

# Climate Smart Agriculture, need for 21st century to achieve socio-economic and climate resilience agriculture in India: A geospatial perspective

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**Abstract.** Climate change is now widely recognized as the major environmental threat occurring mainly due to increasing greenhouse gases in the atmosphere and causing the extinction of biodiversity and enhances disruptions to ecosystems. Climate change risks are found to be very significant and would have a profound impact on the livelihoods of millions of poor people in India. In the present study, we have analyzed datasets of agriculture Greenhouse gases (GHGs) emission (1990-2016), poverty, anthropogenic biomes, agriculture crop production scenario (2008-2017), seasonal soil moisture status present (2006-2015) and deficit (compared with 20 years' time periods), present (1970-2000) annual mean, future (2050) precipitation and temperature scenario of India and investigated the spatial pattern and relationship incorporating in remote sensing and GIS for the better comprehension of the impact of climate changes on the socio-economic dimension of the people. The total GHGs emissions (CO<sub>2</sub> equivalent) from agriculture in India were showing the increasing trend (approximately 1% annually) whereas the increasing trend has decreased notably in the last five years. The states of Bihar, Uttar Pradesh, West Bengal, Assam, Punjab, and Tamil Nadu and Andhra Pradesh of India were found producing higher GHGs emissions from agriculture. The present soil moisture and the deficit during the *Kharif*, *Rabi*, and *Zaid* seasons vary geographically whereas soil moisture deficit during the *Kharif* season was found very significant over most of the districts of Ganga and Brahmaputra basin. The present mean annual temperature and precipitation patterns were found very significant in arid and semi-arid regions which are known as the farmer's suicide hotspot and are predicted to threaten more in the future (2050). The evaluation highlights the need for synergic approaches such as climate-smart agriculture (CSA) to address the impact of climate change in food production and farmers' livelihood. Such an investigation gives a solid understanding of a paradigm shift in the adaptation of CSA an approach in prevailing new climate change reality at country or regional levels for achieving socio-economic and climate resilience agriculture in India.

**Key words:** climate, greenhouse gas, India, Remote Sensing, socio-economic, soil moisture.

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## 1. Introduction

Climate-smart agriculture (CSA) is an approach for transforming and reorienting agricultural development under the

new realities of climate-induced risk (Lipper et al., 2014). Food and Agricultural Organization (FAO) was first floated the word Climate-Smart Agriculture (CSA) in 2010 to address the challenge of food security and demand, liveli-

hood and the climate change impact with insights in technical, institutional, policy and financial responses which will meaningfully transform agriculture in developing countries (FAO, 2010). The World Bank (2018) has defined CSA as an integrated approach to managing landscapes/cropland to achieve the three important goals:

1. Enhancing productivity in terms of food to boost the income of poor people and to provide nutrition and livelihood security especially in rural fringe mainly depends on agriculture.
2. Increasing resilience for reducing risk to drought, pests and diseases, and building capacity to transform in the face of longer-term stresses.
3. Minimizing GHGs emissions in food production and with an aim to avoid deforestation and identify the mechanism to reduce carbon from the atmosphere.

The CSA is extremely important around the globe, especially in developing countries, including India. The majority of farmers in India are from weak socio-economic backgrounds and suffering from difficulties due to increasing cost of cultivation (chemicals, seeds and equipment) (Sadashiv, 2015). This has been increasing several folds because of climate-induced risk in agriculture (Goparaju & Ahmad, 2019) i.e., the increase in temperatures (Sharma, 2018), abrupt rainfall patterns (World Bank, 2013), floods (Josh, 2018), frequent droughts (Tyalagadi et al., 2015), water deficiency (Pangaluru et al., 2019) which in the majority of the case leads to crop failure. Furthermore, cropland in India is suffering because of fertility depletion (Aggarwal, 2018), erosion (Oldeman et al., 1991), and water stress (Shiao et al., 2015). In recent studies based on long term NDVI, it was observed most of the vegetation (agriculture and the forest) in India is losing its greenness (Chakraborty et al., 2018; Ahmad et al., 2019a) which manifest their degradation.

India has signed the Paris Agreement in November 2016 with the basic aim to reduce the GHGs emission whereas agriculture is the second-largest contributor to GHGs emission after the energy sector (Patra & Babu, 2017). The future climate-induced risks to farmers in India will be more severe (Goparaju & Ahmad, 2019). Such challenges need concrete synergic strategies from local to national levels. Climate-Smart Agriculture has the potentiality to overcome such challenges (Lipper et al., 2014) and can be stretched from village to country-level if it is adequately supported by grants, technical knowledge, and well-defined guideline (Goparaju & Ahmad, 2019).

The aim of the study was to evaluate the importance of CSA using socio-economic and climatic datasets, and examine spatial pattern or relationship in GIS for the better comprehension of the impact of climate change and the socio-economic dimension of the people. Such an investigation gives a solid understanding of a paradigm shift in the adaptation of CSA an approach in the prevailing new

climate changes the reality for achieving socio-economic and Climate resilience agriculture in India.

## 2. Methodology

In the present study, we have used several datasets (Table 1) such as GHGs emission from agriculture (FAO, 2019), the percentage of people living Below Poverty Line (BPL) (Lewis, 2013), anthropogenic biomes of India as transformed by sustained human population density and land use (Ellis et al., 2013), major agriculture crop production (2008-2017) (FAO, 2019), Terra Climate a high spatial resolution (4-km) monthly global dataset of soil moisture (Abatzoglou et al., 2018), present and future climate data (Fick & Hijmans, 2017), ancillary datasets and literature for the better understanding of GHG emission, socioeconomic condition, anthropogenic biomes, seasonal (Kharif, Rabi, and Zaid) soil moisture distribution pattern and the deficit, major agriculture crop production scenario, present, and future impact of climate change. The procedures we have followed are rectification, digitization to bring the percentage of people living Below Poverty Line and anthropogenic biomes map of India into the GIS domain (Ahmad & Goparaju, 2017). The monthly soil moisture data were arranged systematically (Zhao & Siebert, 2015) for generating (decadal monthly average) their pattern (district wise) for three seasons of India. Furthermore, we have generated season-wise soil moisture deficit by comparing it with the past decadal monthly average (1976-1985). The present (1971-2000) climate data such as annual mean temperature (BIO1) and annual mean precipitation (BIO12) were

Table 1. Various datasets and their sources used in this study

Data used	Source/References
GHG emission from agriculture	FAO (2019)
Percentage of people living Below Poverty Line (BPL)	Lewis (2013)
Anthropogenic biomes of India as transformed by sustained human population density and land use	Ellis et al. (2013)
Major agriculture crop production (2008-2017)	FAO (2019)
Terra Climate a high resolution global dataset of monthly soil moisture	Abatzoglou et al. (2018)
Present and future climate data	Fick and Hijmans (2017)

analyzed to investigate the future district wise trends in the states of India (2050). The Erdas Imagine and Arc GIS software were adequately utilized whenever and wherever it required for achieving the aims and objectives of the study.

