Trends in Agro-Meteorological Parameters as Groundwater Exploitation Indicators

A A Pathak¹, S Nizar¹ and B M Dodamani²

¹ Research Scholar, National Institute of Technology Karnataka, Surathkal, India
² Associate Professor, National Institute of Technology Karnataka, Surathkal, India
E-mail: abhipathak2013@gmail.com

Abstract. Rainfall being a major component of the hydrologic cycle, influences the agricultural practices in an area. Thus, trends in rainfall as well as rainy days are of major concern to farmers. Present study focusses on understanding the rainfall trends and its spatial distribution along with the trends in vegetation. An approach where Normalized Difference Vegetation Index (NDVI) procured from MODIS NDVI as an indicator for vegetation was used in this study. Mann Kendall trend test was performed on a 0.25-degree gridded data and the trends were then compared with the distribution of groundwater stress map of the study area. The study tries to examine the coupled use of NDVI and rainfall trends to decrypt the groundwater exploitation in the region. Further Ghataprabha river basin being susceptible to drought by hosting most of the significantly decreasing trend was investigated further. The propagation of severe drought return periods within the basin resembles the agro-meteorological trends. Even within the limitations of the present study, the methodology with further modifications promises to portray strong indication of groundwater exploitation.

1. Introduction
Economy of the Indian subcontinent is mainly controlled by agricultural sector where 65% of the total cultivable land is rain fed. Rainfall being the major source of water for agriculture is confined to the monsoon season from June to September. A small variation in its temporal or spatial distribution may lead to drastic changes in the agricultural productivity. Extensive studies have been carried out in India by different researchers to analyse rainfall and rainy-day trend at monthly, seasonal and annual time scale [1]-[5]. Specifically, Goswami and Ramesh (2007) observed decreasing trends in both number of rainy days and rainfall over India [6]. Joshi and Pandey (2011) studied rainfall trend and its spectral analysis over India for a longer period (1901-2000) and observed negative trends in rainfall over the Himalayan and other regions of India [7]. Decreasing trend in annual rainfall and an increasing trend in rainy days over Mahanadi and Krishna river basins were noted by Kumar and Jain (2010) [8].
Recent developments in the remote sensing and its allied applications enables to monitor vegetation dynamics from space with different indices. Among them, Normalized Difference Vegetation Index (NDVI) is widely used to capture variations of vegetation. Temporal and spatial trends in NDVI indicates its changes over an area and helps to explore regional interactions between vegetation and different climatic variables [9]. Many studies were reported on inter relationship between rainfall and NDVI at different regions of the world [10]-[13]. In the semi-arid and arid climatic condition most of the vegetation depends on rainfall with an increasing vegetation trend with increasing rainfall. Hosconlo et al (2014) reported increasing trend in vegetation in the parts of Africa even though the rain fall reduces significantly which indicates increase in the irrigation activity with other source of water in that region [14]. Similar conditions can also be observed in the study conducted by Herrmann et al.,...
Application of NDVI is not only limited to its relationship with precipitation but is also extended to analyse crop yield, soil moisture, temperature [17] and drought assessment [18], [19]. The complex association between groundwater levels and vegetation at regional scales has also been inspected with the aid of NDVI [20]. Effect of groundwater level fluctuation on different vegetation were carried out by Froend and Sommer, 2010 [21]; Chen et al., 2014 [22]. The present study aims to understand the spatiotemporal variation of rainfall, rainy days and vegetation trends over the study area by employing the non-parametric Mann Kendall trend test. The study further attempts to identify severe groundwater exploitation regions with the aid of rainfall and NDVI trends. The area experiencing significant negative trends in rainfall and rainy days was further explored for its susceptibility towards drought. The study is conducted in the south Indian state of Karnataka with an average annual rainfall that varies from 3456 mm at Coastal Karnataka to 731 mm over North Interior Karnataka. In terms of area prone to drought, Karnataka ranks second in India after Rajasthan. Recently, the Govt. of Karnataka has declared 157 of the 177 taluks as affected by the drought (Karnataka state natural disaster monitoring centre 2012).

