7 Comparative Assessment of Projected Suitability of Finger Millet Crops in Tamil Nadu and Parambikulam Aliyar Basin Using ECOCROP Model: A Geospatial Approach

P. Dhanya, T. Sankar, and V. Geethalakshmi

Abstract

Climate change is anticipated to pose extensive adverse effects on the range and suitability of various crop-growing areas across the tropics. The agro-climatic suitability of the finger millet (Ragi) crop in Tamil Nadu and Parambikulam Aliyar Basin (PAB) is simulated using an updated version of the FAO's ECOCROP model integrated with DIVA-GIS software. The WorldClim dataset is used worldwide in climate change-related suitability studies. For this purpose, CCSM4 datasets, one of the global circulation models (GCMs) whose climate projections were employed in the IPCC's Fifth Assessment Report, are utilized based on RCP 2.6. The RCP 2.6 scenario projects an average global warming increase of around 1 °C by the end century. The results indicate that DIVA-GIS embedded in the ECOCROP model is an efficient tool in identifying the agro-climatic suitability of finger millet crops for the state as a whole and at the PAB basin scale. Changes in the current suitability (as a mean value for the period between 1970 and 2000) and future simulated suitability conditions for the year 2050 show that there may be a positive change of about 30–40% more areas under excellent future suitability class for the finger millet crop in the state and PAB. The findings reveal that Tirupur, the northern part of Krishnagiri, a small patch in Erode, parts of Kanyakumari, Thoothukudi, etc., have shown unsuitable or very marginally suitable for finger millet crops in the future under the purview of climate change. The places that are likely to be excellent for cultivation in the future are Nilgiris, southwest of Coimbatore, Theni, Dharmapuri, Salem, and north part of Namakkal. Vellore, Nagapattinam, Thiruvarur, Cudullore, Kancheepuram, Thiruvallur, and others come under excellent to very suitable categories. The outcomes from the secondary data analysis based on efficient cropping zones and ECOCROP model-based outcomes have been further evaluated for better comparative analysis. As per the current situation, most of the state districts fall under highly inefficient zones except 5–6. It is alarming to note that even though there is current climatic suitability as per ECOCROP, finger millet cultivation in coastal areas of Kancheepuram,

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Thiruvannamalai, Villupuram, Cuddalore, Ariyalur, Thiruvarur, and Nagapattinam is completely neglected. It is significant to note that currently, there are no most efficient cropping zone (MECZ) in the state. Hence, ample scope for wider scaling up of its cultivation. India, with its National Mission on Sustainable Agriculture and Food Security, is working toward food and nutritional security. Hence enhancing more areas under finger millets in suitable zones would be highly appreciated.

Keywords

Crop suitability · Agro-climatic zones · ECOCROP model · Geospatial modeling · Finger millet · Parambikulam Aliyar Basin

7.1 Introduction

Geospatial technologies provide huge potential for climate change impact, vulnerability assessments, and land use planning (IPCC 2012). Worldwide, geospatial tools, particularly maps, are extensively utilized to convey spatial disparities in climate change and land degradation (Fish 2020; Quach and Jenny 2020). Geospatial models support crucial spatial data analysis and modeling to evaluate climate change's current and anticipated implications and variability on major crops (Das et al. 2017). Several scholars have proposed conducting an elaborate investigation at the local level to measure the effects and enhance our understanding of crop susceptibility and societal reactions to climate change. (Knight and Messer 2012; Ramachandran et al. 2017).

Rain-fed farming in India faces multiple problems due to the vagaries of monsoons, rising temperatures due to climate change, water shortages, and so forth (Sivakumar et al. 2005). In the semi-arid tropics of South Asia, subsistence farmers cultivate finger millet (*Eleusine coracana* [L.]) as a principal food crop. It constitutes an essential element of farming systems in arid and semi-arid regions. In India, the promotion of rice and wheat cultivation was prevalent during the Green Revolution in the 1960s and 70s. However, the production and consumption of wide traditional millet varieties started diminishing across the nation (Rurinda et al. 2014). Nonetheless, as almost 60% of the cultivated land in the country is rain-fed and not irrigated, farmers growing rice and wheat are excessively dependent on climatic conditions, which are increasingly becoming unfavorable for farming due to the impacts of climate change. Hence more climate-resilient crops have to be promoted in the future. The cultivation of major cereals is surpassed by millets in terms of tolerance to environmental stresses due to several morpho-physiological, molecular, and biochemical characteristics possessed by the latter (Bandyopadhyay et al. 2017). Millets, a climate-resilient crop, can increase farming communities' income and food security in arid and semi-arid regions. Their extensive root systems enable them to endure various ecological conditions even in the face of water scarcity. (Satyavathi et al. 2021).

Karnataka, Andhra Pradesh, Odisha, and Tamil Nadu are the main states where finger millet is predominantly cultivated in India. Side by side, the finger millets can be grown as a cereal crop in arid and semi-arid regions. This crop is known to have the capacity to withstand drought conditions (Gupta et al. 2017). It is a wonder crop because it is rich in calcium, about ten times that of rice or wheat (Shukla et al. 2015). Millets are cultivated over an area of 15.48 million hectares in India, resulting in a production of 17.2 million tons and a yield of 1111 kg/ha (Directorate of Economics and Statistics 2015). The chapter endeavored to understand the potentiality of the geospatial model eco crop to assess the suitability of drought hardy crops for the state as a whole and the PAB in particular based on the suitability of finger millet presently and in the future.

Tamil Nadu's geographic location renders it susceptible to natural calamities, including cyclones, droughts, floods, and tsunamis caused by earthquakes (Varadan and Kumar 2015). Increased frequency of unexpected dry spells and rising temperatures are likely to negatively impact soil moisture availability, thereby increasing the risk of crop failure in semi-arid south India. Research on the impact of climate change on the phenology and grain yield of cereal crops has been focused mainly for the eastern delta regions of Tamil Nadu (Yadav et al. 2015). In Tamil Nadu, finger millet (Ragi) is cultivated as a Rabi season crop from October to March. In the state, finger millet is known as Ragi or 'Kelvaragu.' It is farmed as a dry land crop during the northeast monsoon seasons in Tamil Nadu. Hence the current necessity is to discover crops and cropping systems that are more climate-resilient and better suited agro ecologically. It must also provide better performance in terms of economic yield and livelihood security for the farmers of Parambikulam Aliyar Basin (PAB) and the state.