### 3. Results

#### 3.1. Greenhouse gases (GHGs) emission from agriculture

Analysing data revealed that total GHGs emissions from agriculture in India have been increasing annually at a rate of approximately 1%, however, since 2011, the GHGs emission has been in a stable condition (Fig. 1). The state of Bihar, Uttar Pradesh, West Bengal, Assam, Haryana, and Punjab were the main contributors to GHGs emissions. Among the different sectors of agriculture, GHGs emission from enteric fermentation was highest between the periods of 1990-2016, followed by rice cultivation, synthetic fertilizers, manure left on pasture, manure management, crop residues, and burning-crop residues.

#### 3.2 Anthropogenic biomes and major agriculture crop production scenario

By 2000, the majority of land use land cover had been transformed into rangelands, croplands, villages leaving significant low of the terrestrial biosphere virgin and semi-natural (Fig. 2) The rice villages were found significantly higher in the state of Bihar, Uttar Pradesh, West Bengal, Assam, Punjab, and Tamil Nadu and Andhra Pradesh whereas irrigated villages were significantly higher in Haryana (Fig. 2). Most of these states and their districts were the major sources of GHGs emission between the study periods. Evaluating the major agriculture crop production in India between the periods 2008 and 2017, it has been revealed that the annual mean production of rice, wheat, maize, pulses, sunflower seeds, sugar cane, and potato were 154.85, 88.85, 22.78, 0.88, 0.54, 333.91 and 42.12 million tons respectively (Fig. 3).

#### 3.3. Socio economic scenario

The socio-economic status of the states in India is shown in Figure 4. It has been revealed that 26.7% of the total districts of India have 0-10% populations living in

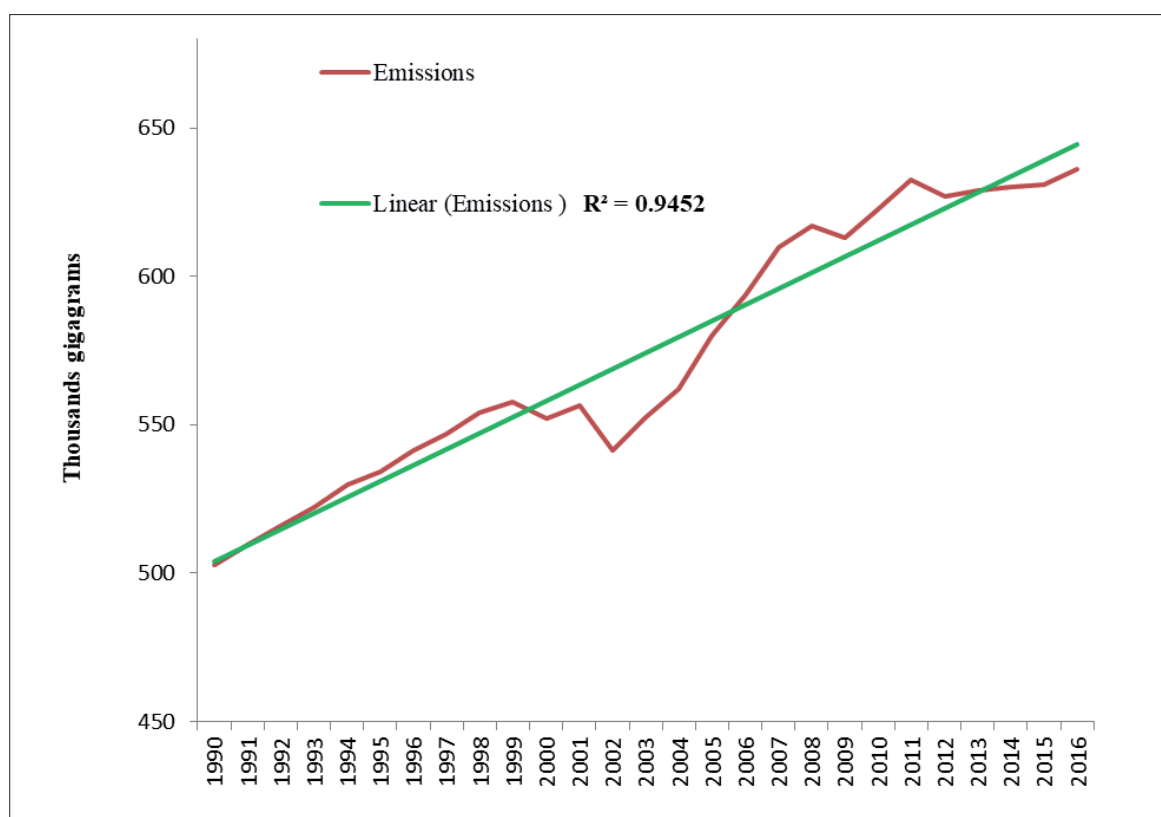


Figure 1. Total emissions of GHGs from agriculture (CO<sub>2</sub> equivalent) between 1990 and 2016 in India (FAO, 2019)

poverty lines, 18.8 % districts have 11-20% populations living below poverty lines, 18.8 % of districts have 21-30% populations living below poverty lines, 16.7 % of districts have 31-40% populations living below poverty lines and 19% of the districts have 41-80% populations living below poverty lines. The significantly high poverty percent are dominant in the majority of states such as Odisha, Chhattisgarh, Bihar and Madhya Pradesh.

