# Water footprint assessment towards food sustainability for the valley region of Manipur, North East India

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**Water is a scarce resource. Thus water consumption by crops needs to be monitored to maintain future food sustainability. Water footprint (WF) is a tool to estimate water consumption by humans and the available freshwater. Assessment of WF is significant for planning and managing water scarcity and food security. Rice is a staple crop in Manipur, North East India, requiring a large amount of water for production. In this study, the WF of rice is estimated for the valley region of Manipur for three years using satellite remote sensing and meteorological datasets. The critical parameters required for assessing WF of rice are evapotranspiration, precipitation and yield. For the analysis of WF, MODIS 8 daily evapotranspiration data and the CHIRPS dataset were used for evapotranspiration and precipitation respectively. Three components of WF were analysed in order to attain the Sustainable Development Goals of the United Nations. The analysis of green and blue water footprints suggests that the green-to-blue water footprint ratio is 0.8 to 10. The area exhibits a green-to-blue ratio of less than 1, which indicates a greater utilization of irrigation water (blue water) in comparison to rainwater (green water). A value less than 1 demonstrates the need to reduce blue water use in these areas by selecting alternative food crops and increasing green water throughout the valley region to achieve the food sustainability goal.**

**Keywords:** Food sustainability, rice, satellite data, valley region, water footprint.

THE primary users of the available freshwater resources are agriculture and food production[1,2]. By 2050, the population of the world is projected to increase by 9.8 billion[3,4]. The demand for food and farmlands will increase to meet this large population[5]. Several experts have predicted that human dependence on water resources will significantly increase, posing issues for food security and environmental sustainability[6–8]. Addressing water stress has been given priority by the sustainable development goals (SDGs) of the United Nations due to its strong interdependence with other SDGs[9–11]. Water stress is predicted to be one of the top worldwide concerns over the next 10 years[12,13]. A key priority is the development of indices that show freshwater resources per unit quantity of agricultural production from a specific management system[14]. The concept of water footprint (WF) denotes the volume of water required at a local or global scale to facilitate the production of a commodity or provision of a service[15]. WF can measure the environmental sustainability of water consumption for any product.WF assessment explains how activities and goods are related to water scarcity and pollution, and offers a fresh approach to managing water resources[16]. WF of crops will assist in examining how climate, soil and agricultural conditions relate to food and water supply[17]. The green, blue, and grey WFs are the three components that give an in-depth understanding of how much water is used in crop production. The amount of rainwater consumed is indicated by green WF. Irrigation water is employed in crop production through the blue WF. The quantity of freshwater required to remove the same volume of contaminants is referred to as the grey WF. Recently, methods for estimating WF using remote sensing data have been proposed. Measurement of the green and blue WFs in areas with sparse ground data can be complemented by the high temporal and spatial coverage of satellite missions. Romaguera *et al.*[18] proposed a method to estimate the green and blue WTs of crops using remote sensing data on a global scale. However, this method has the least number of applications due to limitations in the availability of data[19]. Velpuri and Senay[20] provided insights on the relative contributions and the spatio-temporal dynamics of green and blue water evapotranspiration, which could lead to improved water resources management. Madugundu *et al.*[21] compared the remote sensing and agrometeorological methods of WF for silage maize and carrot crops. Anna *et al.*[1] estimated the annual blue and green water fluxes of various land use land cover (LULC) classes employing a set of seven global remote sensing-based evapotranspiration products and four alternative methodologies. Naresh *et al.*[14] assessed the WF of rice production and consumption in subtropical India using remote sensing. They also discussed the potential of using remote sensing techniques for water management studies. Swadhina and Jeganathan[22] estimated WF using MODIS evapotranspiration data and CHIRPS rainfall data.

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Rice is one of the major consumers of freshwater, requiring more water than other cereal crops[23,24]. Significant irrigation projects are frequently proposed to accommodate the water demand for rice production[25]. The challenges of sustainable rice farming are due to shifting global climate patterns, decreased per-person availability of surface and groundwater resources and competition for the limited water resources from other industries. For the vast majority of people, especially those from Asia, rice is the staple crop. Furthermore, in Asian countries, flood-irrigated rice uses more than 45% of the total freshwater[26]. By 2025, it is predicted that approximately 17 to 22 million acres of Asia's irrigated rice land will encounter water scarcity[27,28]. The success of rice production in Asia will determine the future stability of the World's food supply[28]. India is the largest exporter of rice worldwide. The country produces 20% of the world's total rice production in a 44 m ha area[29]. To meet the demands of its expanding population, India is predicted to produce 130 Mt of rice by 2030 (refs 30, 31). Rice is grown in various agro-ecological zones of the country. It is primarily cultivated during the wet season when rainfall distribution is variable.

