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Research paper

Climate change impacts on water flux dynamics in Shingoda basin having agriculture and forest ecosystems: A comprehensive analysis

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ABSTRACT

An assessment of climate chnage and its impacts on water fluxes in the Shingoda basin of the Saurashtra region having 14% agriculture and 75% forest were made through analysis of time series (1951-2100) of bias corrected maximum/minimum temperature and rainfall (RCP4.5), rreference evapotranspiration (ET_o), evapotranspiration (ET_c) and runoff. Results showed significant climate changes in the basin, with day mean temperature rising from 24.4°C in the second half of the 20th century to 26.5°C and 27.9°C in the first and second half of the 21st century, respectively. During the first and second half of the 21st century, seasonal rainfall increased by 23.0% and 46.33%, and runoff rose by 46.78% and 86.40% compared to the second half of the 20th century. However, annual reference evapotranspiration (ET_o) decreased by -1.41% and -6.5%, and crop evapotranspiration (ET_c) decreased by -3.2% and -9.8% in the same periods. The analysis also revealed a deficit of -16.10% in downward water flux (rainfall) in the first half of the 20th century, followed by a surplus of 8.46% and 28.37% compared to the upward flux (ET_c) in subsequent periods. The upward water flux deficit during 2nd half of 20th century were supported by evidence of depleted groundwater levels and seawater intrusion in the study area.

Keywords: RCM, SWAT, Simulation, Climate Change, Water Flux, Evapotranspiration

Climate change resulting from global warming has become an established reality, with its effects being observed worldwide over an extended period of time. Termed as "global warming," climate change is an undeniable phenomenon that is modifying the temporal and spatial distribution of water resources. Its far-reaching consequences encompass profound impacts on society, economy, agricultural production and ecological systems, thereby capturing increasing attention from academic and governmental institutions worldwide. The hydrosphere of the earth has been particularly influenced by climate change, with a focus on water fluxes such as rainfall, runoff, evaporation and evapotranspiration, which hold utmost significance for agricultural practices. Despite the rise in CO_2 levels, climate change can have direct and indirect adverse effects on agriculture, as well as water and food security. Numerous studies have provided compelling evidence of global warming and climate change and their impact on water fluxes, such as rainfall, runoff and evapotranspiration (ET_o) or crop water requirements which have been discussed at length by Anonymous, (2017), Lunagaria *et al., (*2015), Rank *et al., (*2020) and Pandey (2023).

Meteorological parameters exert a significant influence on water dynamics in vegetation, impacting crucial fluxes such as evaporation, evapotranspiration, rainfall and runoff. Effective management of these fluxes is imperative to optimize productivity and ensure the sustainability of water resource management (Rank and Satasiya, 2022). With an ever-increasing population, the need to enhance productivity from limited resources becomes crucial. This can only be achieved through the implementation of various technological interventions in water management (Rank and Vishnu, 2021; Rank and Satasiya, 2022; Rank and Vishnu, 2022; Rank *et*

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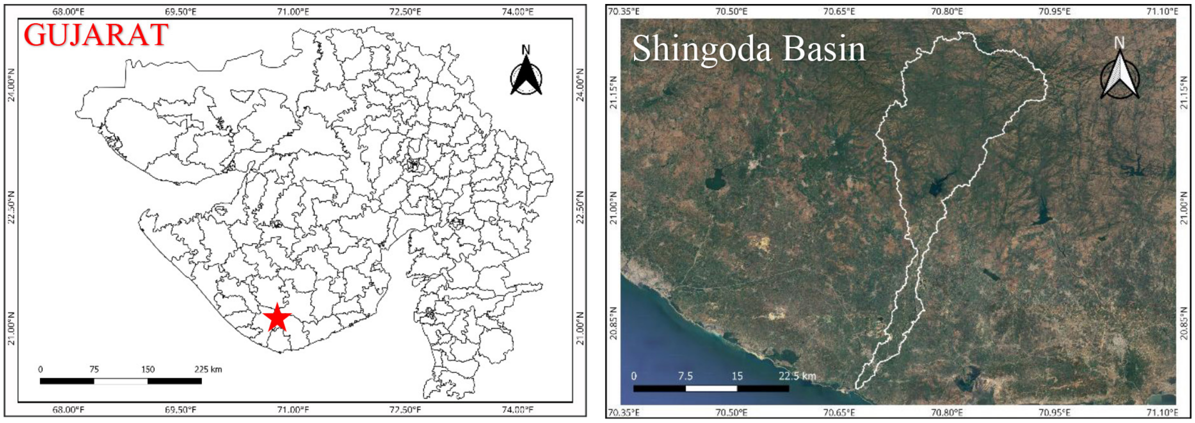

Fig. 1: Location of Study Area

al., 2022; Rank *et al.,* 2023). The impacts of climate change on water fluxes vary across regions due to changes in rainfall patterns, temperature, humidity, wind speed and sunshine hours as reported by Rank *et al.* (2020). Recognizing the importance of location-specific studies, this research aimed to assess the climate change impacts on water fluxes in the forest and agricultural ecosystems of the Shingoda basin in Gujarat, India.