7.2 Materials and Methods

7.2.1 Study Area

Tamil Nadu, which falls under the semi-arid tracts of south India, is being considered for the study. The state of interest is located in southern India, bordered on the north and northwest by the states of Andhra Pradesh, Karnataka, and Kerala and the Bay of Bengal and the Indian Ocean in the eastern and southern parts, respectively. In the present chapter, crop suitability and efficient cropping zone identification for finger millet crops for 38 districts is carried out in general. In order to understand the changing in crop suitability at the basin level Parambikulam Aliyar Basin (PAB), in Coimbatore district, Tamil Nadu, is taken into consideration (Fig. 7.1). This research was conducted as part of the climate change and crop simulation study proposed under DST project entitled "Enhancing climate change adaptive capacity and agricultural productivity in Parambikulam Aliyar Basin areas through ICTs and other technological interventions (2019–2022). Understanding the impact of climate change on climate-resilient crops is one of the study's main components. The study area is located around the foothills of Valparai, in the Anamalai Hills of the Western Ghats. During the southwest monsoon season, this area receives good amount of rain, unlike other parts of state; however, a large portion of the land falls within regions that experience a rain shadow effect. Even though there are two dams, such as Aliyar and Thirumurthy dams, on the rivers Aliyar and Palar, respectively, to serve the irrigation needs of the basin, many parts in the northeastern parts of the basin are under rain-fed cultivation. These areas' major seasonal crop cultivation is groundnuts, maize, sorghum, and finger millets.

7.2.2 Agro-climatic Requirement of Finger Millet Crop

For ideal growth, it is necessary to have daytime temperatures ranging from 30 to 34 °C and nighttime temperatures ranging from 22 to 25 °C, in addition to ample sunlight. The optimal conditions for its growth are typically found in regions with an annual precipitation of approximately 100 cm. It is possible to cultivate this crop in various types of soil, including nutrient-rich loam and shallow upland soils with sufficient organic matter. Nonetheless, the cultivation of this crop is best suited to porous, light red loam, or sandy loam soils with efficient internal drainage. The cultivation of this crop can also be considered in black soils with adequate drainage, as it can tolerate some degree of water stagnation. Soils with a pH ranging from 4.5 to 8.0 are most suitable for the optimal growth of finger millet crop, while heavy clay soils with inadequate drainage capacities should be avoided.

7.2.3 ECOCROP Modeling Method

Crop suitability analysis was conducted for the state of Tamil Nadu and Parambikulam Aliyar Basin using the global meteorological data provided by WorldClim. The Eco Crop Model is a mechanistic model that utilizes temperature and rainfall ranges from the FAO-EcoCrop database, which are based on expert knowledge (http://ecocrop.fao.org). The model takes climatic factors

