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Identification of groundwater drought prone zones in the Peddavagu and Ookachetti vagu watersheds, tributaries of the Krishna River, India.

The Peddavagu and Ookachetti vagu watersheds located in the semi-arid regions of Mahabubnagar District are highly dependent on groundwater for irrigation owing to unreliable rainfall and over extraction of groundwater. The present study has been conducted to identify spatio-temporal groundwater droughts and drought prone zones. Temporal groundwater droughts have been determined using a standardized water level index (SWI) along with spatial groundwater droughts using spline interpolation in GIS. The study shows that the groundwater droughts varied among the stations during the observation period, i.e. 1998 to 2011. However, the spatial assessment show that the region as such experienced more mild groundwater droughts except during severe meteorological drought years (1998, 2002, 2004 and 2008), this indicates that the region has good scope for groundwater exploitation during dry spells and initial stages of droughts. Therefore it is critical to have plans for the development of groundwater to cope with drought.

Keywords: groundwater levels, groundwater drought, SWI; spline interpolation

Introduction

Groundwater is the main source of water supply to meet water demand for anthropogenic, agriculture and industrial purposes in the semi-arid regions as rainfall is unevenly distributed over space and time. Moreover, it also provides resilience to water supplies during the initial stages of a drought (Hughes *et al*. 2012) as well as during dry spells. Groundwater availability of a region is dependent on several factors like slope, depth of weathering, the presence of fractures, surface water bodies, canals etcetera (Ganapuram *et al*. 2009). Groundwater availability in the semi-arid regions faces challenges because of recurrent droughts and excessive groundwater withdrawals for agricultural production (Fishman *et al*. 2011). The problems associated with excessive groundwater extraction are fall in water table, resource depletion, deterioration of water quality, increase in extraction costs and groundwater droughts (Moench 1992, Wada *et al*. 2010). Generally, droughts are classified into meteorological, agricultural, hydrological and socio-economic droughts (Wilhite and Glantz 1985), but groundwater drought is relatively new and its assessment is useful in planning drought coping measures (Mishra and Singh 2010). In the semi-arid regions, streams and channel have either intermittent flow or dry up during non-monsoon periods resulting in groundwater fluctuations as well as groundwater droughts (Bhuyian 2008). Hence, it has been assumed to be as an optimal time to study the occurrences of groundwater droughts as very limited research has been conducted on groundwater droughts (Mishra and Singh 2010). Groundwater drought occurs owing to the impacts of drought on groundwater systems; generally it starts with a decrease in groundwater recharge followed by fall in groundwater levels and decrease in groundwater discharge (van Lanen and Peters 2000).

The analysis of groundwater availability contributes for the analytical understanding of groundwater crisis (Shah 2008), role of small aquifers supporting groundwater irrigated areas (Shiklomanov 2000), policy making in groundwater stress areas and the role of groundwater aquifers under climate change conditions (Ribot *et al*. 2005). Several studies have been conducted on groundwater statistics, but few are available on groundwater drought assessment. Akther *et al*. (2010) analysed the spatial and temporal fluctuations of groundwater level data from Dhaka City, Bangladesh. It has been reported that groundwater declined continuously as recharge was lower than exploitation of groundwater. The study also made recommendations to have a sustainable management of the water resources to meet the quantitative water demands. Theodossiou and Latinopoulos (2006) studied basic statistics as maximum and minimum value, mean, median and standard deviation of groundwater level data. They also conducted a spatial analysis of groundwater level of 31 wells using kriging interpolation method. Bloomfield and Marchant (2013) analysed time series of groundwater level data to characterise groundwater droughts using standardised groundwater level index in the United Kingdom. Bhuiyan *et al*. (2006) developed SWI index to assess groundwater recharge-deficit. It has been noted that the index functioned well in monitoring hydrological droughts in Aravalli terrain. Mishra and Nagarajan (2013) have investigated and categorised the hydrological droughts in Tel river basin for pre-monsoon and post-monsoon groundwater levels using SWI and GIS. The study revealed very low variation in groundwater levels and had reportedly good scope for groundwater development and exploitation. Amin *et al.* (2011) conducted a study using SWI to assess the groundwater recharge deficit. Furthermore, the SWI values have been interpolated for visual comparison. The study revealed high groundwater consumption in the Fars province of Iran. So to ensure long term sustainability of watersheds the Iranian government recommended programs to reduce groundwater consumption. Owrangi *et al*. 2011 developed a method for drought identification, where remotely sensed indices such as NDVI, VCI and TCI were compared with ground based indices such as SPI and SWI. Instead of correlation coefficients, spatial correlation using visual comparison was employed in the analysis. The results have shown that drought severity index (DSI) values estimated considering vegetation health well correlated with the current months SWI data.

Uneven and erratic rainfall distribution in the semi-arid regions of the lower Krishna Basin has increased pressure on available groundwater (Venot *et al.* 2007). Furthermore, recurrent meteorological droughts in the lower Krishna basin have increased the pressure on groundwater as it is the major water supply source (Biggs *et al*. 2007, Gaur *et al*. 2007). The Peddavagu and Ookachetti vagu watersheds are located in the lower Krishna Basin. Agriculture is the main livelihood of rural people in this basin. With persistent rainfall failures and lack of surface water availability, farmer's dependency on groundwater for irrigation has increased in lower Krishna basin (Venot. 2009). With the increased dependence on groundwater for irrigation, the decline in groundwater recharge and levels poses a threat to farmer's livelihood. However, assessment of groundwater level fluctuations and droughts provides a better perspective of groundwater conditions in the region. Some studies on drought assessment using rainfall analysis (Ganapuram *et al*. 2014), water demand and supply (Ganapuram *et al*. 2012), and topographic features (Ganapuram *et al*. 2013) have been presented elsewhere, but research focusing on groundwater levels fluctuations and groundwater droughts of these watershed are not available.

Hence, the present study has been undertaken to assess the pre-monsoon, monsoon and post-monsoon groundwater levels fluctuations, groundwater droughts and groundwater drought prone zones.

Study area

The study area consists of two Ookachetti vagu and two Peddavagu watersheds of the lower Krishna Basin. It is situated in Southern Telangana Agro-climatic zone, of

Telangana state, India. The study area lies between 77^{o} 28' 33.799" to 78^{o} 13' 31.134" East longitude and 16^{o} 11' 45.63" to 17^{o} 8' 23.744" North latitude (Figure 1). The total geographical area of the basin is 4353 sq. km spreads in 31 *mandals* of Mahabubnagar district and 3 *mandals* of Ranga reddy district. The altitude of the basin ranges from 191 m to 637 m. The basin consists of two medium reservoirs, namely Koil sagar, and Sarla sagar, and two small reservoirs Kanayapalli cheruvu and Raman pahad. The climate of the area transits from tropical to subtropical Climate. The region has four distinct climatic seasons as summer, winter, south west and north east monsoon. The mean annual rainfall in the basin is around 663 mm. It is received mainly during the south-west (June - September) monsoon season. The summers are relatively hot and the period is from March to May with temperature ranging from 32 to 41.5^{o}C. The winter temperature ranges from 16.9 to 19.1^{o}C i.e. from November to January. Agriculture and allied activities are the main livelihood opportunities of the rural families in the Basin. The region follows two agricultural seasons, viz, *kharif* (June to October) and *rabi* (November to March). Paddy is predominantly grown in the basin, along with other crops as sorghum, pearl millet, finger millet, maize, groundnut, castor, vegetables, sunflower, chilli, and red gram are also being cultivated. *Kharif* crop cultivation is dependent on rainfall and groundwater, but *rabi* crop is solely dependent on groundwater owing to the depletion of water in surface water bodies. Irrigation water during *rabi* season is mainly obtained from groundwater pumped from open wells that are 10 to 20 m deep or bore wells that are 80 to 100 m deep installed with submersible pumps. The major soils found in the basin are clayey soils, cracking clay soils, gravelly clay soils, gravelly loam soils, and loamy soils. The geology of the basin forms part of the stable Bharwar Craton of South Indian Shield. Granite, Migmatities and Genesis rocks are the predominant geology type in Peninsular Gneissic complex that are exposed as high hill ranges, linear ridges and domes. The region also comprises of conglomerate, quartzite, limestone, dolomite and shale. Groundwater occurs in all the above geological formations based on the depth and degree of weathering and fracturing of a region.

