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Analysing relationship between soil moisture and rainfall from remote sensing approach

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Abstract
The intricate relationship between soil moisture and rainfall plays an important part in surface hydrology. Conventionally, the analysis of this complex relationship is established by the data of soil moisture and rainfall that are collected through in-situ observations at limited locations. In the present study, available remote sensing product of soil moisture with the organization and Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS) that provide global coverage rainfall data at 5Km resolution has been utilized to analyse the co-relation of rainfall and soil moisture at regional level. The statistical inference of the derived results indicates that there is moderate to limited correlation coefficient between soil moisture and rainfall in the selected study regions during the observation period. Also, remotely sensed soil moisture data has less significance in dense vegetation and areas having good source of existing surface & subsurface water sources with water harvesting structures.

Keywords: Soil moisture, rainfall, remote sensing

Introduction
"Soil moisture is the total amount of water, including the water vapour, in an unsaturated soil." The soil moisture content in topsoil plays a significant role in heat exchange between the land and the atmosphere with other hydrological processes such as flood and drought prediction etc. From agriculture perspective, soil moisture is essential in irrigation scheduling, assessing crop stress and improving crop production. Therefore, due to its effect in agricultural ecosystem and importance in hydrological cycle this is a significant component in weather forecasting, simulating yield and in advance prediction of natural calamities such as drought, flood etc.
The cumulative relationship of precipitation and soil moisture impacts the surface water and energy budget cycle and ingredient of this associated parameters are simple and complex at same time. As soil moisture spatial and temporal patterns are depended on the variability of precipitation, runoff, and evapotranspiration. Furthermore, precipitation dependent role in soil moisture availability and variability is uncertain considering the other above mentioned hydrological components. (Sehler *et al*. 2019) [7].
The refereed literature suggests that at regional scale the correlation between soil moisture and precipitation is more complex and may vary in interconnection (positive/negative) and magnitude (weak/strong). The final finding of these studies shows mixed results of direct positive correlation between precipitation and soil moisture and negatively correlated in certain regions considering the role of environmental factors like land use and land cover, prevailing weather positions/conditions and climatic regimes as also deciding factors in soil moisture interaction with rainfall. Moreover, the limited data availability of soil moisture in earlier time also put constraints in understanding the nexus of soil moisture and rainfall. SMAP launched in 2015 provided the platform to access high-resolution global soil moisture data. [Rossato *et al*., 2017] [6].
The objective of this study is to assess the remote sensing derived soil moisture data and then correlating the same with rainfall for investigating the soil moisture variability in the study region.

Materials and Methods
Study Area
The studies were conducted at two different sites one in each: Rajkot (22.3°N 70.78°E) and Bharuch (21.7°N 72.97°E) districts of Gujarat. The soil of the selected study region varies from shallow medium black in Rajkot to deep black loamy sand in Bharuch district. The rainfall at all these selected locations generally falls from July to September.

The climate of the Rajkot district is hot semi-arid whereas Bharuch district has a tropical savanna climate, and its weather is strongly moderated by the Arabian Sea.
The fifth longest river of India i.e., Narmada flow across Bharuch and Rajkot lies on the bank of seasonal rivers Aji and Nyari which mostly remain dry except monsoon season and therefore has no major source of surface water like exist in Bharuch district. Bharuch is an agricultural district, and the major crops are Cotton, Tur and other important crops are sugarcane, Wheat, Pulses etc. contrarily Rajkot is considered as a prime industrial town for cotton and woollen textiles. [M. Kulshrestha *et al*., 2009, cgwb.gov.in, Bharuch.nic.in] [8].