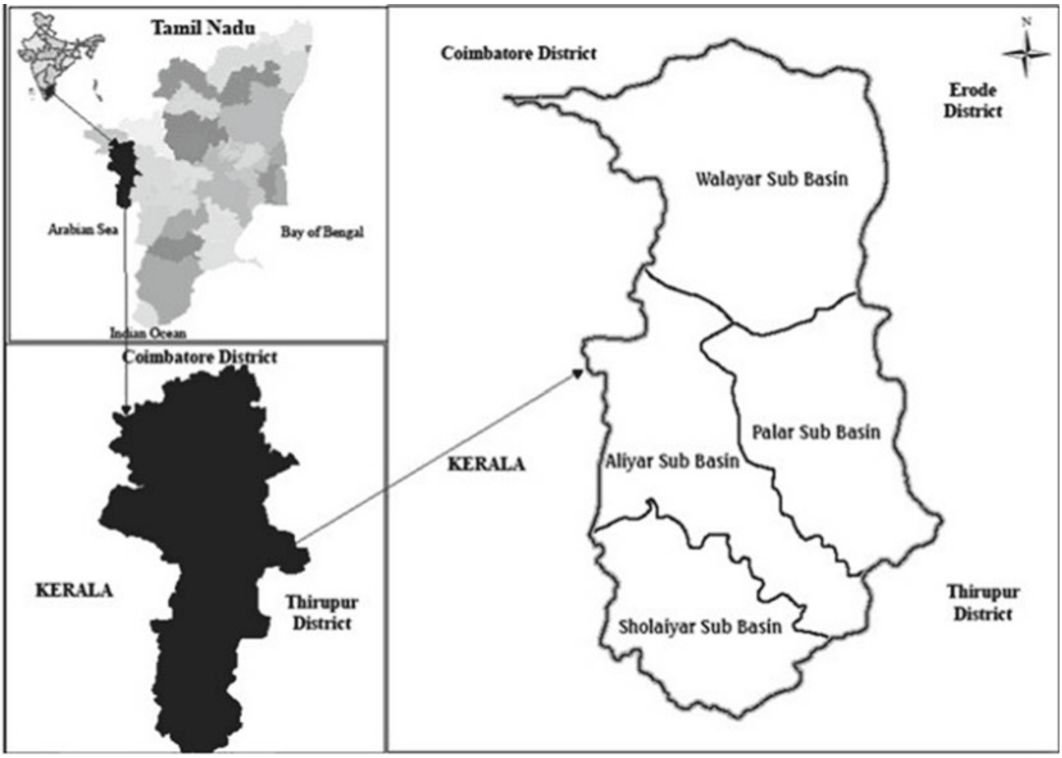


Fig. 7.1 The geographical area of interest in the research

as inputs to identify the appropriate environmental conditions for a crop, and generates a score indicating its suitability as output (Ramirez-Villegas et al. 2013). The range of agroecological suitability is fixed mainly based on a pair of variables, i.e., temperature and rainfall. The ranges of temperature and rainfall are characterized by both the absolute range, which includes the minimum and maximum temperatures and rainfall necessary for crop growth, as well as the optimum range, which includes the minimum and maximum temperatures and rainfall that are ideal for crop growth. By employing gridded temperature and rainfall statistics, the algorithm of the model calculates the environmental conditions throughout the growing season at a specific location. When the conditions are beyond the absolute thresholds, the suitability index is zero (not suitable); when they are between absolute and optimum thresholds, the suitability score ranges from 1 to 99, and when they are within the optimum current climate (WorldClim ver. 1.4) and future climate (CCSM4 RCP 2.6—2050). The RCP 2.6 pathway represents a low emissions scenario in which global greenhouse gas emissions peak around 2020 and then rapidly decline, leading to a stabilization of atmospheric concentrations at around 450 parts per million (ppm) CO_2 equivalent by 2100. The RCP 2.6 scenario is often used as a benchmark for assessing the impacts of climate policies and mitigation efforts on future climate change. After generating the suitability scores, they are classified into different categories based on their level of suitability, which includes very marginal (1–20%), marginal (20–40%), suitable (40–60%), very suitable (60–80%), and excellent (80–100%). Climate datasets for the current climate, WorldClim version 1.4, available at http://www.worldclim.org, was used. The global climate layers (climate grids) with a 30 arc-second spatial resolution (approximately 1 km × 1 km) are utilized to depict the monthly climatology (maximum, minimum, and mean temperatures and total monthly rainfall) representative of the years 1970–

2000. These datasets, were downloaded from http://worldclim.org/cmip5_30s. The downscaled versions of the CCSM4 GCM projections were calibrated, or bias-corrected, against the WorldClim 1.4 baseline for present-day climate.

7.2.4 Identification of Efficient Cropping Zones

Time series data on Crop production and productivity were gathered for a period of 30 years (1985–2015) from the Crop Production Statistics Information System, as well as season and crop reports (SCR) specific to the area. Additionally, data on the total cultivable area of Tamil Nadu were collected for a period of 15 years (2000–2015). Efficient Cropping Zones were identified based on a temporal database of area and production for various districts in Tamil Nadu; RSI (Relative Spread Index) and RYI (Relative Yield Index) were calculated as decadal average periods. The statistical formulas utilized in this study to compute the Relative Yield Index (RYI) and Relative Spread Index (RSI), as well as the criteria employed to categorize the Efficient Cropping Zone (EFC), adapted from researches of Pradip et al. (2018), Sankar et al. (2019), Kowshika and Sankar (2020), are given as follows (Table 7.1).

$$\mathrm{RYI} = \frac{\text{Mean yield of a particular crop in the district}}{\text{mean yield of a particular crop in the state}} * 100$$

7.2.5 Mapping of Efficient Cropping Zones

District-level Efficient Cropping Zones of finger millet (Ragi) crop over Tamil Nadu state for three decadal maps of 1985–1995, 1996–2005, and 2006–2015 were mapped and compared with the average period (1985–2015). ArcGIS v10.5 software was employed to generate all of the maps used in this study.

7.3 Results and Discussion

7.3.1 Changes of Area and Yield

Data shows that the area under finger millet showed a general declining trend in the state until 2012–2013. After that, it showed a slight increasing trend in the state (Fig. 7.2). Cultivated areas under finger millet showed a drastic decline in the Coimbatore district (Fig. 7.3).

The average productivity of finger millet in the state is 3338 kg/Ha, and in the Coimbatore

$$\mathrm{RSI} = \frac{\text{Area of particular crop expressed as \% of the total cultivable area in the district}}{\text{Area of crop expressed as a percentage to the total cultivable area in the State}} * 100$$

Table 7.1 Criteria for classification of efficient cropping zones

Sl. No	RSI	RYE	Cropping zone
1	> 100 (High)	> 100 (High)	Most Efficient Cropping Zone (MECZ)
2	> 100 (High)	< 100 (Low)	Efficient cropping zone (ECZ)
3	< 100 (Low)	> 100 (High)	Not efficient cropping zone (NECZ)
4	< 100 (Low)	< 100 (Low)	Highly inefficient cropping zone (HICZ)