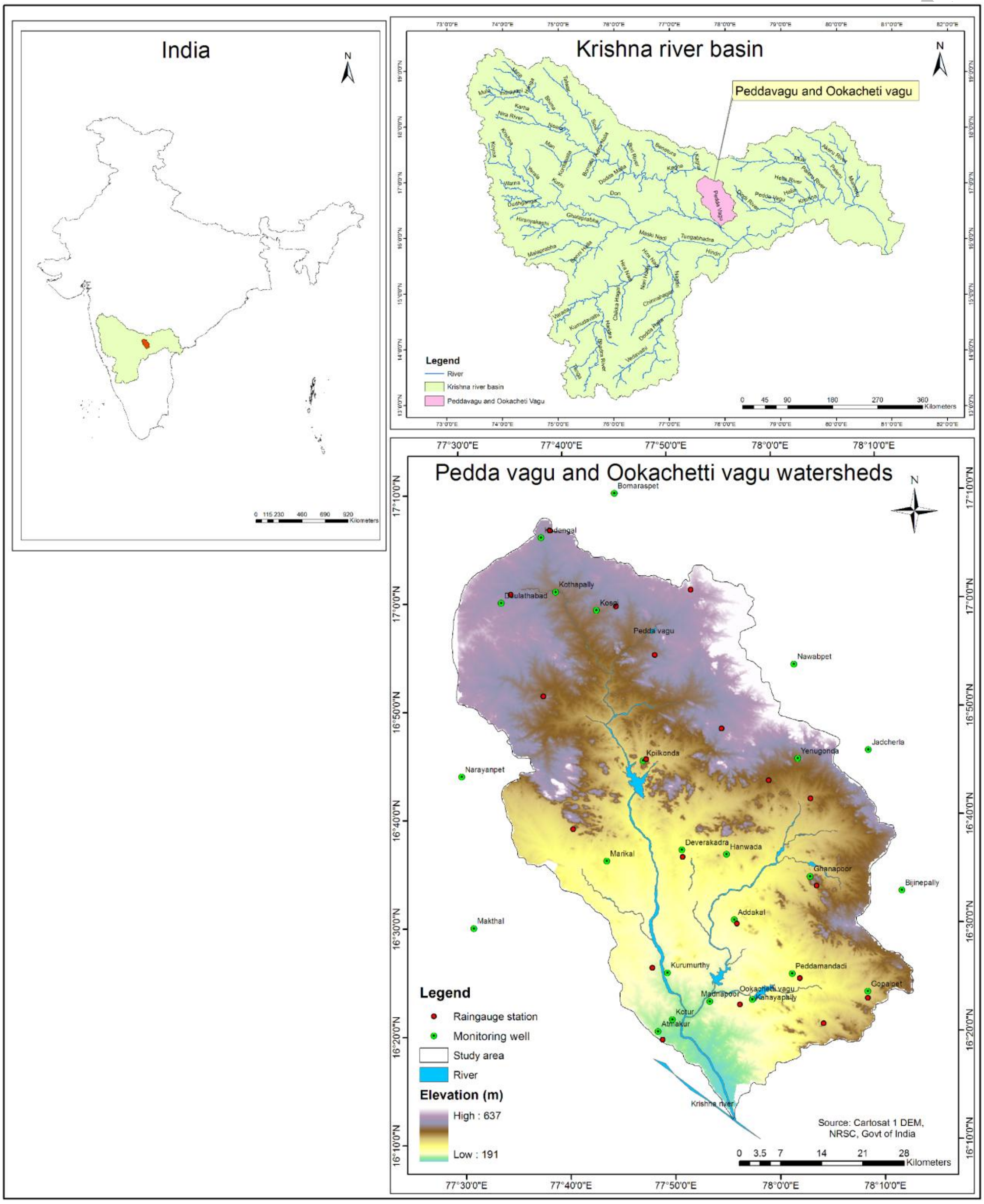

Figure 1. Location map of Peddavagu and Ookachetti vagu watersheds.

Materials and methods

Groundwater levels information of 18 observation wells located in the basin has been collected for the period 1998 to 2011 from groundwater Department, Mahabubnagar District. Several standard statistical parameters like mean, median, minimum (Min), maximum (Max), standard deviation (SD), coefficient of skewness, coefficient of kurtosis, and coefficient of variability have been ascertained for pre-monsoon, monsoon and post-monsoon groundwater levels. Rainfall data for 20 meteorological stations available for the period 1986 to 2013 has been collected from District Collectorate office, Mahabubnagar District, and the Directorate of Economics and Statistics, Hyderabad, India. The percentage annual rainfall departure from the long term mean annual rainfall (Pai *et al*. 2011) of the station was estimated for all the stations**.** Percent rainfall variation of each year was further categorised into four percentage ranges i.e. 0 to 10, 10 to 15, 15 to 20 and greater than 20. *Mandal* level *kharif* and *rabi* cropped area details for 2001, 2004 (dry year), 2005 (wet year) and 2011 were collected from the Directorate of Economics and Statistics, Hyderabad, India. The percentage variation of the *kharif* and *rabi* cultivated crop areas with respect to 2001 have been estimated for 2004, 2005 and 2011, years 2001 and 2011 were used to assess the variations over the decade, while 2004 and 2005 were analysed to assess crop area changes during the dry and wet years respectively.

Computation of standardised water-level index (SWI)

Groundwater levels measured during pre-monsoon, monsoon and post-monsoon seasons were used to determine the groundwater drought conditions. SWI developed by Buyian 2004 is based on groundwater for assessing groundwater droughts, groundwater levels anomaly in aquifers and also provides inferences about aquifer recharge. The assessment of groundwater levels provides insights about the groundwater drought occurrences, for this 18 groundwater monitoring wells located in the basin and eight around the basin were used. The groundwater droughts were assessed for all the three seasons of the basin for all the stations using the below formulae (1).

$$SWI = (W_{ij} – W_{im})/ SD \qquad (1)$$

Where W_{ij} is the seasonal groundwater level for “i”th and “j”th observation, and W_{im} its seasonal mean and SD is standard deviation. Unlike other ground based indices, SWI index positive values correspond to drought and negative values to “no drought”, Table 1 shows SWI ranges and drought categories.

Table 1. Classification of SWI values and groundwater drought categories

S. No	SWI Range	Drought class
1	> 2.0	Extreme
2	> 1.5	Severe
3	> 1.0	Moderate
4	> 0.0	Mild
5	< 0.0	None

Source: Bhuiyan 2004

Furthermore, SWI values of different stations were presented in graphical format to study the temporal variations of groundwater droughts. SWI graphs were used to determine groundwater droughts, and severity based on table 1. It also depicts the five drought classes of groundwater abnormality ranging from none to extreme severity along with corresponding SWI ranges. SWI graphs show only point temporal information about drought characteristics but lack spatial perception. So, the mapping of spatial variation and extent of SWI values using interpolation was considered imperative to get insights about the spatial drought severity variation and extent of droughts.

Spatial groundwater drought severity assessment

The spatial extent and severity of groundwater droughts and groundwater drought prone were demarcated using point SWI values in Geographic Information Systems (GIS). Several interpolation methods like spline, kriging and IDW are available in GIS for generating or predicting surfaces from known point information. Among the above interpolation methods, spline and kriging provide better spatial quality of the predicted surfaces compared with IDW (Hutchinson and Gessler 1994, Hartkamp *et al*. 1999), while the advantage of spline over kriging is that it is faster and easier to use. The spatial extent and variation of groundwater drought severity for post-monsoon, monsoon and pre-monsoon were mapped using SWI values using spline interpolation method in GIS environment for 2001, 2004, 2005 and 2011 years. Moreover, the drought severity was classified into extreme, severe, moderate, mild and none as per Table 1.

Results and discussions

Descriptive statistics of pre-monsoon, monsoon and post-monsoon groundwater levels

The pre-monsoon groundwater level data of the 18 observation wells is presented in table 2. Atmakur region has a shallow groundwater level ranging from 5.62 to 13.03 m bgl (meters – below ground level). Atmakur has also been the only station in the basin that recorded groundwater level depth below 10 m bgl with a mean depth of 8.67 m bgl. The mean water level depths, ranging from 10-15 m bgl were discovered in Adakkal, Devarkadra, Doulatabad, Ghanpur, Gopalpet, Koilkonda, Kosgi, Madnapur (Kothakota), Yenugonda (Mahabubnagar) and Peddamandadi regions. While the mean water level depths ranging from 15 to 20 m bgl were noted at Dhanwada, Hanwada, Kodangal, Kothapally and Nagarkurnool regions. The minimum water level depths of 4.92 m bgl and 5.62 m bgl were recorded at Atmakur and Koilkonda, but the maximum water level depths of 27.01 m bgl and 27.51 m bgl were recorded at Chinnachinta kunta and Kanayapally (Kothakota) regions.

Monsoon groundwater depth details of the 18 observation wells are shown in table 2. Mean groundwater levels of below 10 m bgl were found at Addakal and Atmakur, while 10 to 15 m bgl were observed at Devarkadra, Doulatabad, Ghanpur, Gopalpet, Kodangal, Koilkonda, Kosgi, Madnapur (Kothakota), Yenugonda (Mahabubnagar) and Peddamandadi regions. Some regions that recorded mean water levels of 15 to 20 m bgl were observed to be at Dhanwada, Hanwada, Kothapally, and Nagarkurnool. Whereas mean groundwater levels of more than 20 m bgl were observed at Chinnachinta kunta and Kanayapally (Kothakota) regions. The post-monsoon groundwater levels presented in table 2 show that mean groundwater levels below 10 m were shown at Addakal, Atmakur, Doulthabad, Ghanpur, Gopalpet, Hanwada, Kodangal, Koilkonda, Kosgi, and Mahabubnagar. The mean groundwater levels ranging from 10 to 15 m bgl were observed at Devarakadra, Madnapoor (Kothakota), Kothapally and Peddamandadi, while Dhanwada and Nagarkurnool recorded between 15 to 20 m bgl. Moreover, Chinnachinta kunta and Kothakota (Kanayapally) recorded more than 20 m bgl.

On the whole, post monsoon mean groundwater levels have been better than pre-monsoon and monsoon mean groundwater levels. The standard deviation, coefficients of variation (CV), skewness (CS) and kurtosis (CK) are shown in table 2. A standard deviation closer to zero indicates that the data points are close to mean and uniform, conversely a higher standard deviation indicates a wide variance from the mean. Additionally, CV close to 0 indicates uniformity of data while 1 indicates high variability of the data. The standard deviation and CV show low variability in pre-monsoon and monsoon groundwater levels, while relatively high variability was observed in post monsoon groundwater levels at all the locations. CS near to zero infers normal distribution of the data, negative and positive values indicate negatively and positively skewed distribution of the data. The CK less than zero show low degree of peaked condition and positive kurtosis shows a high degree of peaked condition. Relatively extreme positive skewness and kurtosis values were observed during post monsoon water levels compared to pre-monsoon and monsoon water level that infers that the water levels were relatively good and high during post-monsoon.

