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RESEARCH ARTICLE

Sustainable water resource management under changing climate in north interior Karnataka: Insights from CROPWAT modelling on soybean

Hemareddy Thimmareddy[1*], R H Patil[2], Bheemashankar Biradar[3], Mohammed Rizwan Saif[4], Mahesh Haroli[5], Amith G[5], Arjun Shreepad Hegde[6] & Devappa[7]

[1]Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Department of Agronomy, University of Agricultural Sciences, Dharwad 580 005, Karnataka, India

[3]Department of Agricultural Meteorology, University of Agricultural Sciences, Dharwad 580 005, Karnataka, India

[4]India Meterological Department, Itanagar 791 111, Arunachal Pradesh, India

[5]Centre for Climate Resilient Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Iruvakki, Shivamogga 577 201, Karnataka, India

[6]Zonal Agricultural and Horticultural Research Station, Hiriyur, KSNUAHS, Shivamogga 577 412, Karnataka, India

[7]Division of Agriculture Physics, Indian Agricultural Research Institute, New Delhi 110 012, India

[8]Department of Soil and Water Conservation, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: hemaraddi4138406@gmail.com

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Abstract

The increasing scarcity of water resources, exacerbated by both natural factors such as increasing erraticity of rainfall over space and time and human-induced mismanagement practices, poses a significant global challenge. This study focused on the North Interior Karnataka (NIK) region, characterized by a semi-arid ecosystem, where water resources are under pressure due to a growing demand for food and changing climates. Soybean is an important oilseed crop in NIK and it faces challenges related to climatic variability, thus requires quantifying crop water demand and its management in coming years. CROPWAT model was used to estimate soybean crop water requirement in response to changing climates. Weather data was analysed, including rainfall and temperature, from recent past three decades (1991-2020) and projected climates of coming three decades (2021-2050) across 12 districts of NIK. The model simulated output revealed an increasing trend in reference evapotranspiration under projected climates, driven by rising temperatures. Spatial distribution maps across NIK illustrated impact on Crop Evapotranspiration (ET_c) and Irrigation Requirements (IR), with variations among districts. Further, this study examined the effects of delayed sowing on ET_c, revealing a decreased pattern over 60 years. Effective rainfall also influenced irrigation requirements, showing an increase in most districts under projected climates. This work underscored the urgency of efficient use of water. The CROPWAT model proved effective in estimating soybean water requirements, providing valuable insights for sustainable agricultural practices in the face of changing climates and water challenges.

Keywords

CROPWAT; crop evapotranspiration; effective rainfall; irrigation requirement; NIK

Introduction

Water is becoming increasingly scarce worldwide. Aridity and recurring drought in each region are natural causes for water scarcity. Human activity induced desertification and mismanagement of rainfall water have aggravated water scarcity while at the same time increasing population is creating an additional burden on it (1). The quality of water is deteriorating day by day, making worst scenario of quality available water. Thus, improved management and planning of the water resources are needed to ensure suitable use and distribution of the water among competing users. Scarce water resources and increasing competition for water will reduce further its availability for irrigation. Achieving better efficiency of water use will be a primary challenge for the near future and will include employment of advanced techniques and practices that deliver a more accurate supply of water to crops (2).

Soybean is a pulse-cum-oilseed crop popularly known as 'miracle crop' due to its high protein (42-45 %) and oil (19-20 %) content. It being the leguminous crop has the capacity to fix the nitrogen thereby increasing soil fertility. It enhances soil fertility by fixing atmospheric nitrogen at the rate of 125-150 kg/ha of N and leaves around 30-40 kg/ha of N for succeeding crops (3). The plant residues that are added to soil decompose in a shorter period and improve the soil physical conditions and fertility status of the soil. Being rich in protein, carbohydrates and minerals, soybean cake is used also as manure.

Soybean contributes around 43 % to the total oilseeds and 25 % to the total oil production in the country. It grew to 121.19 m ha in the world producing 336.62 m t at a productivity of 2780 kg/ha (4). Currently India holds fourth position in production with 12.98 m t from 12.14 mha a productivity of 1069 kg/ha. However, in Karnataka state, it is cultivated in 0.38 m ha with the production and productivity of 0.44 m t and 1147 kg/ha, respectively. Belagavi, Bidar, Dharwad, Haveri and Bagalkote districts are the major soybean growing districts of Karnataka from NIK region (5).

