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Research Article

Trend analysis and variability of satellite-based soil moisture data for the Lower Bhavani basin, Tamil Nadu using Google Earth Engine

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Abstract
Soil moisture is a significant hydrological component that is dynamic in nature. The variation in soil moisture in the basin scale would affect the vegetation, ecology and environment. Soil moisture trend analysis aids in providing the variation of soil moisture over the basin. The present study aimed to analyse the soil moisture trend in Lower Bhavani basin, Tamil Nadu from 2003-2022. Satellite-based soil moisture Global Land Data Assimilation System (GLDAS) data was extracted from the Google Earth Engine (GEE) platform to analyse the variation and trend over the period of time. The highest and lowest soil moisture was observed during monsoon and summer months and its percentage variation was studied. Using Man-Kendall test and Sen's slope, trend analysis was calculated for two decades (2003-2012 and 2013-2022). In 2003-2012, an increasing trend of soil moisture was observed during winter (October to February); from 2013-2022, an increasing trend was observed during both winter (October to February) and monsoon seasons (June to September). The remaining season did not follow any trend, and there was no decreasing trend in soil moisture. The trend analysis of the study will help to monitor and manage the environmental system across the Lower Bhavani basin.

Keywords: GLDAS, Google Earth Engine, Soil moisture, Trend analysis

INTRODUCTION

Soil moisture is a vital parameter in the hydrological cycle and climatology. It represents the amount of water in the soil that can be used for vegetation growth. Soil moisture aids in managing water resources and regulation of the ecosystem that varies on spatial and temporal scales (Brown *et al.,* 2011). Soil moisture can be measured *in situ* using direct methods on point measurements and indirectly using remote sensing methods for larger scales (Janani *et al.,* 2023). Remote sensing provides directly available soil moisture datasets that can be accessed on a grid basis for a particular basin or watershed scale (Kim *et al.,* 2018).
Google Earth Engine (GEE) is a cloud-based platform with a catalogue from which direct datasets can be accessed. The geospatial analysis and time series data can be obtained from the GEE platform using python code or JavaScript. For this study, Global Land Data Assimilation System (GLDAS 2.2) data was utilized from GEE platform for reviving soil moisture data. GLDAS dataset provides various directly existing data,

including land surface state and flux models (Fang *et al.,* 2009). GLDAS data provided soil moisture data from 2003 to the present and from which the trend analysis was studied.

Trend analysis is a technique to examine long-term historical data and to predict future outcomes (Craig *et al.,* 2002). The most common methods for studying trend analysis are the Man-Kendall test and Sen's slope estimator. These tests provide the trend followed in soil moisture data. The trend may be increasing or decreasing, or it may not follow any trend. Majorly, the trend analysis is studied for climatological and hydrological parameters like precipitation (Mallick *et al.,* 2021; Mondal *et al.,* 2012), temperature (Dawood, 2017; Yadav *et al.,* 2014), and runoff (Nyikadzino *et al.,* 2020; Danneberg, 2012). The present study aimed at utilizing the directly available soil moisture datasets from GEE platform, i.e., GLDAS soil moisture data from 2003-2022, for studying the trend analysis using the Man-Kendall test and Sen's slope estimator for Lower Bhavani basin, Tamil Nadu.

MATERIALS AND METHODS

Study area

Lower Bhavani Basin is located in Erode district of Tamil Nadu and is in between latitudes 11° 15' and 11° 45' North and longitudes 77° 00' and 77° 40' East (Fig. 1). The study area covers 2424 km^2. The study area's northern region is hilly and forested, with the highest elevation measuring 1473 metres above mean sea level. Sandy clay loam, sandy clay and loamy sand make up the majority of the basin's texture. The temperature of the region ranges from 22 to 40 °C. On average, the region receives 575.55 mm to 840.64 mm of rain annually, with the southwest and northeast monsoons bringing the heaviest downpours (Anand and Karunanidhi, 2020).

Google Earth Engine – GLDAS soil moisture dataset

Google Earth Engine (GEE) is a cloud-based geospatial processing service that performs geospatial analysis with the help of Java or Python scripts. GEE platform is interactive for large-scale global geospatial datasets. It provides global historical satellite data as well as directly available datasets, which aids in monitoring and managing the environment and natural resources. This study used Global Land Data Assimilation System (GLDAS 2.2) data to analyse soil moisture trends. GLDAS data was provided by NASA Goddard Earth Sciences Data and Information Services Center. GLDAS offered data such as soil moisture, surface runoff, evapotranspiration, heat flux etc. The data availability of GLDAS was from 2003 to the present. The soil moisture time series was executed for the Lower Bhavani basin for two decades (2003-2022) in the GEE platform. The monthly data was taken for performing the trend analysis of soil moisture.

