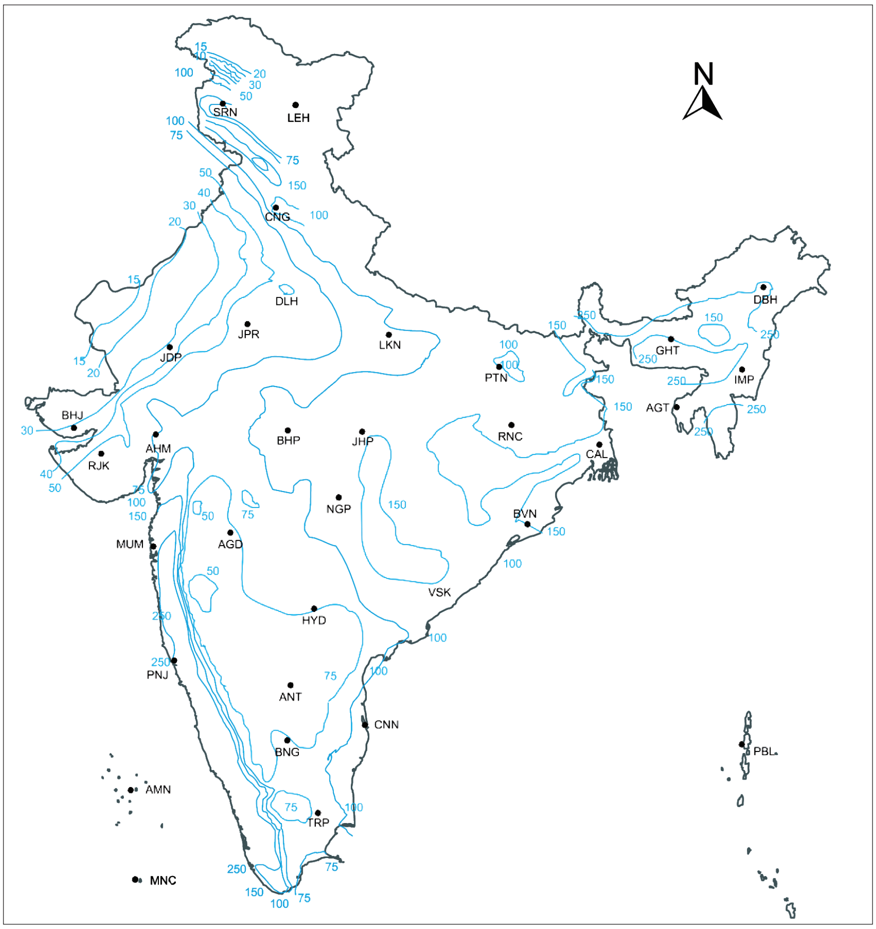

Fig. 2 - Zones of average annual rainfall (values in cm) (Manual for Drought Management 2016).

Fig. 2 - Zone di precipitazione media annuale (valori in cm) (Manual for Drought Management 2016).

unlike western Countries (e.g., the annual rate of evaporation for the state of Maharashtra is 2367 mm), particularly in arid regions (IMD 2017). Under this situation, crop water requirement is very high, which poses additional pressure on the water resources.

Geology and hydrogeology

The geology of the Country is characterized by formations from Precambrian to Quaternary (Das 2008). The major part of the Country, is characterized by basement crystalline rocks belonging to Pre-Cambrian period, which cover almost the entire peninsula, the eastern part of the Country and the extra-peninsular regions (Fig. 3). The geology of the Country is shaped by vast crystalline Cratons and sedimentary mobile belts. There are formations of Proterozoic sediments of Cudapah basin covering part of the southern peninsula. Also, there are Vindhyan sediments occupying the central part of India. Quite a large part of the Country, particularly central India, is characterized by Gondwana group of rocks belonging to carboniferous to Cretaceous period. A very small part of the southern India is characterized by sedimentary formations of Cretaceous period and called as Cretaceous of Tiruchanapalli. A very vast part of the Country is characterized by basaltic formation belonging to upper Cretaceous to Eocene period. There are formations of Jurassic period and covers part of Kutch. These older formations are covered by vast alluvial formations of the Indo-Gangetic plain and many other