NIK region consists of semi-arid climate at 300 to 730 meters elevation that constitutes the northern part of the South Indian state of Karnataka. This region lies within the Deccan thorn scrub forests eco-region, which extends north into eastern Maharashtra. This region is predominantly covered with rich black cotton and red loamy soils, gently sloping lands and plains and summits of plateau and table lands. NIK region is one of the drier regions of India receiving ~660 mm rainfall per annum (6). Though the region is semi-arid, part of Belagavi district receives mean annual rainfall of 870 mm, that makes western taluks of Belagavi lush and green throughout the year whereas Vijayapura district receives as low as 540 mm of rainfall annually in the region making it much drier (7). In this context, the study was planned to estimate the water requirement of soybeans for the changing climates of North Interior Karnataka (NIK) using CROPWAT model.

The CROPWAT model is a decision support system developed by the Land and Water Development Division of FAO in 1990 for planning and management of water for irrigation. CROPWAT is a computer-based tool to carry out standard calculations for reference evapotranspiration, crop water and irrigation requirements of different crops and more specifically for the design and management of irrigation schemes. This study aims to estimate the future water requirements of soybean in NIK using the CROPWAT model by comparing them with past climatic conditions. Additionally, the study seeks to formulate suitable adaptive strategies to mitigate the impacts of climate change on soybean water demand.

Methodology

This study included NIK region which is one of the meteorological sub-divisions as per India Meteorological Department (IMD) classification and this sub-division consist mostly semi-arid plateau and constitutes the northern part of the Karnataka state. It consists of 12 districts namely Bagalkote, Belagavi, Ballari, Bidar, Dharwad, Gadag, Haveri, Kalaburagi, Koppal, Raichur, Vijayapura and Yadagiri (Fig. 1). Cereals like bajra, sorghum, maize, paddy, wheat, minor millets and pulses like chickpea, pigeon pea, greengram, soybean, blackgram, cowpea and oil seeds like groundnut, sunflower, soybean, sesame, castor, safflower and commercial crops like sugarcane, chilli and cotton are the major crops grown in this region. Some of the horticulture crops like grapes, pomegranate, mango, guava, lemon, banana along with most vegetables etc., are also grown. The minimum data set to run the FAO CROPWAT model was collected in this study and is briefed below here.

Climate / Rainfall data: The climate data, including that on rainfall, were downloaded from NASA power web portal for the period from 1991 to 2020 (*https://power.larc.nasa.gov/data-access-viewer/*) where as projected climate data for the coming three decades (2021-2050) were downloaded from Copernicus Climate Change Service (IPSLCM5A model), RCP 6.0 climate scenario (*https://climate.copernicus.eu*). The collected data from 1991 to 2050 were compiled and categorized into six decadal periods and further monthly averages for all these data were also calculated. The data were then averaged to past climate (1991-2020) and projected climate (2021-2050) for the analysis (Table 1). The analyzed weather data along with data on soybean crop were fed into CROPWAT model to calculate Reference Evapotranspiration (ET_o).

Crop data*:* The minimum dataset required to run CROPWAT model, including those on phenology, were collected from a field experiment carried out during Kharif 2020 and 2021 as part of All India Coordinated Research Project (AICRP) on soybean with four dates of sowing starting from 7th June to 28th June at weekly interval, whereas the crop coefficient data of soybean were collected from the FAO chapters. The crop coefficient values (K_c) for initial, mid and late growth stages were borrowed from the FAO publications (8) (Table 2).

Soil data: Soil characteristics of the two most predominant soils from each district of NIK region *i.e.,* black clay and red sandy loam soils were collected from ICAR web portal (*https://krishi.icar.gov.in/Geo_Portal.jsp*) including from NBSS & LUP (*http://www.bhoomigeoportal-nbsslup.in/*).