Groundwater aquifer

Groundwater occurs in all the geological formations of the basin that include peninsular gneissic crystallines, conglomerates, sandstone, green shale, basalts and metabasalt rock types. The Archaean crystalline rocks types observed in the basin are gneisses, pink and grey granites. The occurrence of groundwater is governed by the depth and degree of weathering and fracturing. The thickness of weathering of crystalline rocks ranges from 10 to 30 m. Groundwater also occurs under water table conditions in weathered mantle and semi confined to confined aquifer conditions in the fractured and jointed rocks. The depth of dug wells in the weathered zone and crystalline rocks varies from 6 to 20 m with 2 to 3m column of water withdrawal during summer months and well yield range of 250 and 350 cu.m/day. The discharge of the successful bore wells ranges from 0.5 to 6 liter per second (lps). Groundwater in Cuddapah and Kurnool formations are represented by quartzites, shales, sandstones and limestones. Shales are less permeable, while sandstones and limestones yield copious amount of water. The depth of shallow aquifers of irrigation wells ranges from 5 to 28m with yield range between 170 cu.m/day to 250 cu.m/day during post monsoon.

The Deccan traps formations such as by vesicular-amygdoloidal and massive basalt are not favourable for shallow aquifers. But the contact zones underlying lime stones, shales and granites are favourable for deep bore wells. The aquifers in pink granite have more groundwater potential than the grey granites. Majority of the aquifer zones in the region have depth range between 15 to 25 meters below ground level (m bgl) under unconfined aquifer conditions. For irrigation purpose, the shallow aquifer system is explored using the dug wells down to the depth of 12 to 20m and dug-cum-bore wells down to the depth of 40 m. The yields of dug wells ranges between 180 and 250 m3/day. The discharges of the shallow bore wells range from 3 to 4 lps. It has been observed that about 80% of major aquifer zones are encountered between the range of 25 and 70 m and 15% of fracture zones are encountered in a depth range of 70 to 150 m depth. Beyond the depth of 150m, aquifers are very rare except along major lineaments and deep valleys. Discharge of the successful wells range between 3 and 5 lps. The groundwater occurrence is very poor in the hills and highly dissected areas, while moderate groundwater potential is observed in moderately dissected areas and good groundwater is available in un-dissected and valley filled areas. The groundwater potential is good over moderately dissected plateau.

Groundwater level fluctuation

Groundwater level fluctuations between pre-monsoon and post-monsoon for the observation period 1998 to 2011 are presented in table 3. The negative values indicate an increase in the depth of groundwater levels, while the positive values indicate a decrease in groundwater level depth. In general, the groundwater levels at all the stations have been quite variable both in space and time. The pre-monsoon water levels indicate the extraction or abstraction of groundwater from the wells. Where the positive groundwater level fluctuation values infer that the groundwater level fall. The post-monsoon groundwater levels with negative fluctuations indicate rise in groundwater level due to recharge from rainfall and irrigation. However, the positive fluctuation values during post-monsoon indicate abstraction due to excessive groundwater irrigation. In severe meteorological drought years i.e. 1999, 2002, 2004 and 2008 (Gaur *et al*. 2007, Ganapuram *et al*. 2014) most of the regions in the basin recorded -2 to 2m fall/rise in groundwater levels, whereas in wet year i.e. in 2005 most regions witnessed more than 4m rise in groundwater levels. Similarly, rise in water level was also noted in other years but only in regions that recorded good rainfall, refer table 3.

Meteorological drought assessment using percentage rainfall deviation

The percentage rainfall deviation from the mean rainfall was utilised to assess the meteorological droughts occurrence of all the stations. The drought occurrences of all the stations are set forth in the table 4. Almost all the stations in the basin have experienced extreme and severe droughts of greater 20% and 15-20% respectively from mean rainfall of the station. The following years i.e. 1999, 2002, 2004, 2006, 2007, 2008 and 2011 have recorded severe and extreme droughts in the basin, which were in agreement with droughts categorised using rainfall anomaly index (RAI) (Ganapuram *et al*. 2014).

Temporal groundwater drought assessment using SWI

SWI values for pre-monsoon, monsoon and post-monsoon were estimated for all the 18 groundwater observation wells located in the basin. Temporal variations of SWI values computed for pre-monsoon, monsoon and post-monsoon are presented in figure 2a, 2b and 2c. The above graphs show inter-seasonal variations over the years at all the stations, where positive values correspond to dry regions and negative values correspond to wet regions. It has been demonstrated from the SWI time series graphs that the severity of groundwater droughts varied during the three seasons over the time. Depending on the severity ranges shown in table 1, the groundwater droughts have been classified into extreme, severe, moderate and mild, where extreme droughts have greater than 2, severe droughts range from 1.5 to 2, moderate droughts range from 1 to 1.5 and mild droughts range from 0 to 1. Furthermore, occurrences of groundwater droughts classified under the three seasons have been presented in table 5. Visual assessment of SWI time series graphs shows inter-seasonal variations in the severity of groundwater droughts at all the locations. Comparisons of inter-seasonal SWI variations show that post monsoon groundwater levels have been better than pre-monsoon and monsoon groundwater levels. The water levels have been higher in post monsoon than monsoon as there has been some time lag between rainfall and groundwater recharge primarily due to variations in topographical and geological settings of the neighbourhood (Kondoh *et al*. 2004). The difference in post-monsoon and monsoon water levels also varies depending on the groundwater withdrawals for irrigation (Garg and Wani 2013). Moreover, from the interpretation of SWI graphs and table 5 it was observed that extreme droughts occurred in Atmakur, Ghanpur and Koilkonda in 1998, Atmakur in 2000, Doulathabad, Gopalpet, Kodangal, Kosgi, and Peddamandadi in 2004,Kodangal and Pedamandadi in 2005 and 2011. Furthermore, severe, moderate and mild droughts occurred during the three seasons as reported in table 5. The results show that the basin was dominated by mild severity groundwater droughts over the years except in the severe meteorological drought years 1999, 2002 and 2004.

The matrix of occurrences of number of groundwater droughts under different severity categories during the three seasons is presented in table 6. Extreme groundwater droughts were experienced once during monsoon season in Ghanpur and Peddamandadi regions and once during post-monsoon in Atmakur, Doulatabad, Gopalpet, Kodangal, Koilkonda, Kosgi and Peddamandadi regions. The basin as such has not experienced many severe groundwater droughts, twice groundwater droughts were reported in Gopalpet and Kosgi during monsoon and Kothakota, Kothapally (Midjil) and Nagarkurnool during post-monsoon. Moderate droughts occurred two to three times in several regions, with Ghanpur region recording maximum of four moderate droughts during post-monsoon. Otherwise, the region has experienced two to nine times mild groundwater droughts during all the three seasons. It was noted that Atmakur, Doulatabad, Ghanpur, Kothapally, Kothakota and Dhanwad regions have recorded more mild severity droughts than other regions during the three seasons. Furthermore, frequencies of droughts were estimated by dividing the total number of groundwater droughts with duration period and are presented in table 7 along with percentage of drought occurrences and recurrence of droughts. The frequencies of droughts ranged from 0.29 to 0.71 per year during pre-monsoon, 0.21 to 0.64 during monsoon and 0.36 to 0.64 per year during post-monsoon. The frequencies show that Atmakur, Dhanwada, Kothapally, Gopalpet, and Doulatabad experienced droughts more frequently than other regions. The recurrence of droughts show that groundwater droughts occurred every alternate year in almost all regions except Ghanpur and Nagarkurnool regions, Ghanpur region experienced droughts every four years during monsoon and Nagarkurnool region experienced droughts every three years during post-monsoon. Recurrences of droughts of other locations of the three seasons are provided in table 7.

Groundwater drought severity mapping

Spatial groundwater drought severity variation maps were prepared with SWI values using Spline interpolation method in a GIS environment. Groundwater drought severity maps of pre-monsoon, monsoon and post-monsoon were established for 2001, 2004 (dry year), 2005 (wet year) and 2011. Groundwater drought severity maps of 2001 (Figure 3a) and 2011 (Figure 3b) were used to assess decade differences, while 2004 (Figure 4a) and 2005 (Figure 4b) were mapped to study changes during the dry and wet years of the basin. Drought severity maps were categorised into four classes as per table 1 with different colours and were presented in figures 3a, 3b, 4a and 4b. The basin is divided into two agro-climatic zones namely southern Telangana zone and scarce rainfall zone based on rainfall and elevation. The northern parts up to centre of the basin are categorised under southern Telangana zone, while some portions in the central part towards south come under scarce rainfall zone (Valli *et al*. 2013). The tones of the groundwater drought severity varied from red to blue, where red colour indicated extreme droughts, orange indicated severe droughts, yellow indicated moderate droughts and light blue indicated mild droughts, while blue colour indicated wet periods.

