Subsurface dams to harvest rainwater— a case study of the Swarnamukhi River basin, Southern India

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Abstract Declining water level trends and yields of wells, deterioration of groundwater quality and drying up of shallow wells are common in many parts of India. This is mainly attributed to the recurrence of drought years, over exploitation of groundwater, increase in the number of groundwater structures and explosion of population. In this subcontinent, the saving of water has to be done on the days it rains. India receives much of its rainfall in just 100 h in a year mostly during the monsoon period. If this water is not captured or stored, the rest of the year experiences a precarious situation manifest in water scarcity. The main objective behind the construction of subsurface dams in the Swarnamukhi River basin was to harvest the base flow infiltrating into sandy alluvium as waste to the sea and thereby to increase groundwater potential for meeting future water demands. An analysis of hydrographs of piezometers of four subsurface dams, monitored during October 2001–December 2002, reveals that there is an average rise of 1.44 m in post-monsoon and 1.80 m in the pre-monsoon period after the subsurface dams were constructed. Further, during the pre-monsoon month of June, much before construction of subsurface dams in October 2001, the water level was found fluctuating in the range of 3.1–10 m, in contrast to the fluctuation ranging from 0.4 to 3.1 m during the period following the construction of dams. Hence, the planning of rainwater harvesting structures entails thorough scientific investigations for identifying the most suitable locations for subsurface dams.

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Résumé La diminution des niveaux d'eau ainsi que des capacités hydrauliques des puits, la détérioration de la qualité de l'eau souterraine ainsi que l'assèchement de puits de faibles profondeurs sont chose commune dans plusieurs régions de l'Inde. Cela est principalement du à la récurrence d'années sèches, à la surexploitation de la ressource en eau souterraine, à l'augmentation du nombre de captages d'eau souterraine, et à l'explosion démographique. Dans cette partie du globe, l'économie de l'eau doit se faire à partir des jours de pluie. L'inde reçoit la majorité de sa précipitation annuelle en moins de 100 heures associées à la période de la mousson. Si cette eau n'est pas captée et entreposée, le reste de l'année fait face à une pénurie et à une rareté de l'eau disponible. L'objectif principal de la construction de barrages souterrains dans le bassin de la rivière Swarnamukhi est de favoriser l'infiltration des eaux de ruissellement en direction des sables alluvionnaires qui, autrement, seraient perdues en mer, ce qui permet d'augmenter le potentiel en eau souterraine afin de répondre à la demande future en eau. L'analyse des hydrographes produits par des piézomètres installés dans quatre (4) barrages souterrains, suivis d'octobre 2001 à décembre 2002, a révélé une remontée moyenne des niveaux de 1,44 m et de 1,80 m respectivement avant et après la période de la mousson, et ce après l'installation des barrages souterrains. De plus, durant le mois de juin, précédant la mousson, bien avant la construction des barrages souterrains en octobre 2001, les niveaux d'eau ont fluctué entre 3,1 m et 10 m, en comparaison avec des fluctuations oscillant entre 0,4 m et 3,1 m lors de la période suivant la construction des barrages souterrains. Par conséquent, la planification d'une procédure de collecte des eaux de pluies par des structures adaptées impose des études scientifiques complètes, permettant d'identifier les emplacements les plus favorables à la construction des barrages souterrains.

Resumen La tendencia a la disminución de niveles de agua y del rendimiento de pozos, el deterioro de la calidad del agua subterránea y la sequía de pozos de agua poco profundos son comunes en muchas partes de la India. Esto se atribuye principalmente a la recurrencia de años de sequía, la sobreexplotación de aguas subterráneas, el incremento en el número de estructuras que explotan aguas subterráneas y la explosión de la población. En este subcontinente los ahorros de agua deben llevarse a cabo cuando llueve. La