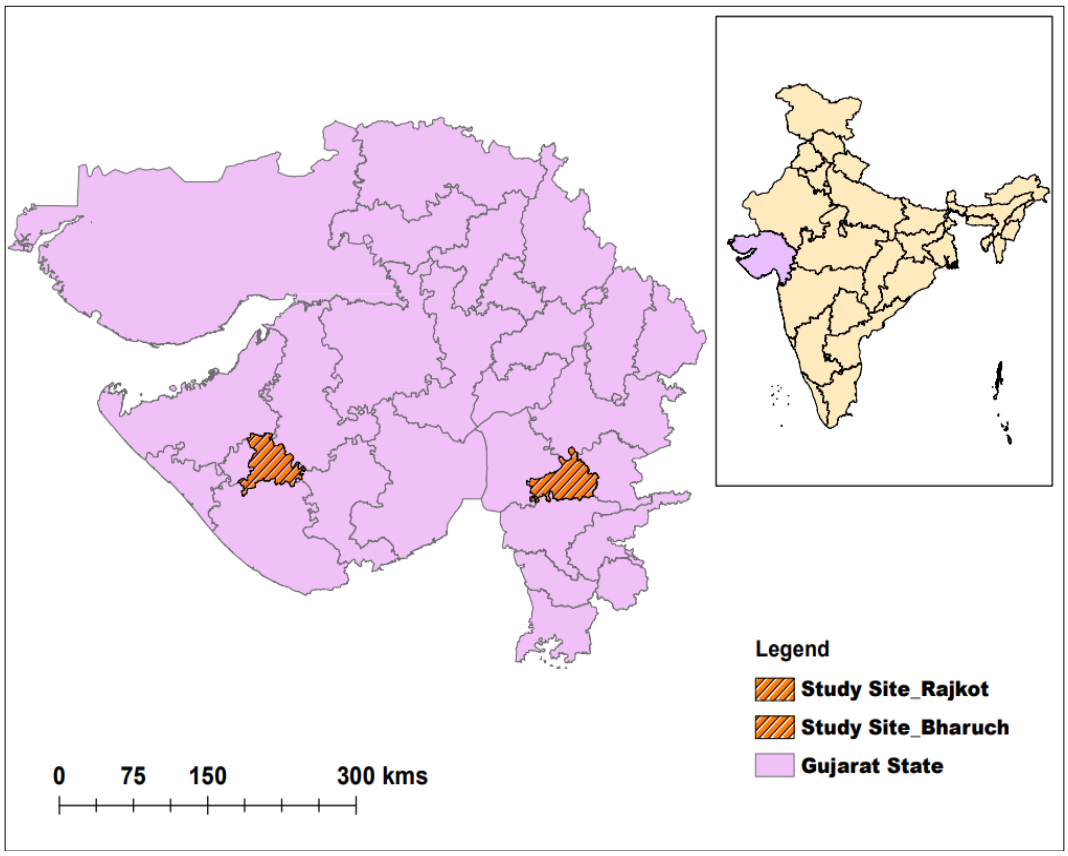


Fig 1: Geographic Location of Study Regions in Gujarat State

Data
Soil Moisture Data fetched from internal database of the organization that is a default product of SM-SMAP-L-DESCV4.0.
Rainfall data come from CHIRPS i.e., an Infrared Precipitation station data of Climate Hazards centre, U.S. CHIRPS is available since 1981 to near present that incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for various applications like trend analysis and seasonal drought monitoring. CHIRPS was initially developed for International Development Famine Early Warning Systems Network (FEWS NET). CHIRPS uses the Tropical Rainfall Measuring Mission Multi-Satellite Precipitation Analysis version 7 (TMPA 3B42 v7)7 to calibrate global Cold Cloud Duration (CCD) observations for building the rainfall datasets through a "smart interpolation" approach. [Funk *et al*. 2015] [1].

Methodology
To analyse the relationship between soil moisture and rainfall, daily datasets for both the parameters were downloaded from their respective sources and pre-processed for uniformity and same spatial coverage. For this, the entire monsoon season 2022 and post monsoon 2022-23 (covers the complete Kharif and Rabi season) was considered. Additionally, one to one daily data matrix was formed to understand the variability in datasets and selecting the study time-zone considering the availability of both the parameters.
After the pre-processing and validation of daily data, a Time series analysis for two selected locations was done for identifying the nature of the relationship exist between soil moisture and rainfall in that region. Then for final conclusive discussion on results achieved was summarized statistically by presenting the correlation coefficient and monthly max of soil moisture and rainfall data.

Results and Discussions
The purpose of this research was to analyse the complex relationship of soil moisture and rainfall using remote sensing data of SMAP and spatial rainfall data from June,2022 to March 2023. To attain this objective, time series analysis was performed on daily data (as data particularly for soil moisture was not available on equivalent time-intervals). The derived results are presented below in figure 2 and 3 respectively.