2. Study area
Karnataka which is one of the prominent state in India is situated in the Deccan plateau bounded between 11° 30' N and 18° 30' N latitudes and 74° E and 78° 30' E longitudes. Figure 1 shows the location of Karnataka with the green shaded region masking the Western Ghats mountain ranges running parallel to the west coast. Accounting for about 5.05% of the total population of the country, Karnataka is the 9th most populated state in India (Census 2011). Covering a total land area of 1,91,791 km², Karnataka alone concentrates five of the six major climate types of the entire Indian Union [23]. The coastal strip, the Western Ghats and the Deccan plateau are the three principal physical zones in the state. The southwest monsoon from June to September (JJAS) accounts for almost 80% of the annual rainfall. The spatial distribution of rainfall reveals the distinct interaction of Western Ghats mountain ranges with the south west monsoon. The 1500 km long Western Ghats also known as the Great Indian Escarpment runs parallel to the western coast through Kerala, Karnataka, Tamil Nadu and Maharashtra. These Western Ghats mountain belts provide a unique orographic framework inducing excess turbulence which steers the atmospheric circulation triggering precipitation [23].

![Map of the study area](image-url)
3. Data and methodology

To assess the possible relationship between rainfall, rainy day and NDVI trends at a finer resolution, the Indian Meteorological Department (IMD) 0.25° Gridded Rainfall Dataset is adopted. The dataset comprises of over 6955 rain gauge stations, covering a longer period of 110 years over the Indian main land. The detailed description of the dataset has been discussed by D. S. Pai et al. (2014) [24]. They have also compared the Gridded dataset with other existing datasets showing comparable results. In addition, their results show that the low rainfall in the lee ward side of the Western Ghats and heavy rainfall areas in the orographic region of the west coast are realistically represented in the dataset. MODIS NDVI data products with a resolution of 250 m from 2000 to 2013 was downloaded and was considered for the present study. These data were further processed with ArcGIS-9.3 software.

3.1. Mann Kendall trend test

The Mann-Kendall (MK) trend test [25], [26] is used in this study. This test is commonly employed to detect monotonic trends in environmental, climate or hydrological data series. Being a non-prismatic approach, it requires no assumption about the distribution of the data. The null hypothesis for the test that there is no trend in the series is checked against the alternate hypothesis that the data follows a monotonic trend. The computations assume that the observations are independent. MK test was performed for rainfall, rainy day and for NDVI for the period of post monsoon, monsoon and post monsoon seasons. The magnitudes of these trends were then estimated by Sen’s-Slop method. Before comparing rainfall trends and NDVI trends graphically, the MODIS NDVI was resampled to the resolution of rainfall grid.

3.2. Reconnaissance Drought Index (RDI)

Reconnaissance Drought Index (RDI) was established [27] and was then categorized as meteorological index. RDI describes climatic water deficiency by considering the ratio of aggregated Precipitation (P) to the total Potential Evapotranspiration (PET) for a certain time period. RDI considers both rainfall and temperature in the form of PET to frame drought characteristics and thus overcomes one of the major drawback of the most popularly used Standardize Drought Index (SPI). Calculation of RDI involves, fitting appropriate distribution (usually 2 parameter Gamma distribution) to the P / PET ratio and CDF of the distribution is converted in to standardized normal distribution with mean 0 and standard deviation 1 to arrive RDI value. Negative values of RDI indicates dry condition whereas positive values indicate wet period. RDI classifies extreme severe, moderate and mild condition when its value will be less than 2, between -1.5 to -2, between -1 to -1.499 and between 0 to -1 respectively [28]. Temperature based Penman-Monteith reference evapotranspiration [29] was calculated with the aid of NASA’s NEX-GDDP temperature data [30].