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India recibe la mayor parte de lluvia en sólo 100 horas cada año durante el período del monzón. Si esta agua no se capta o almacena, el resto del año queda en una situación precaria de escacez de agua. El principal objetivo al construir embalses a nivel de subsuperficie en la cuenca del río Swarnamukhi es la cosecha del flujo de base que infiltra los aluvios de arena y que debería generar un flujo de agua que se desecha en el mar. La consecuencia es el incremento del potencial de agua subterránea para satisfacer la demanda futura. El análisis de los hidrógrafos de piezometros de 4 embalses de subsuperficie que fueron monitoreados desde octubre 2001 hasta diciembre 2002 revela que hubo un incremento promedio de 1.44 metros después del monzón y de 1.8 metros antes del monzón una vez que se construyeron los embalses. Adicionalmente durante el mes de junio, mucho antes de la construcción de embalses de subsuperficie en octubre del 2001, se observaron variaciones en el nivel de agua en un rango de 3.1 a 10 metros, en contraste a la variación de 0.4 a 3.1 metros durante el período posterior a la construcción de los embalses. En consecuencia el planeamiento de estructuras para la captación de lluvia involucra investigación científica exhaustiva para identificar los lugares idóneos para la ubicación de embalses de subsuperficie o subterráneos.

Keywords Rainwater harvesting · Water resources · Sub-surface dam · Swarnamukhi River · Groundwater level fluctuations

Introduction

In India there are a few years of very good rainfall and many years of low rainfall. Even during low rainfall years there occurs high runoff causing flash floods of short duration. If these flash floods are harnessed for recharging the depleted aquifers, there will be sufficient improvement of water supply. For all the fairly large amount of rainfall in India, much of it is lost through runoff due to the absence of sufficient sites for storage and impounding. There is thus an imbalance between recharge and groundwater development in many parts of the country (Raju 1998). It is a paradox that the town of Chirapunji in Meghalaya State, northeast India, which has the distinction of an annual rainfall in excess of 11,000 mm, experiences water scarcity for nine months of the year. Conservation of a significant proportion of local rainfall during non-monsoon months by storage in underground cisterns is necessary in order to reduce dependence on imported water supplies in Bangalore City (Curtis 1998). Rainwater harvesting and groundwater recharge should be encouraged with the participation of every member of the village community. Concerted efforts for promoting and accelerating groundwater recharge through the adoption of rainwater harvesting methods are to be preferred to the artificial recharge of groundwater. Some artificial recharge methods by the uninitiated invariably pose the great danger of polluting one of the few sources of unpolluted water in the country (Radhakrishna 2003).

Surface storage of water has serious disadvantages such as evaporation losses, pollution problems, submersion of valuable land, and silting up of dams. In recent years, groundwater dams (i.e. subsurface dams) have been constructed to solve many of the aforesaid problems. Such devices are not new. Groundwater dams were constructed on the island of Sardinia in Roman times and similar structures to dam groundwater were developed by old civilizations in Tunisia of North Africa.

Sustainable management of groundwater is of vital importance to economically weaker communities in rural India. In watersheds or sub-basins in which around 50% of the available groundwater resources are being utilized, the emphasis is now being shifted from groundwater development to sustainable groundwater management. This shift ensures long-term availability of adequate quantity and acceptable quality of groundwater (Limaye 2003). In the over-exploited watersheds, it is necessary to impose pumpage control and to apply provisions of groundwater legislation. India's ancient tradition of community based water harvesting through the involvement of individual households is fading away (Agarwal and Narain 1997). This predicament has necessitated the increased role of governments (Central and State) in water management.

Water harvesting

Rainwater harvesting by runoff conservation structures (gully plug, rockfill dams, check dam and bench trenching) is basically intended to slow or stop the running water (contour trenching and subsurface dams) and to infiltrate (percolation tank) into the underground. A survey of developments in the past decade shows that numerous projects have been undertaken to promote local water harvesting both in urban and rural areas in India. In drought prone areas rainwater harvesting is undertaken to address the serious problems of drought and water scarcity. The people of the State of Rajasthan, who have a long-standing tradition of rainwater harvesting (Agarwal and Narain 1997) used drought relief aid for developing 100,000 water-harvesting structures. Water conservation measures in Wagarwadi watershed, Maharastra, are responsible for raising the water table by about 2 m in the wells located within 200 m on the down stream side of nala (i.e. stream) bunds and in other wells located adjacent to the water conservation structures. Water conservation structures of Wagarwadi watershed are responsible for groundwater recharge estimated at 6 ha m per year and a rise of 0.5 to 2.5 m of the water table at different locations (Gore et al. 1995).

The Government and non-governmental agencies in India are increasingly involved in water harvesting in rural areas. Areas of low to moderate rainfall occurring mostly in a single monsoon period do require all efforts to conserve rainwater. Various widely practiced methods of artificial recharge of groundwater such as gully plugging, contour trenching and bunding, rock fill dams, check dams, percolation dams and subsurface dams are being employed for increasing the contact area and resident time

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of surface water with the soil to maximize the quantity of water percolation and augment groundwater storage.