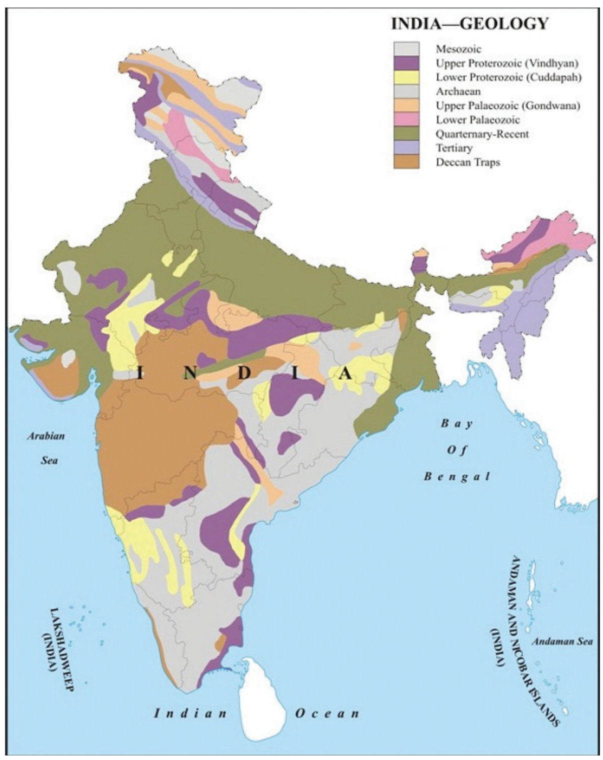

Fig. 3 - Geology of India (www.mapsofindia.com).

Fig. 3 - Carta geologica dell'India (www.mapsofindia.com).

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Tab. 1 - State wise groundwater resources availability, utilization and categorization of assessment units in India (IWR 2011).

Tab. 1 - Disponibilità e utilizzo delle risorse idriche sotterranee in India. Categorizzazione per Stati e Territori (IWR 2011).