**3.4. Soil moisture scenario during major cropping season**

The investigation of long-term district wise soil moisture present (2006-2015) and deficit (comparing it with 20 years back decadal (1976-1985) data) during the *Kharif* (Fig. 5), *Rabi* (Fig. 6) and *Zaid* season (Fig. 7) highlights

the interesting trend. During the *Kharif* season, soil moisture was found considerably high in coastal districts of the Western Ghats, North-Eastern districts and North-Eastern districts of Central India. Low soil moisture was found in the majority of arid and semi-arid area's districts. Soil moisture deficit during the *Kharif* season was found very significant over most of the districts of Ganga and Brahmaputra basin.

The district-wise soil moisture pattern during *Rabi* season was found very similar to the pattern of the *Kharif* season except in few districts of Tamil Nadu and Andhra Pradesh where the soil moisture appreciably improved while comparing it with the *Kharif* season. Soil moisture deficit was found more pronounced during *Rabi* season while comparing it with the *Kharif* season and further overtaken some more districts of the southeastern part and all

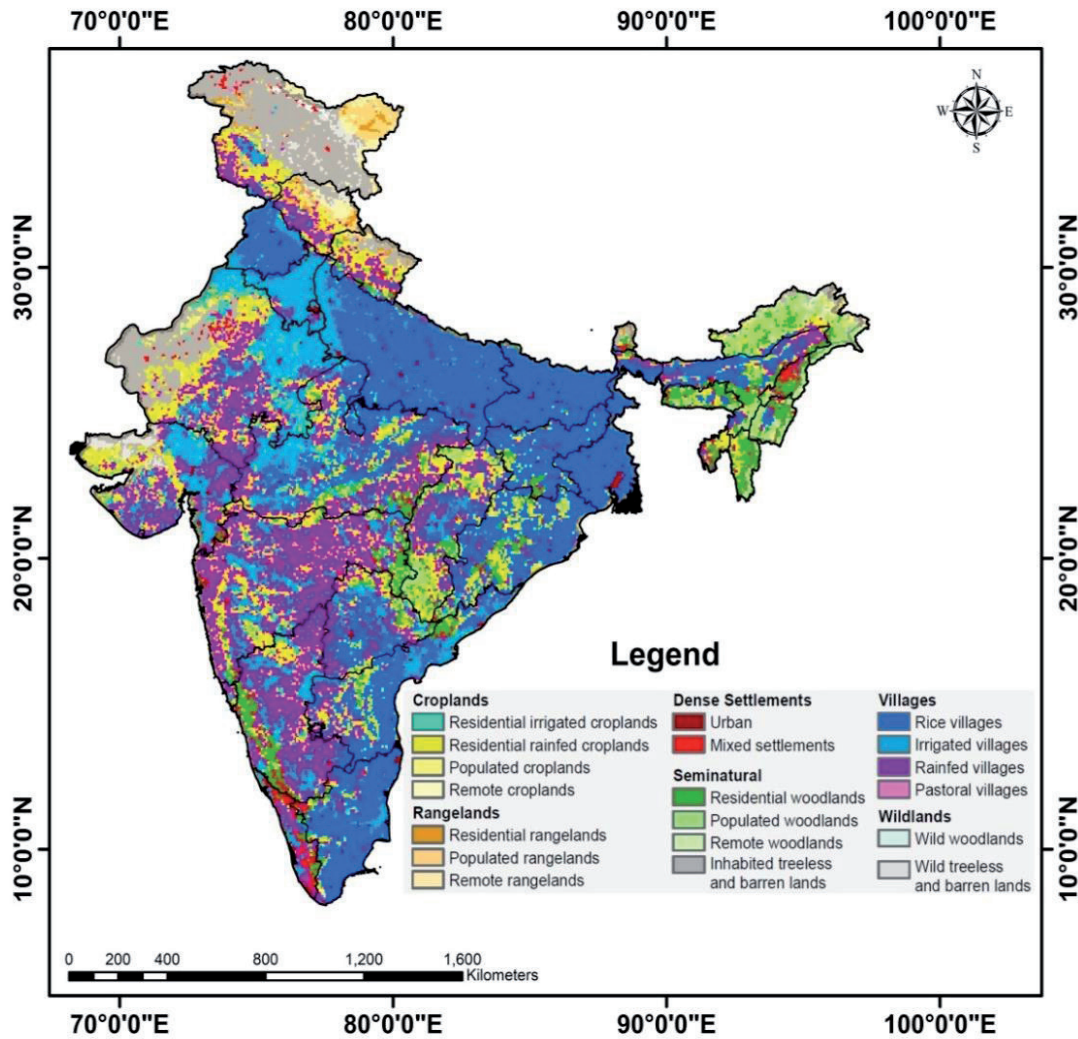


Figure 2. Anthropogenic biomes for the year 2000 of India describe potential natural vegetation, biomes, as transformed by sustained human population density and land use including agriculture and urbanization (Ellis et al., 2013)

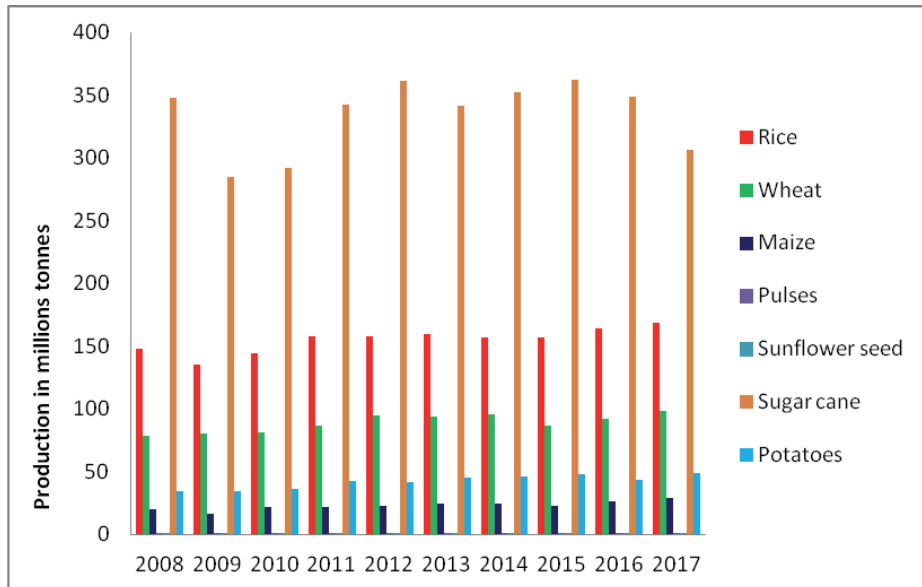


Figure 3. Major agriculture crops production (2008-2017) in India (FAO, 2019)