Visual assessment of 2001, 2004, 2005 and 2011 maps show that the spatial extent and severity of droughts varied during pre-monsoon, monsoon and post-monsoon. The pre-monsoon and monsoon maps of 2001 (Figure 3a) shows small patches of extreme droughts in the central part of the basin that are in scarce rainfall zone near Marikal and Devarakadra region, while during the post-monsoon western part and Ghanpur region in east experienced moderate droughts. It was observed that almost all the regions in the central portion from north to south during post-monsoon were wet. Interpretation of pre-monsoon and monsoon seasons maps of 2011 (Figure 3b) shows that Yenugonda

(Mahabubnagar) and surrounding regions experienced extreme to mild droughts, whereas during post-monsoon season Yenugonda, Koilkonda and Devarkadra that are in southern Telangana zone experienced mild droughts. Table 8 shows percentage crops cultivated areas of different regions of the basin; negative indicates decrease and positive indicates increase in crop cultivated areas. The 2001-2011 decadal change in *kharif* crop cultivated area shows that Gandeed, Kodangal, Maddur and Wanaparthy regions recorded 20% decrease due to decrease in rainfall despite of good groundwater levels. The decade change in *rabi* crop cultivated area show improvement in all the regions in 2011 owing to increase in groundwater levels except in Atmakur and Bhootpur that are located in southern telangana zone.

The visual assessment of 2004 (Figure 4a) pre-monsoon, monsoon and post-monsoon SWI maps show big variability in groundwater drought severity. Pre-monsoon map shows that southern regions near Devarkadra, Marikal and Kurumurthy experienced severe to mild droughts, while north-west regions experienced mild droughts. During 2004 monsoon rainfall failures, the whole basin experienced mild droughts with small spaces of extreme to moderate droughts surrounding Gopalpet and Kurumurthy regions in south and Kodangal region in the north. During the 2004 monsoon rainfall failure, the basin was subjected to mild droughts, but post-monsoon most of the regions experienced extreme to mild droughts, extreme droughts occurred near Gopalpet, Peddamandadi and Kanayapalli regions in the south and around Doulatabad, Kosgi and Kodangal in the north. The central portion of the basin categorised as scarce rainfall zone constituting Koilkonda, Hanwada, Addakal and Ghanpur experienced severe droughts while Devarakadra and Yenugonda suffered mild droughts. The crop change analysis of 2001-2004 show that major portion of the basin recorded decrease in cultivated area except Ghapur, Peddamandadi and Kothakota regions during *kharif* season and with omission of Maddur and Mahabnagar regions in rabi season. The impact of 2004 monsoon rainfall failures has also resulted in extreme to moderate groundwater droughts in pre-monsoon and monsoon seasons of 2005 except in regions surrounding Ghanpur and Atmakur regions in monsoon. Even though 2005 (Figure 4b) being the wettest year of the basin, the 2001-2005 kharif crop change assessment show more than 20% decrease (table 8) in agriculture at Dhanwada, Gandeed, Kulkacherla, Kosgi, Kodangal and Maddur that are in scarce rainfall zones experienced decreased rainfall as well as fall in water-levels owing to 2004 drought. The post-monsoon map of 2005 shows small portions experienced mild groundwater droughts near Peddamandadi, Ghanpur, Marikal and Kurumurthy that are under southern Telangana zone.

Overall drought prone zone maps of the basin shown in figure 7 were estimated by dividing total groundwater droughts of the three seasons occurred during the observation period. The drought prone zone map of monsoon shows that major portion of the basin in the eastern side from north to south show that the region experienced 25 to 50% of droughts during observation period, while western part from north to south experienced droughts greater than 50% of the times. During post-monsoon south-western regions and the central portion of the north experienced droughts less than 50% of the time whereas other regions experienced droughts greater than 50% of the times. It is observed that in this region, meteorological and groundwater droughts don't correspond as rainfall occurrence varied among the regions, as well as due to the variations in groundwater recharge. On the whole, the basin mostly experienced mild droughts during the observation period except during severe meteorological drought years. This implies that there is excellent potential for exploitation of groundwater for irrigation during dry spells and droughts with proper groundwater development plans.

Conclusions

The present study presented a methodology to identify and demarcate groundwater droughts and drought prone zones in semi-arid regions. The region experienced recurrent meteorological droughts of severe and extreme droughts (Ganapuram *et al.* 2014) having a percentage of greater than 15-20 and greater than 20% respectively. Whereas extreme and severe groundwater droughts occurred very only during adverse meteorological drought years, otherwise mild and moderate groundwater droughts have been widespread in the basin. Temporal SWI graphs showed that groundwater levels varied both in space and time among the three seasons, this inferred variable impact on regions due to groundwater droughts. It was important to note that except during extreme meteorological drought years like 1999, 2002 and 2004 almost all the regions experienced mild and moderate groundwater droughts. It inferred that huge time lag existed between meteorological and groundwater droughts because of fluctuating groundwater recharge, topography and groundwater withdrawals. The extreme north-east and north-west regions that are in elevated areas of the basin have less scope for water resources development, but south central regions have good scope for water development as the region experienced mild droughts. Furthermore from figure 7 it's obvious that regions experienced droughts less than 50% of the time and have better scope for water development as they are in the low lying areas than regions that are more than 50% of the times drought prone that are located in high elevated regions. The results shown that the region is dominated by mild and moderate groundwater droughts that imply the region have good scope for groundwater exploitation for meeting water demands. However, a planned development is fundamental for meeting the ever increasing water demands of the basin to cope with droughts.

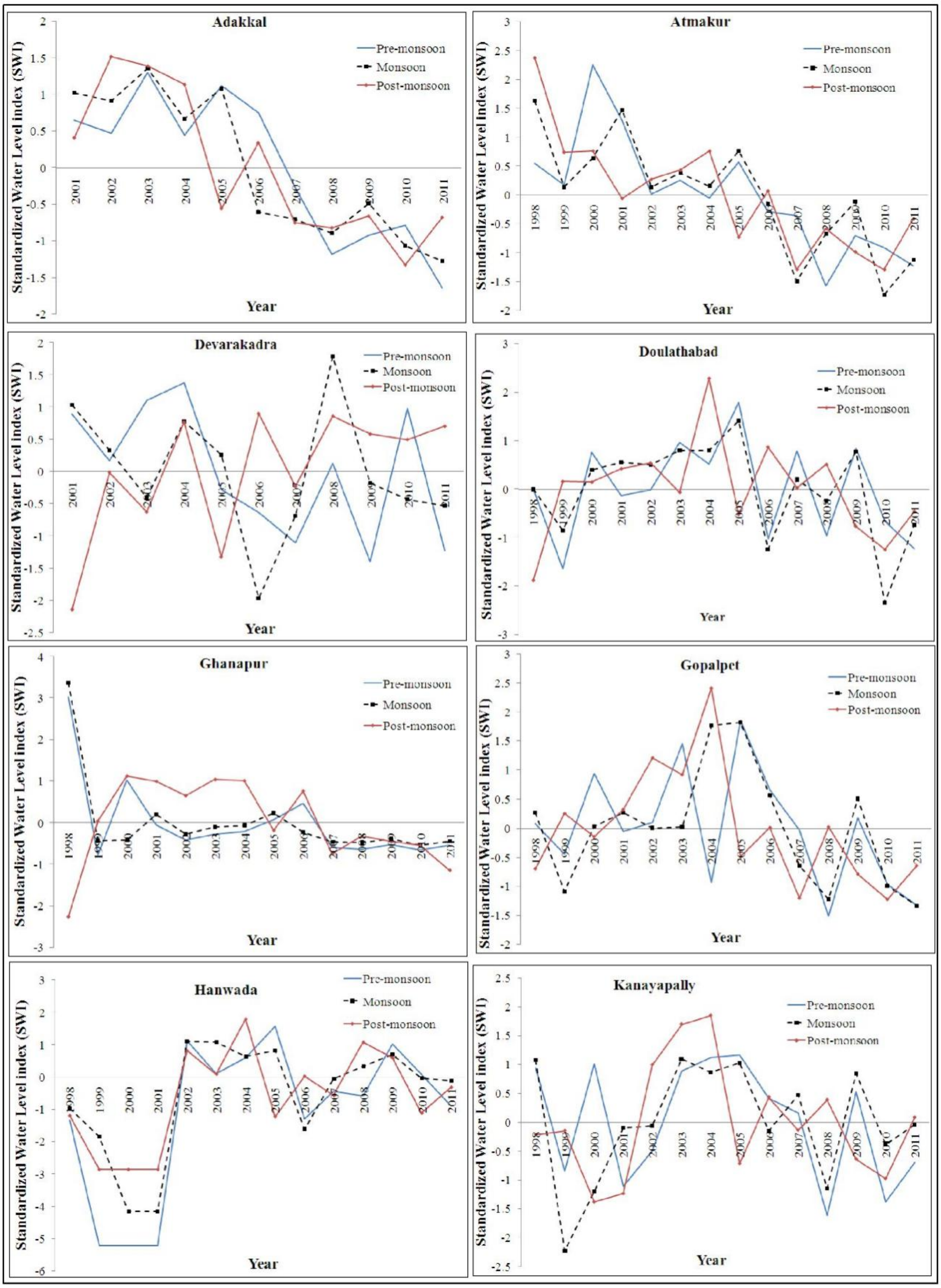

Figure 2a. Temporal variation of pre-monsoon, monsoon and post-monsoon SWI of different locations.