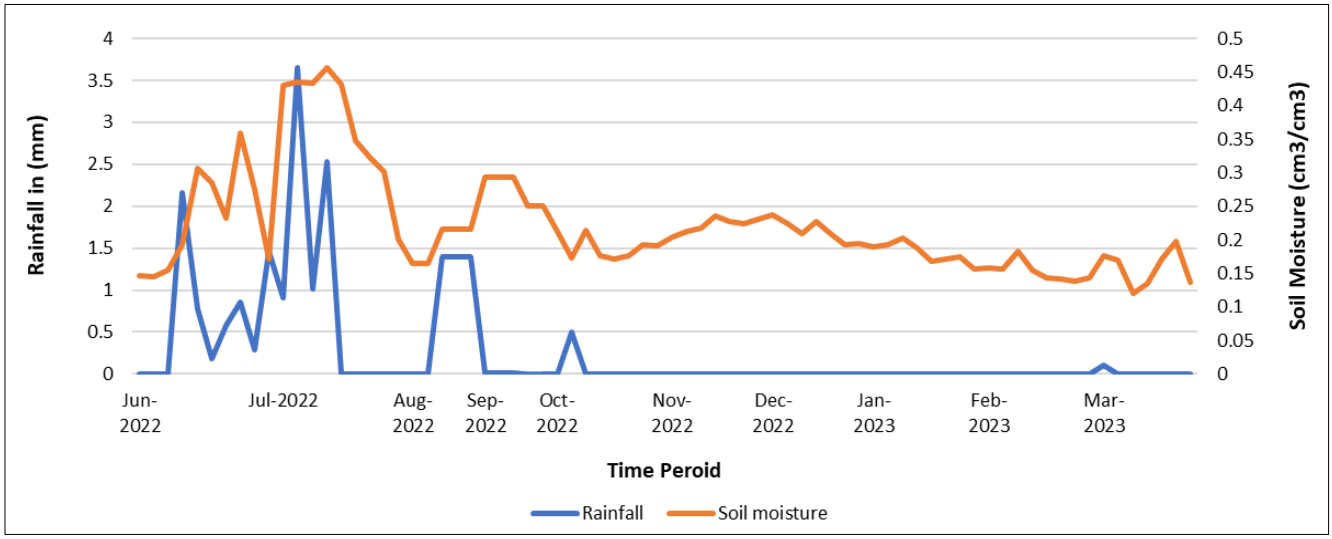


Fig 2: Time Series Analysis for Selected Location in Rajkot

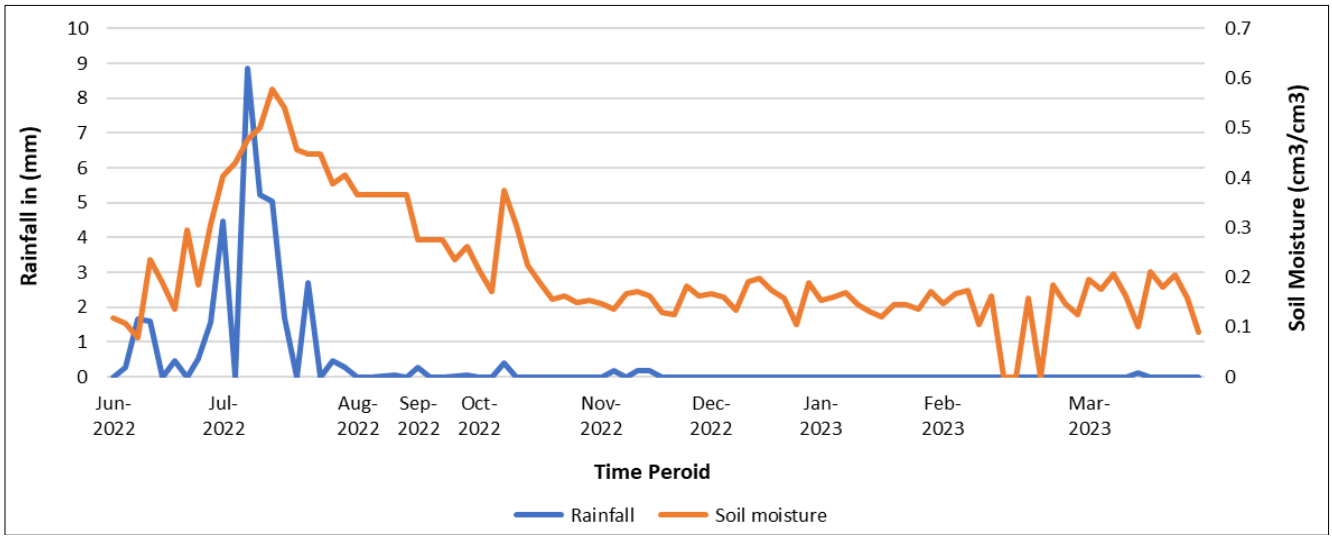


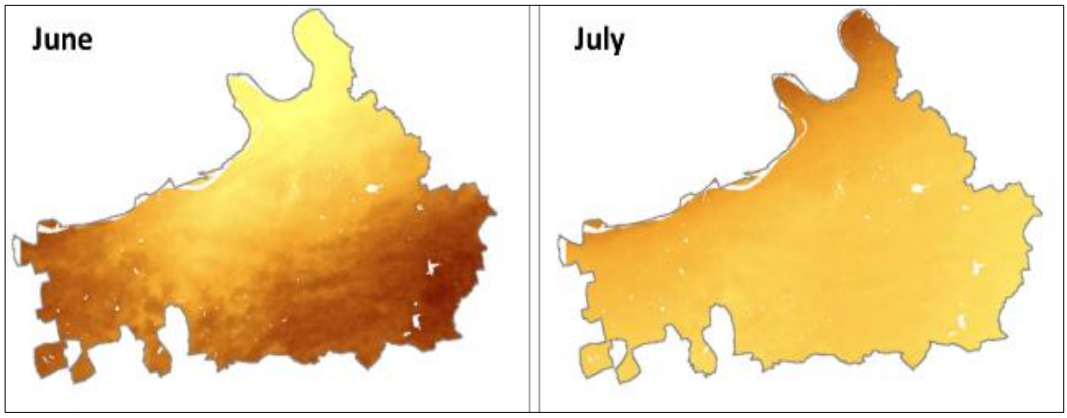
Fig 3: Time Series Analysis for Selected Location in Bharuch

The above linear plot diagram indicates that soil moisture and rainfall follow the similar pattern but limited or no rain doesn't lead to complete non-availability of soil moisture in the soil.

This could be attributed to soil profile of the area under consideration that has capacity to retain the soil moisture and the land cover type of the study region. In our case, one of selected location i.e., falls in Bharuch has one of major river i.e., Narmada that flow across through it and has good water harvesting structures that provides the sufficient support system in maintaining the water level in the soil.

In addition to time series analysis, the monthly maximum rainfall and soil moisture data for location site 1 in Bharuch and another location site 2 in Rajkot is shown below to highlight the availability of soil moisture in monsoon and post monsoon period including winter season and corresponding rainfall. Finally, the correlation coefficient of both variables is deduced for arriving at final remarks.

Location Site 1: Bharuch [Monthly Soil Moisture and Rainfall]