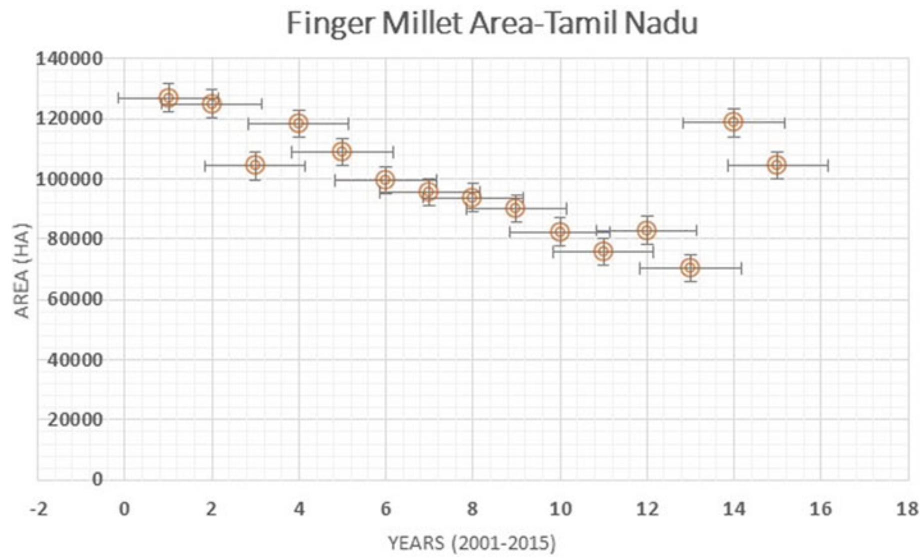


Fig. 7.2 Trend of finger millet growing areas in the state from 2001 to 2015

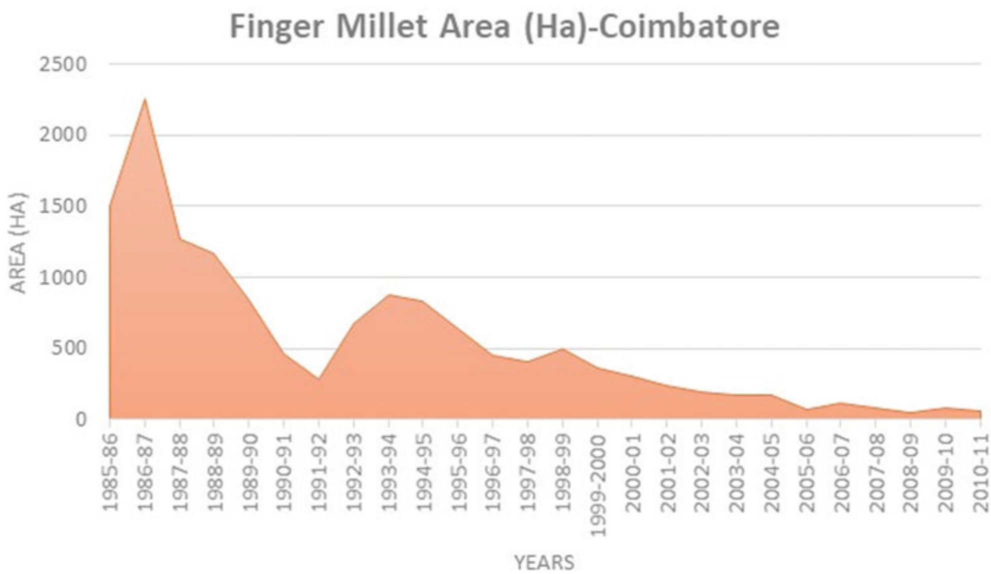


Fig. 7.3 Trend of finger millet growing areas in the Coimbatore from 2001 to 2015

district, it is 2401 kg/Ha from 2011–2012. There is a huge spatial disparity in the yield of Ragi crops in the state (Figs. 7.4 and 7.5). The data clearly explains how climate variability impacts crop area and yield. 2002–2003 show a striking reduction in crop yield and area due to drought.

7.3.2 Finger Millet Current and Future Suitability

This study involved simulating the current and potential suitability of finger millet crops in the future based on the ECOCROP model.

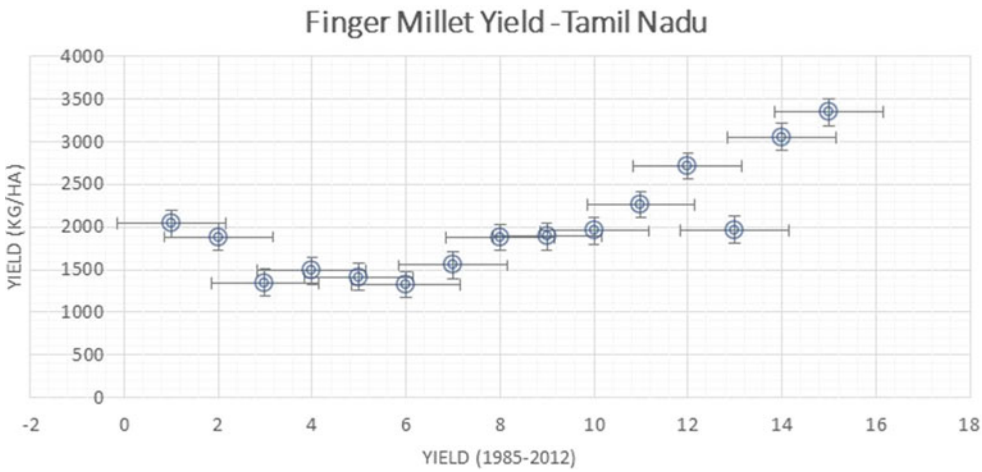


Fig. 7.4 Trend of finger millet yield in the state from 2001 to 2015

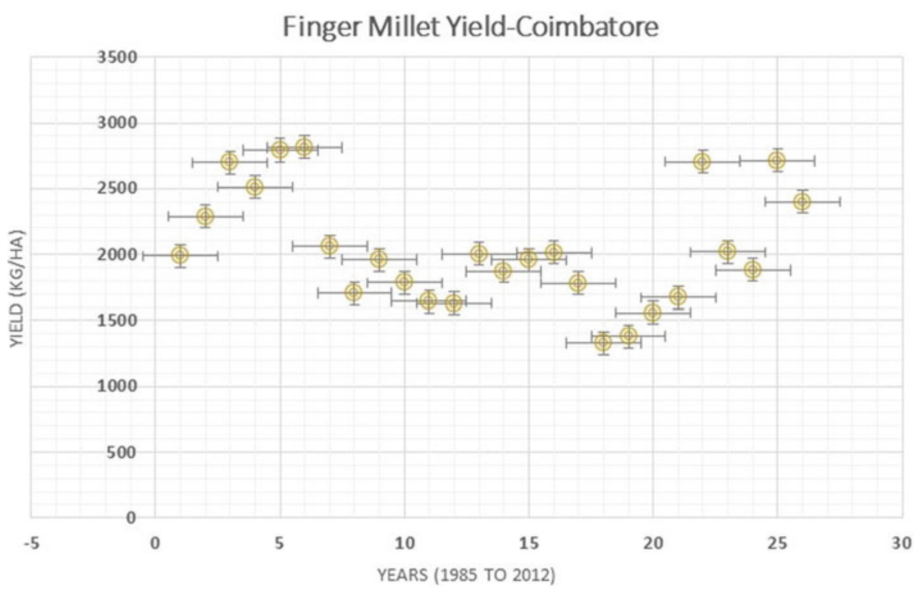


Fig. 7.5 The trend of finger millet yield in Coimbatore district from 2001 to 2015

Regarding current agro-climatic suitability, northeast agro-climatic zones are found to be more suitable for finger millet cultivation. However, Thoothukudi, Virudhanagar, Madhurai, Thiruppur, Karur, Erode, central and north Coimbatore, Salem, Namakkal, and Perambalur comes under not suitable categories based on the current climatic conditions, agro-climatic suitability. The districts, Sivagangai, east of Pudukottai, Thiruvannamalai, Villupuram, and so on come under marginally suitable classes (Fig. 7.6).