Mann Kendall test

Mann Kendall is a statistical test used to compare the magnitudes of soil moisture data and examine regional and temporal hydroclimatic trends. The non-parametric Man-Kendall test was used to analyse the soil moisture trend over the period (2003 – 2022) in the Lower Bhavani basin. It is possible to utilize the Mann-Kendall test with data sets with irregular sample intervals and missing data because it does not need any assumptions about the statistical distribution of the data. Mann-Kendall test statistic is computed using the following equation (Kendall 1975):

$$S=\sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad \text{Eq. 1}$$

The trend test is applied to two-time series: x_k, which is ranked from k = 1, 2,…..n-1, and x_j, which is ranked from j= k+1, 2,….. n. Every data point x_i is used as a reference, which x_j is compared to the other data points so that,

$$sgn(x_j - x_k) = \begin{cases} +1 \ if \ (x_j - x_k) > 0 \\ 0 \ if \ (x_j - x_k) = 0 \\ -1 \ if \ (x_j - x_k) < 0 \end{cases} \quad \text{Eq. 2}$$

The variance of Man-Kendall (s) statistic is calculated as,

$$(S) = \frac{[n((n-1)(2n+5)) - \sum_{i=0}^{n} t(t-1)(2t+5)]}{18} \quad \text{Eq. 3}$$

The notation t indicates the extent of every specific tie, and t represents the sum of all ties.Z statistics are computed by the given equation in situations where the sample size, n, is morethan 10. The values of S and Var(S) are used to compute the test statistic Z as follows:

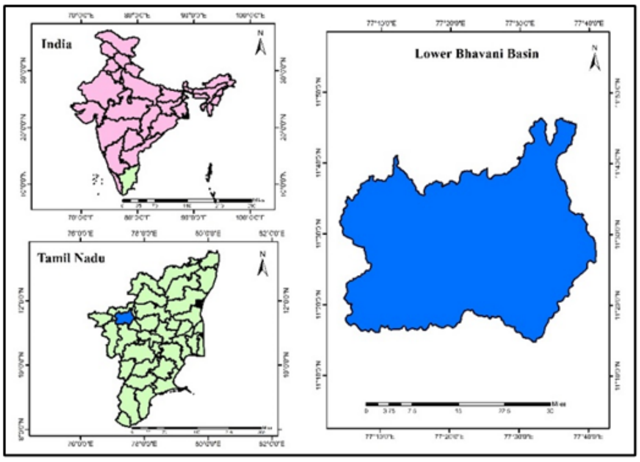

Fig 1. *Study area map of the Lower Bhavani basin, Tamil Nadu*

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(s)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{var(s)}} & if\ S < 0 \end{cases} \quad \text{Eq. 4}$$

Z number that is positive or negative denotes an upward or downward trend, respectively. The Z value is used to assess the existence of a statistically significant trend. At a significance level of 0.05, the Z values were examined.

Sen's Slope Estimator Test:

Simple linear regression is one of the most popular models to find linear trends. Sen's slope estimator method can be used when the trend is assumed to be linear and is one tool for developing linear relationships. In this method, the slopes of data pair (T_i) was determined by (Sen 1968),

$$T_i = \frac{x_j - x_k}{j - k} \quad for\ i=1,2.......n \quad \text{Eq. 5}$$

Where x_j and x_k are data values at times j and k (j > k). The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Q_i = \begin{cases} T_{\frac{n+1}{2}} & n\ is\ odd \\ \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+2}{2}}\right) & n\ is\ even \end{cases} \quad \text{Eq. 6}$$

A positive value of Qi indicates an upward (increasing) trend in the time series, whereas a negative value indicates a downward (declining) trend.

RESULTS AND DISCUSSION

Analysis of soil moisture variation

The most current satellite soil moisture monitoring initiatives aim to gauge near-surface moisture (Djebou and Singh, 2015). Satellite soil moisture data GLDAS was obtained for Lower Bhavani basin from the GEE platform from 2003 to 2022. In these two decades, soil moisture variation was studied on a monthly and yearly basis. In month wise, soil moisture variation (Fig. 2) shows seasonal dissimilarities. The highest soil moisture was observed during the monsoon months of October, November and December. The lowest soil moisture was observed during March, April and May, depicting the basin's summer season. The post-monsoon and pre-monsoon seasons have moderate soil moisture ranges.