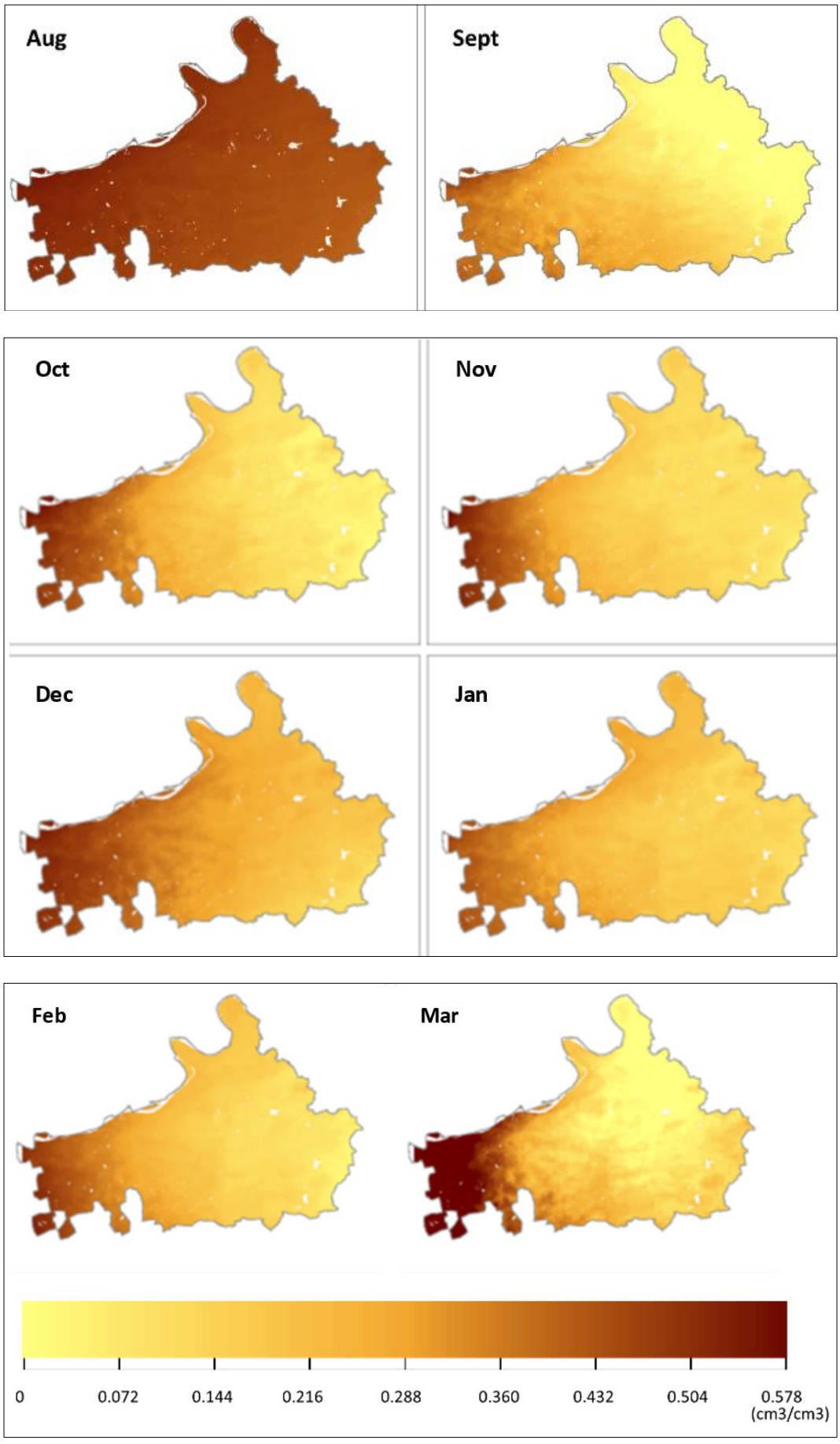
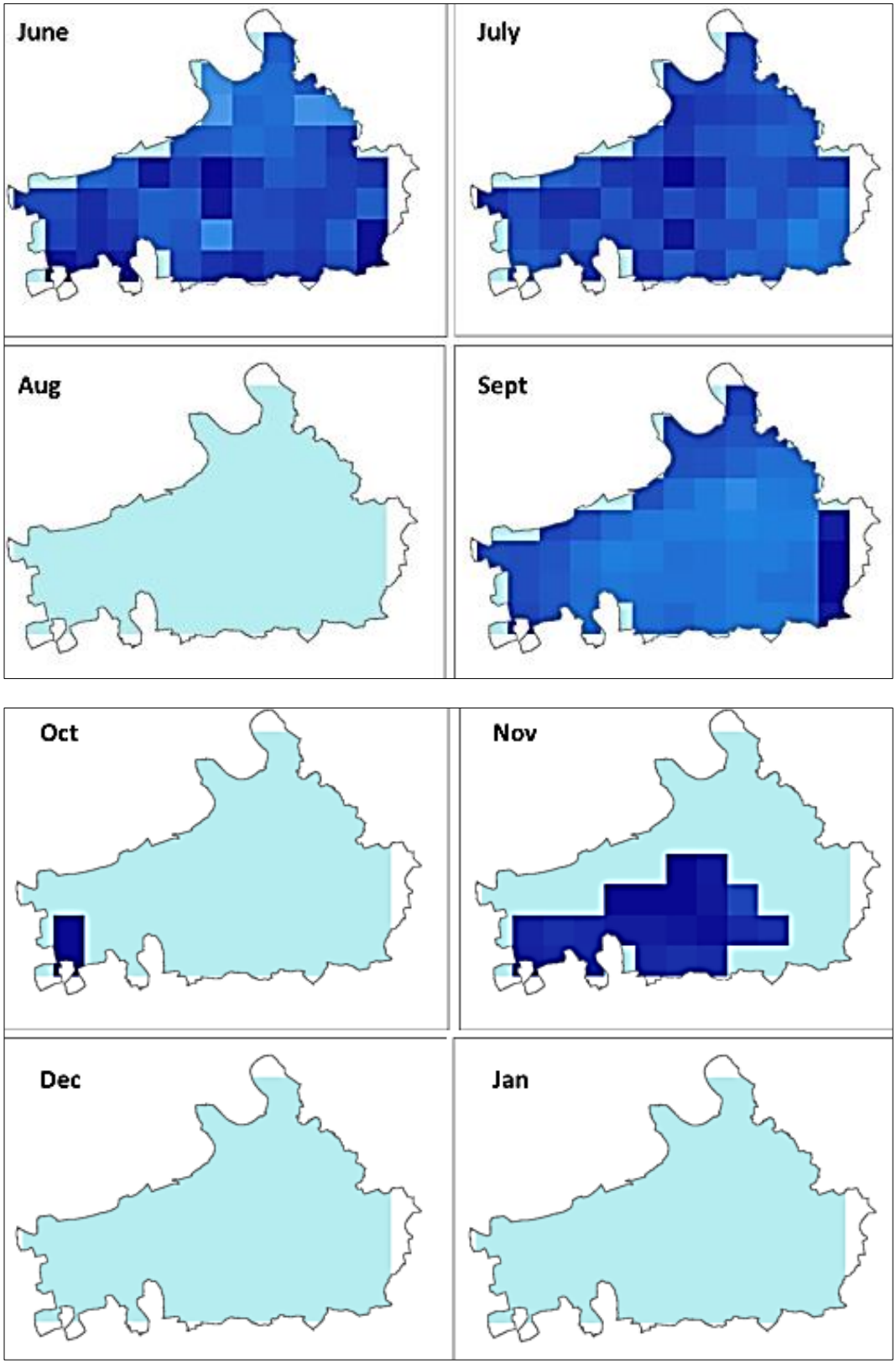