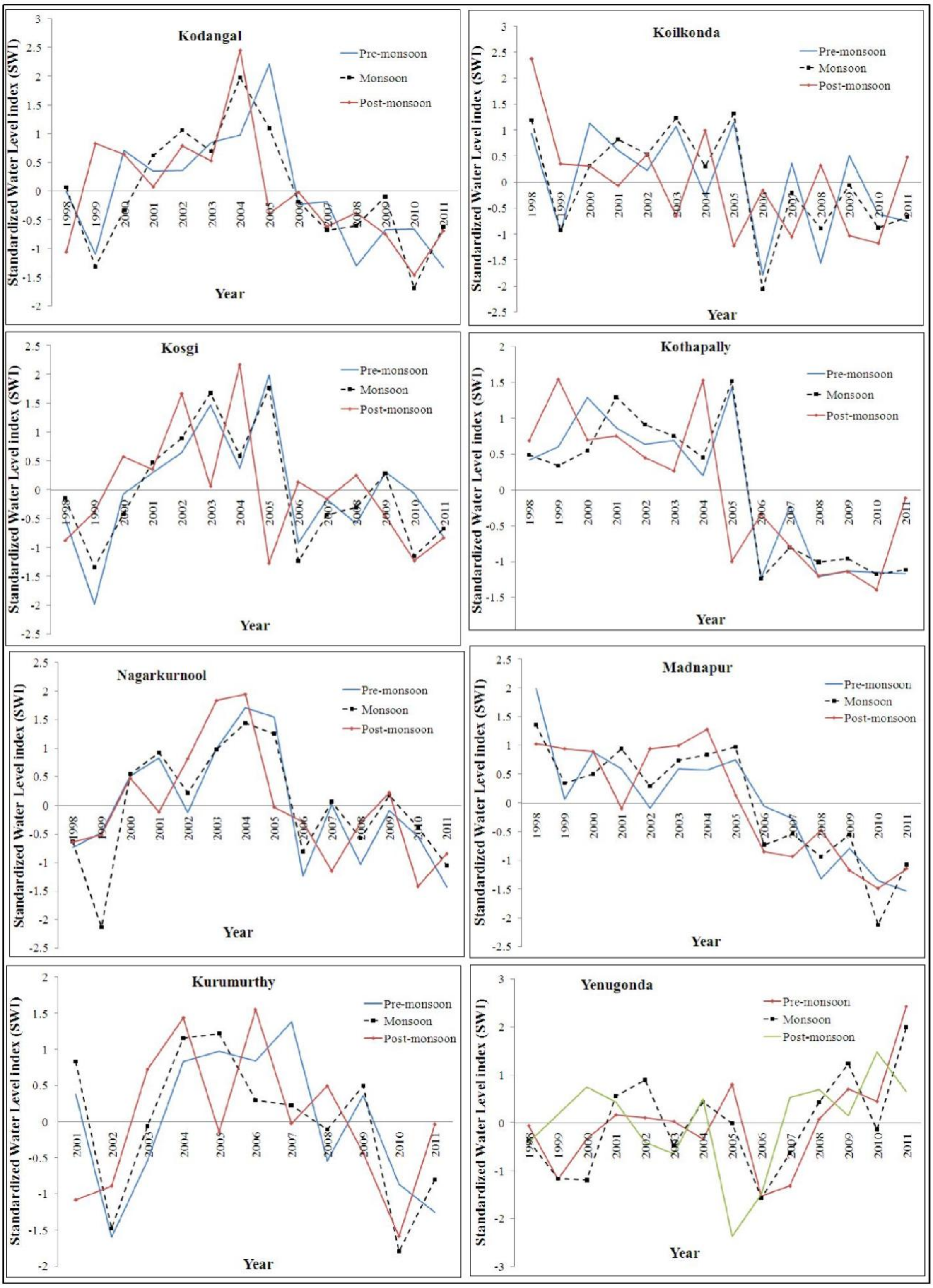

Figure 2b.Temporal variation of pre-monsoon, monsoon and post-monsoon SWI of different locations.

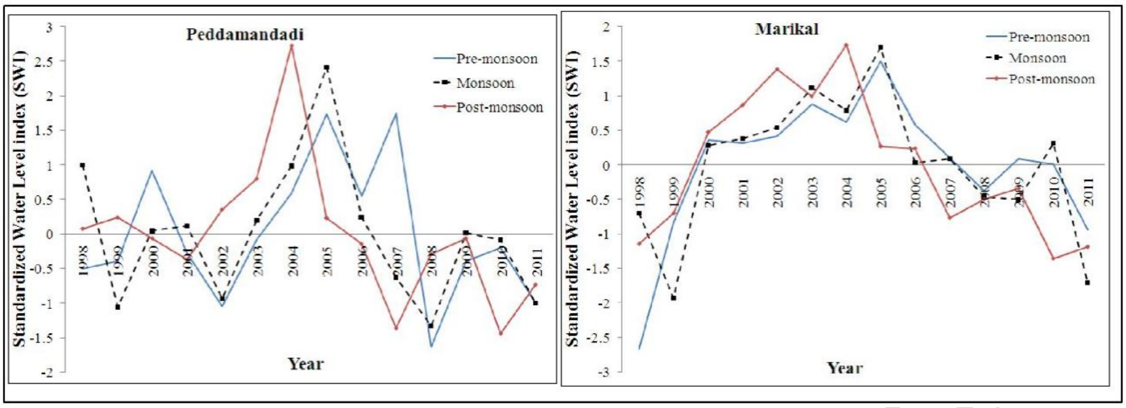

Figure 2c. Temporal variation of pre-monsoon, monsoon and post-monsoon SWI of Peddamandadi and Marikal.

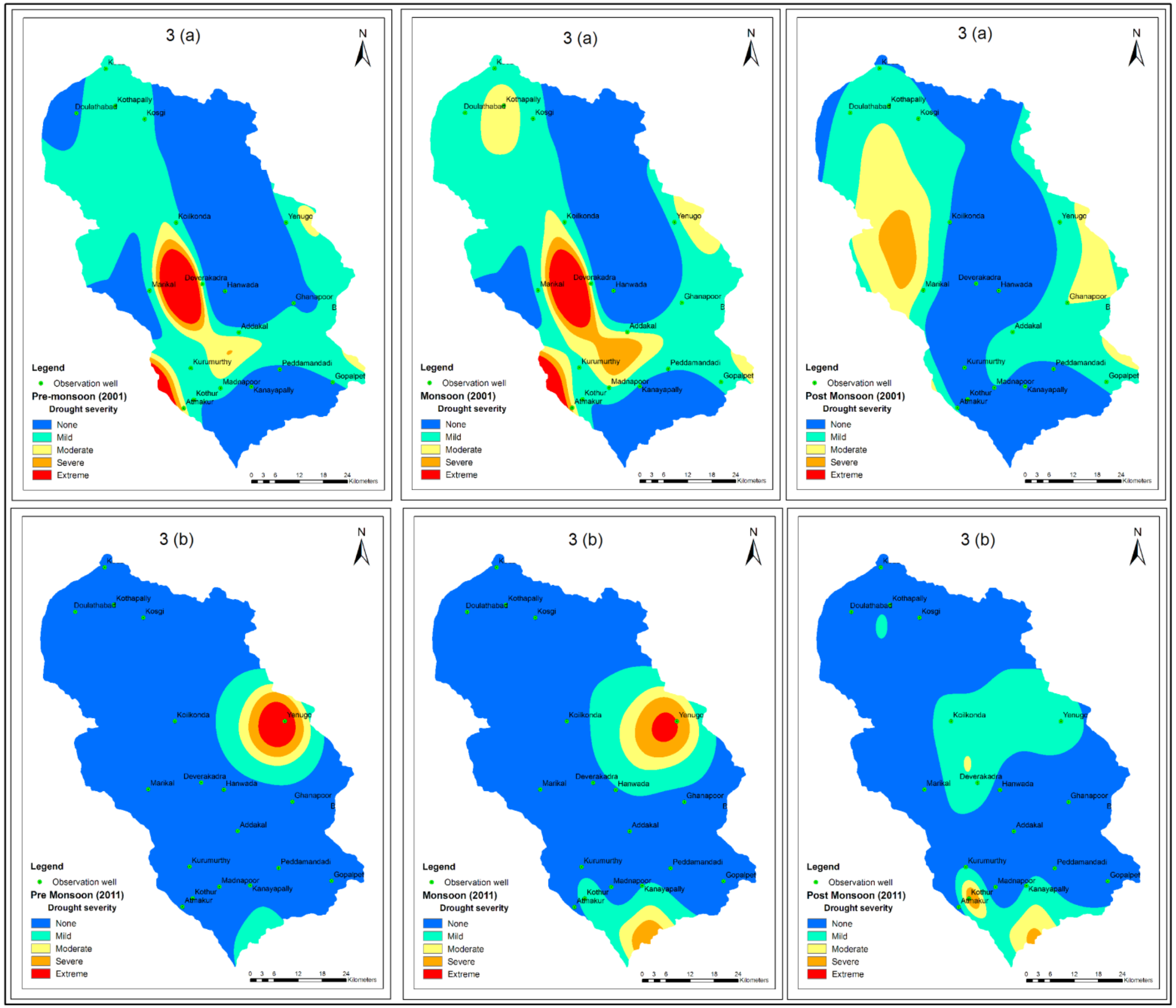

Figure 3. Decadal groundwater drought change assessment of pre-monsoon, monsoon and post monsoon, (a) 2001 and (b) 2011.