The year-wise soil moisture variation over Lower Bhavani basin was studied (Fig. 3) and this aids in predicting climate extremities that has occurred over the period. The highest soil moisture was observed in 2022, 2021, 2008 and 2010. Several different parameters influence the soil moisture range, such as precipitation, temperature, vegetation and evapotranspiration on the basin scale (González-Zamora *et al.,* 2021). The lowest soil moisture was observed in 2013, 2016, 2003 and 2004. Due to a lack of the northeast monsoon in 2013, Tamil Nadu experienced a drought year (Rajendran, 2014). The dry condition of Tamil Nadu was more particular in the year 2016 because of deficit rainfall and 17.8% of the Total Geographical Area of the Tamil Nadu state was under extreme drought conditions (Kumar *et al.,* 2021).

Percentage of soil moisture variation

The soil moisture percentage was calculated monthly for the study period from 2003-2022 (Fig 4). The highest soil moisture percentage over the years were 9.3, 9 and 8.9 % during the wet months of November, December and October. The months of September (8.5 %), January (8.5 %), August (8.3 %), July (8.1 %), February (8 %) and June (8 %) hold similar moisture ranges. Whereas soil moisture decreased in the summer months of May (7.8 %), March (7.8 %) and April (7.7 %).

Seasonal trend analysis of soil moisture data

Trend analysis was carried out for soil moisture data using the non-parametric Man-Kendall test and Sen's slope estimator for the Lower Bhavani basin for two decades (2003-2012 & 2013-2022). The Mann-Kendall test was employed to determine trends in soil moisture for monsoon, pre-monsoon, post-monsoon and winter

Table 1. Estimated Sen's Slope and Kendall's test statistics (Z) values for two decades

Years	Season	p value	z value	Tau	Sen's Slope (Q)	Intercept	Trend
2003-2012	Pre monsoom	0.720	0.357	0.111	0.030	22.104	No Trend
	Monsoon	0.283	1.073	0.288	0.142	22.516	No Trend
	Post monsoon	0.152	1.431	0.377	0.147	25.246	No Trend
	Winter	0.020	2.325	0.600	0.223	23.702	Increasing
2013-2022	Pre monsoom	0.210	1.252	0.334	0.102	21.145	No Trend
	Monsoon	0.012	2.504	0.644	0.277	22.136	Increasing
	Post monsoon	0.175	1.355	0.388	0.418	24.301	No Trend
	Winter	0.012	2.504	0.644	0.381	22.152	Increasing

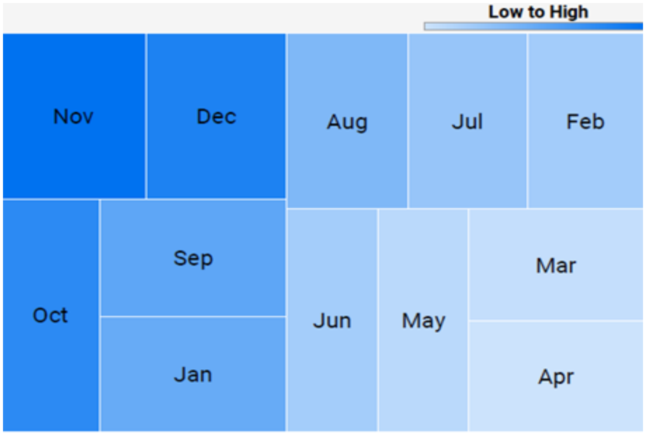

Fig. 2. *Month wise soil moisture variation from 2003-2022*

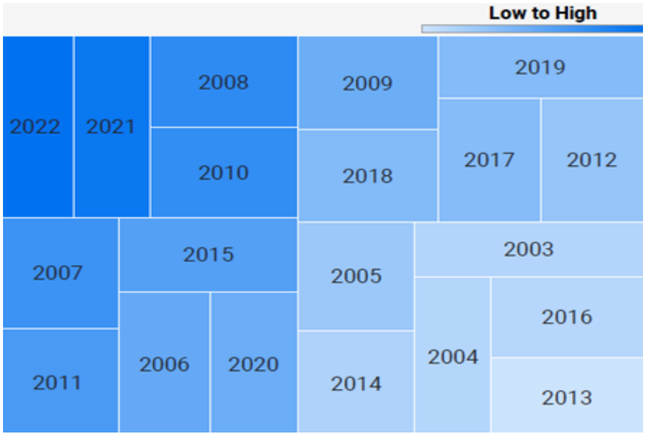

Fig 3. *Year wise soil moisture variation from 2003-2022*

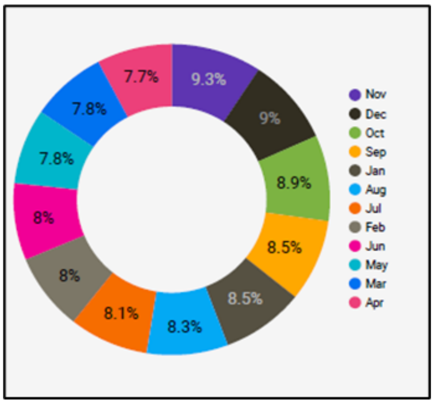

Fig 4. *Cumulative Percentage monthly soil moisture variation from 2003-2022*

season. Sen's slope estimator measures the magnitude of the trend for each season. The result of the study is presented in Table 1.