4. Results and discussions

Mann Kendall trend test have been performed at grid level of 0.25° to identify trend in rainfall time series. Sen’s slope analysis was then performed at each grid to determine the magnitude of change. Since the rainfall varies seasonally, pre-monsoon, monsoon and post-monsoonal trends were found separately. Figure 2 and 3 shows the results of rainfall and rainy-day trends over the study area. During the pre-monsoon season North Interior Karnataka and Coastal Karnataka exhibits a decreasing trend whereas South Interior Karnataka shows an increasing trend. Sen’s slope estimate shows that out of 252 grid points 131 points have a decreasing magnitude whereas 121 have increasing magnitude. Out of the 131 decreasing points 17 are significantly (95% significant) decreasing and are concentrated around Ghataprabha river basin.
The Ghataprabha river basin is one of the important southern sub basins of Krishna River in its upper reach. It’s a semi-arid region in which rainfall is confined to monsoon season from June to October where the annual average rainfall varies from 5000 mm (at Western Ghats) to 600 mm and average annual rainy day varies from 120 days to 44 days. In the analysis of rainy day trends during the monsoon season four grids stood out with almost 2.5 times more increasing/decreasing trend. These locations are marked as heavily decreasing and heavily increasing trend in figure 3b. Not only the amount of precipitation but also its frequency is decreasing in the basin as evident from the rainy-day trends during the pre-monsoon season (Figure 3a). Being an agriculture dominated basin this could forecast serious consequences in its yield and may even be an indicator of draught. But as a contradiction to the above decreasing trends, the NDVI shows increasing trends (Figure 4) suggesting an alternate source of water for the crops in the basin. According to Shah (2009) [31], India experiences a steep increase in agricultural groundwater use since 1960. Thus the increase in NDVI despite a decrease in precipitation could be accounted to the use of groundwater. This is also evident from the groundwater exploitation map (Figure 5) published by the Central Groundwater Board (2011).
The map portrays most of the Ghataprabha basin to be either over exploited or in a semi-critical state. Thus in an agrarian country like India a decrease in rainfall trend coupled with an increase in NDVI could indicate an over exploitation of groundwater to compensate the agricultural water demand. A similar situation occurs during the monsoon season over the north interior Karnataka indicating ground water stress.

![Groundwater exploitation map of Karnataka for 2011](Source: CGWB)

**Figure 4.** Mann Kendall trend and Sen’s slope estimate of NDVI from 2000-2013. (a) Pre-Monsoon (b) Monsoon (c) Post-Monsoon.

During the monsoon season there is a line of significantly increasing trend parallel to the Western Ghats mountain ranges indicating a significant increase in orographic precipitation along the mountains. These Western Ghats mountain belts provide a unique orographic framework inducing excess turbulence which steers the atmospheric circulation triggering precipitation [23]. North interior Karnataka shows decreasing Sen’s slope magnitudes with few significantly decreasing trends. Significant decreasing trends are visible over coastal as well as north interior Karnataka. Even during
the monsoon season, certain areas around Ghataprabha river basin persists with significantly decreasing trends though the NDVI is increasing (Figure 4). This indicates the continued dependence on groundwater even during the monsoon season. During the post-monsoon season there are few significant trends, most of which are increasing. Coastal Karnataka shows an increasing trend with significant trends concentrated along the Western Ghats. North and South interior Karnataka is devoid of significant trends. Thus, being a hotspot of decreasing trends, the Ghataprabha basin is further investigated for its vulnerability to drought.

Assessment of drought and its return periods has been conducted using RDI over a Ghataprabha river basin. Impact of drought on different sectors water resources can be ascertain with the different time scales of drought. 6 month drought, being an intermediate time scale, which could reflect its impact on Irrigation as well as on other water sources sectors. To quantify drought characteristics, RDI of 6 month time scale has been calculated for all the grid points of the basin and average severity of the basin has been depicted in the Figure 6.