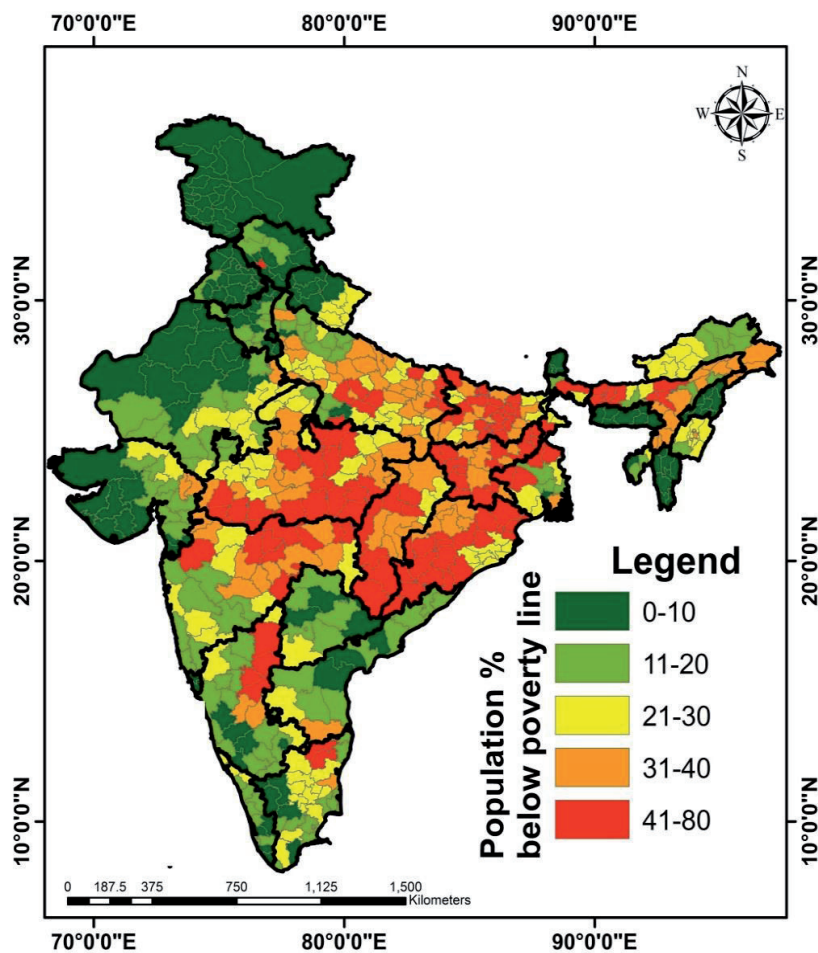


Figure 4. District wise percentage of people living Below Poverty Line (BPL) (Lewis, 2013)

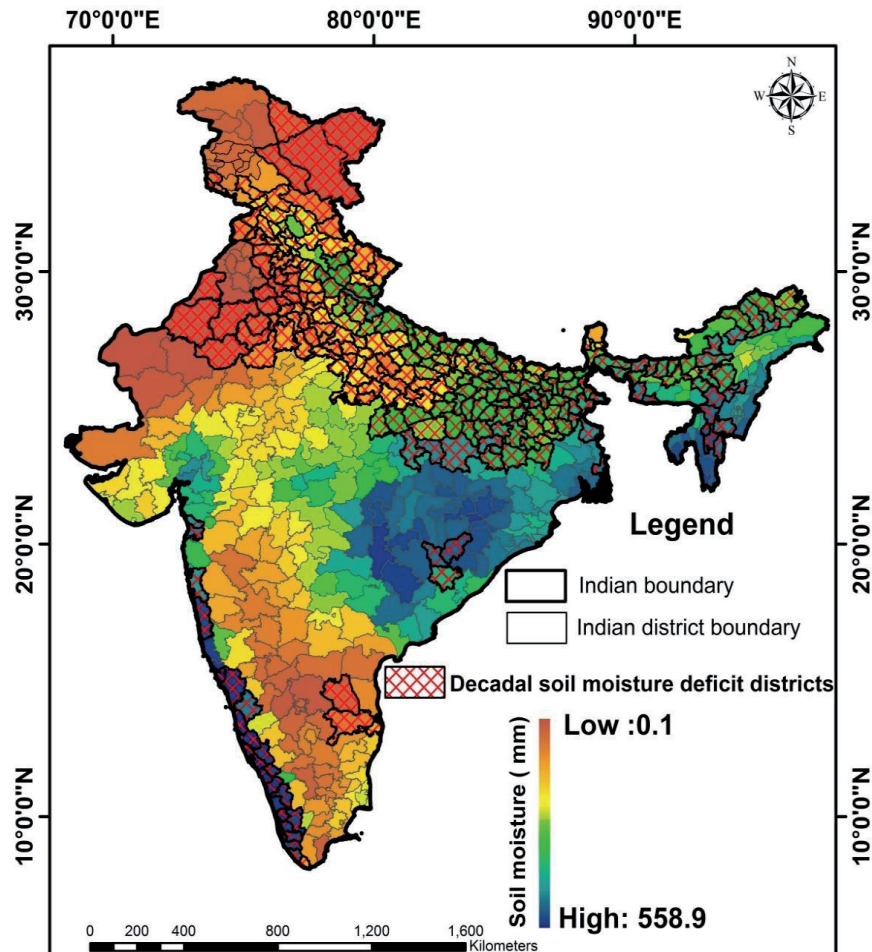


Figure 5. Soil moisture pattern (district wise) of *Kharif* season (present decadal monthly average: 2006-2015) overlaid with soil moisture deficit (compared with past 20 years back decadal monthly average: 1976-1985) districts of India

districts of North East of India. The deficit patterns during this season were more in the northern districts of India. Soil moisture in all seasons was found good in some of the highest tribal-dominated districts of northeast states (Chhattisgarh, Jharkhand and Orissa) as shown in Figure 5, 6, and 7 (blue to green colour in the map).

