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Groundwater depletion and groundwater balance studies of Kandivalasa River Sub Basin, Vizianagaram District, Andhra Pradesh, India

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ABSTRACT

The Kandivalasa River Sub Basin near Cheepurupalli town of Vizianagaram district, Andhra Pradesh, India was monitored for groundwater levels at 41 observation wells during 2013–2015. Along with groundwater levels, the daily rainfall data is also collected for these years. A continuous decrease in groundwater levels was observed during the study period more particularly in the year 2015 which also had minimum rainfall. Groundwater depletion is observed mostly in the Eastern and South Western part of the basin where pumping wells are more. Groundwater balance studies have indicated that 11.3 MCM of groundwater can be utilized in the basin annually. However, the net annual groundwater draft has been found to be 16.6 MCM. Hence, over abstraction of 5.66 MCM is the main cause for depletion of groundwater levels. The water conservation and groundwater recharge measures have to be taken up at Chinnanadipally and Dummeda villages in the basin to have sustainable groundwater utilization in the basin.

1. Introduction

India is currently the world's largest consumer of groundwater, withdrawing more than double the amount of groundwater drawn by the USA (Shah, 2005). Over the years, increasing dependence on groundwater has created imbalance in the groundwater availability and long term withdrawal is exceeding long term recharge, leading to the depletion of groundwater level. Since agriculture is the main occupation in the study area which is Kandivalasa River Sub Basin (KRSB) near Cheepurupalli town of Vizianagaram district, Andhra Pradesh, India, the farmers are mainly dependent on groundwater for irrigation in non-monsoon period (November to May). To meet the challenges of depleting groundwater levels and thereby drying up of bore wells in the non-monsoon season, the management and development of groundwater resources is essential in the study area. Hence, it is very important to know about the extent of natural recharge occurring to the aquifer of the region. Moreover, the groundwater recharge estimation is a key component in groundwater flow or transport models.

Satish Chandra and Saksena (1975), Athavale et al. (1992), Kumar and Seethapathi (2002) have carried out groundwater balance studies and quantified groundwater resources in various hard rock regions of India. Naga Rajani et al. (2006), have used remote sensing and GIS techniques for groundwater exploration and identification of artificial recharge sites in Kurmapalli watershed in Nalgonda and Ranga Reddy districts of Telangana, India. Rangarajan et al. (2009) have estimated the natural recharge and its relation with aquifer parameters near Tuticorin Town, Tamilnadu, India. Varalakshmi et al. (2014) have studied the groundwater recharge studies by using GEC-1997 guidelines in the Osmansagar and Himayathsagar catchment areas which are comprised of basaltic and granitic terrains respectively in the Telangana State. The study has concluded that the percent rainfall converting to the groundwater recharge is nearly 22% in the basin. Khadri and Moharir (2015) have analyzed the seasonal groundwater fluctuations with reference to the rainfall received by the Man River Basin, Maharashra, India. The study also interpreted that the high level extraction of groundwater during non-monsoon period for irrigation purpose is causing groundwater fluctuation in the study area.

The main objective in this study is to evaluate the existing groundwater resources and stage of development (percentage of renewable groundwater utilized annually) in the Kandivalasa River Sub-Basin by using Groundwater Estimation Committee (GEC) methodology (GEC, 1997). For sustainable development of water resources, it is imperative to make quantitative estimation of the available water resources. These studies can be useful for overall development of the basin on sustainable basis.

2. Hydrogeology of the study area

Kandivalasa River Sub-Basin (KRSB) (Fig. 1) near Chipurupally town of Vizianagaram district of Andhra Pradesh, India, is covered with