Regarding future suitability, Tirupur, the northern part of Krishnagiri, a small patch in Erode, the eastern part of Krishnagiri, parts of Kanyakumari, Thoothukudi, and so on have

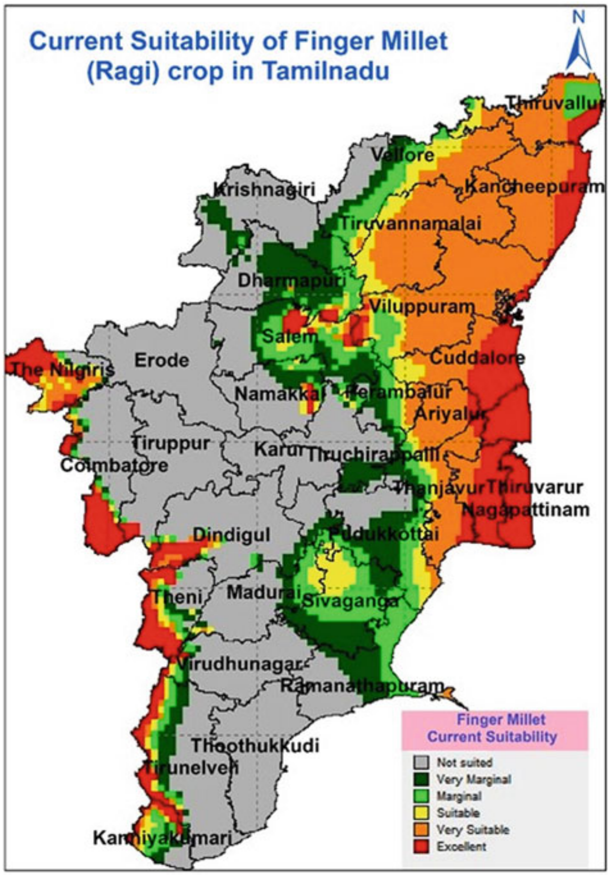


Fig. 7.6 Current suitability of finger millet (Ragi) crop over Tamil Nadu

shown not suitable or very marginally suitable for finger millet crops in the future. The places which are excellent for cultivation in the future are Nilgiris, southwest of Coimbatore, Theni, Dharmapuri, Salem, and north part of Namakkal, whereas Vellore, Nagapattinam, Thiruvarur, Cudullore, Kancheepuram, Thiruvallur, etc., come under excellent to very suitable categories (Fig. 7.7).

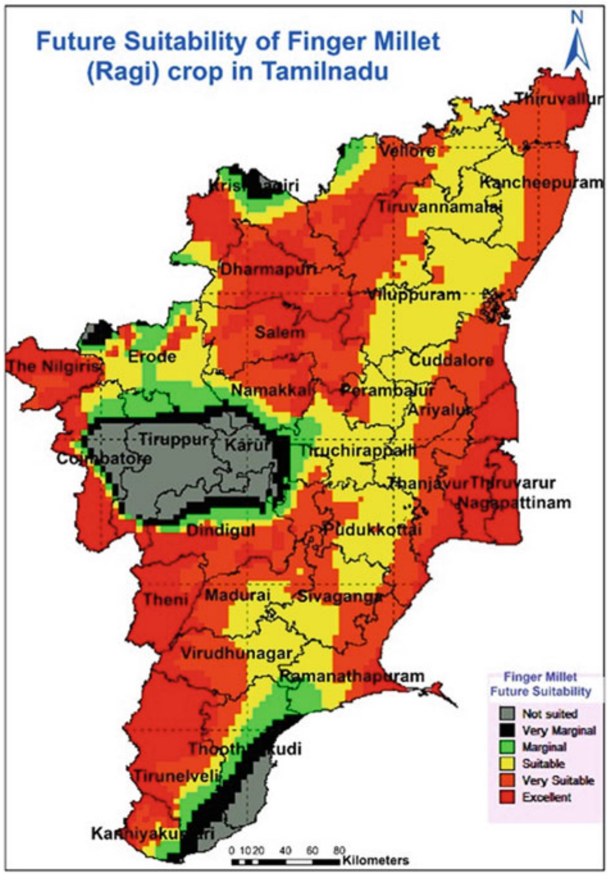
7.3.3 Current and Future Suitability Finger Millet: Parambikulam Aliyar Basin

As far as Parambikulam Aliyar Basin (PAB) is concerned, more areas may come under excellent, very suitable, and suitable categories in the future than in the current situations. As far as current climatic conditions are concerned, only 50–60% of the grids are under excellent and very suitable for finger millet cropping; however, 70–80% of the areas can be anticipated to be an excellent category in the PAB in the future (Fig. 7.8). The areas around the northeastern parts of the PAB come under marginally to very marginally and not suitable for the cultivation of finger millets in the current conditions and under projected future climatic conditions based on IPCC's RCP 2.6.