### 3.5. Climate data present and future scenario

The investigation of the present long term (1971-2000) annual mean of temperature and precipitation and their future (2050) trends were observed (Fig. 8 and Fig. 9). The present mean annual temperatures as well as precipitation pattern were found very remarkable in arid and semi-arid regions. The future precipitation deficits were also observed over part of the Western Ghats which are known for rich biodiversity and agriculture production (Kumar & Takeuchi, 2009).

Approximately 70% of the country's geographical area will face more or less threat by 2050 due to an increase in temperature ( $>2^{\circ}\text{C}$ ) and deficit in precipitation patterns. The major agriculture producing states of India such as Kerala, Karnataka, Punjab, Haryana, Assam, Chhattisgarh, Bihar, West Bengal, Telangana and parts of Gujarat and Maharashtra will face more climate-induced risk that can significantly impact future agriculture production.

## 4. Discussion

### 4.1. Greenhouse gases (GHGs) emission from agriculture

Growing international concern and cooperation regarding the climate change problem have increased the need to consider the uncertainty in inventories of GHG emissions.

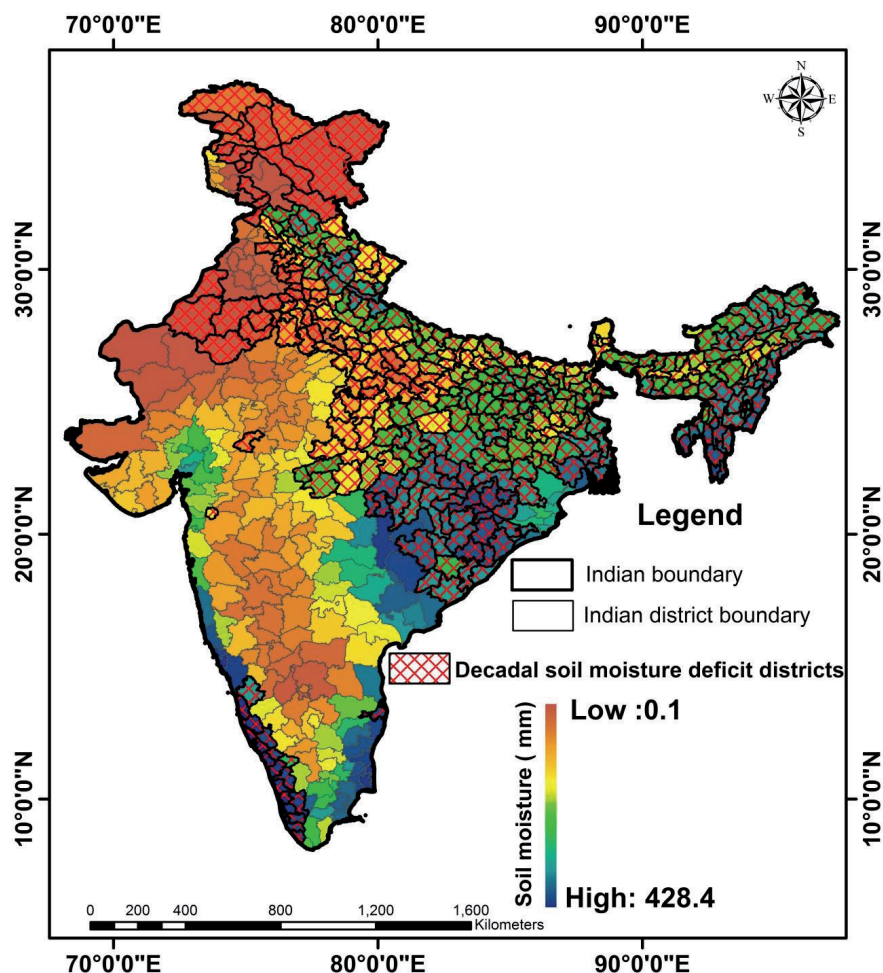


Figure 6. Soil moisture pattern (district wise) of *Rabi* season (present decadal monthly average: 2006-2015) overlaid with soil moisture deficit (compared with past 20 years back decadal monthly average: 1976-1985) districts of India

Greenhouse gases such as carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) are increasing significantly these days on the earth surface leading to increasing the global mean temperature and creating a risk of climate change and associated extreme climatic events (IPCC, 2007; 2014). Agriculture activities contribute approximately 29% of GHGs emissions (CGIAR, 2012). We have evaluated the long term (1990-2016) total emissions ( $\text{CO}_2$  equivalent) from agriculture in India, which is given in Figure 1. GHGs emission from Indian agriculture was found increasing continuously at a rate of 1% although it has become stabilized since 2011. The majority of the GHGs emissions were contributed by Ganga and Brahmaputra basin sprawling over five major agricultural states. Similar results were revealed from the study by Patra & Babu (2017) and Carlson et al. (2016). The GHGs emissions from cultivated cropland are very significant in the Ganga-Brahmaputra basin (Carlson et al., 2016) which are

highly fertile land and support crucially in food security and livelihood of most poor people (Kumar, 2017). Almost half of the total agricultural GHGs emissions were from enteric fermentation as India is the top cattle producer in the world (Indexmundi, 2019) which contributes a large section of  $\text{CH}_4$ . Rice is the most cultivated crop in India, which was found as the second-largest contributor to GHGs emissions. Other sectors of agriculture such as synthetic fertilizers (14.3%), manure left on pasture (10.5%), manure management (4.7%), crop residues (3.7%) and burning crop residues (0.6%) contributed to the remaining fraction of total agricultural GHGs emissions (FAO, 2019).