In the first decade (2003-2012), the result indicated that no trend was followed for pre-monsoon, monsoon and post-monsoon seasons. For the winter season, soil moisture showed an increasing trend over the period of time. For second decade (2013-2022), a rising trend was followed during the winter and monsoon seasons and no trend was followed for the pre-monsoon and post-monsoon seasons. Fig. 5 represents the Z value and Fig. 6 depicts the Sen's slope of monsoon, pre-monsoon, post-monsoon and winter seasons for two decades.

From the results, it can be summarized that soil moisture varies on a seasonal basis (Jackson *et al.,* 2010). Also, the trend test indicated an increasing trend and no trend based on the season. There was no decreasing trend in soil moisture over the basin. The GLDAS satellite soil moisture data that were used in this work to test trend analysis produced positive outcomes and aided in estimating the trend over a longer time frame (Liu *et al.,* 2019).

Conclusion

The present study analysed the GLDAS satellite-based soil moisture data from GEE platform for Lower Bhavani basin from 2003-2022. The Lower Bhavani basin was dominated by vegetation and it is necessary to study the soil moisture variations and trends followed over the period of time. For two decades, the highest soil moisture was observed during monsoon months and lowest was observed during summer months. And the percentage of soil moisture was higher during the wet months of October (8.9 %), November (9.3 %) and December (9 %) and decreased in March (7.8 %), April (7.7 %) and May (7.8 %). Man-Kendall test and Sen's slope

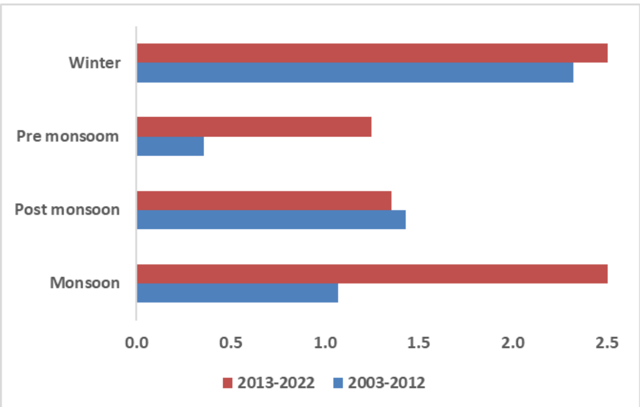

Fig. 5. *Seasonal soil moisture Z value*

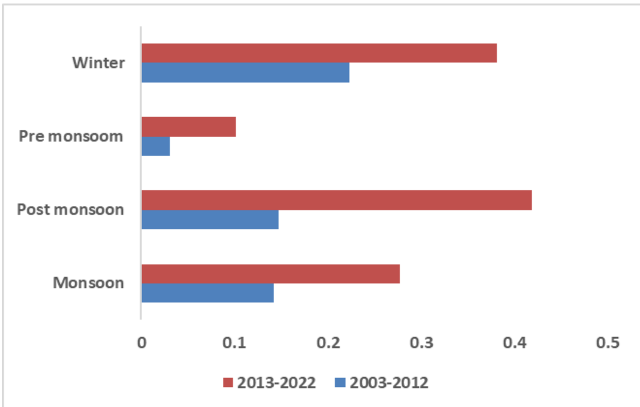

Fig. 6. *Seasonal soil moisture Sen's slope*

estimator showed a seasonal trend of soil moisture over the basin. In 2003-2012, an increasing trend was observed during winter; from 2013-2022, an increasing trend was observed during both winter and monsoon seasons. The remaining season (pre-monsoon and post-monsoon) does not follow any trend; also, there is no decreasing trend in soil moisture. The study's findings can be used to monitor ecosystems in the context of climate change. Similarly, the methods used might effectively manage water resources at the watershed level. The long-term soil moisture data analysis was possible by applying remote sensing advancements and utilising the GEE platform for diversified ecosystems.

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Conflict of interest

The authors declare that they have no conflict of interest.

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