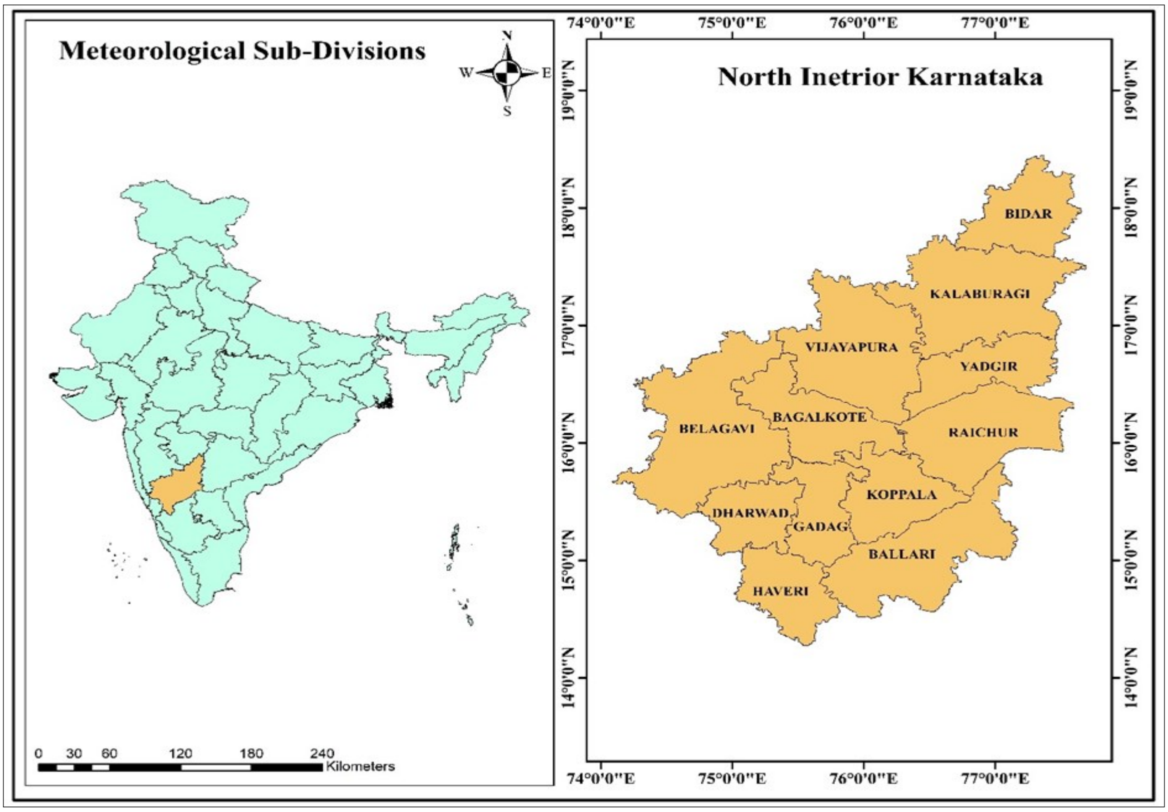


Fig. 1. Study area map.

Table 1. Average weather data during Soybean cropping period (Jun-Sept) of all the 12 districts of NIK for the past climate (1991 - 2020), the projected climate (2021 - 2050) and the difference between the two periods

Districts	Past climate (1991-2020)			Projected climate (2021-2050)			Difference between past & projected climate		
	Rain (mm)	Temp (˚C)	RD	Rain (mm)	Temp (˚C)	RD	Rain (mm)	Temp (˚C)	RD
Bidar	640	26.7	108	812	30.2	81	172	3.6	-27
Bagalkote	444	26.1	95	804	28.4	84	360	2.4	-10
Belagavi	959	25.2	119	637	28.3	85	-322	3.1	-34
Vijayapura	397	27.0	81	819	28.3	87	422	1.4	5
Ballari	419	26.3	82	784	30.1	85	364	3.7	3
Dharwad	870	25.0	117	637	28.3	85	-233	3.3	-34
Gadag	521	25.7	106	652	28.2	88	131	2.5	-19
Kalaburagi	531	27.2	98	809	30.3	79	278	3.1	-19
Haveri	986	25.1	119	652	28.2	89	-333	3.1	-30
Koppal	393	26.2	26	582	28.2	89	189	2.0	63
Raichur	453	27.5	85	802	30.3	84	349	2.8	-3
Yadagiri	461	27.4	93	802	30.3	84	341	2.9	-9
NIK	**589**	**26.3**	**94**	**733**	**29.1**	**85**	**143**	**2.8**	**-9**

*Temp- Temperature, RD- Rainy days

Table 2. The crop coefficient values (K_c) for initial, mid and late growth stages of soybean

Stages/crops	Soybean	
	Days after sowing	K_c values
Initial	15	0.40
Development	18	-
Midseason	45	1.14
Lateseason	17	0.50
Total	95	-

Results and Discussion

Reference Evapotranspiration (ET_o), Crop Evapotranspiration (ET_c), Effective Rainfall (ER) and Irrigation Requirement (IR) play crucial roles in estimating crop water demand and requirements, especially in the context of current and future climates. These parameters are fundamental for informed water resource management and the promotion of sustainable agricultural practices. ET_o serves as a foundational measure for evaporation and transpiration rates under standard conditions, providing essential information for estimating overall water requirements (8). ET_c builds upon ET_o by incorporating crop-specific factors and growth stages, delivering more precise insights into the actual water needs of crops during critical growth periods (8).