State / Union Territory	Annual replenish able groundwater resource (bcm)	Natural discharge during non-monsoon season (base flow through rivers) (bcm)	Net annual groundwater availability (bcm)	Annual Groundwater Draft (bcm)	Stage of Groundwater Development (%)	Categorization of assessment areas (number)	
						Over-exploited watershed	Critical watersheds
States							
Andhra Pradesh	36.50	3.55	32.95	14.90	45	219	77
Arunachal Pradesh	2.56	0.26	2.30	0.0008	0.04	0	0
Assam	27.23	2.34	24.89	5.44	22	0	0
Bihar	29.19	1.7	27.42	10.77	39	0	0
Chhattisgarh	14.93	1.25	13.68	2.80	20	0	0
Delhi	0.30	0.02	0.28	0.48	170	7	0
Goa	0.28	0.02	0.27	0.07	27	0	0
Gujarat	15.81	0.79	15.02	11.49	76	31	12
Haryana	9.31	0.68	8.63	9.45	109	55	11
Himachal Pradesh	0.43	0.04	0.39	0.12	30	0	0
Jammu & Kashmir	2.70	0.27	2.43	0.33	14	0	0
Jharkhand	5.58	0.33	5.25	1.09	21	0	0
Karnataka	15.93	0.63	15.30	10.71	70	65	3
Kerala	6.84	0.61	6.23	2.92	47	5	15
Madhya Pradesh	37.19	1.86	35.33	17.12	48	24	5
Maharashtra	32.96	1.75	31.21	15.09	48	7	1
Manipur	0.38	0.04	0.34	0.002	0.65	0	0
Meghalaya	1.15	0.12	1.04	0.002	0.18	0	0
Mizoram	0.04	0.004	0.04	0.0004	0.90	0	0
Nagaland	0.36	0.04	0.32	0.009	3	0	0
Orissa	23.09	2.08	21.01	3.85	18	0	0
Punjab	23.78	2.33	21.44	31.16	145	103	5
Rajashtan	11.56	1.18	10.38	12.99	125	140	50
Sikkim	0.08	0.00	0.08	0.01	16	0	0
Tamil Nadu	23.07	2.31	20.76	17.65	85	142	33
Tripura	2.19	0.22	1.97	0.17	9	0	0
Utter Pradesh	76.35	6.17	70.18	48.78	70	37	13
Uttaranchal	2.27	0.17	2.10	1.39	66	2	0
West Bengal	30.36	2.90	27.46	11.65	42	0	1
Total States	432.42	33.73	398.70	230.44	58	837	226
Union Territories (UTs)							
Andaman & Nicobar	0.330	0.005	0.320	0.010	4	0	0
Chandigarh	0.023	0.002	0.020	0.000	0	0	0
Dadra & Nagar Haveli	0.063	0.003	0.060	0.009	14	0	0
Daman & Diu	0.009	0.0004	0.008	0.009	107	1	0
Lakshadweep	0.012	0.009	0.004	0.002	63	0	0
Ponducherry	0.160	0.016	0.144	0.151	105	1	0
Total UTs	0.597	0.036	0.5566	0.181	33	2	0
Grand Total	433.02	33.77	399.25	230.62	58	839	0

alluvial formations with little extent forming productive aquifer systems (Raju 1998).

The availability of groundwater in the Country is limited, as the major part of the Country is characterized by older crystalline and volcanic rocks with poor primary porosity and poor infiltration capacity which is reflected in terms of permeability 1.98 to 3.40 m^2/day. However, in the vast Gangetic alluvial plains, Gondwana sandstone has good porosity in the range of 28-34 % and therefore hosts productive aquifers (Todd 1980; Das 2008).

Discussion

Present groundwater scenario

The groundwater assessment in India is carried out on watershed basis where a watershed is a hydrological entity with a single outlet with average area ranges between 200-300 km^2. Table 1 shows Statewise groundwater situation in terms of groundwater availability utilization and categorization of assessment units (watershed) in India. The table indicates that the annual groundwater recharge in the Country is 433.02 bcm and the present utilization for all purposes is 230.62 bcm, while the availability of groundwater is 399.25 bcm. The groundwater needs are catered through 9.2 million dug wells, 11 million bore wells (mainly used for drinking water purposes) and 9.10 shallow tube wells. Groundwater extraction (annual draft) is worth 230 bcm, with 58 % of stage of development i.e. ratio of annual draft with annual availability. The water levels in the phreatic zones range between 4-10 m below ground level (bgl) for the major part of the Country, however the water table ranges between 15-20 m bgl in the western part of the Country, particularly in the states of Rajasthan and Gujarat. The average seasonal fluctuation of phreatic aquifers is between 4-6 m. The annual yield of the abstraction structures i.e. dug wells with depth range varying between 12-15 m ranges between 0.01 to 0.015 mcm in general. However, the yield of the bore well is around 0.02 mcm since the depth of the bore well is more i.e. in the range of 60-90 m in promising aquifers.

The groundwater situation discussed above indicates that the country has a good groundwater potential. Even then, the Country experiences acute scarcity of drinking water since historical periods in the event of drought. Some of the examples of historical droughts are 1630, 1680, the most recent is 1972 and it is still continuing (Chowdhury et al. 1989; De et al. 2005; Manual for Drought Management, 2016; Zhang et al. 2017). Thus drought is a regular feature every year and therefore the Government has to spend on drinking water supply to mitigate the drought situation. The scarcity of groundwater is further aggravated due to tremendous rise in population (the current population in India is nearly 1250 million, while in 1951; the population was one third of the present one). In 2050, the population would be nearing 1500 million, which will pose heavy pressure on the available groundwater resources.