Figure 4: Monthly Soil Moisture for Study Period: June,2022-March,2023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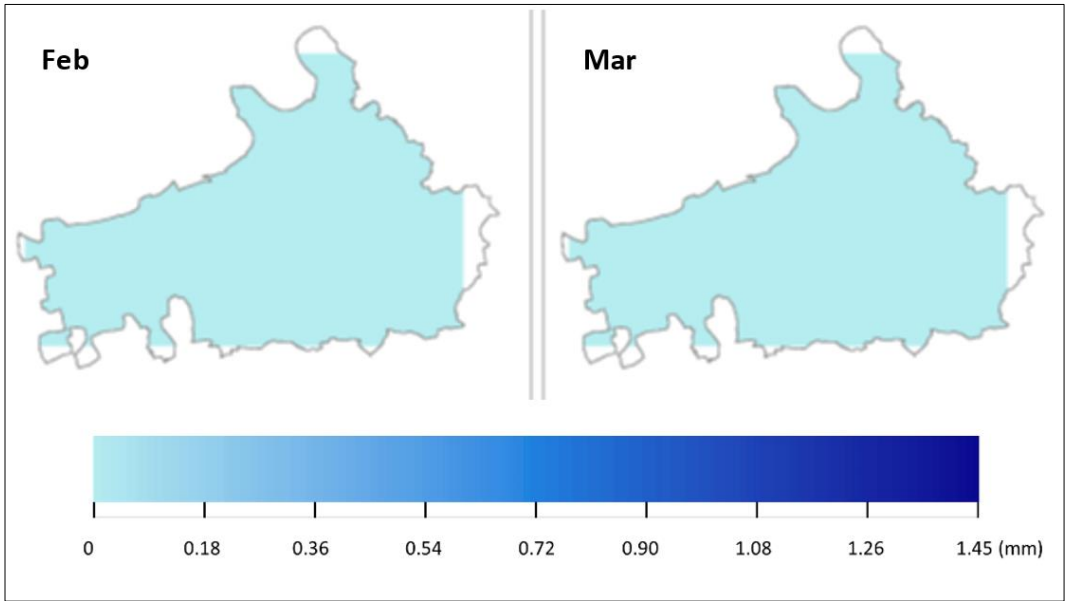
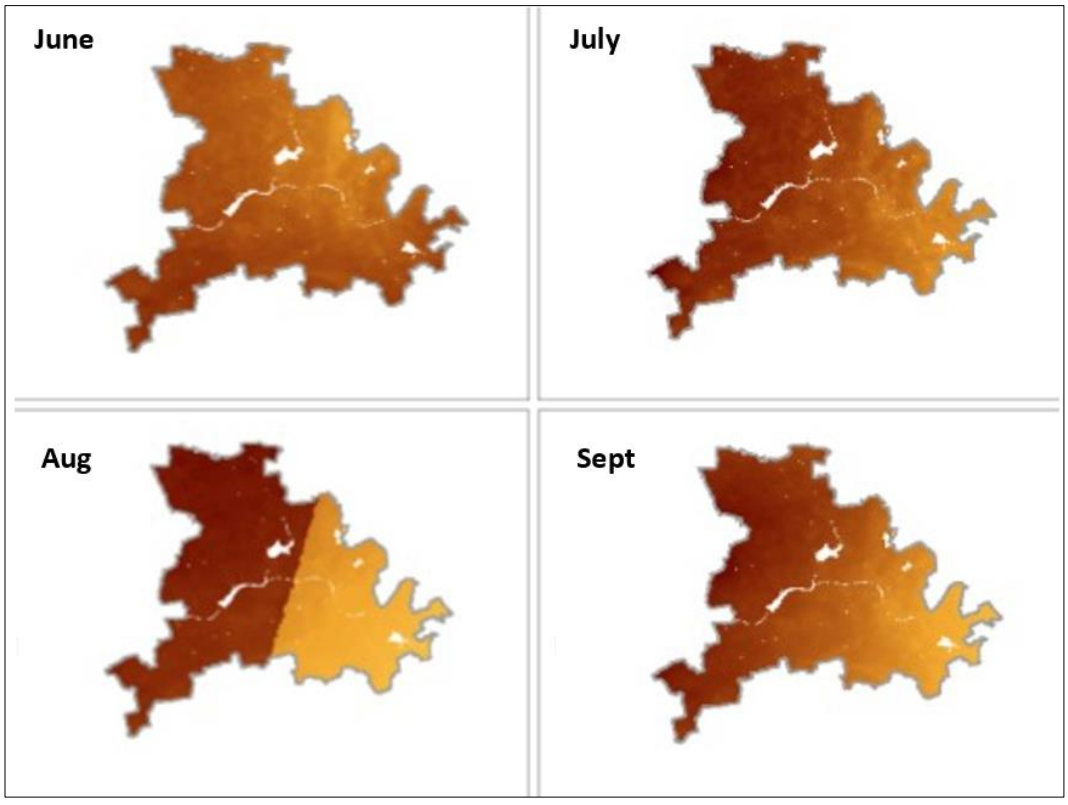
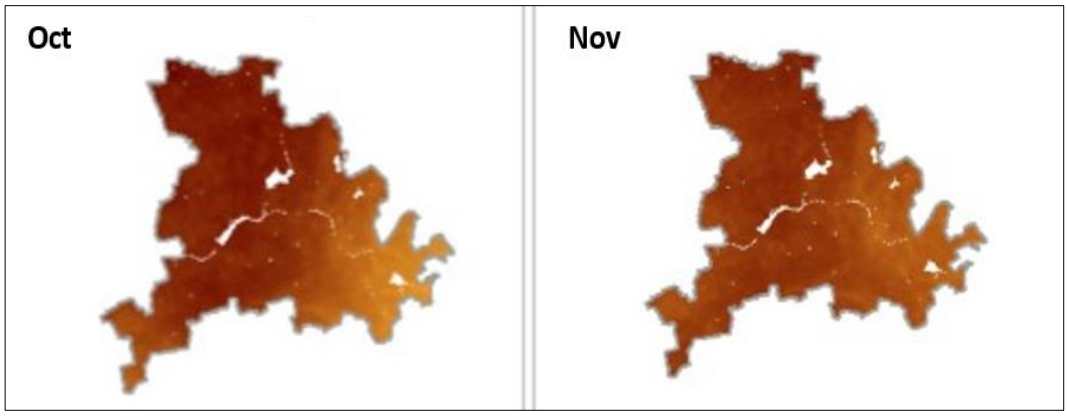