7.3.4 Efficient Cropping Zones

Multitudes of factors affect an area to be an efficient cropping zone (ECZ) for a particular crop. Among all factors, climate, weather, soil

Fig. 7.7 Future suitability of finger millet (Ragi) crop over Tamil Nadu



quality, and land management, higher yield plays a critical role in deciding the efficacy of an area to be suitable for the further spread of a particular crop. ECZs can be classified based on their high Relative Spread Index (RSI) and Relative Yield Index (RYI). RSI is influenced by factors such as the availability of seeds, fertilizers, water, pesticides, labor, technology, and government policies, whereas RYI is determined mainly by the climate and weather conditions specific to the region (Sankar & Kowshika, 2020). Based on the secondary data, districts that come under efficient cropping zones are Erode, Salem, Dharmapuri, and Vellore from 1985 to 1995. However, during 1996–2005, Vellore and Thiruvallur districts also came into the category. Data showed that Krishnagiri also fell into the efficient cropping zone category from 2006 to 2015. (Figs. 7.9 and 7.10). If we consider the overall suitability of finger millet crop for 30 year period, all five districts, namely Erode, Salem, Dharmapuri and Vellore, and Krishnagiri, come under efficient cropping zones (Figs. 7.11 and 7.12).

The outcomes from the secondary data analysis and ECOCROP model-based analysis have been evaluated for comparative analysis. As per the current situation, all other districts in the state fall under highly inefficient zones. It is alarming to note that even though the area has been identified as climatically suitable as per ECOCROP model-based analysis (Fig. 7.6), finger millet cultivation in coastal areas of Kancheepuram, Thiruvannamalai, Villupuram, Cuddalore, Ariyalur, Thiruvarur, and Nagapattinam is completely neglected. It is significant to note that the state has no most efficient cropping zone (MECZ).

The WorldClim dataset is used worldwide in climate change-related suitability studies

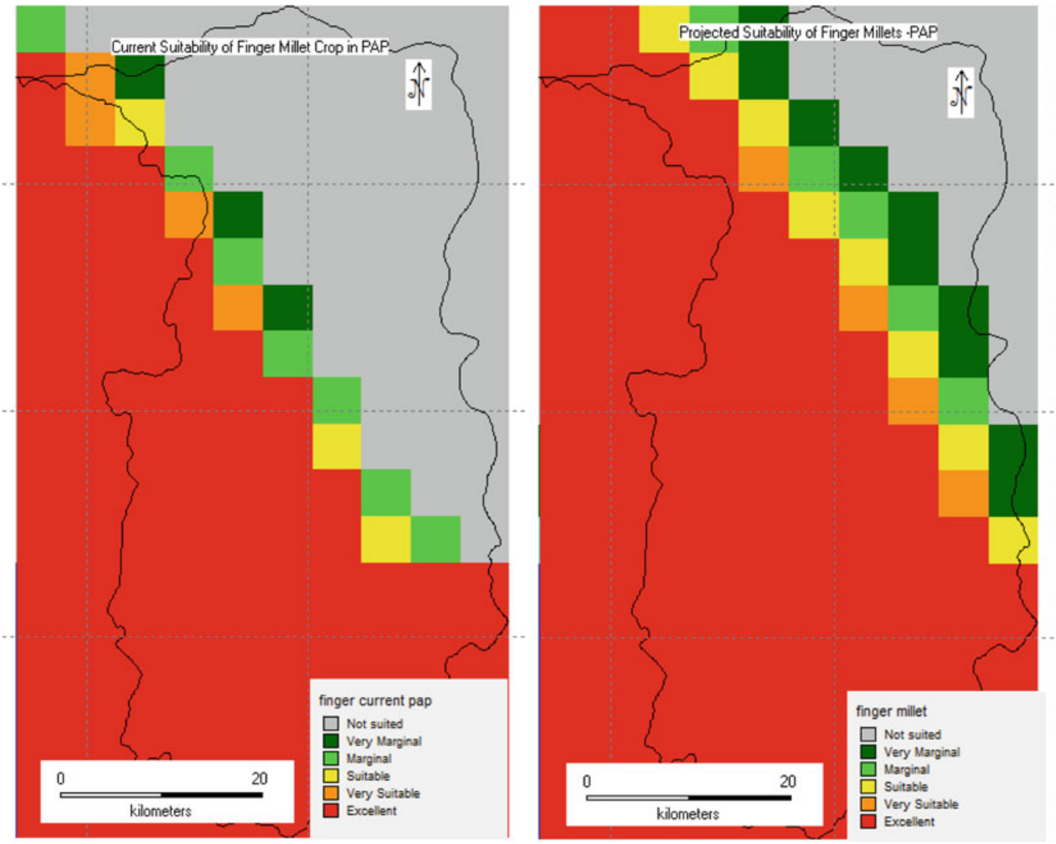


Fig. 7.8 Current and future suitability of finger millet crop to climate change in PAB basin

(Hijmans et al. 2001), such as those by Lane and Jarvis (2007), Ramirez-Villegas et al. (2013). The CCSM4 is one of the GCMs whose climate projections were used in the Fifth Assessment IPCC report. The RCP 2.6 scenario projects an average global warming increase of 1 °C in the end century period. Two sets of crop suitability maps were generated for the state of Tamil Nadu and the PAB using the FAO crop ecological database. These maps represented the suitability of crops under both present and future climate conditions. Agro-meteorological settings cause wide instabilities in finger millet crop growth, development, and harvest. It shows a conducive environment for the future spread of finger millet crops growing in 70–80% of areas of the state of Tamil Nadu.

Finger millet is a highly nutritious cereal. Finger millet is rich in vitamins, minerals, and fiber, which can offer several health benefits. The high potassium content in finger millet promotes healthy kidney and heart function, while also aiding in the transmission of nerve signals. In addition, finger millet is an excellent source of B vitamins that support brain function and healthy cell division. Knowing its significance, to ensure sustainable growth in millet production, FAO (2012) recommends the immediate adoption of innovative practices. These practices are crucial for providing access to nutritious food for those suffering from malnutrition and hunger, improving the global supply chain, and reducing food wastages. Following India's request, FAO has agreed to celebrate 2023 as the 'International Year of Millets.' India's Millet Mission focuses on developing farm gate processing and empowering farmers through collectives, enhancing value-addition, and ensuring that farmers have