Around 90% of the grossed crop area (GCA) in Manipur, North East India, is covered by rice[32]. The arrival of the southwest monsoon primarily marks the beginning of paddy cultivation. Despite having an ideal agro-climate, rice farming in Manipur has not been satisfactory[33]. The demand for paddy crops has grown significantly over time and is now much higher than the supply in the state. The decrease in cultivable land and water supply impacts paddy output. Careful management of water resources is necessary to meet the rising demand for agricultural water for sustainable development with a growing population. WF will be less if rice production is increased while using less water. This study assesses the WF in rice for food sustainability using remote sensing and meteorological data.

## Materials and methodology

### *Study area*

Manipur in NE India comprises hill and valley regions. The valley region is divided into four districts: Imphal East, Imphal West, Bishnupur and Thoubal. The valley area is located between 24°13′ and 25°06′N lat. and 93°41′ and 94°08′E long., with a total area of 1909.867 sq. km. The temperature ranges from 5.43°C to 33.3°C. The annual rainfall of the area is 1469.79 mm. The study area has been separated into four LULC classes: agricultural area, water body, settlement area and vegetation. Among these, the agricultural area occupied the maximum space. In valley districts, rice is one of the crops that are most commonly planted and has an average yield of 3.5 tonnes/ha (ref. 34). There are lakes, small rivers and streams in the valley area that flow into Loktak Lake, the biggest freshwater lake in NE India. It provides water for cultivation, hydropower production and drinking purposes. Figure 1 shows the location map of the valley region of Manipur.

### *Data acquisition and methodology*

For the assessment of spatial WF, crop evapotranspiration (ET) and effective rainfall were derived from remote sensing data and crop-related data from the Department of Agriculture, Manipur. The non-agricultural regions of the study area were masked out from the LULC generated using Landsat-8 image. This study was conducted for the 2018–20 growing season (June to September). For estimating the component of WF, the volumetric technique proposed by the water footprint network (WFN 2019) and ISO 14046 (ISO 14046 2017) was used.

*Rainfall:* Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) daily data at 0.05° spatial resolution was used to estimate adequate rainfall in this study. CHIRPS data were downscaled to 500 m. The downscaled data were validated using four station data from the Directorate of Environment and Climate Change, Manipur. When compared to other satellite rainfall products like Tropical Rainfall Measuring Mission (TRMM), Climate Prediction Center Morphing Technique (CMORPH) and Global Satellite Mapping of Precipitation (GsMaP), the CHIRPS rainfall data perform reasonably well at both regional and global levels[35,36].

*Effective rainfall:* The effective rainfall ($P_{\text{eff}}$) is the proportion of precipitation that can be stored in the root zone of

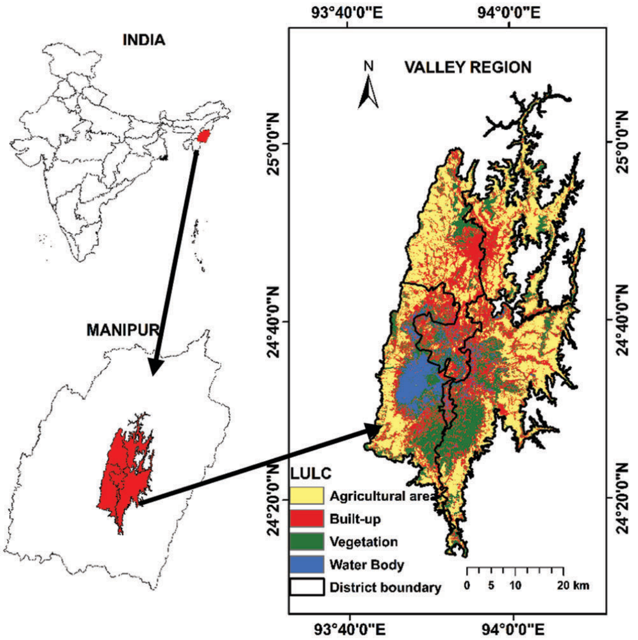

**Figure 1.** Location map of the study area with land use land cover map.

the crop. It is determined using the USDA SCS method[37], and can be expressed as