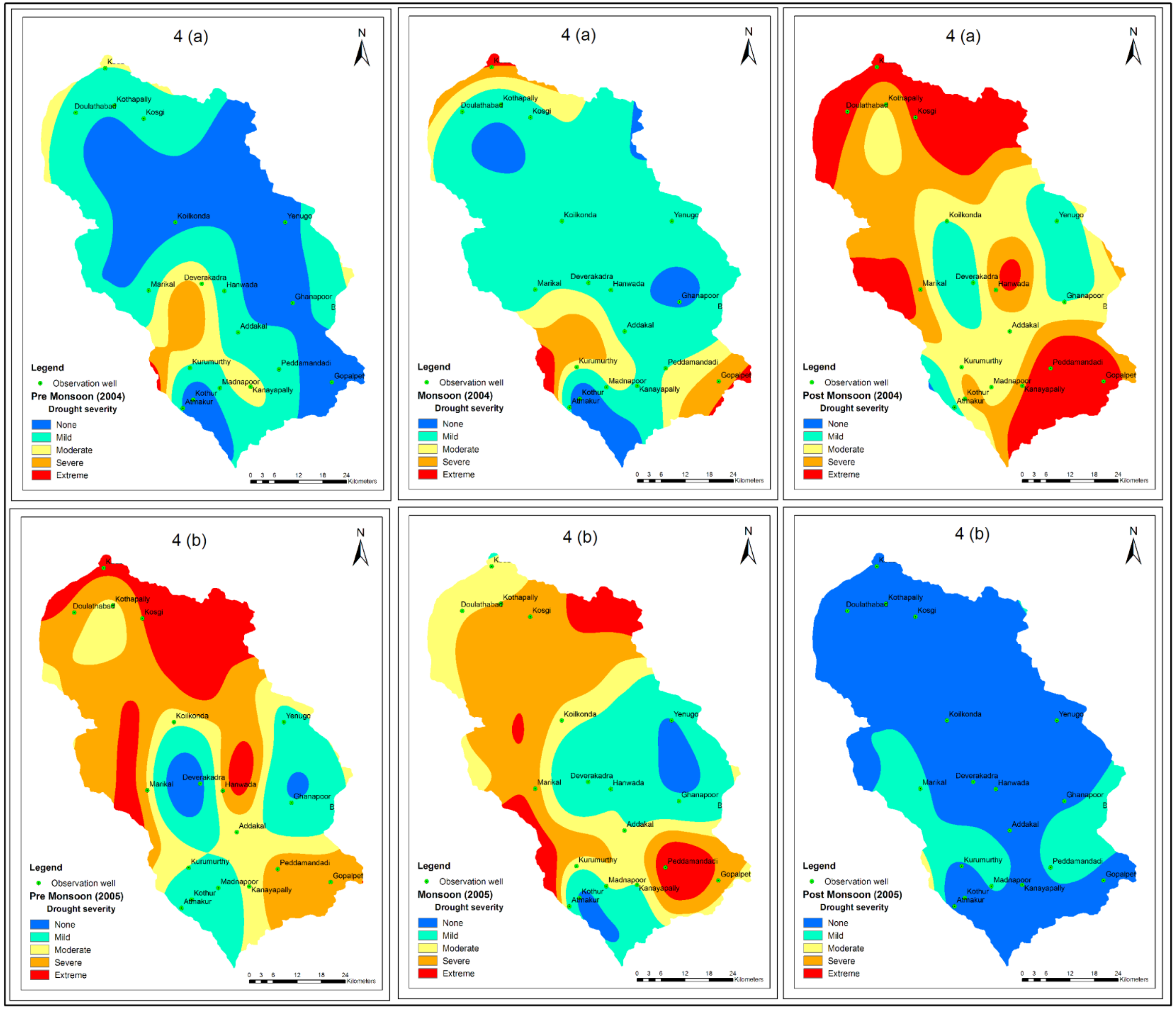

Figure 4. Spatial distribution of pre-monsoon, monsoon and post monsoon groundwater drought severity (a) dry year - 2004 and (b) wet year - 2005.

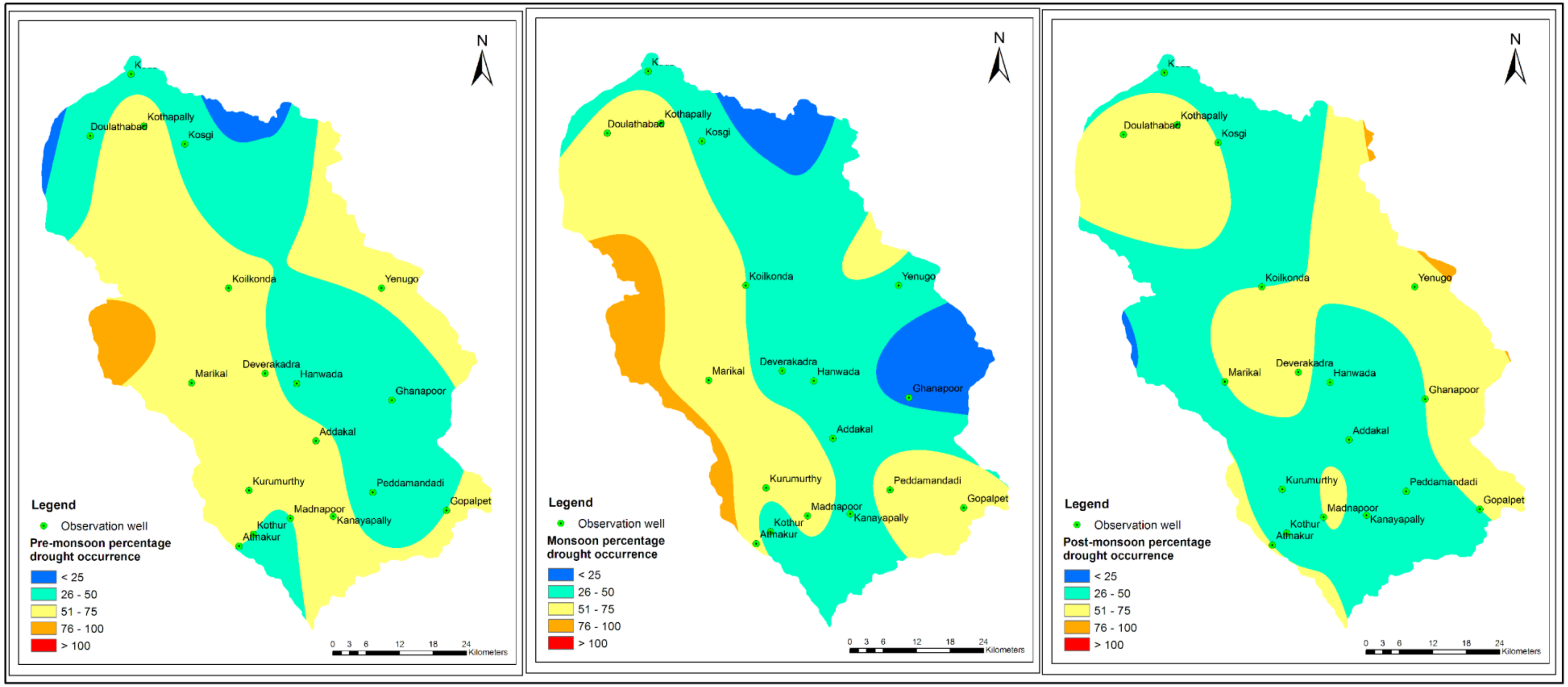

Figure 5. Overall drought proneness (%) during pre-monsoon, monsoon and post-monsoon of the basin

Table 2. Descriptive statistics of pre-monsoon (PrM), monsoon (M) and post-monsoon (PoM) groundwater levels