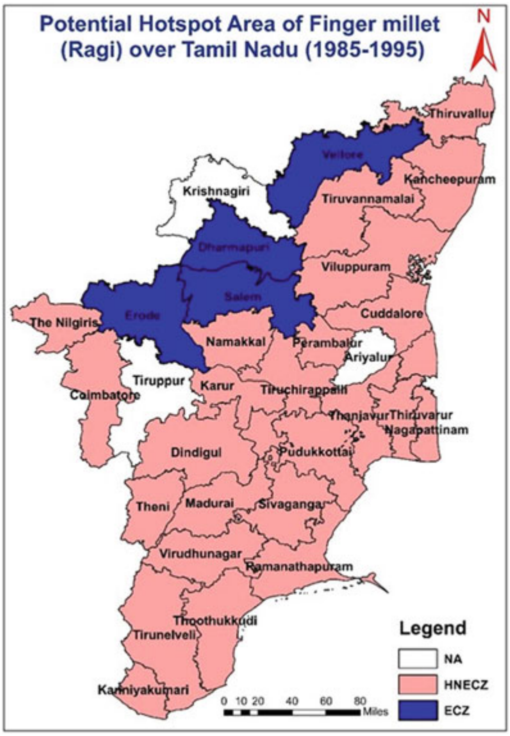


Fig. 7.9 Efficient cropping zone (ECZ) of finger millet (Ragi) crop during 1985–1995 over Tamil Nadu

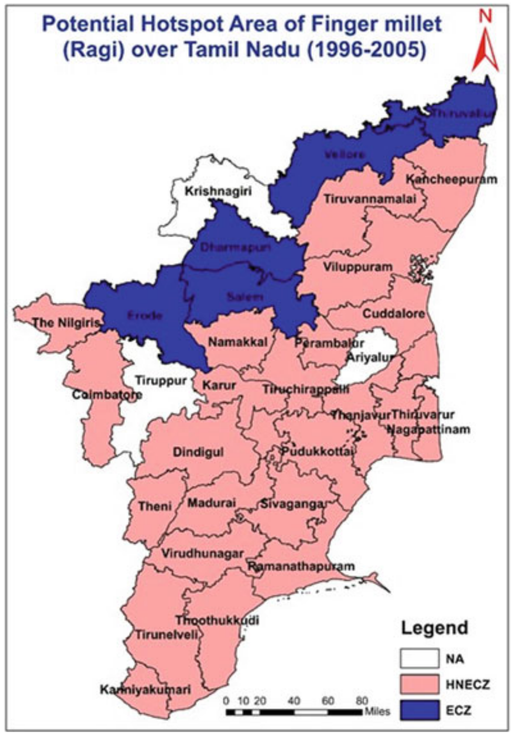


Fig. 7.10 Efficient cropping zone (ECZ) of finger millet (Ragi) crop during 1996–2005 over Tamil Nadu

access to better quality millet seeds. Finger millet yield in central Nepal has been increasing at 7.39 and 36.9 kg/ha yearly, even in lower tropical and upper tropical to subtropical climates, respectively (Luitel et al. 2019). In this purview, geospatial modeling using ECOCROP would assist in selecting the most suitable location for cultivating millet crops (Parthasarathy et al. 2016).

7.4 Conclusion

The suitability of finger millet crops in Tamil Nadu state and the PAB, in particular, has been analyzed using the ECOCROP agro-climatic spatial modeling tool. The analysis outcomes would definitely benefit the farmers, agricultural researchers, policymakers, and other stakeholders in identifying the potential finger millet growing areas. Improvements in inputs, weather early warnings, cultivation practices, post-harvest technologies, and value-added services are critical steps toward improving livelihood and nutritional security. Modeling shows much better suitability for finger millet cultivation in the entire state, especially in northeast coastal areas and Nilgiris, southwest of Coimbatore, Theni, Dharmapuri, Salem, and the north of Namakkal, Vellore districts, etc. With its National Mission on Sustainable Agriculture and Food Security, India is working toward food and nutritional security. It is working together to scale up nutrition in SUN countries. Different organizations are working internationally, nationally, and regionally to achieve and enhance nutritional security by promoting millet varieties. These geospatial modeling analyses enabled us to understand the state and basin-level potential zones.

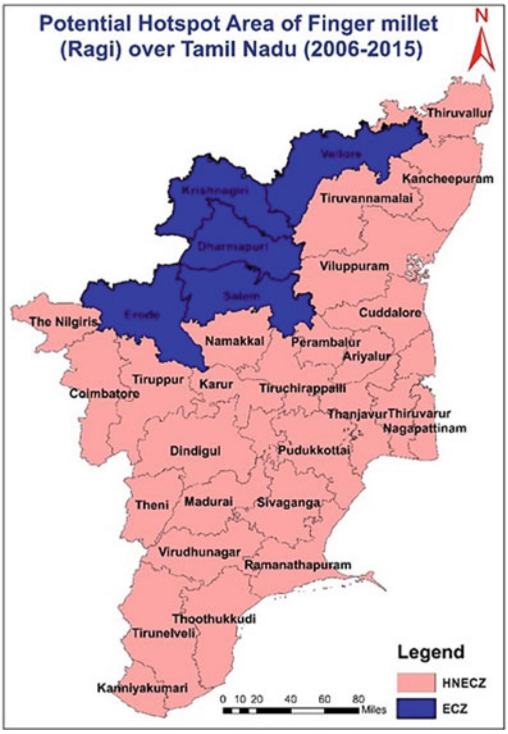


Fig. 7.11 Efficient cropping zone (ECZ) of finger millet (Ragi) crop during 2006–2015 over Tamil Nadu