A subsurface dam, intended for arresting the groundwater flow in a natural aquifer, is constructed across a valley by digging a trench to bedrock. The trench has at its base an impervious wall which is covered with excavated material until the trench is completely concealed. The reservoir thus built can never be totally drained and can be used throughout the dry season, depending upon the storage volume, to meet the water demand. Sub-surface dams are often built in riverbeds that generally constitute highly permeable aquifers with good storage potential. The most common type of sub-surface dams are clay, concrete, stone masonry and brick walls built in excavated trenches of 3–10 m deep. The advantages of subsurface dams include low-cost construction and very low evaporation, besides, the utilization of more land area for cultivation.

Case study of Swarnamukhi River subsurface dams

The Swarnamukhi River basin is essentially a semi-arid tract with an average annual rainfall of 1,000 mm. The river basin is occupied by granite and granitic gneisses. With alluvium thickness in the range of 3–7.5 m, the underlying weathered granite occurs at a depth ranging from 9 to 16 m, the depth up to which dug wells are pierced. The Swarnamukhi River has occasionally dried up, impinging on the irrigation and drinking needs. Impounding more base flows in the Swarnamukhi River basin necessitates the development of a watershed program constituting sub-surface dams and other groundwater structures scientifically designed. The purpose of construction of subsurface dams in the Swarnamukhi River basin is to harvest the base flow going in sandy alluvium and thereby to increase groundwater resource potential.

Need for the construction of sub-surface dams across Swarnamukhi River

1. Sand quarrying along the river course has decreased the thickness of sandy alluvium in which maximum storage of water occurs.
2. Over-exploitation of groundwater in excess of the annual replenishment has caused continuous decline of water levels and a decrease in yields from shallow wells along the river courses.
3. Vagaries of monsoons are invariably marked by insufficient rainfall.
4. Construction of Kalyani Dam (a tributary to Swarnamukhi River) to meet drinking water needs to the Tirupati-Tirumala region has reduced stream flow at Swarnamukhi River.
5. An imperative for restoring the perennial nature of the river course through such basin development activities in order to augment the water table in the adjacent wells.

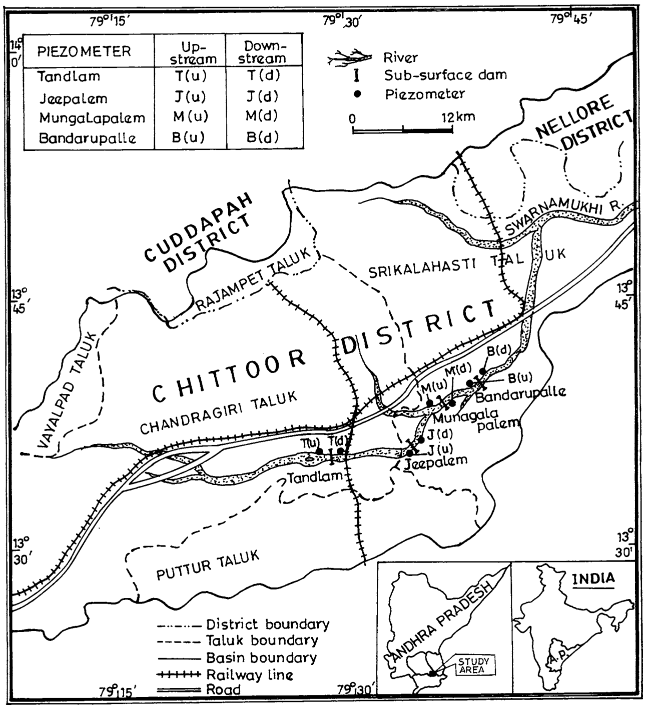

Fig. 1 Location map of subsurface dams across Swarnamukhi River basin

Results and discussion

The construction of subsurface dams is one of the components envisaged for rejuvenation of the Swarnamukhi River basin. Like surface runoff, groundwater also leaves the basin as base flows if it is not harnessed. Hence, the movement of groundwater in the river course has been checked to utilize it for stabilization of Rabi season (October to December) crops like groundnut and paddy as well as early Kharif (June to September) paddy crop by construction of subsurface dams across Swarnamukhi River basin at appropriate places. Suitable sites for subsurface dams (Fig. 1) have been selected by studying the topographic and geological maps. The data on the depth to rock was collected from resistivity soundings carried out along the course of proposed subsurface dam alignment. A few auger holes have been drilled to corroborate the results of the resistivity survey. The results of these investigations led to the construction of four subsurface dams. The dam wall occupies very little space without any buttresses.