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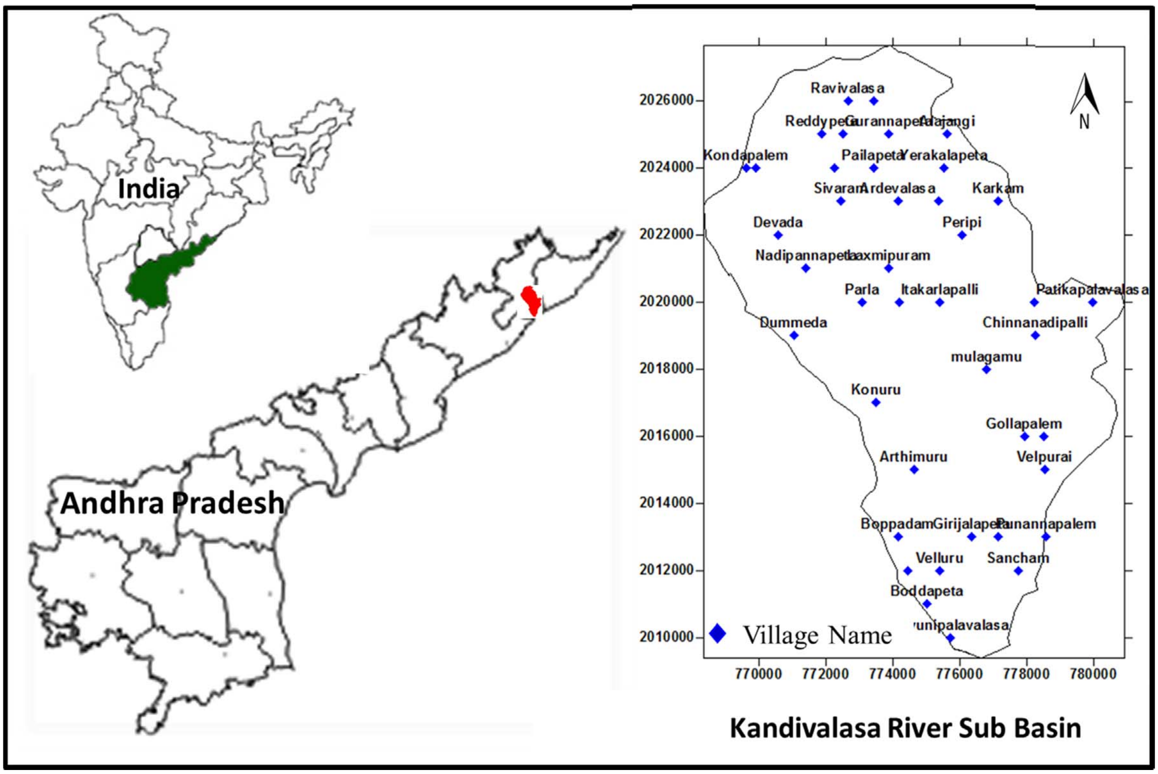

Fig. 1. Location of Kandivalasa River Sub Basin in the Vizianagaram District.

a typical khondalitic suite of rocks and is situated between east longitudes 83°32′15" to 83°39′10" and north latitudes of 18°9′15" to 18°19'54" having an areal extent of 121 km^2 is selected for this study. It forms a part of Survey of India toposheet nos. 65 N/11 and 65N/12. In general the area is covered by a thick soil cover (1–4 m) followed by weathered and fractured khondalitic formation underlain by basement of granite gneiss. The area is highly disturbed due to folding, faulting and fracturing with isolated hills covered by khondalitic rocks on the top and lateritic soils on the sides (Fig. 2). Occasionally quartz veins are seen exposed to surface often serving as guide to locate high yielding wells. The topography of the area is undulating. At all locations between hills there is a high slope in the foot hill region and a gentle slope towards the valley (Fig. 3).

Frequently small plateaus are also observed. The average annual rainfall is around 1000 mm. Groundwater occurs under water table conditions in the weathered portion of the khondalite. The fact that the raise of water level in the bore well after penetrating the fractured environment and drying up of nearby open wells due to pumpage of bore wells, demonstrate that the weathered and fractured environment are hydraulically connected. Therefore, the fractured environment is under semi confining conditions (Venkateswara Rao and Briz Kishore, 1991).

3. Methods

The groundwater levels of the 41 observation wells covering entire Kandivalasa River Sub Basin are monitored for both pre and post monsoon seasons of 2013, 2014 and 2015 (Plate 1). The GPS survey has been done at all the observation wells. Groundwater contour maps in the basin are also prepared by using SURFER software (Oseji Julius, 2011) to know the direction of groundwater flow. The daily rainfall data of five mandals (an administrative unit within a district) namely Cheepurupally, Garividi, Nellimarla of Vizianagaram district and Ranastalam and Laveru mandals of Srikakulam district covering entire basin is also collected from Andhra Pradesh State Economics and Statistics department. The monsoon rainfall is estimated for each mandal (Table 1). The seasonal changes of groundwater levels of all the individual wells are carefully observed from the year 2013–2015. The analysis of depletion of groundwater levels during this period has been carried out in the basin by using well census data and rainfall data (Nandargi et al., 2014) of the basin. The groundwater fluctuation map (Chyan-Deng et al., 2007) is prepared for the year 2015 using SURFER software.

In order to find out the causes for the groundwater depletion scenario in the basin, the groundwater recharge, the groundwater abstraction and the groundwater balance in the basin are estimated by using GEC-1997 guidelines (Kumar, 2012). The stage of the groundwater development is calculated (Sitender and Rajeshwari, 2015) and finally the groundwater recharge areas and pumping areas are identified with the help of groundwater flow maps (Singhal and Gupta, 2010).