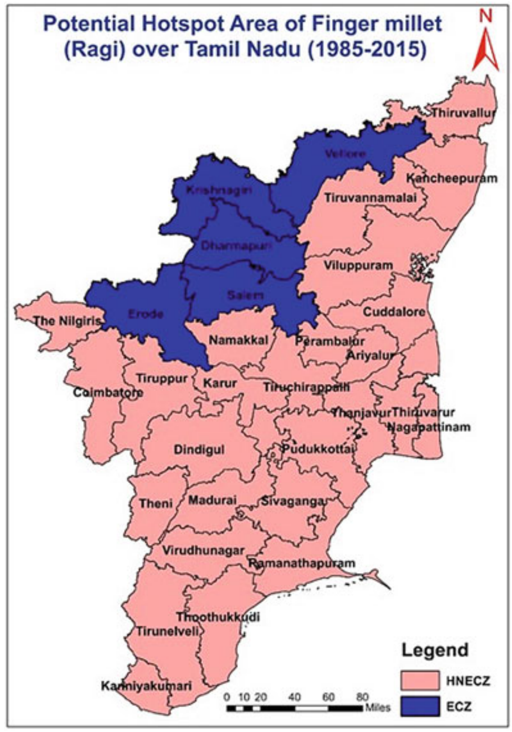


Fig. 7.12 Efficient cropping zone (ECZ) of finger millet (Ragi) crop during 1985–2015 over Tamil Nadu

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Conflict of Interest The authors state that they do not have any conflicts of interest.

References

Bandyopadhyay T, Muthamilarasan M, Prasad M (2017) Millets for next generation climate-smart agriculture. Front Plant Sci 8:1266. https://doi.org/10.3389/fpls.2017.01266

Das J, Gayen A, Saha S, Bhattacharya SK (2017) Modelling of alternative crops suitability to tobacco based on analytical hierarchy process in Dinhata subdivision of Koch Bihar district, West Bengal. Model Earth Syst Environ 3(4):1571–1587. https://doi.org/10.1007/s40808-017-0392-y

FAO (2012) Food security and nutrition and sustainable agriculture, accessed from Food security and nutrition and sustainable agriculture. Department of Economic and Social Affairs (un.org).

Fish CS (2020) Cartographic content analysis of compelling climate change communication. Cartogr Geogr Inf Sci 47(6):492–507. https://doi.org/10.1080/15230406.2020.1774421

Gupta SM, Arora S, Mirza N, Pande A, Lata C, Puranik S, Kumar J, Kumar A (2017) Finger millet: a "certain" crop for an "uncertain" future and a solution to food insecurity and hidden hunger under stressful environments. Front Plant Sci 8:643. https://doi.org/10.3389/fpls.2017.00643

Hijmans RJ, Guarino L, Cruz M, Rojas E (2001) Computer tools for spatial analysis of plant genetic resources data: 1 DIVA-GIS. Plant Genet Resour Newsl 127:15–19

IPCC (2012) IPCC: Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA, 582 pp

Knight KW, Messer BL (2012) Environmental concern in cross-national perspective: the effects of affluence, environmental degradation, and world society. Soc Sci Q 93(2):521–537

Koushik N, Sankar T (2020) Potential zones of turmeric and coriander cultivation in Tamilnadu. Int J Environ Clim Change 10(12):20–30. https://doi.org/10.9734/ijecc/2020/v10i1230281

Luitel DR, Siwakoti M, Jha PK (2019) Climate change and finger millet: perception, trend and impact on yield in different ecological regions in Central Nepal. J Mt Sci 16:821–835. https://doi.org/10.1007/s11629-018-5165-1

Parthasarathy U, Nandakishore OP, Jayarajan K, Saji KV, Babu KN (2016) Prediction of crop suitability of certain Indian spices—A GIS approach. In: Raju N (ed) Geostatistical and geospatial approaches for the characterization of natural resources in the environment. Springer, Cham. https://doi.org/10.1007/978-3-319-18663-4_124

Pradip CS, Panneerselvam RD, Bharathy Dheebakaran GA, Geethalakshmi V, Ragunath KP, Kowshika N (2018) Status of Bengal gram over Tamilnadu. Agric Sci Dig 38(3):193–196

Quach Q, Jenny B (2020) Immersive visualization with bar graphics. Cartogr Geogr Inf Sci 47(6):471–480. https://doi.org/10.1080/15230406.2020.1771771

Ramachandran A, Dhanya P, Jaganathan R, Rajalakshmi D, Palanivelu K (2017) Spatiotemporal analysis of projected impacts of climate change on the major C3 and C4 crop yield under representative concentration pathway 4.5: Insight from the coasts of Tamil Nadu, South India. PLoS ONE 12(7):e0180706. https://doi.org/ https://doi.org/10.1371/journal.pone.0180706.

Ramirez-Villegas J, Jarvis A, Läderach P (2013) Empirical approaches for assessing impacts of climate change on agriculture: the EcoCrop model and a case study with grain sorghum. Agric for Meteorol 170:67–78

Sankar T, Arul Prasad S, Dheebakaran GA (2019) Identification of efficient cropping area for groundnut over north-western zone of Tamil Nadu. In: Proceedings of the national seminar on current trends and challenges in sustainable agriculture. ISBN: 978-93-5351-321-4

Sankar T, Kowshika N (2020) Delineating efficient cropping zones of potato and chilli in Tamilnadu. Int J Environ Clim Change 10(11):143–154. https://doi.org/10.9734/ijecc/2020/v10i1130275

Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK (2021) Pearl millet: A climate-resilient nutricereal for mitigating hidden hunger and provide nutritional security. Front Plant Sci 12:659938. https://doi.org/10.3389/fpls.2021.659938

Shukla A, Lalit A, Sharma V, Vats S, Alam A (2015) Pearl and finger millets: the hope of food security. Appl Res J 1:59–66

Sivakumar MVK, Das HP, Brunini O (2005) Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. Clim Change 70:31–72. https://doi.org/10.1007/s10584-005-5937-9

Varadan RJ, Kumar P. (2015) Mapping agricultural vulnerability of Tamil Nadu, India to climate change: a dynamic approach to take forward the vulnerability assessment methodology

Yadav MK, Singh RS, Singh KK, Mall RK, Patel CB, Yadav SK, Singh MK (2015) Assessment of climate change impact on productivity of different cereal crops in Varanasi India. J Agrometeorol 17(2):179–184