Figure 6. RDI series for Ghataprabha river basin at 6 month time Scale.

The basin experience severe meteorological drought with high intensity of -2.45 during 2011 and this was the main cause for sever groundwater exploitation during 2011 in the region. Along with that major drought episodes were observed during years 1970-1972, 1982-1985 and in 2000-2003. Among them 2000-2003 drought was incensed with the duration of 37 months and the cumulative severity of -31.28.
Figure 7. Severity of RDI return period at (a) 2 year (b) 5 year (c) 10 year.

The severity of the drought time scale (Figure 6) reveals that the frequency of severe drought were increasing with time and is an alarm for upcoming drought events. Spatial variation of drought severity with the return period of 2, 5 and 10 years were presented in the Figure 7 where the propagation of drought severity from eastern part of the basin to west can be observed clearly. Major portion of the basin is prone moderate drought, at least once in a 2 year whereas the eastern part of the basin is prone to severe drought with recurrence period of 5 years. The entire basin undergoes severe drought at least once in a 10 years and trace of the extreme drought can also be observed in certain pockets of the basin.

5. Conclusion
In this study rainfall and rainy-day trends were analysed along with vegetation trends for the pre monsoon, monsoon and post monsoon seasons in Karnataka. Trends of rainfall and rainy days during monsoon periods were increasing significantly in southern parts of Karnataka highlighting the importance of Western Ghats towards increase in orographic precipitation. Whereas significant decreasing trends were observed in certain regions of costal and north interior Karnataka. During pre-monsoon and post monsoon, both rainfall and rainy days were decreasing in the north western part of the area, which covers most of the area in Ghataprabha river basin. Even though with decreasing rainfall trends, the NDVI trends were increasing contradictorily during pre and post monsoon, which pertains severe groundwater exploitation in those seasons. Significant decreasing trends of rainfall and rainy day over Ghataprabha basin, which forces the region to suffer more recurrent meteorological drought episodes leading to severe groundwater exploitations. Return period of severe drought once in a decade emphasises the need of profound drought preparedness strategies and conjunctive use of water resources for the agricultural practise without effecting groundwater levels during deficit rainfall conditions.

6. References
[1] Sarkar R P and Thapliyal V 1988 Climate change and variability. Mausam. 39 127-138.
[2] Lal M 2001 Climate change – implications for India’s water resources. J Ind Water Resour Soc. 21(3) 101–109.
[3] Dash S K, Jenamani R K & Shekhar M S 2004 On the decreasing frequency of monsoon depressions over the Indian region. Current Sci. 86 1404–1411.
[4] Jain S K. & Kumar V 2012 Trend analysis of rainfall and temperature data for India. Current Science. 102(1) 37–49.
[5] Raju B C K, & Nandagiri L 2017 Analysis of historical trends in hydrometeorological variables in the upper Cauvery Basin, Karnataka, India. Current science. 112(3) 577-587.
[6] Goswami P, and K V Ramesh 2006 A comparison of interpolated NCEP (I-NCEP) rainfall with high-resolution satellite observations, Geophys. Res. Lett. 33 L19821.
Trend and spectral analysis of precipitation over India during 1901–2000. *Journal of Geophysical Research.* 116.

Kumar V, Jain S K and Singh Y 2010 Analysis of long-term rain-fall trends in India. *Hydrol. Sci.* J. 55 484–496

Mabuchi K, Sato Y and Kida H 2005 Climatic impact of vegetation change in the Asian tropical region. Part I: Case of the Northern hemisphere summer. *J. Climate.* 18 410–428.

Davenport M L and Nicholson S E 1993 On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa, *Int. J. Remote Sens.* 14 2369–2376.

Santos P and Negri A J 1997. A comparison of the normalized difference vegetation index and precipitation for the Amazon and Northeastern Brazil. *Journal of Applied Meteorology.* 36(7) 958-965.