3.1. Water-table fluctuation method

The study of groundwater level fluctuations helps to understand the depletion and recharging conditions of an aquifer. Physical-based techniques like water-table fluctuation method have traditionally and widely been used more than chemical based techniques for estimating groundwater recharge in semiarid regions (Healy and Cook, 2002). The groundwater recharge has been calculated by using Water Table Fluctuation method (WTF method) as per methodology recommended by Groundwater Estimation Committee (GEC, 1997). The water table fluctuation method is based on distinct changes in seasonal (pre and post monsoon) groundwater levels. Among the physical methods, the water-table fluctuation method links the change in groundwater storage with resulting water table fluctuations through the storage parameter (i.e., specific yield in unconfined aquifer).

The WTF method is based on the recharge effect, i.e. the rise of the water table due to previous rainfall. Careful analysis of the records enables the exclusion of variations in the water table due to fluctuations

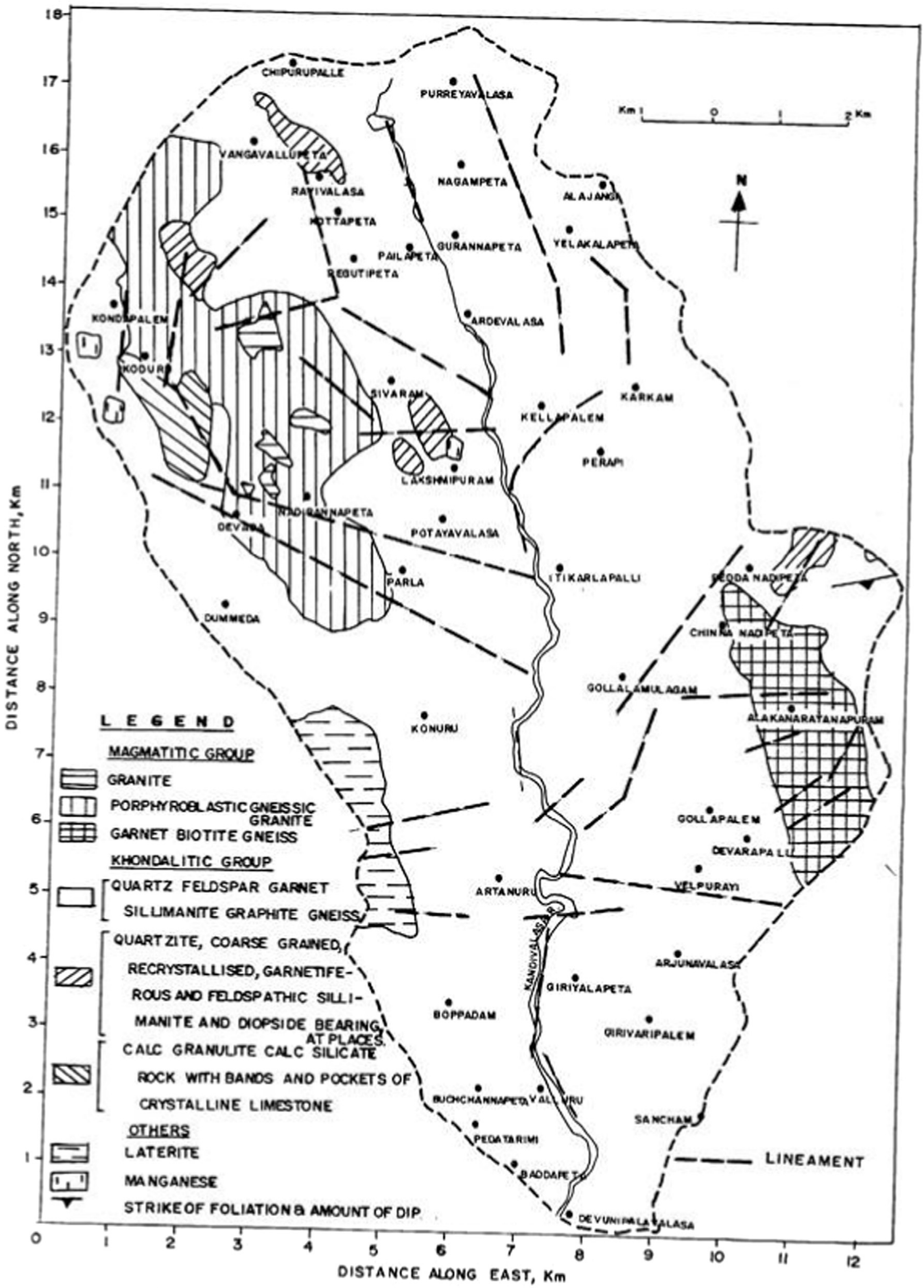

Fig. 2. Geology map of the Kandivalasa River Sub Basin (Venkateswara Rao and Briz Kishore, 1991).

in climate and anthropogenic activities (pumping, irrigation, land use, etc.) (Healy and Cook, 2002). The WTF method is based on the premise that the rise in groundwater levels in unconfined aquifers is due to recharging water arriving at the water table (Delin et al., 2007). Recharge is calculated in the WTF method using the formula (GEC, 1997).

$$\text{Groundwater Recharge} = \text{Geographical area} \times \text{Specific Yield} \times \text{Rise in the water table}$$

The WTF method is used in this study because frequent and accurate water level measurements are available in all the observation wells of the entire basin.