Effective Rainfall (ER) is indispensable for evaluating the contribution of natural precipitation to crop water availability. It represents the proportion of rainfall that effectively contributes to soil moisture during the crop period, making it a critical factor, particularly in regions with variable precipitation patterns (9). Irrigation Requirement (IR) becomes vital in arid and semi-arid regions, where it quantifies the additional water necessary for optimal crop growth, compensating for deficits in effective rainfall. Accurate assessments of IR are essential for efficient irrigation management and the promotion of sustainable agriculture, particularly in the face of changing climates (10).

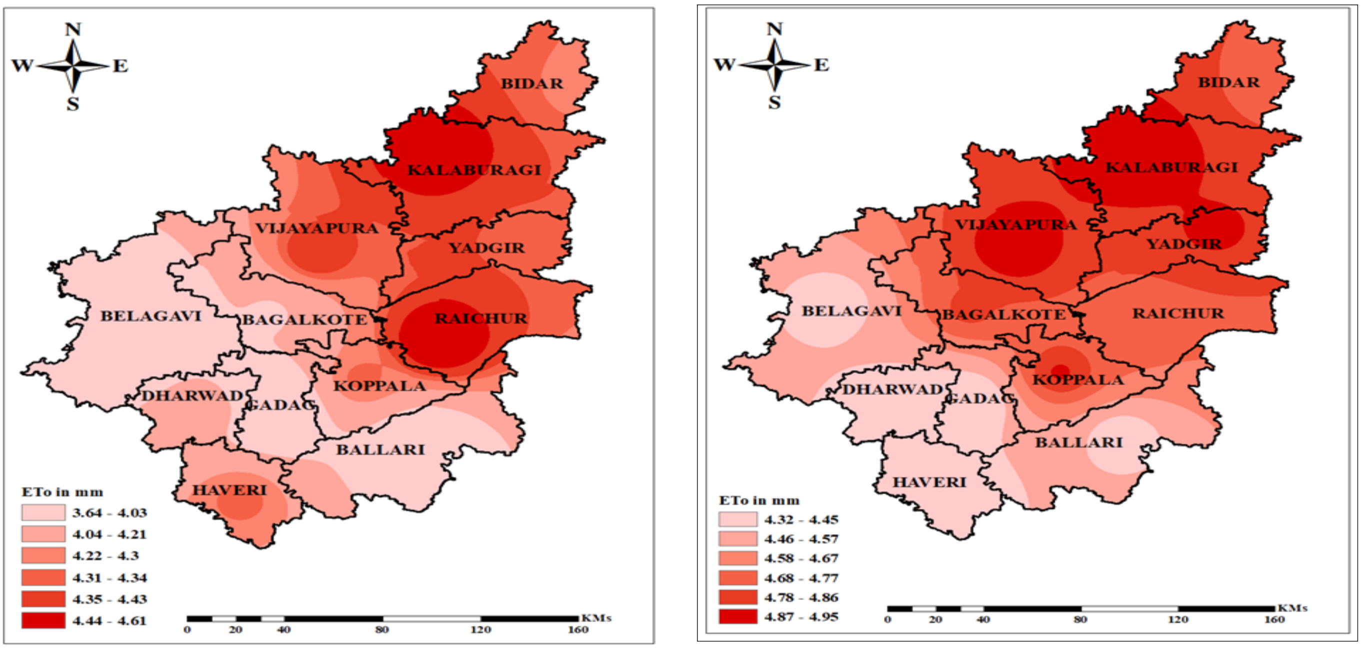
Reference Evapotranspiration (ET_o)

The decadal average of daily Reference Evapotranspiration (ET_o) across all four dates of sowing (DOS) during soybean crop growing season (June-September) were simulated to be the highest for Bidar and Kalaburagi districts (5.42 mm/day) during 2031-2040 decade whereas the lowest ET_o was simulated for Haveri district (3.63 mm/day) during 1991-2000, closely followed by Belagavi district (3.65 mm/day) during two consecutive decades 1991-2000 and 2001-2010 (Table 3). As expected, with rise in temperature, the ET_o of all 12 districts of NIK were higher in projected climates (2021-2050) compared to past climates (1991-2020) during Kharif season of soybean crop growing season (Fig. 2). This is mainly due to the increased average temperature during crop period (June-September) in the projected climates (2021-2050) compared to past climates (1991-2020) for all 12 districts of NIK region (Fig. 2). The highest differences between projected and past climate scenario were simulated for Ballari district (1.08 mm/day) followed by Belagavi district (0.93 mm/day) whereas the lowest difference was simulated for Koppal district (0.14 mm/day) followed by Vijayapura district (0.33 mmday^{-1}) (Table 3). The green gram crops under projected climate (2021-2050) and observed increased ET_o in June and July months of greengram cropping period (June-September) by 41 and 26 mm, respectively. Though the ET_o has decreased in the August and September months (2-5 mm day^{-1}), the change was negligible. The author concludes that the late onset or decreased rainfall in the month of June and increased rainfall in August and September months under projected climate has direct influence.