Fig 5: Monthly Rainfall(mm) for Study Period: June,2022-March,2023

Location Site 2: Rajkot [Monthly Soil Moisture and Rainfall]





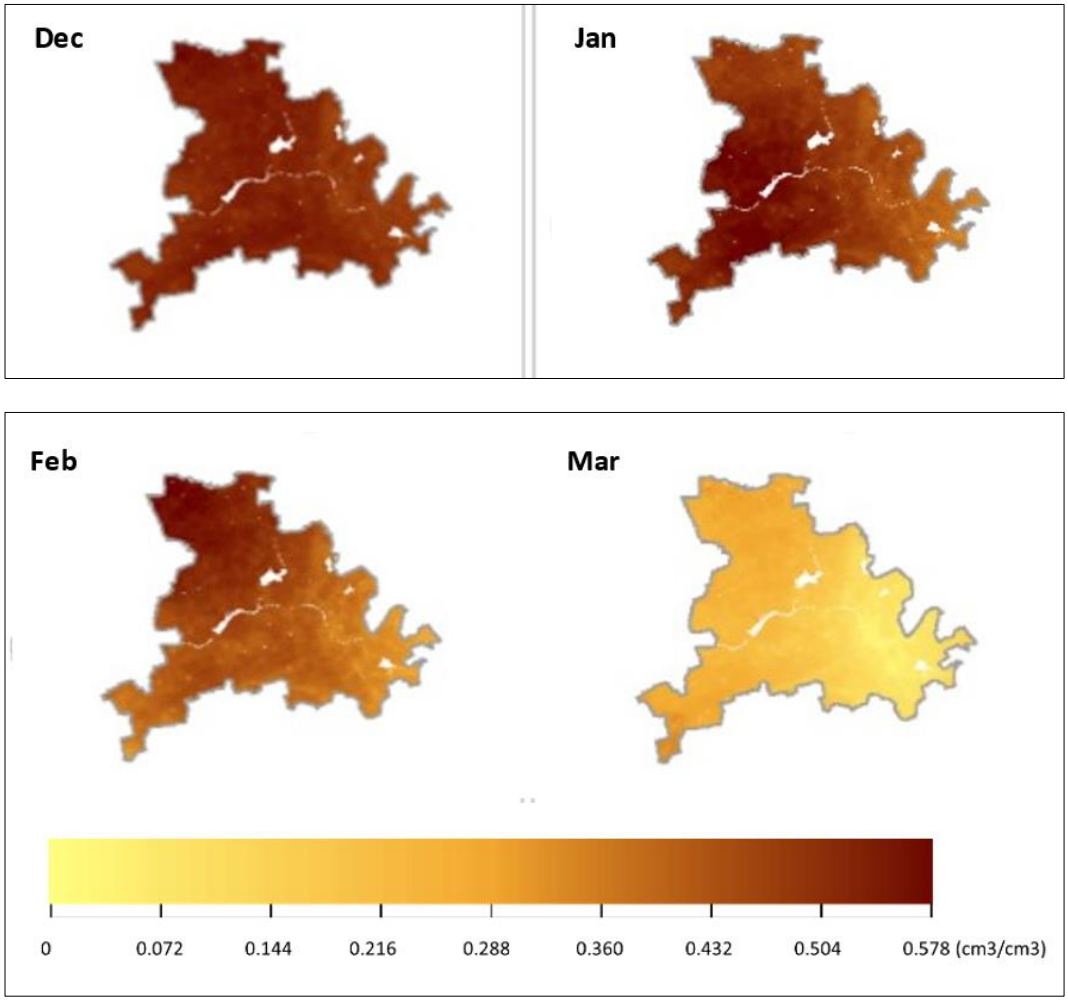
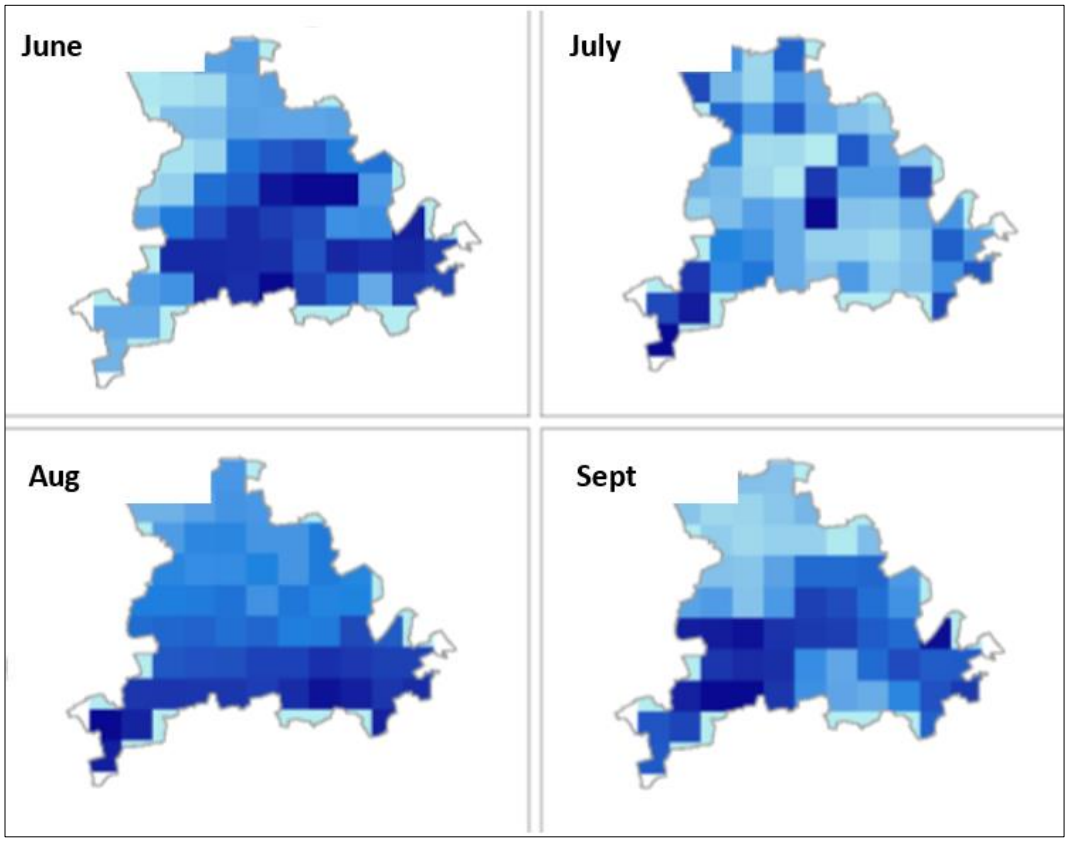