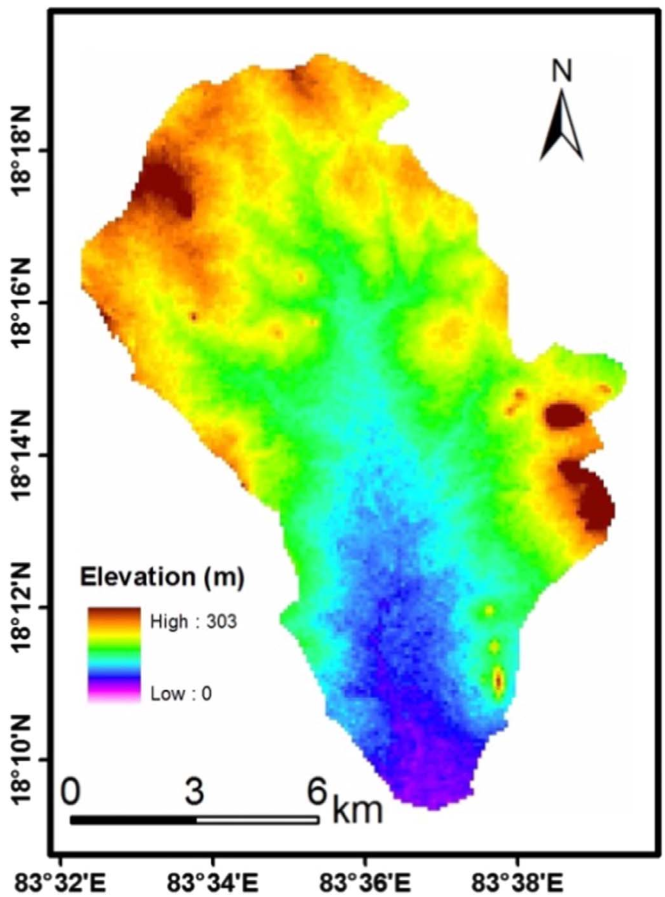

Fig. 3. Digital Elevation Map of the Kandivalasa River Sub Basin.

Plate 1. Filed Photograph of measuring groundwater levels in the Kandivalasa River Sub Basin.

Table 1
Monsoon rainfall in the Kandivalasa River Sub Basin.

Year	Rainfall in 'mm'	% of deviation
2013	1051.5	− 7
2014	891.7	−21
2015	984.4	−13

Table 2
Norms for Specific Yield (GEC, 1997).

S.No.	Rock Type	Specific Yield as a fraction		
		Recommended	Maximum	Minimum
1	Karstified Limestone	0.08	0.15	0.05
2	Sandstone	0.03	0.05	0.01
3	Weathered Granite, Gneiss and Schist with Low Clay content	0.03	0.04	0.02
4	Laterite	0.025	0.03	0.02
5	Limestone	0.02	0.03	0.01
6	Weathered or Vescular Jointed	0.02	0.03	0.01
7	Weathered Granite, Gneiss and Schist with Significant Clay Content	0.015	0.02	0.01
8	Quartzite	0.015	0.02	0.01
9	Phyllites, Shales	0.015	0.02	0.01
10	Massive Poorly Fractured Rock	0.003	0.003	0.002

Table 3
Total Groundwater Recharge in the KRSB with WTF method.