Crop Evapotranspiration (ET_c)

In comparison to the climates of the past decades (1991-2020), the simulated evapotranspiration (ET_c) for the projected period (2021-2050) exhibited notable variations. The model simulated maximum increases in ET_c by 47.8 mm and 47.3 mm, respectively, for Belagavi and Ballari districts. In contrast, Koppal and Vijayapura districts were simulated to witness reduction by 20.9 mm and 17.9 mm, respectively, under the projected climates (Table 4) (Fig. 3).

This divergence can be attributed to the substantial disparity in Reference Evapotranspiration (ET_o) between the past and projected climates, particularly for Ballari and Belagavi districts. Conversely, Koppal and Vijayapura districts demonstrated the smallest difference in ETo during the soybean crop growing season (June-September) between the two climate periods (Table 4).



a) Past climate (1991-2020) **b**) Projected climate (2021-2050)

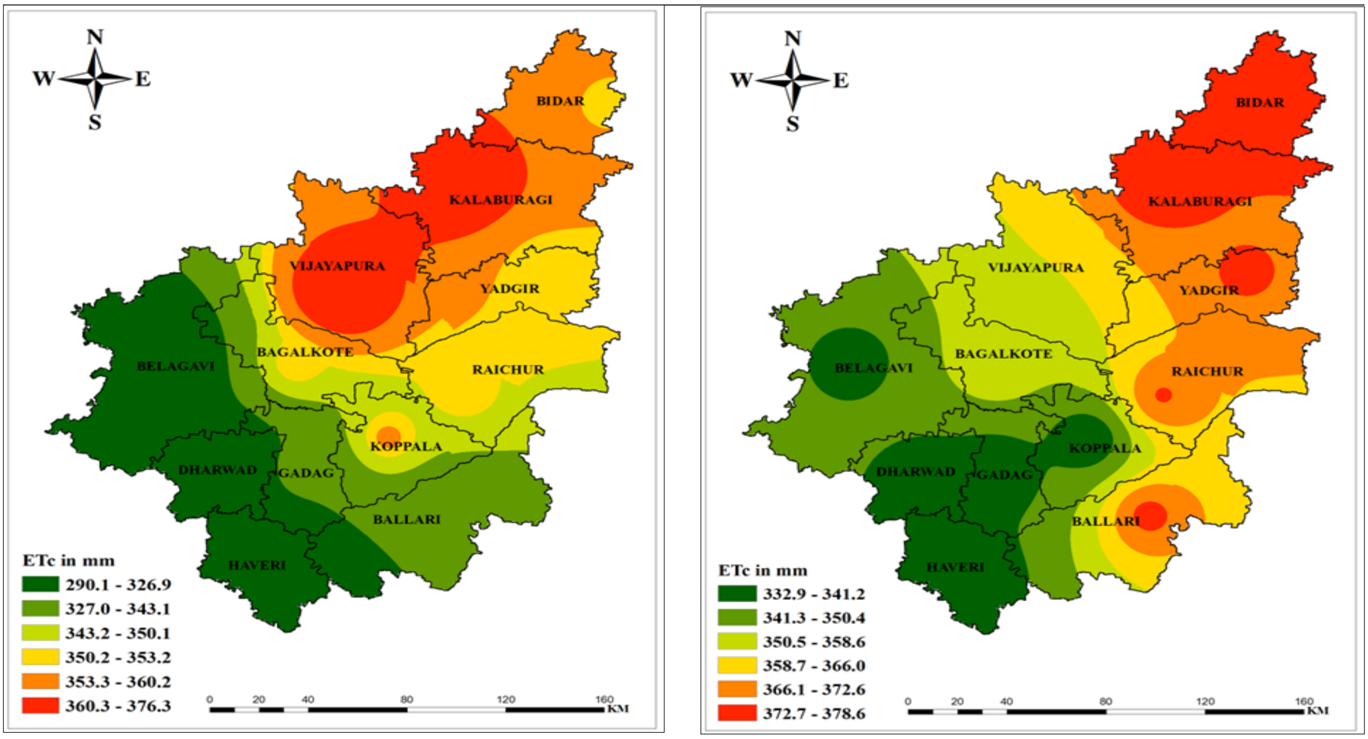
Fig. 2. Spatial distribution of Reference Evapotranspiration (ET_o) (mm day^{-1}) under both past (1991-2020) and projected (2021-2050) climatic scenarios for soybean crop duration (June-September) across NIK.