Mao J F, Shi X Y, Thornton P E, Piao S and Wang X 2012 Causes of spring vegetation growth trends in the northern mid-high latitudes from 1982 to 2004. *Environmental Research Letter.* 7 014010.

West T O, Page Y L, Huang M, Wolf J and Thomson A M 2014 Downscaling global land cover projections from an integrated assessment model for use in regional analyses: results and evaluation for the US from 2005 to 2095, *Environmental Research Letter.* 9 064004.

Hoscilo A, Balzter H, Bartholomé E, Boschetti M, Brivio P A, Brink A Clerici M and Pekel J F 2015 A conceptual model for assessing rainfall and vegetation trends in sub-Saharan Africa from satellite data, *Int. J. Climatol.* 35 3582–3592.

Herrmann S M, Anyamba A, Tucker C J 2005 Recent trends in vegetation dynamics in the African Sahel and their relationship to climate, *Glob. Environ. Change.* 15 394–404.

Huber, S., Fensholt, S., and Rasmussen, K., 2011 Water availability as the driver of vegetation dynamics in the African Sahel from 1982 to 2007 *Global and Planetary Change.* 76 186–195.

Lakshmi Kumar T V, Koteswara Rao K, Humberto Barbosa and Emily Prabha Jothi 2013 Studies on spatial pattern of NDVI over India and its relationship with rainfall, air temperature, soil moisture adequacy and ENSO, *GEOFIZIKA* 30

Kogan, F N 1995 Application of vegetation index and brightness temperature for drought detection. *Adv. Space Res.* 15 91–100.

Karnieli A, Agam N, Pinker R T, Anderson M., Imhoff M L, Gutman G, Panov N, and Goldberg A 2010 Use of NDVI and land surface temperature for drought assessment: Merits and limitations. *Journal of Climate.* 23(3) 618–633.

Doble R, Simmons C, Jolly I and Walker G 2006 Spatial relationships between vegetation cover and irrigation-induced groundwater discharge on a semiarid floodplain, Australia. *Journal of Hydrology.* 329 (1) 75-97.

Froend R and Sommer B 2010 Phreatophytic vegetation response to climatic and abstraction-induced groundwater drawdown: Examples of long-term spatial and temporal variability in community response. *Ecological Engineering.*

Chen Y, Li W, Xu C, Ye Z, Chen Y 2014 Desert riparian vegetation and groundwater in the lower reaches of the Tarim River basin, *Environ Earth Sci.*

Gunnell Y 1997 Relief and Climate in South Asia: the Influence of the Western Ghats on the Current Climate Pattern of Peninsular India, *International Journal of Climatology.* 17 1169–1182.

Pai D S, Sridhar L, Rajeevan M, Sreejith O P, Sabthai N S, & Mukhopadyay B 2014 Development of a new high spatial resolution (0.25° × 0.25°) Long Period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *Mausam.* 65(1) 1–18.

Kendall M G 1955 Rank Correlation Methods. *Griffin,London.*

Mann H B 1945 Nonparametric tests against trend, *Econometrica.* 13 245-259

Tsakiris G, Vangelis H 2005 Establishing a drought index incorporating evapotranspiration. *Eur Water.* 9 10 1–9
[28] Zarch M, Malekinezhad H, Mobin M H, Dastorani M T, and Kousari M R 2011 Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. Water Resources Management. 25(13) 3485–3504

[29] Allen R G, Pereira L S, Raes, D, and Smith M. 1998 Crop Evapotranspiration, (Guidelines for Computing Crop Water Requirements, Irrigation and Drainage Paper 56, FAO, Rome).

[30] Thrasher B, Xiong J, Wang W, Melton F, Michaelis A, Nemani R, 2013 Downscaled climate projections suitable for resource management. Eos Trans. Am. Geophys. Union. 94 321–323.

[31] Shah T 2009. Climate change and groundwater: India’s opportunities for mitigation and adaption. Environ. Res. Lett. 4 035005.