$$P_{\text{eff}} = P_{\text{total}}\,(125 - 0.2P_{\text{total}})/125;\ \text{for } P_{\text{total}} < 250\ \text{mm}, \quad (1)$$

$$P_{\text{eff}} = 125 + 0.1P_{\text{total}},\ P_{\text{total}} > 250\ \text{mm}, \quad (2)$$

where $P_{\text{total}}$ is the total precipitation (mm).

*Evapotranspiration:* MODIS Global Terrestrial Evapotranspiration Algorithm (MOD16) has been an operational ET product for the vegetated land of the world regions since 2000 (ref. 38). The Penman–Monteith equation and energy partitioning equation provide the framework of estimation of ET in MOD16 (ref. 39). The MOD16 package contains datasets for actual evapotranspiration (AET), potential evapotranspiration (PET), latent heat flux (LE) and potential latent heat flux (PLE) for eight-day, monthly and annual periods. From the USGS Earth Explorer, MOD16 with 500 m spatial resolution was downloaded. All pixels in the photographs were multiplied by 0.1 to rescale them from 0.1 mm eight-day or 0.1 mm month to the correct units (mm eight-day or mm month)[40]. Due to the lack of ground data, validation of MOD16 was done using AET estimated from Penman–Monteith reference ET and crop coefficient.

Green evapotranspiration ($ET_{\text{green}}$) and blue evapotranspiration ($ET_{\text{blue}}$) are WF components. These are estimated using separate formulas. Green evapotranspiration is the difference between adequate rainfall and crop evapotranspiration over the crop period.

$$ET_{\text{green}} = \min\,(ET, P_{\text{eff}}). \quad (3)$$

The crop evapotranspiration from irrigation demand is represented by $ET_{\text{blue}}$. When the irrigation water needs of the crop are completely satisfied and considered zero, it is presumed that its $ET$ requirements are satisfied by adequate rainfall.

$$ET_{\text{blue}} = \max\,(0, ET - P_{\text{eff}}). \quad (4)$$

*Water footprint assessment:* WF has three components, viz. blue, green and grey. The blue WF shows irrigated agriculture, while the green WF rainfed conditions[41] and the grey WF is the amount of groundwater contaminated by fertilization. The total WF of crops is the sum of green, blue and grey WFs.

The green and blue WFs are represented by the following equations

$$WF_{\text{green}} = 10 \times \frac{ET_{\text{green}}}{Y}, \quad (5)$$

$$WF_{\text{blue}} = 10 \times \frac{ET_{\text{blue}}}{Y}, \quad (6)$$

where $Y$ is the crop yield (kg/ha).

The grey WF ($WF_{\text{grey}}$) was computed by multiplying the chemical application rate by the leaching run-off fraction and dividing the result by the minimum allowable concentration minus the concentration in naturally occurring water. There is not enough information to assess the use of other fertilizers and pesticides; only nitrogen contamination is considered. According to the Department of Agriculture, Manipur nitrogen fertilizer application rate in the state was 25 kg/ha. The leaching factor was assumed to be 0.1 (ref. 42). The concentration in natural water, $C_{\text{nat}}$ was assumed to be 0 mg/l and the maximum acceptable concentration ($C_{\max}$, 10 mg/l)[43].

$$WF_{\text{grey}} = \left(\frac{\alpha \times AR}{C_{\max} - C_{\text{nat}}}\right) \times \frac{1}{Y}, \quad (7)$$

where $AR$ is the rate of chemical application (kg/ha) and $\alpha$ is the leaching run-off fraction.

## Results and discussion

### Validation of remote sensing data

Even though satellite retrieval methods are subject to systematic biases and inaccuracies, they can be used to detect vast areas with exceptional temporal and geographic accuracy. As a result, before using satellite-based data, the level of uncertainty must be assessed by comparison to ground-based data. The accuracy was assessed using performance metrics like $R^2$ of Pearson's correlation coefficient, root mean square error (RMSE) and mean absolute error (MAE). The monthly rainfall data from CHIRPS and station data were in good agreement. The statistical parameters $R^2$, RMSE and MAE were 0.85, 2.15 and 0.77 respectively. The MOD16 ET was compared with the results obtained from AET. $R^2$, RSME and MSE were 0.82, 3.95 and 1.23 respectively.