Table 3. Average reference ET (mm/day) for soybean crop period (June-August) of all 12 districts of NIK at decadal interval

Districts	1991-2000	2001-2010	2011-2020	2021-2030	2031-2040	2041-2050	1991-2020 (A)	2021-2050 (B)	B-A
Bidar	350.1	348.5	360.4	365.2	393.3	377.4	4.57	5.31	0.74
Bagalkote	347.3	352.8	358.9	346.1	360.4	363.3	4.32	5.06	0.74
Belagavi	289.7	290.5	292.8	321.7	340.5	354.2	3.68	4.61	0.93
Vijayapura	373.3	373.5	382.3	346.5	364.2	373.3	4.67	5.00	0.33
Ballari	351.8	351.3	279.1	353.6	389.8	380.7	4.05	5.13	1.08
Dharwad	294.5	295.3	294.5	321.1	340.1	353.8	3.72	4.60	0.88
Gadag	329.4	329.7	339.8	320.1	334.7	348.1	4.14	4.53	0.39
Kalaburagi	365.9	365	377.3	365.1	392.7	375.5	4.69	5.31	0.62
Haveri	289.6	291.3	289.4	319.3	333.1	346.4	3.65	4.51	0.86
Koppal	354.2	352.7	356.8	319.4	334	347.5	4.38	4.53	0.14
Raichur	349.2	350.4	355.5	363.4	385.9	370.3	4.36	5.22	0.85
Yadagiri	348.3	349.4	354.4	363.4	386.2	371.2	4.35	5.23	0.87
NIK	336.9	337.5	336.8	342.1	362.9	363.5	4.215	4.92	0.7025

Table 4. The Crop Evapotranspiration (ET_c), Effective Rainfall (ER) and Irrigation Requirement (IR)of soybean (in mm) under past 30 years (1991-2020), projected 30 years (2021-2050) and difference between them across 12 districts of NIK

	1991-2020 (A)			2021-2050 (B)			Difference between past and projected climates (B-A)		
	ET_c (mm)	ER (mm)	IR (mm)	ET_c(mm)	ER (mm)	IR (mm)	ET_c (mm)	ER (mm)	IR (mm)
Bidar	353	380.6	28.1	378.6	398.5	51.3	25.7	17.9	23.2
Bagalkote	353	312.3	78.5	356.6	376.7	48.3	3.6	64.4	-30.3
Belagavi	291	448.4	2.6	338.8	360.7	39.2	47.8	-87.7	36.6
Vijayapura	376.4	261.1	131.9	358.5	409.5	28.4	-17.9	148.4	-103.4
Ballari	327.4	271.7	85.1	374.7	393.4	46.4	47.3	121.8	-38.7
Dharwad	294.7	434.6	4.3	338.4	360.7	38.9	43.6	-73.9	34.6
Gadag	333	318.9	61.4	334.3	369.4	29.5	1.3	50.4	-31.9
Kalaburagi	369.4	330.4	73.9	377.8	394.4	54.9	8.4	64.1	-19
Haveri	290.1	453.1	2.3	332.9	369.4	29	42.9	-83.7	26.7
Koppal	354.5	256.1	119	333.6	369.4	29.4	-20.9	113.3	-89.6
Raichur	351.7	290	87.9	373.2	409.5	36.3	21.5	119.5	-51.5
Yadagiri	350.7	294.6	84.2	373.6	409.5	36.6	22.9	114.9	-47.6
NIK	337.1	337.7	63.3	355.9	385.1	39.0	18.9	47.5	-24.2



a) Past climate (1991-2020)

b) Projected climate (2021-2050)

Fig. 3. Spatial distribution of Crop Evapotranspiration (ET_c) under both past (1991-2020) and projected (2021-2050) climatic scenarios for soybean across NIK.

Consequently, the temperature differences between the last two decades and the projected climates were also minimal in Koppal and Vijayapura districts.

With delay in sowing, the average ET_c across 60 years period considered in this study showed decreasing patterns for all the districts of NIK region (Table 5). These results were in accordance with the findings previous works reported that normal soybean sowing recorded 16 per cent higher seasonal ET_c compared to the late sowing (11).