Year	Amount of recharge in MCM
2013	13.92
2014	14.60
2015	11.30

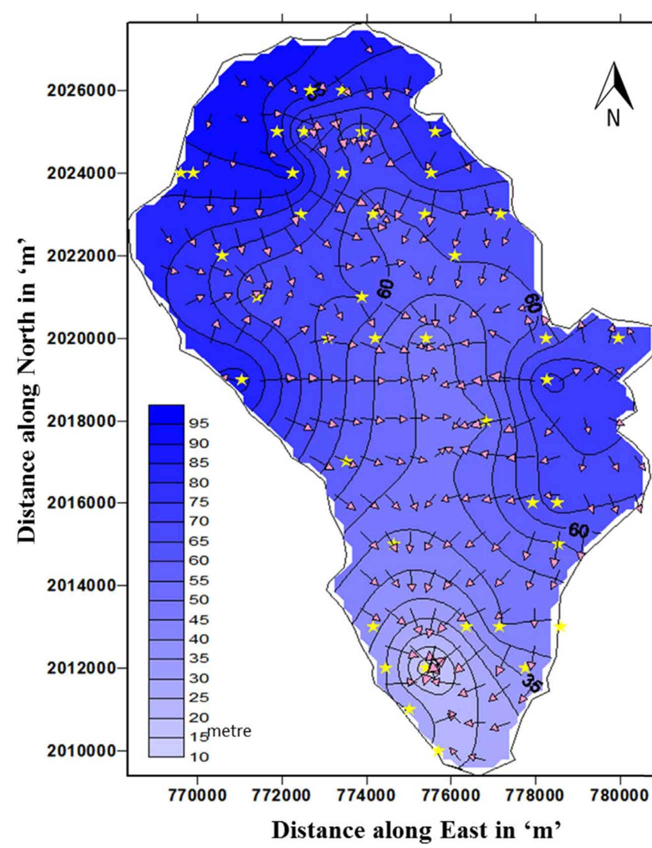

Fig. 4. Groundwater contour map of post monsoon season of 2013 in the KRSB.

To estimate the groundwater level rise in the basin, the pre monsoon and post monsoon groundwater levels at 41 locations covering entire basin were collected during the years 2013, 2014 and 2015. The difference of depth to water levels between pre and post monsoon seasons is estimated and is contoured using SURFER software. The rise in the water table during the rainy season is used to estimate the recharge.

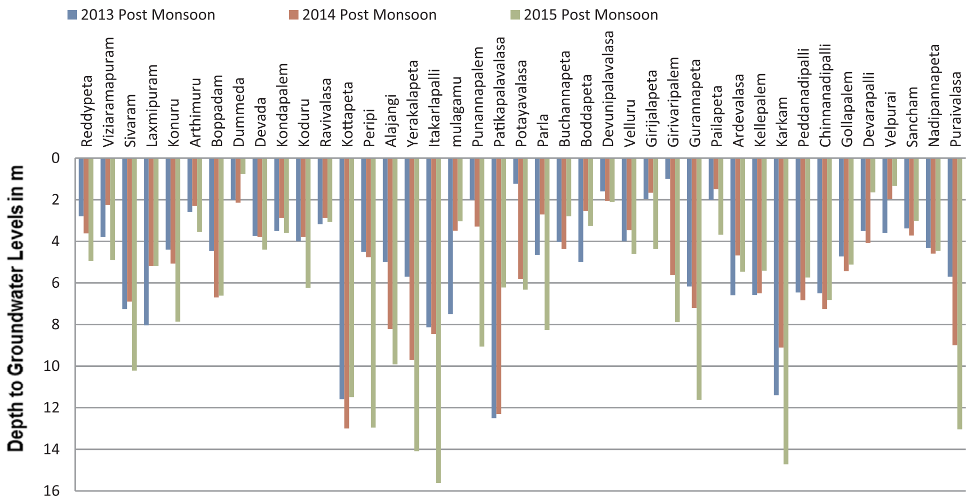

Fig. 5. Depth to groundwater levels in the KRSB during post monsoon seasons.

Since pumping for irrigation during monsoon period is negligible, the rise in water table is primarily due to the rainfall recharge. Areas between successive contours of groundwater level fluctuations are estimated by using the Arc GIS 9.3 software.

To apply the WTF method, an estimation of the specific yield (S_y) at the depth of water table fluctuation is required. The specific yield (S_y) values of different formations are adopted from the recommendations of the groundwater estimation committee (GEC, 1997) based on local geology. As per local geology of the study area, the recommended specific yield value of 3% is adopted for calculating the groundwater recharge (Table 2).

The total groundwater recharge with WTF method by applying the suitable specific yield to the basin is presented in the Table 3. The obtained total groundwater recharge with water table fluctuation method (Table 3) is the recharge directly occurring from the precipitation, tanks and water conservation structures such as check dams, contour bunds and contour trenches.

4. Results and discussion

4.1. Groundwater depletion scenario in the basin

In all the seasons under observation, static water levels are more than 10 m below ground level (b.g.l.) in North Eastern part and below 5 m of b.g.l. in the West, South and South Eastern part of the basin (Fig. 4). By using above mean sea level (a.m.s.l.) data, the groundwater flow directions are modelled with Surfer software. The flow directions indicate that the groundwater flow is towards the main stream which is flowing from North to South direction. Hence the water levels are following the topography of the basin.

Since agriculture is the main occupation in the study area, the farmers are mainly dependent on groundwater for irrigation in non-monsoon period. According to the well census data collected from electricity department of each mandal (administrative unit), nearly 1800 bore wells are being pumped in the basin having an area of 121 km^2. This huge pumping is one of the reasons for groundwater depletion in the basin.

The average annual rainfall of the basin is 1131 mm (CGWB, 2013), with percent of deviation varying from −7% to −21% of the normal rainfall. During the study period due to the less average annual rainfall occurred in the basin during the years 2014 and 2015 when compared to the year 2013 (Table 1).