Fig 6: Monthly Soil Moisture for Study Period: June,2022-March,2023



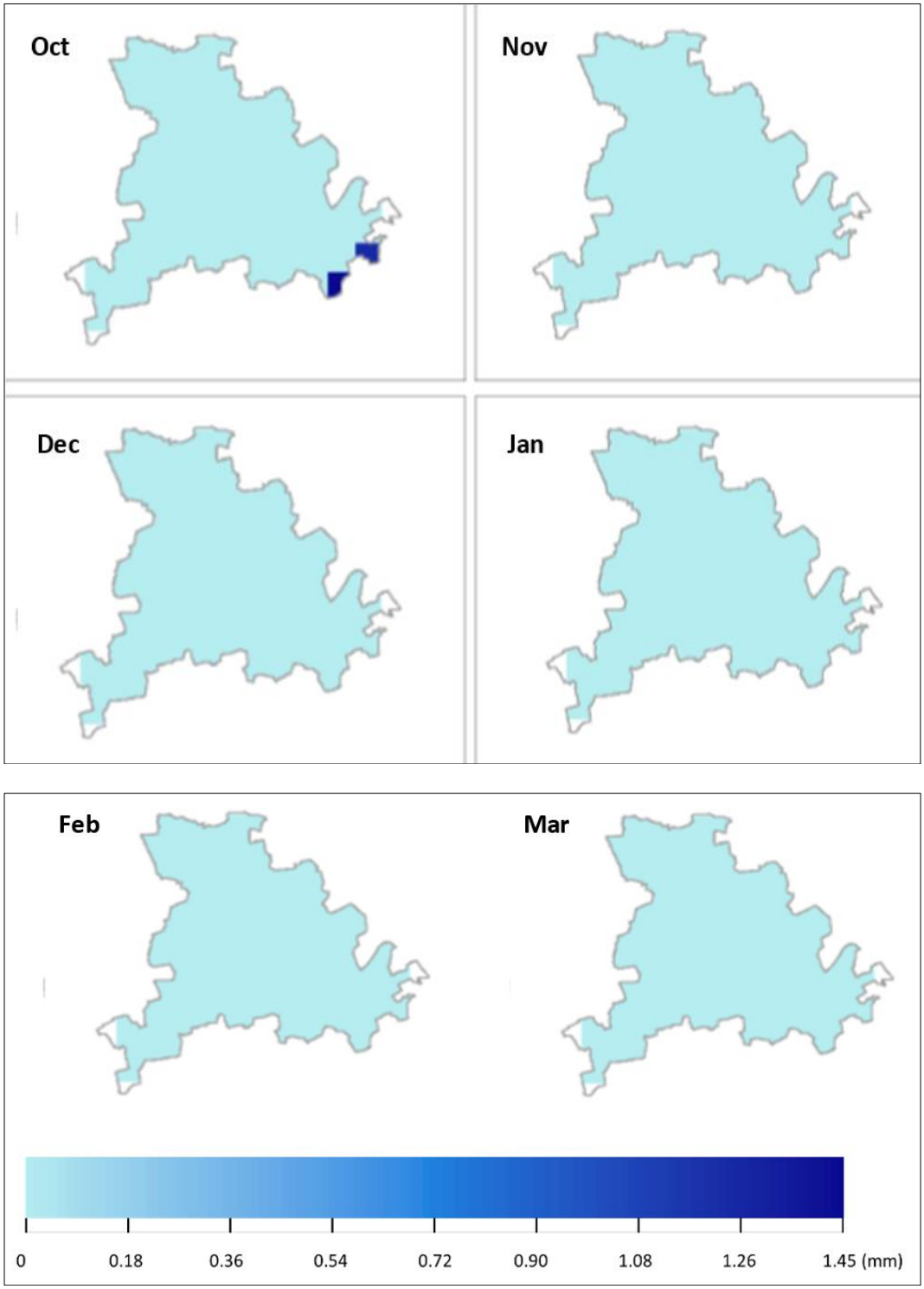


Fig 7: Monthly Rainfall(mm) for Study Period: June,2022-March,2023

Location Site 1: Bharuch [Correlation Coefficient]