Effective Rainfall (ER)

The model simulated values of Effective Rainfall (ER) for all districts, except Belagavi, Dharwad and Haveri districts, exhibited an increase under the projected climates (2021-2050) when compared to the past (1991-2020) (Table 4). This arises from the fact that Belagavi, Dharwad and Haveri districts will receive less rainfall during the projected climate period during June to September months in contrast to the past (1991-2020). In contrast, the remaining nine districts recorded higher rainfall with uneven distribution (reduced rainy days) during the projected

Table 5. Seasonal Crop Evapotranspiration (ET_c), Effective Rainfall (ER) and Irrigation Requirement (IR) in soybean (mm) for the four dates of sowing (DOS) across past (1991-2020) and projected (2021-2050) climates of NIK

Particulars	Past climate				Projected climate			
	07-Jun	14-Jun	21-Jun	28-Jun	07-Jun	14-Jun	21-Jun	28-Jun
ET_c	340.2	333.8	338.1	337.7	376.6	347.8	390.2	357.7
ER	345.5	307.9	303.1	336.2	363.9	313.1	353.4	405.6
IR	62.3	88.7	92.0	66.5	24.7	74.1	103.0	10.0

climates (2021-2050) for the same crop growing period (June-September) directly influencing on reduced ER (Table 1).

Under delayed sowing, an increasing trend in the average ER across all districts of NIK over a span of 60 years (Table 5) was simulated. This can be attributed to a rise in both the quantity and frequency (not intensity) of heavy rainfall during the crop growing period from June to September (Tables 1). Specifically, the months of July and August are projected to receive higher rainfall and a larger number of rainy days compared to June across most districts of NIK for the period from 1991 to 2050. These findings shows very much align with previous works (12), Ministry of Earth Sciences (MoES), Government of India, which states that Karnataka state typically receives the maximum rainfall in July (i.e., 32 % of the Southwest monsoon rainfall), followed by August (26 %), June (24 %) and September (18 %).

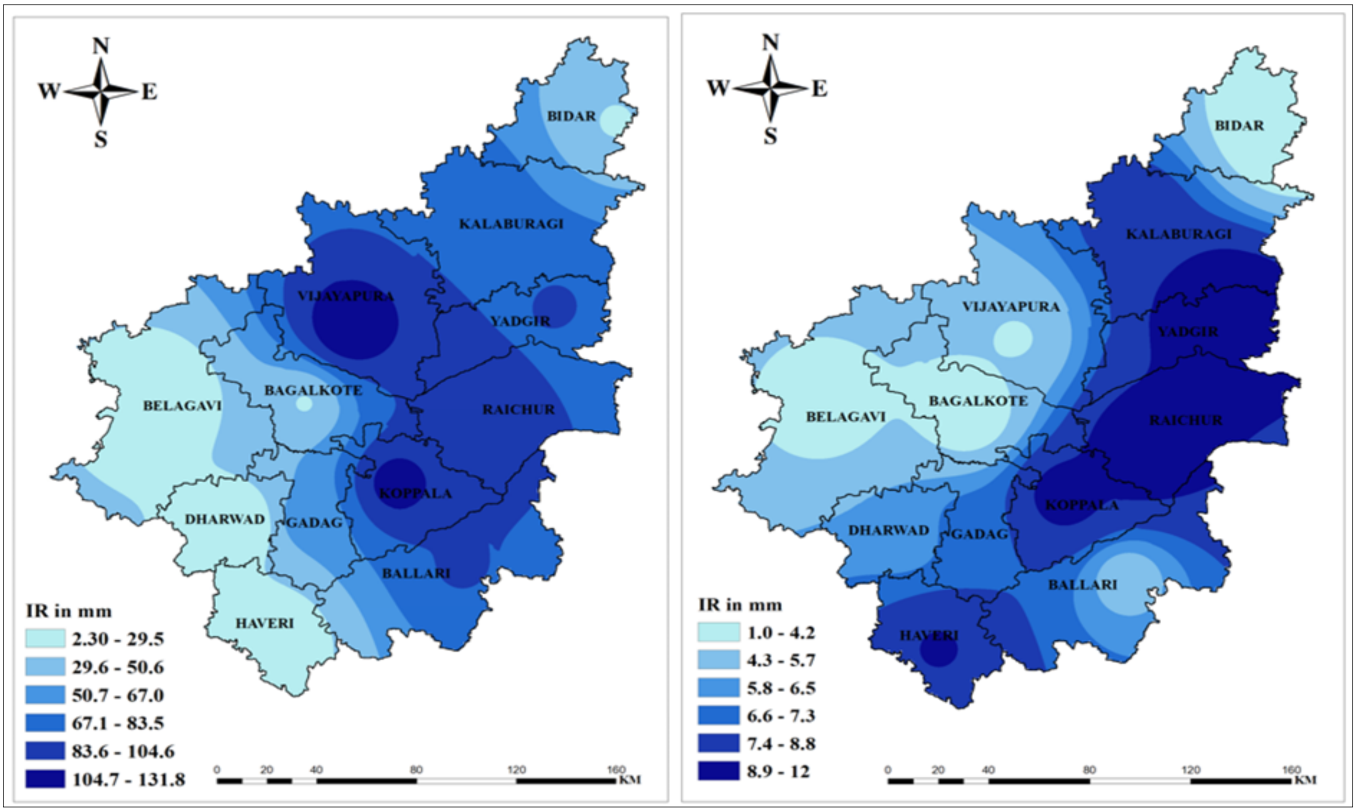
Irrigation Requirement (IR)