The Subsurface dam (Fig. 2) was constructed with puddled clay 0.9 m thick which has been keyed into a hard-end connection on either side of the river bank. Details of length and depth of subsurface dams in the Swarnamukhi River basin are shown in Table 1. The top of subsurface dams has been limited to 1 m below riverbed level to allow excess flow downstream, to flush the salts accumulated and to leave unaffected the riparian rights of the farmers downstream. The dam has been keyed into weathered bedrock 0.55 m below the bedrock surface. The clay wall was compacted with wooden rammers in order to obtain proctors' density. The

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Table 1 Details of length and depth of subsurface dams in the Swarnamukhi River basin

SL No	Subsurface dam	Length (m)	Depth (m)	Slope in the vicinity of dam	Maximum depth to weathered rock (m)	Cost of construction in Rupees (US Dollars)
1	Tandlam	300	5.00	1 in 500	6.00	1,800,000 (36,000)
2	Jeepalem	340	6.30	1 in 360	7.30	3,700,000 (74,000)
3	Munagalapalem	210	3.00	1 in 450	4.00	900,000 (18,000)
4	Bandarupalle	193	3.00	1 in 900	4.00	1,500,000 (30,000)

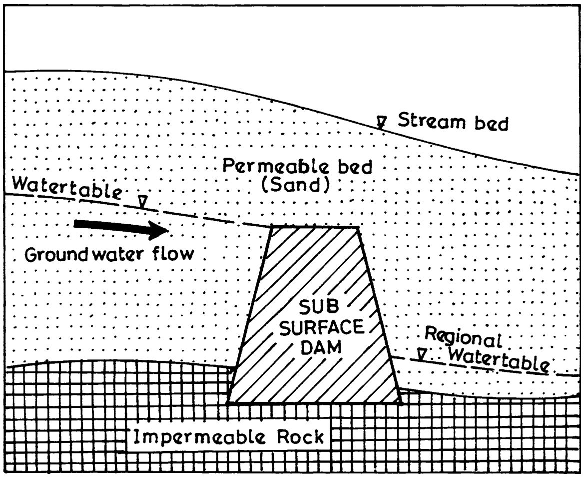

Fig. 2 Schematic diagram of subsurface dam

clay balls were so prepared as to imbibe optimum moisture content. In order to retain this moisture content for a longer period, 200 µ low-density polyethylene film was emplaced on the upstream, downstream and top of the dam in order to protect the clay wall from yielding to cracks.

The imperviousness due to the dam has been proved by the study of upstream and downstream water levels monitored in the piezometers erected 200 m away from the dam alignment. In order to establish the trends in the water level fluctuations monitored at fortnightly intervals, well hydrographs are drawn for Tandlam, Jeepalem, Munagalapalem and Bandarapalli subsurface dams and are shown in Figs. 3 and 4.

The hydrograph of Tandlam subsurface dam (Fig. 3) shows that the water level fluctuations are around 1.5 m after the construction of the subsurface dam. This points to the improvement and stability of water levels in the upstream side of the subsurface dam. The well density in the upstream side of the Tandlam subsurface dam is about 285. The very high density in the left bank with a thickness of sand ranging from 9 to 10 m is in contrast to the low density of wells on the right bank marked by the shallowness of the sand bed. Following the construction of the dam the water level fluctuation in the right bank was around 1.5 m (very minimum) because of the low well density coupled with the limited overdraft in existing wells and absence of any cultivable land for development of agricultural activities. Hence there is an indirect benefit to the areas further away from the dam due to a rise in the water table. On the other hand, the water level fluctuations, as revealed by the hydrograph of a piezometer at the Jeepalem subsurface dam (Fig. 3), are around 7 m. The large water level fluctuations are due to the presence of 382 tube wells on the upstream side of the dam causing overdraft of groundwater for agricultural activity and to the small thickness of the sand bed in the upstream side of the subsurface dam.