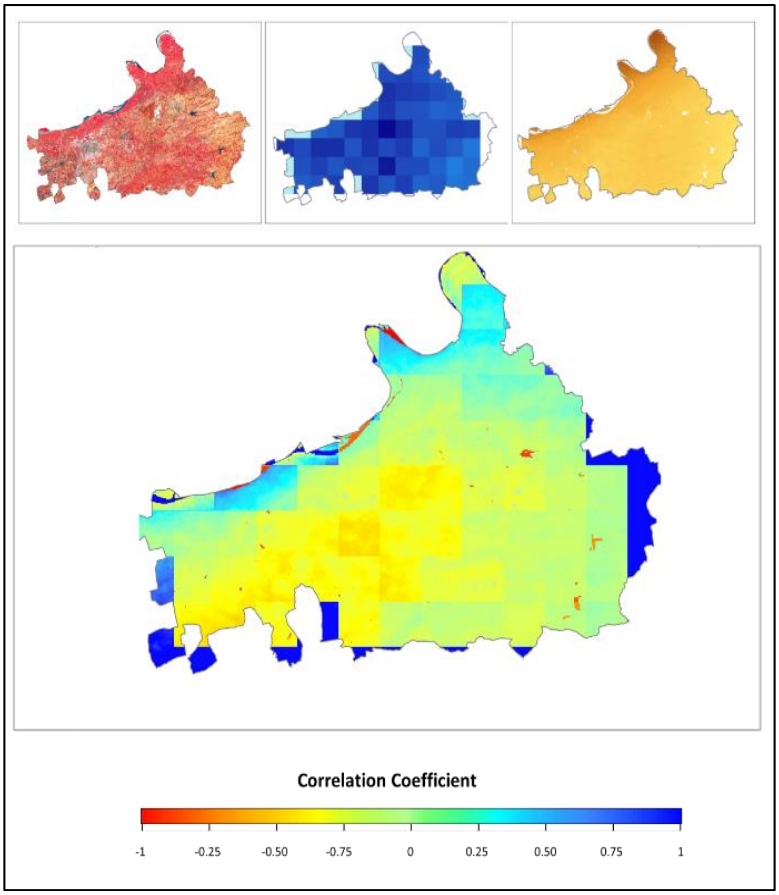


Fig 8: Correlation Coefficient (Rainfall x Soil Moisture)

Location Site 2: Rajkot [Correlation Coefficient]

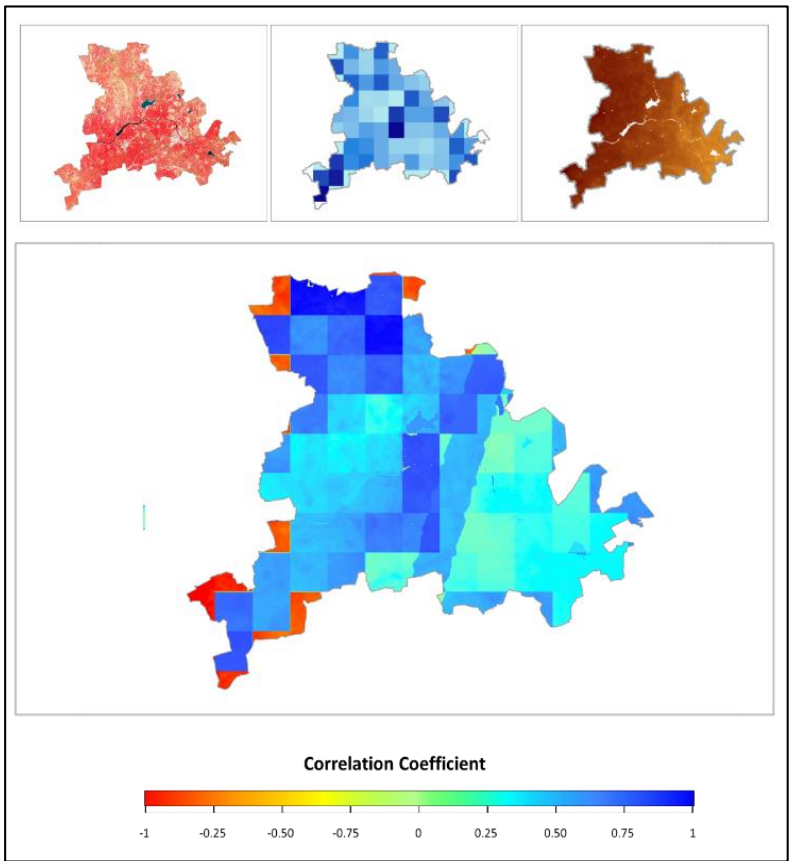


Fig 9: Correlation Coefficient (Rainfall x Soil Moisture)

Findings

1. Rainfall is not a sole dependent/deciding factor for Soil Moisture Availability. It's variability also effect by the land cover of the region and other environmental factors (climate regime and weather parameters) and hydrological parameters (evapotranspiration etc).
2. The soil texture is the prime information required to analyse the soil moisture content present. This is described by correlating rainfall figures (8 & 9) with soil moisture that indicates the equal proportions of sand and clay respond more towards soil moisture content data as compared to scenario where the preponderance either clay or sand does it to limited extent as evident in Rajkot.
3. Lastly, this study provides a platform to support validation of the remote sensing driven soil moisture data from SMAP using CHIRPS rainfall data. The rainfall data assisted in validating the SMAP data because in selected locations when rain increased moderately or to an extent then soil moisture also increased (Figure 2 & 3). The more apparent and distinct results require its availability at equal time intervals along with other related or dependent variables (mentioned above).

Conclusion

The major focus of this research is to analyse the relationship between rain and soil moisture using remote sensing driven soil moisture and modelled CHIRPS data from 1st June 2022 to March 31, 2023. For calculating the correlation coefficient and their relevance in investigating the relationship monthly max of each dataset were created for coherent results. Most grids showed a moderate correlation between soil moisture and CHIRPS rainfall data in site 1 located in Bharuch and moderate to high (positive correlation) in site 2 located in Rajkot. It could also be stated the dry regions has good correlation than humid locations.

The study key findings also revealed that relationship between the soil moisture and rainfall is deeper than what is assumed during the initiation of the study. This is somewhat explained by time-series analysis which shows soil and rain though follow a pattern, but no rain doesn't mean no soil moisture or vice versa. Further, both the parameters are not related in those regions that have major river basins that could be due to plausible hydrological cycle and physical process happens in that ecosystem.

Also, remote sensing driven soil moisture data seem to be validated in this study using CHIRPS rainfall data as it is noted that in case a little increase in rainfall lead to increase in soil moisture content. The conclusive remarks affirms that study could be make more firmly by incorporating landcover and land use information with climate regime of the selected study region.

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