#### 4.2. Anthropogenic biomes and major agriculture crop production scenario

Humans population have altered the form and process of many ecosystems across the Earth's biosphere as per as

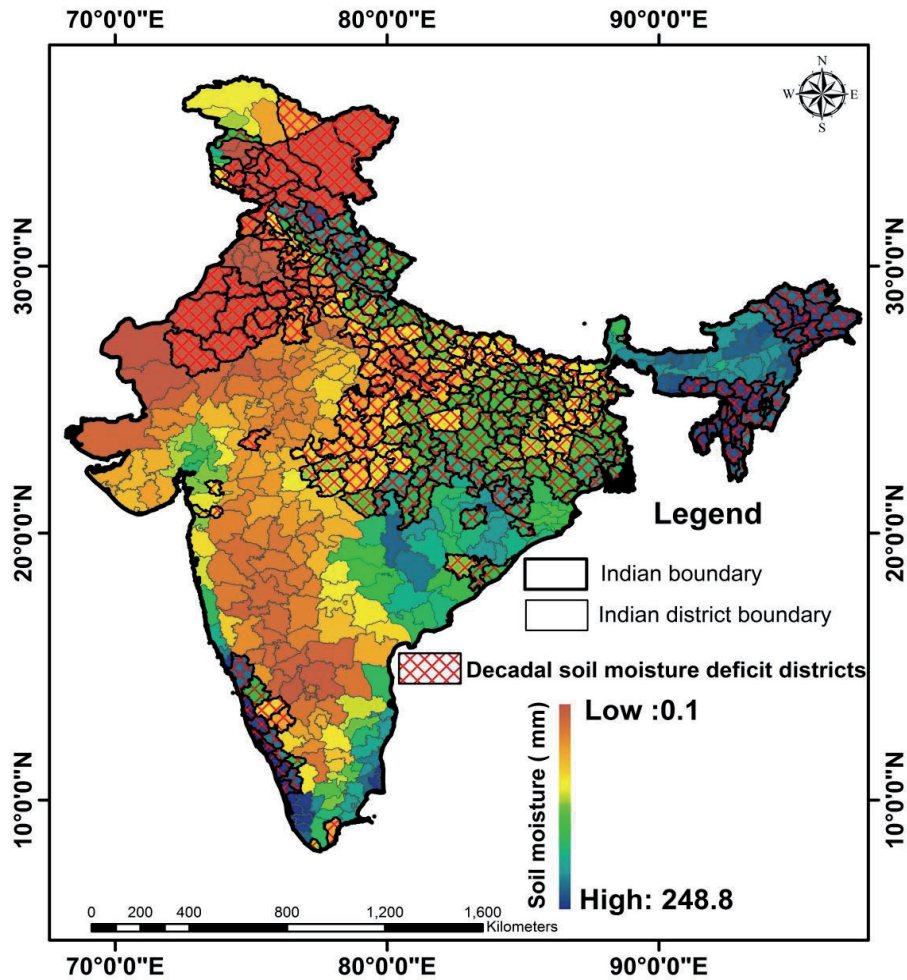


Figure 7. Soil moisture pattern (district wise) of *Zaid* season (present decadal monthly average: 2006-2015) overlaid with soil moisture deficit (compared with past 20 years back decadal monthly average: 1976-1985) districts of India

their needs in due course of time (Dearing et al., 2006; Ellis et al., 2010). Results of the study show that the significant land-use transformations in the anthropogenic biomes had been taken place by 2000 of India. This is due to the large-scale implication of the Green Revolution after the 1970s, which resulted in the conversion of natural forest lands into rangelands and croplands (Ellis et al., 2010). Most of such converted areas were used for rice, wheat and maize cultivation in the states of Bihar, Uttar Pradesh, West Bengal, Assam, Punjab, and Tamil Nadu, Andhra Pradesh and Haryana (Fig. 2). The majority of these states and their districts are the major sources of GHGs emission (Carlson et al., 2016; Patra & Babu, 2017). These lands are the major sources of the country's food production. Most of the agricultural lands in India have not facilitated through the irrigation system and hence the *Kharif* crops are dependent on monsoonal rainfall. The changing nature of the In-

dian monsoon because of climate change (Goswami et al., 2016) influences production (Prasanna, 2014). The agriculture crop production needs to be increased remarkably by adopting the high yielding varieties of climate-resilience crops (FAO, 2012) to meet the future food demand.

#### 4.3. Socio economic scenario

Socioeconomic aspects of the people are important as a CSA adaptation strategy (Howland et al., 2018). As per the World food programme, India carries an enormous burden of food insecurity (over 195.9 million people) despite some improvements in the nutritional status of children but still below acceptable levels whereas the micronutrient deficiencies are alarming as India ranks 103 out of 119 countries (WFP, 2019). India is the country where the smallholder farming community numbers are significantly high.