On account of these consecutive diminished rainfall years, the decline of groundwater levels in the post monsoon season has increased from 2013 to 2015 (Fig. 5). It is also observed that the decline of groundwater levels and groundwater fluctuations are much higher in the year 2015 when compared to the other two years. 22 bore wells in the year 2014 and 28 bore wells in the year 2015 out of 41 bore wells have got depleted water table with respect to post monsoon season of 2013. To show the spatial variation of groundwater depletion in the basin, the contour maps (Fig. 6) of groundwater levels in 'm' below ground level are prepared. It can be observed that the groundwater levels are mainly depleted in the eastern part of the basin where the pumping wells are more (Fig. 6).

The groundwater fluctuation contour map of 2015 (Fig. 7) is also prepared to identify the groundwater depletion. At the places in the Eastern side of the basin namely Karkam, Chinnanadipally and Itakarlapalli villages, and the Boppadam village in South Western side of the basin, the groundwater fluctuations are more where the pumping wells are more than hundred (Fig. 7).

To identify the causes for the groundwater depletion and high groundwater fluctuations in some places in the basin, it is necessary to quantify the natural recharge occurring to the water table and withdrawal or draft of groundwater from the basin. According to the Central Ground Water Board (CGWB) report (CGWB, 2013), the stage of development of groundwater for the three mandals of the study area namely Cheepurupalli and Garividi of the Vizianagaram district and Ranastalam mandal of Srikakulam district are 70% and 104% respectively. i.e., 70% and 104% of renewable groundwater is utilized annually.

4.2. Estimation of annual utilizable groundwater resources

The average annual groundwater recharge in the basin is the average of total groundwater recharge for the years 2013, 2014 and 2015 (Table 3) estimated as per the methodology explained in the article 3.1. The average annual groundwater storage during the study period in the basin is 13.27 MCM. According to GEC norms, the annual utilizable groundwater resources are 85% of average annual groundwater storage. Hence, annual utilizable groundwater resources in the basin is 11.3 MCM.

4.3. Estimation of total groundwater abstraction and the groundwater balance

The groundwater abstraction or draft is the quantity of groundwater withdrawn from the groundwater reservoirs. Annual groundwater draft is equally important to assess the status of the basin for taking up water conservation measures. The estimation of groundwater draft requires well census data. The details of bore wells in the study area were collected from the electricity department of each mandal. The information of number of dug wells were collected from the field and the unit draft