### Water footprint assessment for food sustainability

The volume of water used in an agricultural product varies significantly depending on the geographical location, type of crop, seasonal variation, management practice, etc. In recent years, WF assessments have depicted it as a sustainability evaluation system. Combining WF analysis with sustainability analysis techniques will improve the evaluation of WF used in order to boost the performance of policies on water utilization[44]. The UN SDG 6.4 has issued an order to alleviate water shortage and reduce the number of people affected by water scarcity. Water-use efficiency across all sectors must be significantly increased by 2030. To achieve this SDG, three criteria have been proposed for the WF component[2].

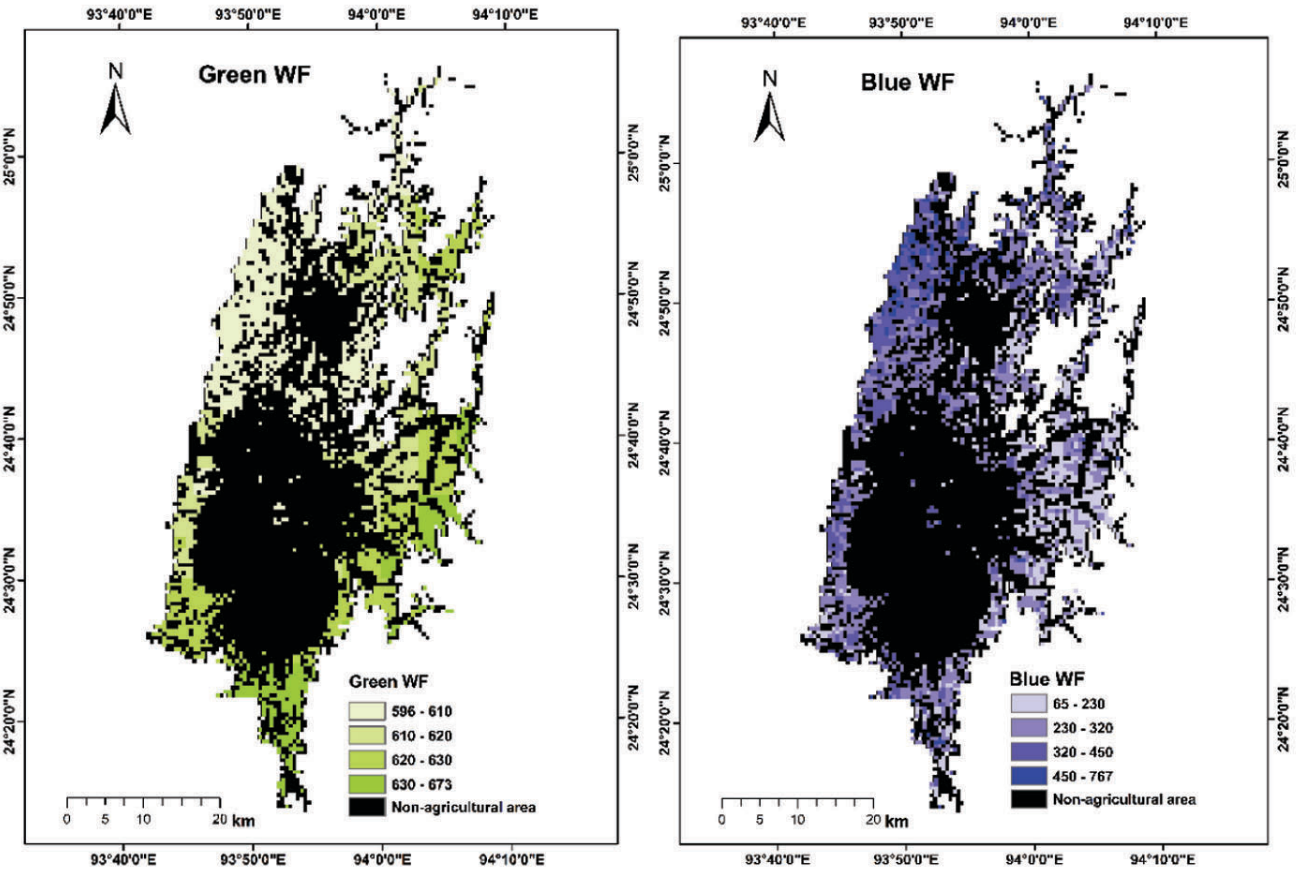

**Figure 2.** Spatial map representing green and blue water footprints (WFs).

*Green and blue water footprints:* The green WF was derived using remote sensing data and ground data. It ranged from 596 to 673 $m^3$/tonne (Figure 2). The green WF has not negatively influenced the environment and socio-economic of the country[45]. It is safe to say that green water can improve future rice production and minimize WF. The blue WF varied from 65 to 786 $m^3$/tonne. The variance in the blue WF indicates how much irrigation water is utilized in different parts of the study area. The blue WF is the most significant in terms of decision-making since it has an immediate impact on society[3]. A global rise in relative ET from irrigation with blue water resources has dramatically impacted the overall water balance of the study region[46]. Implementing on-site rainwater collection and soil conservation techniques for preserving moisture and promoting crops which utilize green water more efficiently can help save blue water resources[47].