Following the construction of the subsurface dam, there are minimum water level fluctuations (around 1.25 m), as indicated by the hydrograph of Munagalapalem subsurface dam (Fig. 4). The high recharge of water from Nakklavanka and Seethakalva streams (the tributaries of Swarnamukhi joining on the upstream side of the Munagapalem subsurface dam) and the thickness of the sandy alluvium (around 10 m) in the Seethakalva stream contribute to the stable water level. Around 640 wells are drilled near the Munagalapaem subsurface dam. Prior to dam construction some of them dried up in the summer months (May to July). It is significant that after constructions of the subsurface dam the storage capacity of water impounded is about 8.67 Mcft, which stabilized 520 acres of paddy crop during the summer season, besides offering improvement of irrigation land. The hydrograph of Bandarupalli subsurface dam (Fig. 4) reveals that the water level fluctuations are around 2.5 m after the construction

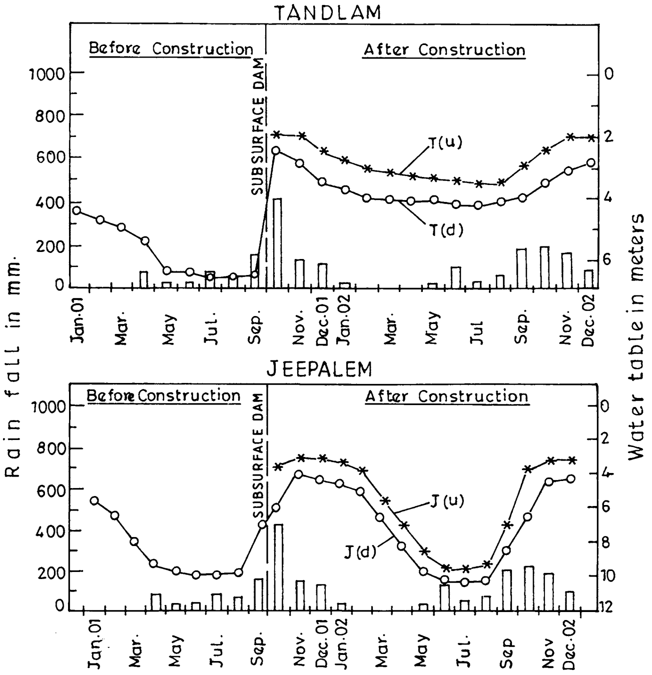

Fig. 3 Well hydrographs for piezometers upstream and downstream of Tandlam and Jeepalam subsurface dams across Swarnamukhi River basin

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Table 2 Water levels monitored in piezometers before and after construction of subsurface dams in the Swarnamukhi River basin

Sl. No	Subsurface dam	Observation well water level before construction of subsurface dam		Water level in upstream piezometer after construction		Rise in water level in corresponding month after construction	
		January (post-monsoon) (m)	June (pre-monsoon) (m)	January (m)	June (m)	January (m)	June (m)
1	Tandlam	4.2	6.3	2.8	3.2	1.4	3.1
2	Jeepalem	6.0	10	3.8	9.6	2.2	0.4
3	Munagalapalem	1.1	3.3	0.3	0.9	0.8	2.4
4	Bandarupalle	1.3	3.2	0.0	2.0	1.3	1.2