Realizing the imbalance between availability and demand, the Government as well as Non-Governmental Organization (NGO) groups embarked upon implementation of appropriate management strategies by construction of water conservation structures in which the generation of sound database on controlling factors is an essential activity. The systematic study vis-a-vis groundwater exploration started in India from 1970 onwards and by now very huge database has been generated. The database so generated forms the input for preparation of development plans.

Scientific inputs

At the beginning of groundwater exploration, conventional techniques of mapping were used. However, since 1980, modern technologies (such as remote sensing, geophysical surveys) have also been deployed for collecting hydrological data. The modern technology has been useful in understanding some of the intricate factors hitherto unknown and has widened the scope of exploration. The study encompasses acquiring data on groundwater structures such as wells, dug wells, distribution of subsurface geological formation and its behavior etc. Remote sensing provides synoptic view of terrain and facilitates the generation of multidisciplinary spatial datasets. This technique has provided new insight to the groundwater exploration. The GIS (Geographic Information System) approach is also being used to generate digital databases. With the advent of GIS technique, it is possible to integrate inter-related spatial data, which in turn facilitates the adoption of multidisciplinary approach and supports decision support system.

From 1970 to 1980, thrust was given on acquisition of data on groundwater parameters. Based on this groundwater exploration work, potential areas for groundwater development were identified for groundwater development. However, since 1980 there was a change in perception of groundwater development in which thrust was given to solve drinking water related problems mainly through drilling of bore wells for drinking water purposes. This programme of drilling of bore wells continued till 1990. During twenty years of systematic studies, the Government was able to solve scarcity problem to some extent e.g. in the State of Maharashtra, on an average four to five bore wells have been drilled in every village for drinking water supply. Before 1972, scarcity was felt because of paucity of structures for withdrawing groundwater; however, by 1990, adequate structures were created, even then the problem of scarcity remained untackled, due to prolonged rainfall deficit, as well as heavy withdrawal of groundwater which resulted in drying up of aquifers. Nearly 30 % of the Country is drought prone, where the average rainfall ranges between 400-600 mm.

Approach to Sustainable Development

Till recent, the geoscientists tried to solve the scarcity problems associated with groundwater by adopting single line approach, in which attention was paid on acquisition of database pertaining to parameters affecting groundwater regime. However, with the advent of modern techniques, like remote sensing and GIS, it was felt that the problem will have to be tackled by adopting multidisciplinary approach (Waters et al. 1990; Tweed et al. 2007; Siebert et al. 2010). Therefore, there is a need to generate a database on correlated data, such as soil, land-use, geomorphology, etc. (Ravi Shankar and Mohan, 2005; Gurugnanam et al. 2008; Kumar et al. 2008; Varade et al. 2011; Ansari and Katpatal, 2018). The database so generated needs to be integrated with the help of GIS technique to support decision support system (Ghayoumian et al. 2005; Jankowski 2006). The plan so developed will be realistic as it is based on an integrated database (Braun et al. 2003; Bühlmann et al. 2010).

There is a need to adopt conjunctive use of surface water and groundwater. It is observed that the scientists and engineers working in both these fields (i.e., hydrology and hydrogeology) work independently. Since surface water and groundwater are interrelated, an approach to conjunctive utilization is required to boost the objective of sustainable management of groundwater resources.