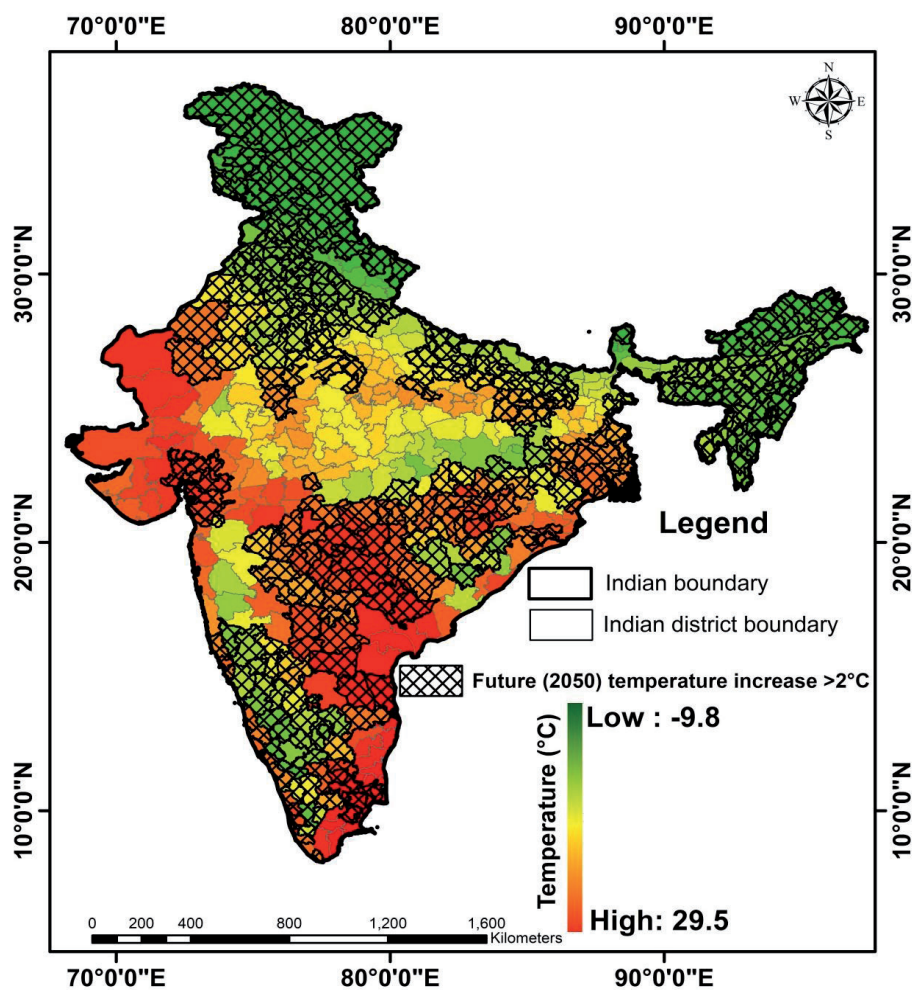


Figure 8. Annual mean temperature (BIO1) present (1971-2000) scenario overlaid with future (2050) temperature (>2°C) increase (Predictive Modeling: HD 4.5 RCP scenario) (Fick & Hijmans, 2017)

They are suffering from poverty and have a weak socio-economic condition. The conditions in the rural area are more critical. The 70% of Indian populations are poor and found in the rural area, whereas 75% of India's family depends on rural income (World Bank, 2013). Reducing rural poverty is one of the biggest challenges and needs an adequate strategy to support long-term benefit to the poor, landless, women, scheduled castes and tribes which are having the weak adaptive capacity to climate change. The analysis of poverty map (Fig. 4) crucially manifested that the eastern part of central India such as districts of Chhattisgarh, Orissa, and Jharkhand have a high percent of the people living below the poverty line and these percent further increases in the vicinity of the forest dominated tribal area (Ahmad et al., 2018; Ahmad et al., 2019b). Tribal are more vulnerable to climate change (Minj, 2013) whereas some farmer's suicidal hotspot districts (Goparaju & Ah-

mad, 2019) of central India needs special priority in implementing the CSA because apart from other factors the severity of the Hunger Index are found alarming (Menon et al., 2009). Women role in CSA is well recognized in the term of their active participation in farm output and their endowment to food security (Agarwal, 2013; Khatri-Chhetri et al., 2019). The socio-economic issues with the gender-gap need to be critically evaluated for adequate priorities for selecting the area for CSA implementation (World Bank Group, FAO and IFAD, 2015; Goparaju & Ahmad, 2019). Such an evaluation process provides a technical understanding of CSA options to establish realistic pathways for enhancing the CSA adoption strategies (Corner-Dolloff, 2014).

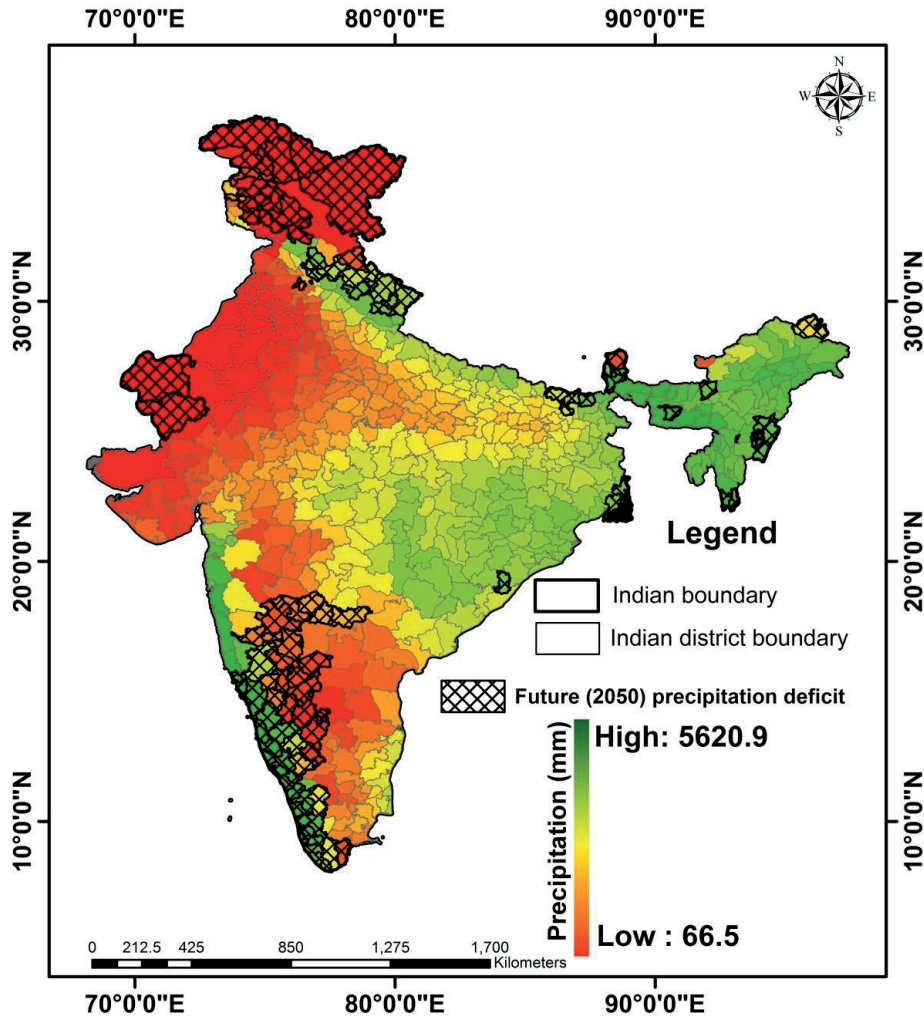


Figure 9. Annual mean precipitation (BIO12) present (1971-2000) scenario overlaid with future (2050) precipitation deficit (Predictive Modeling: HD 4.5 RCP scenario) (Fick & Hijmans, 2017)