*Ratio of green to blue water footprints:* The green-to-blue WF ratio (Figure 3) was generated using green and blue WFs. It ranged from 0.8 to 10. A higher ratio indicates more use of green water in rice production, while a value of less than one indicates the use of more irrigation water than rainwater. The green-to-blue WF ratio has been classified into four categories for this study area. The first category, WF ratio (0.8–2), represents the area that uses more irrigation water to produce rice. This area needs to change rice cultivation to an alternative food crop. The WF ratio of the second and third categories ranges from 2 to 3 and 3 to 5 respectively, reading proper water management and the selection of a variety that requires less water for production. The area under the last category (WF ratio 5–10) has to continue the practice with better management to improve production towards food sustainability.

*Grey water footprint:* The grey WF may help track development towards Target 6.3 (By the year 2030, it is imperative to enhance the quality of water globally through a significant reduction in pollution levels, the elimination of dumping activities, and the minimization of hazardous chemicals and materials.). In agriculture, water is contaminated by pesticides and chemical fertilizers. Three-quarters of the world's nitrogen-related grey WF is produced by crop agriculture[48]. Since nitrogen ions can easily penetrate water bodies and nitrogen fertilizer has the highest pure volume, it is the principal contaminant of water[49]. Equation (7) was used to determine the grey WF, which was 71.82 $m^3$/tonne for a nitrogen application rate of 25 kg/ha and 3.5 tonne/ha of