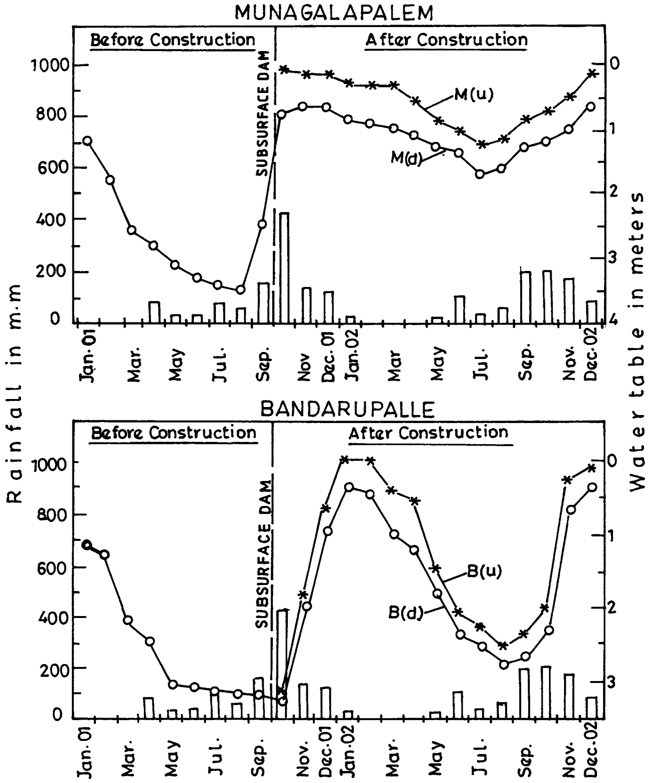

Fig. 4 Well hydrographs for piezometers upstream and downstream of Munagalapalem and Bandarupalle subsurface dams across Swarnamukhi River basin

of the subsurface dam. The very low well density around this subsurface dam is due to the thin sandy layer (the average being 3 m). In the case of the existing 105 wells in the upstream side of this dam area, the discernible development in the groundwater structures (i.e. wells) is made possible through the improvement of water levels by means of constructing the subsurface dam.

Water levels were recorded for 9 months (January 2001 to September 2001) in observation wells upstream and downstream of the dam before and after construction (October 2001 to December 2002) (Munirathnam 2003). Analysis of water tables indicates that there was an average rise of 1.44 m in post-monsoon and 1.80 m in the pre-monsoon periods in the four subsurface dams. Further, the data recorded for the pre-monsoon month of June 2001 is significant in that the pre-construction fluctuation in water level was 3.1 to 10 m as opposed to the fluctuation of 0.4 to 3.1 m after construction (Table 2). It is also important to mention that farmers were restricting the diameter of the delivery pipe of pumps and irrigating as part of the already sown summer groundnut crop during the period preceding the construction of surface dams. Interestingly, after the construction of the subsurface dams, the irrigation activity has become a continuing feature in the summer season, thanks to the artificial recharge of the groundwater.

Conclusions

Rainwater harvesting and artificial recharge have become compulsory in the areas where the pursuits of groundwater development have surpassed the annual replenishment. Involvement of the community is necessary in water management and development by laying greater emphasis on extending and improving local water harvesting systems. It is imperative for the rural areas to participate in watershed development programmes of soil moisture conservation and groundwater recharge such as catchment area treatment through gully plug, rock fill dams, contour trenching and bunding, check dams, percolation tanks and subsurface dams.

This case study indicates that consideration of subsurface dams in the Swarnamukhi River basin is feasible and economical by using cheap material like clay and LDPE Film. From the well hydrographs, the water levels in the upstream piezometers after construction of the subsurface dams average 1.44 m in the post-monsoon and 1.80 m in the pre-monsoon periods. Construction of subsurface dams in the Swarnamukhi River basin increased groundwater storage and thus provided for an increase in land productivity. Watershed management of the basin has improved base flow and improved the storage capacity at subsurface dams and ultimately facilitated the rejuvenation of the river to the extent of becoming a perennial one. The assistance of financial institutions is now very much sought after by the farmers to construct such dams on a co-operative basis. The needs of the basin are to conserve every drop of water and recharge the depleted aquifers.

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References

Agarwal A, Narain S (eds) (1997) Dying wisdom: Rise, fall and potential of India's traditional water harvesting systems. Centre for Science and Environment, New Delhi

Curtis LC (1998) Rainwater Harvesting—A Possible Seasonal Addition to Bangalore Water Supply. J Geol Soc f India 51:455–460

Gore KP, Pendke MS, Mal BC, Gurunadha Rao VVS, Gupta CP (1995) Assessment of impact of water conservation structures on groundwater regime in wagarwadi watershed, Parbhani, Maharashtra. Gondwana Geol Mag 10:63–77

Limaye SD (2003) Some aspects of sustainable development of groundwater in India. IGC'S Eighth Professor Jhingran Mem. Lect., 90th Indian Science Congress, Bangalore 22 pp

Munirathnam P (2003) Rejuvenation of Swarnamukhi River Basin in Chittoor District, Andhra Pradesh, India. Technical Report, pp 1–8

Radhakrishna BP (2003) Groundwater Recharge. J Geol Soc India 62:135–138

Raju KCB (1998) Importance of Recharging Depleted Aquifers: State of the Art of Artificial Recharge in India. J Geol Soc India 51:429–454

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