#### 4.4. Soil moisture scenario during the major cropping season

Soil moisture is one of the important parameters which regulate the nutrient uptake in crops and influence the agricultural production (Sikka et al., 2018) and provides adequate information for the improvement of the irrigation system, supervising the flood risk, assessment of agricultural drought and weather forecast for irrigation (Sebastian, 2019). Soil moisture in the *Kharif* season was found highest in the Western Ghats and north-eastern states while arid and semi-arid regions were found in low soil moisture content. This is due to the fact former two regions are high rainfall areas of the country whereas rainfall in the latter areas are considerably low. Soil moisture deficit during the *Kharif* season in the districts of Ganga and Brahmapu-

tra basin was found significantly higher. This basin retains a significantly high population (630 million inhabitants) and continuously facing anthropogenic pressure on land use land cover (LULC) whereas the seasonal rainfall is also showing a decreasing trend (Kumar & Ambastha, 2016; Diwakar et al., 2017) is the probable appropriate reason of soil moisture deficit.

Comparing with *Kharif* season in the district wise dataset of soil moisture, it was revealed that *Rabi* season was also similar to the pattern of *Kharif* season. However, soil moisture in a few districts of Tamil Nadu and Andhra Pradesh were appreciably improved during *Rabi* season than the *Kharif* season. Soil moisture deficit during *Rabi* season is found more pronounced while comparing it with *Kharif* season and further overtakes some more

districts of the southeastern part and all districts of North East of India. Soil moisture during the *Zaid* season notably reduced (high value: 248.8 mm) in the districts of northern states of the country due to an increase in summer temperature (Pandey, 2018). Soil moisture in all the seasons suffering from extreme poverty can be selected for climate-smart agriculture urgently because of their weak adaptive capacity to climate change. A similar analysis of soil moisture was studied by Pangaluru et al. (2019).

The study of soil moisture scenario is important for crop production (Reichert et al., 2019) and considered as one of the key issues in CSA can be crucially support as a strategy for soil and water conservation for the enhancement of soil moisture. Such strategies are highly useful in low precipitation, rain-fed, moisture deficit area to trap the monsoon rainwater at the watershed level (Sharma, 2009), which in a majority of time goes in vain as runoff loss (<http://www.fao.org/docrep/t1696e/t1696e02.htm>).

#### 4.5. Climate data present and future scenario

Climate change risks are found very significant in India whereas preparations or abilities to respond to the climate changes are inadequate (Bhushan, 2015; WEF, 2018). The climate-induced risks are threatening the crop yields (Goparaju & Ahmad, 2019) due to increase in temperature (Lal et al., 1995), rainfall (Goswami et al., 2006; Kumar et al., 2010) repeated droughts (Ramanathan et al., 2005), and evidence of periodic floods (World Bank, 2013). Projected impact of climate change based on the trends of temperature and precipitation shows that the impact of climate change will be threatened harshly in the near future (2050) in the arid and semi-arid regions. Carleton (2017) recognized these areas as the farmer's suicide hotspots due to the increasing trend of temperature. Some high poverty districts of the state of Orissa, Chhattisgarh, and Bihar will be threatened in the future. The future precipitation deficits were also observed over part of the Western Ghats which are known for rich biodiversity and also agriculture production (Kumar & Takeuchi, 2009)

Based on the above study, we can conclude the GHG emission, anthropogenic pressure on LULC, socio-economic condition of people, soil moisture distribution and deficits are found very pronounced in India. The present temperature and precipitation pattern and future trends in India has been found very challenging which might impact the agriculture production in due course of time. Such analysis importantly highlights a need harmonized policy to prioritize the areas suffering from a new climate change reality to support resilience among most of the marginalized people. There is a need to design a tangible policy by the institutional efforts addressing the deep-rooted socio-economic and climatic problems of agriculture-dependent poor people in all the areas of the country which will sup-

port Climate-smart agriculture (CSA) practices based on indigenous knowledge to improve the farm outputs and livelihoods of the people.

## 5. Conclusion

The paper deals with the datasets such as agriculture GHGs emission, poverty, anthropogenic biomes, agriculture crop production scenario, soil moisture status and deficit, present and future precipitation and temperature scenario which give a better understanding of the impact of climate change and socioeconomic dimension on the people. The result highlights the Greenhouse gases total emissions (CO<sub>2</sub> equivalent) from agriculture in India were showing the increasing trend, and it is notably high in rice-producing regions (Carlson et al., 2016). Agriculture crops (2008-2017) such as rice, wheat, maize, pulses, sunflower seeds sugar cane and potato production in India varies annually and largely depends on Indian monsoonal rainfall pattern need to be increased remarkably for future generations. Special priority in implementing the CSA is important which may reduce the future food deficient under the climate change.

Soil moisture is an important variable in the climate system whereas its long term observation is a critical research gap (Robock, 2015) which was first time addressed at the country level of India. The present soil moisture and the deficit during the *Kharif*, *Rabi* and *Zaid* seasons vary in spatial pattern over India whereas soil moisture deficit during the *Kharif* season was found very notable over most of the districts of Ganga and Brahmaputra basin which provides food security to the millions of poor inhabitants need a synergic strategy for soil and water conservation to enhance the seasonal soil moisture to boost agriculture crops for the future. The present mean annual temperatures, as well as precipitation pattern, were found very significant in arid and semi-arid regions which predominantly identified as the farmer's suicidal hotspot (Carleton, 2017) will be threatened in the future due to variation of precipitation and increasing trends of temperature. Furthermore, such investigation derived from ancillary data along with remote sensing and GIS provide a concrete conception of a paradigm shift in approach for implementing the synergic strategy such as "Climate Smart Agriculture" urgently in prevailing new climate change reality to socio-economic deprived people and farmer inhabitant in different sections of the India for achieving socio-economic and climate resilience.

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