S. no	**Mandal (Village)**	**Pre-monsoon**							**Monsoon**							**Post-monsoon**						
		Min	Mx	Mean	SD	CV	CS	CK	Min	Mx	Mean	SD	CV	CS	CK	Min	Mx	Mean	SD	CV	CS	CK
1	Addakal	6.1	13.6	10.2	2.6	0.3	-0.3	-1.4	6.2	13.3	9.6	2.7	0.3	0.2	-2.0	3.7	12.1	7.6	2.9	0.4	0.5	-1.4
2	Atmakur	5.6	13.0	8.7	1.9	0.2	0.6	0.8	4.2	12.2	8.3	2.4	0.3	-0.2	-0.4	3.7	12.4	6.8	2.4	0.4	0.8	1.0
3	C.C.Kunt (Kurmurti)	19.8	27.0	23.7	2.4	0.1	-0.3	-1.4	18.7	26.1	23.1	2.5	0.1	-0.7	-0.5	18.8	25.9	22.4	2.3	0.1	0.1	-0.7
4	Devarkad	11.9	12.9	12.4	0.3	0.03	-0.1	-1.6	10.0	13.8	12.0	1.0	0.1	-0.1	0.8	8.4	11.7	10.7	1.1	0.1	-1.2	0.6
5	Dhanwad (Marikal)	11.2	19.6	16.6	2.0	0.1	-1.4	3.3	14.4	19.3	17.0	1.3	0.1	-0.5	0.2	13.6	18.6	15.8	1.6	0.1	0.3	-1.1
6	Doulthab	8.7	15.9	12.1	2.1	0.2	-0.02	-0.9	5.1	16.0	11.9	2.9	0.2	-1.0	0.9	2.6	13.6	7.6	2.6	0.4	0.3	1.6
7	Ghanapur	9.3	16.3	10.7	1.9	0.2	2.4	6.6	9.5	17.1	10.5	1.9	0.2	3.4	11.9	8.3	10.4	9.7	0.6	0.1	-0.8	0.3
8	Gopalpet	7.7	14.5	10.8	2.0	0.2	0.3	-0.5	8.6	14.1	10.9	1.7	0.2	0.5	-0.3	5.1	13.7	8.0	2.4	0.3	1.1	1.3
9	Hanwada	12.3	21.5	16.5	3.2	0.2	0.1	-1.3	8.8	20.0	15.8	3.8	0.2	-0.8	-0.4	5.3	15.1	9.3	3.2	0.4	0.3	-0.8
10	Kodangal	11.3	25.5	16.6	4.0	0.2	0.6	0.3	8.5	21.4	14.5	3.5	0.2	0.3	-0.2	3.2	20.1	9.5	4.3	0.5	1.0	1.5
11	Koilkond	4.9	13.8	10.4	3.0	0.3	-0.5	-1.0	3.7	15.0	10.6	3.3	0.3	-0.4	-0.4	1.5	13.0	5.4	3.2	0.6	0.8	1.0
12	Kosgi	6.0	17.0	11.5	2.8	0.2	0.2	0.8	7.8	16.7	11.6	2.8	0.2	0.5	-0.6	4.7	13.7	8.0	2.6	0.3	0.9	0.6
13	Kothkota (Kanyapaly)	21.2	27.5	24.9	2.3	0.1	-0.3	-1.5	19.9	27.6	25.1	2.3	0.1	-0.9	0.3	15.3	27.3	20.4	3.7	0.2	0.6	-0.4
14	Kothakot (Madnapor)	8.6	19.2	13.2	3.0	0.2	0.1	-0.2	5.8	16.8	12.5	3.2	0.3	-0.6	-0.3	6.3	14.6	10.8	3.0	0.3	-0.1	-1.8
15	Mahbubnagar (Yenugonda)	6.9	24.7	13.8	4.5	0.3	0.7	1.8	7.7	19.9	13.1	3.4	0.3	0.3	-0.3	5.5	11.2	9.0	1.5	0.2	-1.1	1.3
16	Midjil(Kotha pally)	11.8	22.4	16.7	4.0	0.2	-0.2	-1.6	11.9	22.6	16.7	3.9	0.2	-0.01	-1.7	7.7	19.2	13.2	3.9	0.3	0.1	-1.3
17	Nagrkurnul	14.2	26.8	19.9	4.0	0.2	0.4	-0.9	8.8	27.1	19.8	5.1	0.3	-0.5	-0.03	12.9	25.9	18.4	3.9	0.2	0.8	0.2
18	Pedamandadi	9.8	15.5	12.6	1.7	0.1	0.4	-0.3	10.4	16.5	12.5	1.6	0.1	0.9	1.3	8.8	13.6	10.4	1.2	0.1	1.3	3.9

Note: *Mandal* is an administrative sub-unit of a district in India

Table 3. Groundwater level fluctuations between pre-monsoon and post –monsoon.

S. No	Location	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	Addakal	NA	NA	NA	3.09	-0.597	1.884	0.446	7.12	3.551	4.156	2.02	2.22	4.51	0.43
2	Atmakur	-2.66	0.5	4.48	4.57	1.307	1.403	0.023	4.771	1.207	4.31	0.26	2.9	3.23	0.53
3	Kurumurthy	NA	NA	NA	4.68	-0.56	-1.672	0.023	3.984	-0.205	4.69	-1.16	3.16	2.79	-1.66
4	Deverakadra	NA	NA	NA	4.28	1.75	2.725	1.325	3.004	0.5	1.55	0.8	0.58	1.48	0.51
5	Marikal	-2.69	0.27	0.75	0.018	-0.625	0.952	-0.797	3.4	1.604	2.27	0.87	1.56	3.07	0.87
6	Doulathabad	9.54	0.7	5.79	3.18	3.121	6.769	-0.418	9.702	0.096	6.141	1.18	8.36	6.47	3.18
7	Ghanapoor	8.07	-0.45	2.25	0.33	-0.154	-0.124	0.026	1.278	1.433	0.38	0.05	0.34	0.17	0.72
8	Gopalpet	4.62	1.29	5.03	1.91	0.133	3.536	-4.85	7.72	4.097	5.61	-0.33	5.04	3.75	1.64
9	Hanwada	6.86	NA	NA	NA	8.155	7.25	3.28	16.173	3.033	7.689	1.87	8.56	11.11	5.45
10	Kodangal	11.71	-0.82	7.22	8.23	5.156	8.262	0.485	17.679	6.311	9.093	3.59	7.7	10.84	4.84
11	Koilkonda	0.2	0.91	7.38	7.02	3.911	10.281	0.951	12.364	0.03	9.417	-0.83	9.82	6.83	1.13
12	Kosgi	4.34	-1.07	1.74	3.32	0.883	7.371	-1.168	12.285	0.519	3.395	1.16	5.48	6.46	3.32
13	Kanayapally	7.4	3.06	11.87	6.49	-0.362	0.174	0.14	9.76	3.797	5.32	-0.67	8.03	4.93	2.55
14	Madnapoor	5.37	-0.2	2.45	4.51	-0.622	1.25	0.344	4.304	4.837	4.446	-0.09	3.6	2.83	1.27
15	Yenugonda	5.1	-0.77	2.14	4.89	5.832	5.865	2.531	11.82	0.082	-1.93	4.11	7.7	4.6	14.7
16	Kothapally	2.47	-0.13	5.88	3.99	4.277	5.225	-1.71	13.106	-0.019	5.77	3.45	3.51	4.46	-0.65
17	Nagarkurnool	1.1	1.66	1.81	5.37	-2.098	-1.547	0.943	7.898	-2.315	6.062	-1.43	0.36	4.87	-0.92
18	Peddamandadi	1.21	1.2	3.75	2.1	-0.033	1.071	-0.021	4.79	3.22	6.644	-0.28	1.55	3.46	1.3

Table 4.Percentage rainfall variation from mean rainfall (%)

S. No	Location	0 to 10 %	10 to 15 %	15 to 20%	>20%
1	Addakal	1989, 1997, 2000, 2006	1992, 2001, 2008, 2011	1994, 2003	1999, 2002, 2004
2	Atmakur	1996, 2001, 2006, 2008, 2011, 2012		2002,	1997, 1999, 2003, 2004
3	Bhoothpur	1990, 1992, 2000, 2001, 2003, 2008, 2011, 2012	1988, 1994, 1996, 2006	2002, 2007	1997, 1999, 2004
4	C.C.kunta	1987, 2006,	1994, 2002		1986, 1992, 1997, 1999, 2004, 2011, 2012, 2013
5	Devarkadra	2000	1996, 2006	1999, 2007, 2008, 2011, 2012	1997, 2004
6	Dhanwada	2001, 2011, 2012	2002, 2006,	2009	1997, 1999, 2004
7	Doulatabad	2006, 2008, 2011	1997, 2000, 2002	2001, 2003,	1999, 2004, 2012, 2013
8	Gandeed	1998, 2003, 2011, 2013	1994, 2008		1986, 2001, 2002, 2004, 2006, 2007, 2010
9	Ghanpur	1992, 2001, 2003, 2008,		1994, 1999, 2010	1986, 1997, 1999, 2002, 2004, 2005, 2011, 2012
10	Gopalpet	1987, 1994, 2002, 2003, 2006	1992, 2001, 2012	2010	1986, 1999, 2004, 2008, 2011
11	Hanwada	2006, 2012	1996, 1997, 2001,		1999, 2004, 2008,
12	Kodangal	1995, 2003, 2011, 2012	1993, 1997	1992, 1999, 2000, 2002,	1986, 1994, 2004, 2013
13	Koilkonda	2011	2012	1997, 1999, 2009	2002, 2004, 2006, 2008
14	Kosgi	1987, 1989, 2000, 2001, 2004		1992	1993, 1994, 1997, 1999, 2002, 2006, 2007, 2008
15	Kothakota	2006, 2007, 2011	2003, 2012	1997, 1999, 2002, 2008	1992, 1994, 2004
16	Kulkacherla	1987, 1992, 1993, 1999, 2001, 2006, 2008, 2011			1986, 1994, 1997, 2002, 2004,
17	Maddur	2008, 2009	2002	2000	1999, 2003, 2004, 2005, 2006
18	Mahabubnagar	1998, 2001, 2006, 2007			1996, 1997, 1999, 2004
19	Peddamandadi	1997, 2002, 2006	2009	2004, 2012	1994, 1999, 2003, 2008, 2011
20	Wanaparthy	1993, 2001, 2003, 2010, 2011	2002	1987, 1992, 2012	1986, 1997, 1999, 2004, 2008

Table 5.Occurrences of groundwater droughts under different severity category and season