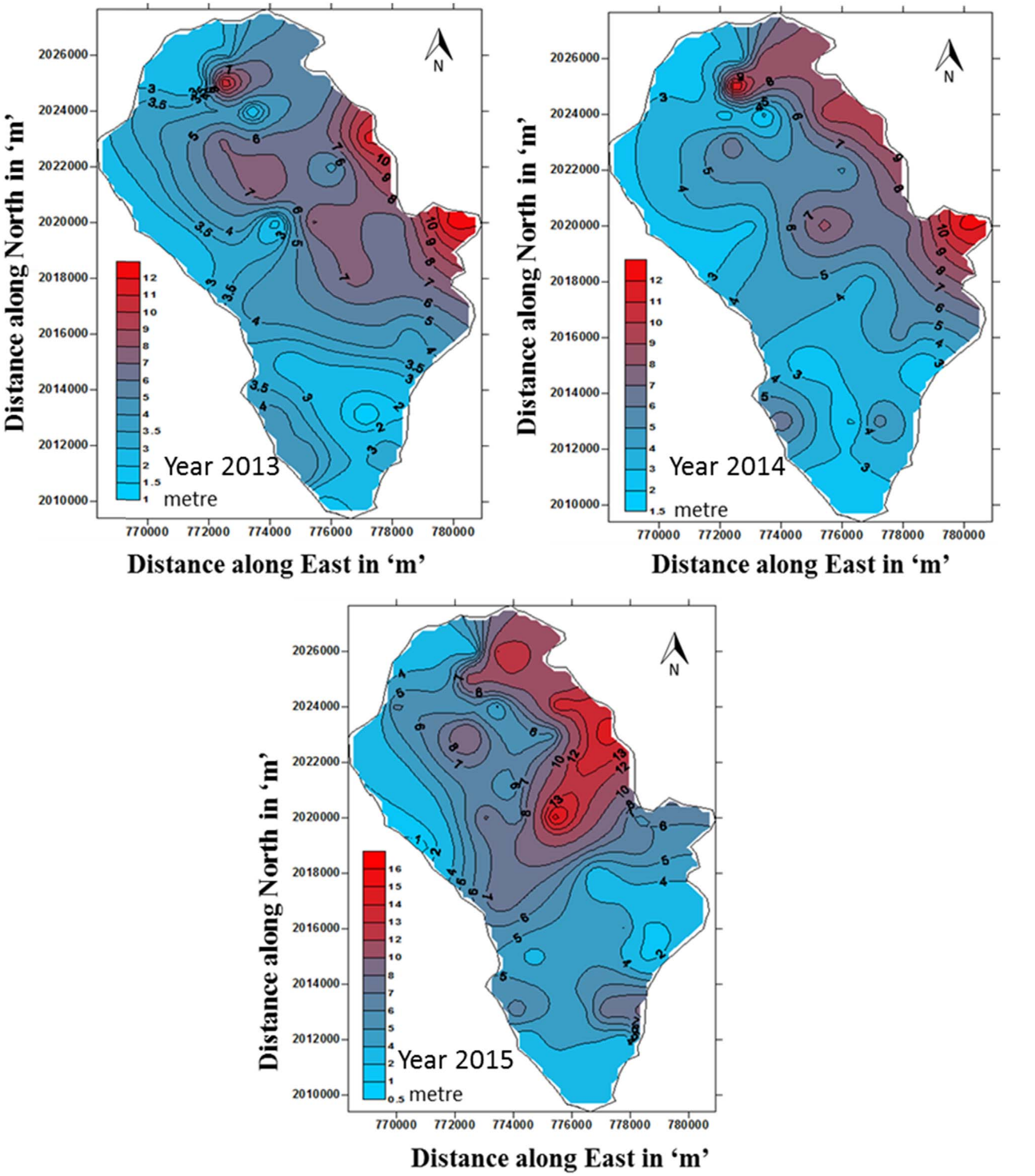

Fig. 6. Contour maps of Post monsoon groundwater levels in the KRSB.

method is considered to estimate the total groundwater draft in the basin from GEC report. The groundwater draft is calculated and is presented in Table 4.

The total quantity withdrawn is termed as gross draft. For working out groundwater balance, 70% of gross extraction is taken which is known as Net Ground Water Draft. The 30% is presumed to go as return seepage to groundwater regime (GCE, 1997). The gross annual groundwater draft in the basin is worked out as 24.235 MCM, while the net annual groundwater draft in the basin is 16.96 MCM.

The groundwater balance is the difference between the annual utilizable groundwater resources and the net annual groundwater draft. Groundwater balance in the study area is –5.66 MCM (11.3 – 16.96 MCM). Therefore, from groundwater recharge and draft studies, a negative groundwater balance has been observed in the study area and the deficit is 5.66 MCM is existing.

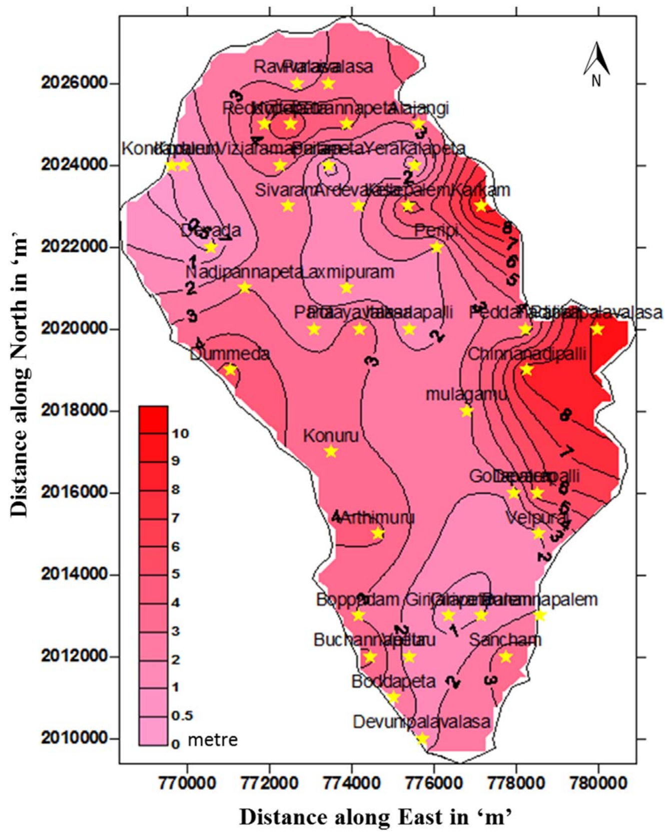

Fig. 7. Contour map of groundwater fluctuations of KRSB during the year 2015.

Table 4
Details of wells and gross draft in the Kandivalasa River Sub Basin.

S.No.	Nature of the well	No. of wells	Draft per well per year in MCM	Gross Draft in MCM
1.	Dug wells	90	0.0035	0.315
2.	Bore wells	1840	0.013	23.92
Total				24.235

Table 5
Categorization of stage of groundwater development (CGWB, 2013).