In the districts of Bidar, Belagavi, Dharwad and Haveri, the Irrigation Requirement (IR) for soybeans is projected to increase under future climate scenarios compared to past climates (Table 4, Fig. 4). This trend appears to be primarily influenced by variations in rainfall and Effective Rainfall (ER) patterns under the projected climates (Table 1). Districts experiencing increased rainfall and higher ER tended to show a decrease in IR, while those with reduced rainfall and ER showed an increase in IR. However, an exception was noted in Bidar district, where the IR increased despite the observed increase in rainfall. This discrepancy could be attributed to Bidar's higher projected temperature increase of 3.6 ^{0}C, which is the highest among all 12 districts in Northern Interior Karnataka (NIK), where the average temperature increase is projected to be 2.8 ^{0}C. Additionally, Bidar is expected to have fewer rainy days, which could further contribute to the increased IR despite the overall rise in rainfall.

The further delay in sowing was simulated to result in an upward trend in the average IR across all districts of NIK over a span of 60 years (Table 5). This can be attributed to the escalating pattern of ET_c and the diminishing pattern of ER associated with delayed sowing across all 12 districts of NIK (Table 4).

Collectively, these parameters contribute to a comprehensive understanding of water demand and availability for crops, supporting decision-makers in planning and managing water resources (13). Given the evolving climate conditions, accurate estimations of these parameters are indispensable tools for adapting agricultural practices, ensuring food security and bolstering resilience in the agricultural sector.

The interplay between ET_o, ET_c, ER and IR reveals a complex web of relationships crucial for understanding water dynamics in soybean cultivation. Elevated ET_o, often associated with rising temperatures in projected climates, directly influences an increase in ETc, signifying heightened crop water demand. This augmented demand poses challenges, especially when ER undergoes fluctuations due to changing precipitation patterns. A reduction in ER exacerbates the reliance on irrigation, exemplified by higher IR, as crops grapple with insufficient natural moisture. Conversely, regions experiencing an increase in ER may witness moderation in IR (14). Furthermore, the study highlights the impact of delayed sowing, showcasing a consistent rise in ET_c and subsequent IR.



a) Past climate (1991-2020) **b)** Projected climate (2021-2050)

Fig. 4. Spatial distribution of Irrigation Requirement (IR) under both past (1991-2020) and projected (2021-2050) climatic scenarios for soybean across NIK.

Conclusion

The study underscores the intricate dynamics of water resources in soybean cultivation within the North Interior Karnataka (NIK) region, grappling with the compounding challenges of increasing water scarcity and erratic climatic patterns. The rising temperatures, evidenced by an escalating trend in Reference Evapotranspiration (ET_o), directly contribute to heightened ET_c and, consequently, augmented IR. ER fluctuations further amplify the reliance on irrigation, especially in districts experiencing reduced natural moisture. The analysis also highlights the impact of delayed sowing, showing a consistent increase in IR under future climate conditions, followed by a decline with the last sowing date. Based on these findings, early sowing in the first week of June or late sowing in early July is recommended for farmers to optimize available moisture and minimize irrigation requirements. These findings emphasize the urgent need for adaptive water management strategies, tailored to the specific climatic nuances of each district to ensure sustainable soybean production.

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Authors' contributions

HT and RHP done the conceptualization. Data curation was done by BB and MH. ASH and AG perform the formal analysis, RHP, ASH and DP performed the investigations and the methodology was carried out by HT, AG and DP. Project administration was done by RHP, MRS and MH. HT, RHP and BB collects the resources and carried out the software part. RHP, MRS and MH performs the supervision. HT and AG done the validation and visualization by HT and BB. HT wrote the original draft. DP, ASH, AG and MRS wrote review & editing. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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