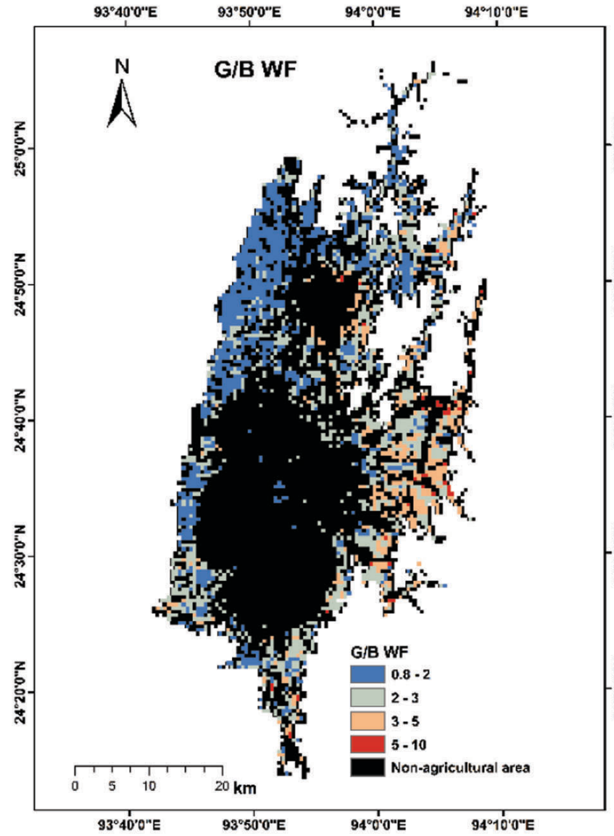

**Figure 3.** Spatial map representing green-to-blue WF ratio.

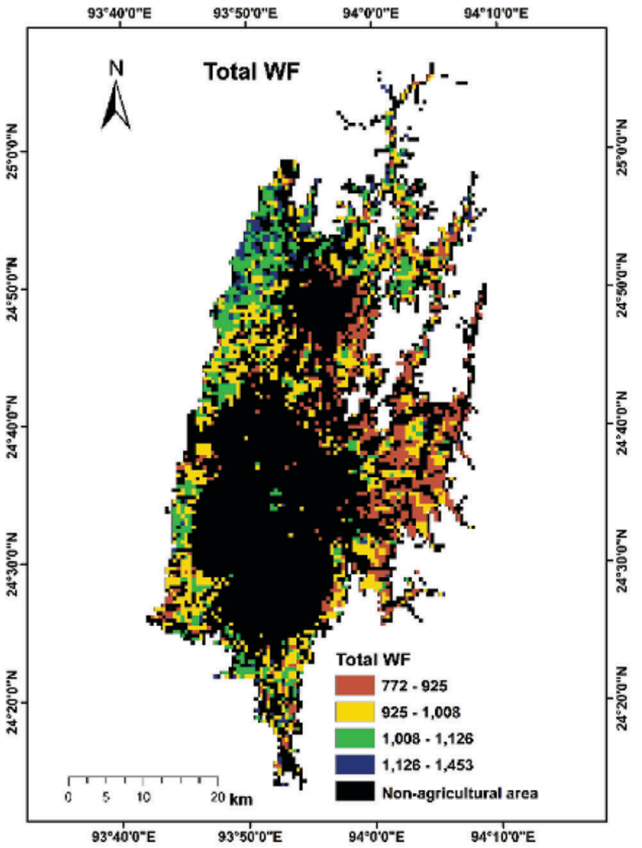

**Figure 4.** Average WF of agricultural area for the valley region of Manipur, North East India.

yield. Chukalla *et al.*[50] estimated the grey WF as 95 $m^3$/tonne by reducing the nitrogen application rate to 50 kg/ha with a 3.7 tonne/ha yield.

*Total water footprint:* WF of the crop is indicated in terms of the volume of water used per yield. It is the sum of the green, blue and grey WFs. The results of the estimation of WF of rice for the valley region of Manipur demonstrate that the WF varies between 772 and 1453 $m^3$/tonne (Figure 4). The WF values were classified into four classes through natural breaks. The low class ranged from 772 to 925 $m^3$/tonne and covered 28% of the agricultural area. The medium class (925–1008 $m^3$/tonne) covered 42% of the total agricultural area, the maximum area among the four classes. The high class (1008–1126 $m^3$/tonne) and very high class (1126–1453 $m^3$/tonne) covered 24% and 6% of the total agricultural area respectively. When the WF values from this study were compared to those by Chapagain and Hoekstra[25], the WF of the present study area was smaller than the national WF. The average WF of rice in Punjab was estimated as 1097 $m^3$/tonne by Durba and Tripti[51]. Due to higher rice productivity in Manipur relative to the national average of 2.7 tonne/ha, as well as the higher rice output over time, WF has decreased. The amount of irrigation used and variation in rainfall are causes of the spatial variation of WF[52]. Vaibhav and Bharat[53] reported that 85–90% of a person's WF comes from indirect consumption in the form of crops and livestock.

## Conclusion

WF of rice was quantified for the valley region of Manipur using remote sensing data and ground data. The blue WF showed significant spatial variation, while the green WF was consistent throughout the valley region. The aim of the SDGs of UN is to maximize the green WF and minimize the blue WF. To reduce the blue WFs in an area with high use of blue water, suitable alternative food crops have been suggested. The green-to-blue WF ratio can be improved by adequately managing water in rice production and encouraging more rainwater use. The application of fertilizers and pesticides should be kept at a minimum to reduce the grey WF. The total WF of the study area was less than the national average, except for some regions having values slightly more than the average. The parameters may significantly influence the spatial variation of WF, and even slight changes can give a difference in the results. Also, cloud coverage during the monsoon season has constraints in acquiring high spatial and temporal remote sensing data.

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