Category	% of development
safe	Less than 70
Semi Critical	70 – 90
Critical	90 – 100
Over Exploited	More than 100

4.4. Estimation of stage of groundwater development

Intensive development of groundwater in certain areas can result in over exploitation leading to decline in the levels of groundwater and sea water intrusion in coastal areas. The development of a groundwater system is considered to be "safe" when the rate of groundwater withdrawal does not exceed the rate of natural recharge.

As per the latest assessment of groundwater resources carried out by the Central Ground Water Board (CGWB, 2013), the assessment units are categorized as 'over exploited', 'critical', 'semi-critical' and 'safe' based on the stage of ground water development. Hence, the groundwater assessment unit is categorized into four different categories based on groundwater resource available and groundwater draft in the basin. The various categories of Groundwater development are presented in the Table 5.

The 'Safe' areas are representing the groundwater potential for development. The 'Semi-Critical' areas need the cautious groundwater development. In the 'Critical' and 'Over-exploited' areas, there should be intensive monitoring, evaluation and future groundwater development with necessary water conservation measures.

The Category of Kandivalasa River Sub Basin is evaluated by following the methodology suggested by GEC (1997). According to this methodology the stage of groundwater development is calculated as 150% indicating the over exploitation of the basin and needs water conservation measures.

5. Identification of recharge locations

Since, the over exploited Kandivalasa River Sub Basin needs more groundwater recharge than pumping, identifying the recharge locations are at most important in the basin. Therefore, an attempt is made towards the identification of recharge and pumping zones in the study area. Singhal and Gupta (2010) explained the different features exhibited by water table contour maps as shown in Fig. 8. Based on the contour maps from Fig. 8 and contour map of the basin (Fig. 4), the locations where the groundwater recharge and groundwater pumping is occurring in the basin are identified.

The high elevated locations of Chinnanadipalli Village which is in the eastern side of the basin and Dummeda village which is in the western side of the basin are identified as the groundwater recharge areas in the basin. The artificial recharge structures and large number of water harvesting structures are to be constructed at these two villages. However, the experiments with the double ring infiltrometer for estimating the infiltration rates should be done to identify the infiltration capacity at these two villages. The pumping areas are identified at Itakarlapalli and Velluru villages. At these places preference must be given to use rainwater, surface water and soil water instead of groundwater. This means that water and soil conservation structures are to be constructed apart from adaptation of mulching techniques to conserve the soil water.

6. Conclusions

In a Khondalitic terrain of the Eastern Ghats of India, the groundwater levels are declining at a rapid rate due to increasing groundwater abstraction and also due to less than normal rainfall in the years 2013, 2014 and 2015. As a consequence, the decline of groundwater levels in the post monsoon season has increased from 2013 to 2015. The groundwater depletion is much higher in the year 2015 when compared to the previous two years. The groundwater levels are mainly depleted in the eastern part and south western part of the basin where the pumping wells are more. From the groundwater recharge and draft studies, a deficit of 5.66 MCM is observed. The stage of groundwater development in the basin is calculated as 150% indicating that the basin is overexploited. From the groundwater flow direction maps, water conservation measures have to be taken up at Chinnanadipally and Dummeda villages in the basin. The places where the high decline in water levels should practice artificial recharge in the study area. In addition, preference must be given to use rainwater, surface water and soil water instead of groundwater. This means that water and soil conservation structures are to be constructed apart from adaptation of mulching techniques to conserve the soil water.

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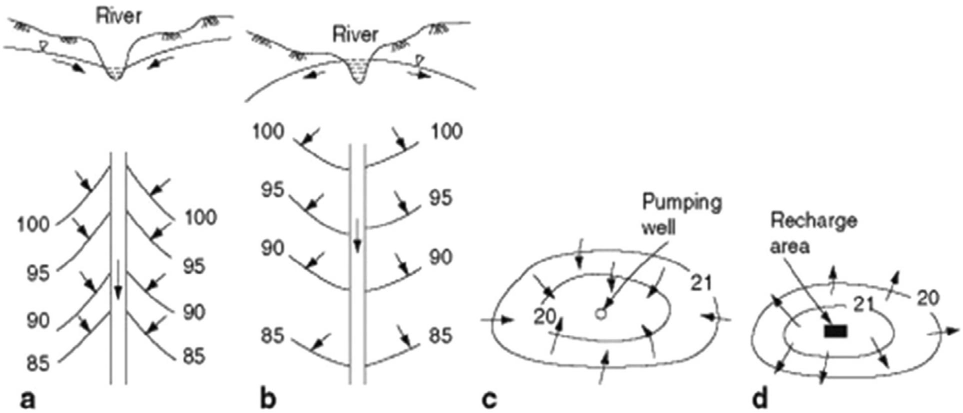

Fig. 8. Features exhibited by water table contour maps: (a) Effluent Seepage (b) Influent Seepage (c) Groundwater Depression (d) Groundwater Mound (Singhal and Gupta, 2010).

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