The data on groundwater availability presented in Table 1 indicates that the present draft is 58 % of the total recharge indicating 42 % of water balance available for exploitation. Under this situation scarcity of drinking water in the event of failure of one monsoon cycle is not expected. But the reality is that most of the area faces acute drinking water scarcity in the event of drought. By analyzing this situation, it is observed that there is an anomaly in present assessment of groundwater resource e.g. the groundwater recharge is calculated by using values of aquifer storage coefficient, which is applied to the entire watershed. However, in hard rock terrain there is no isotropic condition. Under this situation the values of storage coefficient vary from place to place. Therefore, the assessment needs to be carried out for each micro-unit and not for the entire watershed area as in India the average size of watershed is between 200-250 km^2 which covers 3 to 4 different groundwater provinces in terms of storage coefficient. This will facilitate accurate estimation of groundwater recharge and thus will rule out over- estimation of groundwater potential (Chatterjee 2011; Varade et al. 2017c). Similarly, precise mapping of the unworthy area is necessary to have a correct estimation of recharge. Such mapping is possible only through remote sensing technique, e.g., the geomorphological map prepared through remote sensing shows exact extent of unworthy area which does not contribute to recharge. Similarly, in the groundwater assessment currently the withdrawal is calculated by using unit draft which is applied to all the wells in the area under study. Withdrawal so calculated may not give true picture of withdrawal which needs to be assessed through estimation of irrigated area. In this connection, landuse map derived through remote sensing is found to be useful thus facilitates the correct assessment of groundwater withdrawal. Many geoscientists have attempted this exercise, showing that there is an over / under-estimation of recharge (Varade et al. 2014, 2017c).

Groundwater scarcity is a regular status in many parts of the Country and therefore to solve the problem it is necessary to harness surface runoff through construction of water harvesting structures. The estimated runoff in India is 3935 bcm, however, utilizable runoff for irrigation is 690 bcm and groundwater recharge is 433 bcm. This shows that about 1866 bcm surface runoff is available for its storage (IWR 2011). As a result, many governmental agencies working in the field of groundwater and agriculture sector implemented water conservation programmes mainly to harness the available runoff. However, such programmes are site specific. These programmes would be effective only if implemented on a regional scale (watershed basis). The desired impact will only be achieved through integration of correlated databases by using GIS technique (Khare et al. 2016; Varade et al. 2017 a, b).

Considering the high rates of evapotranspiration, the current practice of flow irrigation i.e., distributing water through small field channels is not advisable, therefore it is essential to adopt modern irrigation practices in form of sprinklers, micro-irrigation (drip technique), mainly to improve water use efficiency and reduction in the evaporation losses. Currently the percentage of sprinkles and micro-irrigation is 4.94 Mha which is just 15 % of total irrigation in the country (IWR 2011).

Conclusion and Recommendations

There is a need to generate spatial databases integrating all factors affecting groundwater recharge and withdrawal using remote sensing technique. In the absence of such databases, groundwater development plans would not be fruitful to have desired impact. The aquifer mapping at the micro-level/ local scale is a primary need before undertaking any water conservation programme. The sustainable development of groundwater resources need adoption of a holistic approach, which involves studying parameters related to groundwater and other collateral dataset, such as slope, geomorphology, lineament, soil, landuse, etc. There is a need to have a long term planning by considering future demand of irrigation and drinking water.

Aquifer management plays an important role in achieving the objective of sustainable development. Most of the time, the water conservation programmes are adopted at the micro-level/ local scale ignoring regional setup and hence failing to give everlasting solutions. Water security will be achieved only through adoption of regional approach as watershed is a large unit in which there are varied hydrogeological situation i.e. runoff areas, recharge areas and storage areas. Each area has character facilitating groundwater recharge e.g. runoff areas are amiable to construction of in situ water conservation structures, recharge areas are suitable for construction of water storage structures such check dams while storage areas are suitable for construction of subsurface dykes to prevent base flow and also suitable for adoption of sprinkler irrigation practices to reduce water consumption. Thus in watershed approach each component of the watershed is treated hence facilitates adoption of holistic approach of water conservation. Therefore, groundwater management is a long term exercise, which may take even a decade for its implementation, but the solution will be everlasting.

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