Season	Location	Drought category				Location	Drought category			
		Extreme	Severe	Moderate	Mild		Extreme	Severe	Moderate	Mild
PrM	**Addakal**			2003, 2005	2001, 2002, 2004, 2006	**Kodangal**	2005			2000, 2001, 2002, 2003, 2004
M				2001, 2003, 2005	2002, 2004			2004	2002, 2005	1998, 2001, 2003
PoM			2002	2003, 2004	2001, 2006		2004			1999, 2000, 2001, 2002, 2003
PrM	**Atmakur**	2000		2001	1998, 1999, 2002, 2003, 2005	**Koilkonda**			2000, 2003, 2005	1998, 2001, 2002, 2007, 2009
M			1998	2001	1999, 2000, 2002, 2003, 2004, 2005				1998, 2003, 2005	2000, 2001, 2002, 2004
PoM		1998			1999, 2000, 2002, 2003, 2004, 2006		1998		2004	1999, 2000, 2002, 2008, 2011
PrM	**C.C.Kunta**			2007	2001, 2004, 2005, 2006, 2009	**Kosgi**		2005	2003	2001, 2002, 2004, 2009
M				2004, 2005	2001, 2006, 2007, 2009			2003, 2005		2001, 2002, 2004, 2009
PoM			2006	2004	2003, 2008		2004	2002		2000, 2001, 2003, 2006, 2008
PrM	**Devarakadra**			2003, 2004	2001, 2002, 2008, 2010	**Kothakota (kanayapally)**			2000, 2004, 2005	1998, 2003, 2006, 2007, 2009
M			2008	2001	2002, 2004, 2005				1998, 2003, 2005	2004, 2007, 2009
PoM					2004, 2006, 2008, 2009, 2010, 2011			2003, 2004		2002, 2006, 2008, 2011
PrM	**Dhanwada**			2005	2000, 2001, 2002, 2003, 2004, 2006, 2007, 2009, 2010	**Kothakota (Madnapur)**		1998		1999, 2000, 2001, 2003, 2004, 2005
M			2005	2003	2000, 2001, 2002, 2004, 2006, 2007, 2010				1998	1999, 2000, 2001, 2002, 2003, 2004, 2005
PoM			2004	2002	2000, 2001, 2003, 2005, 2006				1998, 2004	1999, 2000, 2002, 2003, 2005
PrM	**Doulathabad**		2005		2000, 2003, 2004, 2007, 2009	**Mahabubnagr**	2011			2001, 2002, 2003, 2005, 2008, 2009, 2010
M				2005	2000, 2001, 2002, 2003, 2004, 2007, 2009			2011	2009	2001, 2002, 2004, 2008
PoM		2004			1999, 2000, 2001, 2002, 2006, 2007, 2008				2010	1999, 2000, 2001, 2004, 2007, 2008, 2009, 2011
PrM	**Ghanapur**	1998		2000	2005, 2006	**Midjil**			2000, 2005	1998, 1999, 2001, 2002, 2003, 2004
M		1998			2001, 2005			2005	2001	1998, 1999, 2000, 2002, 2003, 2004
PoM				2000, 2001, 2003, 2004	1999, 2002, 2006			1999, 2004		1998, 2000, 2001, 2002, 2003, 2004
PrM	**Gopalpet**		2005	2003	1998, 2000, 2002, 2006, 2009	**Nagarkurnool**		2004, 2005		2000, 2001, 2003, 2007
M			2004, 2005		1998, 2000, 2001, 2002, 2003, 2006, 2009				2004, 2005	2000, 2001, 2002, 2003, 2007, 2009
PoM		2004		2002	1999, 2001, 2003, 2006, 2008			2003, 2004		2000, 2002, 2009
PrM	**Hanwada**		2005	2002, 2009	2003, 2004, 2010	**Pedamandadi**		2005, 2007		2000, 2004, 2006
M				2002, 2003	2004, 2005, 2008, 2009		2005		1998	2000, 2001, 2003, 2004, 2006, 2009
PoM			2004	2008	2002, 2003, 2006, 2009		2004			1998, 1999, 2002, 2003, 2005

Table 6. Occurrences of number of drought events under different categories.

S. No	**Location**	**Extreme**			**Severe**			**Moderate**			**Mild**		
		PrM	**M**	**PoM**	**PrM**	**M**	**PoM**	**PrM**	**M**	**PoM**	**PrM**	**M**	**PoM**
1	Addakal						1	2	3	2	4	2	2
2	Atmakur	1		1		1		1	1		5	6	6
3	Devarakadra					1		2	1		4	3	6
4	Doulthabad			1	1				1		5	7	7
5	Ghanapur	1	1					1		4	2	2	3
6	Gopalpet			1	1	2		1		1	5	7	5
7	Hanwada				1		1	2	2	1	3	4	4
8	Kothakota						2	3	3		5	3	4
9	Kodangal	1		1		1			2		5	3	5
10	Koilkonda			1				3	3	1	5	4	5
11	Kosgi			1	1	2	1	1			4	4	5
12	Midjil					1	2	2	1		6	6	6
13	C.C.Kunta						1	1	2	1	5	4	2
14	Kothakota				1				1	2	6	7	5
15	Dhanwada					1	1	1	1	1	9	7	5
16	Nagarkurnool				2		2		2		4	6	3
17	Peddamandadi		1	1	2				1		3	6	5
18	Mahabubnagar	1				1			1	1	7	4	8

Table 7. Frequencies, percentage occurrence and recurrence of droughts under different categories.

			Total drought events			**Frequency of a drought event**			**Percentage of drought occurrence**			**Recurrence of droughts**		
S. no	**Station**	**Duration, years**	**Pre-M**	**M**	**Post-M**	**Pre-M**	**M**	**Post-M**	**Pre-M**	**M**	**Post-M**	**Pre-M**	**M**	**Post-M**
1	Addakal	11	6	5	5	0.55	0.45	0.45	54.55	45.45	45.45	1.83	2.20	2.20
2	Atmakur	14	7	8	7	0.50	0.57	0.50	50.00	57.14	50.00	2.00	1.75	2.00
3	Devarakadra	11	6	5	6	0.55	0.45	0.55	54.55	45.45	54.55	1.83	2.20	1.83
4	Doulthabad	14	6	8	8	0.43	0.57	0.57	42.86	57.14	57.14	2.33	1.75	1.75
5	Ghanapur	14	4	3	7	0.29	0.21	0.50	28.57	21.43	50.00	3.50	4.67	2.00
6	Gopalpet	14	7	9	7	0.50	0.64	0.50	50.00	64.29	50.00	2.00	1.56	2.00
7	Hanwada	14	6	6	6	0.43	0.43	0.43	42.86	42.86	42.86	2.33	2.33	2.33
8	Kothakota	14	8	6	6	0.57	0.43	0.43	57.14	42.86	42.86	1.75	2.33	2.33
9	Kodangal	14	6	6	6	0.43	0.43	0.43	42.86	42.86	42.86	2.33	2.33	2.33
10	Koilkonda	14	8	7	7	0.57	0.50	0.50	57.14	50.00	50.00	1.75	2.00	2.00
11	Kosgi	14	6	6	7	0.43	0.43	0.50	42.86	42.86	50.00	2.33	2.33	2.00
12	Midjil	14	8	8	8	0.57	0.57	0.57	57.14	57.14	57.14	1.75	1.75	1.75
13	C.C.Kunta	11	6	6	4	0.55	0.55	0.36	54.55	54.55	36.36	1.83	1.83	2.75
14	Kothakota	14	7	8	7	0.50	0.57	0.50	50.00	57.14	50.00	2.00	1.75	2.00
15	Dhanwada	14	10	9	7	0.71	0.64	0.50	71.43	64.29	50.00	1.40	1.56	2.00
16	Nagarkurnool	14	6	8	5	0.43	0.57	0.36	42.86	57.14	35.71	2.33	1.75	2.80
17	Peddamandadi	14	5	8	6	0.36	0.57	0.43	35.71	57.14	42.86	2.80	1.75	2.33
18	Mahabubnagar	14	8	6	9	0.57	0.43	0.64	57.14	42.86	64.29	1.75	2.33	1.56

Table 8. Percentage change in cultivated area

S. no	Station	Mean rainfall (mm)	Elevation (m)	2001-2004		2001-2005		2001-2011	
				Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
1	Adakkal	654.5	356	-4.3	-26.4	-4.9	27.3	5.7	203.7
2	Atmakur	785.2	310	1.1	-20.1	20.5	-25.4	31.1	-49.4
3	Bhootpur	617.4	444	-14.9	-65.3	-4.6	-4.9	14.6	-70.3
4	C.C.Kunta	602.6	330	8.6	-100	23.7	-11.2	52	-9
5	Devarkadra	646.5	370	-24	-69	11.9	-50	6	48.8
6	Dhanwada	675.6	436	-42.1	-70.3	-66.4	-12.5	-9.9	-6.7
7	Doulatabad	757.7	532	-53.5	9.5	-19.8	53.7	3.1	-12.8
8	Gandeed	621.7	510	-59.1	-80.4	-61.6	-81.9	-22.2	137.3
9	Ghanpur	600.8	448	44.3	-78	36	-58	14	61.4
10	Gopalpet	607.2	418	6.1	-90.4	20.1	-90.9	41.1	-19.8
11	Hanwada	678.7	442	-26.3	-26.3	-4.6	43.7	-6.9	-2.9
12	Kodangal	744	356	-22.6	-100	-22.8	208	-23.1	49.1
13	Koilkonda	555.6	442	-0.9	22	-4.3	53.1	17.5	19.7
14	Kosgi	651.1	512	-34.7	-104.2	-22.5	105.1	-11.1	183.7
15	Kothakota	685.9	344	40.9	-88.9	76.5	-94.9	-0.3	18.5
16	Kulkacherla	792.3	566	-41	-86	-49.6	-84.5	-4.8	38.2
17	Maddur	501.8	488	-30.8	60.5	-42.4	197.7	-26.8	154.9
18	Mahbubnagar	803.5	474	-0.5	30.6	11.4	108.5	1.4	185.1
19	Peddamandadi	561.7	383	22.7	-32.9	14.7	51.7	52.7	60.6
20	Wanaparthy	718	445	-15.8	-77.5	-9.2	3.4	-20.2	7.7

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