MATERIALS AND METHODS

Study location

The basin encompasses a total area of 423 sq. km., with agricultural ecosystems covering 14% and forests covering 75% of the area (Fig. 1). The major crops are groundnut, cotton, sugarcane, Mango and coconut. Soil textures in the basin consist of 42% fine, 35% loamy, 22% clayey and 1% fine loamy soils. The climate of the region is classified as tropical and sub-tropical, with the coldest month being January, characterized by a monthly mean minimum temperature of 10 °C. Conversely, May is the hottest month, with a monthly mean maximum temperature of 33.6 ºC.

Data collection

The historical observed data of daily rainfall were obtained from State Water Data Center, Gandhinagar for 1 station falling in basin. The observed meteorological data (maximum/minimum day temperature) for the that station was obtained using the observed data of weather station at Main Sugarcane Research Station, Kodinar and Agro meteorological observatory, Junagadh Agricultural University, Junagadh by comparing the available records of climate data of common periods. Remote sensing digital data of dereferenced digital elevation map (DEM), land use/cover and soil map were sourced from BISAG, Gandhinagar. Simulated data for daily maximum/minimum temperature and rainfall of the RCA4 RCM model were acquired for the base period (1951-2005) and future scenario (2006-2100) under the IPCC SRES RCP4.5 from IITM in Pune.

Bias corrections of simulated climate data

The RCM simulations of temperature and precipitation must be handled with caution as they often show significant biases. Therefore, the bias correction was performed on daily simulated maximum and minimum temperature, as well as precipitation, using the widely used and recommended method known as Probability Distribution Mapping (Teutschbein and Seibert, 2013).

SWAT model application

SWAT is a physically based, spatially semi-distributed and computationally efficient river basin model specifically designed to assess the impact of climate change on water fluxes within the basin over extended timeframes. The bias-corrected data of daily rainfall, maximum and minimum day temperature, dereferenced digital elevation map (DEM), soil map and land use/ cover for the period 1951-2100 were utilized as inputs in the Soil and Water Assessment Tool (SWAT) model. The SCS curve number for the runoff and Hargreaves method for reference evapotranspiration (ET_o) estimation were opted in SWAT model (Neitsch *et al.,* 2005).

Land use/cover evapotranspiration

The land use/cover area within the basin, along with the corresponding evaporative/crop coefficient (K_c), are provided in Table 1. Evaporation from water bodies and evapotranspiration from various agricultural and horticultural crops, forest cover and pastures/sparse grass were estimated by multiplying the crop coefficient with the reference evapotranspiration (ET_o) obtained through the SWAT model (Rank, 2008), Gontia and Tiwari, 2010, Mehta and Pandey, 2016 and Corbari *et al.,* 2017). The basin's equivalent upward water flux (K_{be}) was calculated, taking into account the area weightage.

Climate change and its impact assessment on water flux

The assessment of climate change and its impacts involved conducting trend analyses on seasonal and annual time series data for variables such as day maximum temperature, day minimum temperature, day mean temperature, reference evapotranspiration (ET_o) and water fluxes (rainfall, runoff and evapotranspiration) based on land use and land cover. The trend analysis was performed using the standard methods outlined by Kendall and Gibbons (1990). In the study region, rainfall predominantly occurs between June and October. To account for all pre- and post-monsoon rainfall events, the monsoon, winter and summer seasons were defined as the period

Table 1: Land use/land cover with crop coefficient in the basin

Land use/land cover	Area (Sq.km) during			Crop coefficient (Kc) during		
	Monsoon	Winter	Summer	Monsoon	Winter	Summer
Forest area	315.00	315.00	315.00	0.8	0.55	0.41
Horticulral crops (Mango/ coconut)	9.85	9.85	9.85	0.8	0.8	0.8
Water bodies	7.63	5.72	2.29	0.95	0.86	0.8
Pastures/sparse grass	21.25	21.25	21.25	0.75	0.35	0
Buildup area	4.23	4.23	4.23			
Land occupied in small nalas/bunds	5.45	5.45	5.45			
Groundnut	26.82	0	4.25	0.8		0.8
Cotton	20.86	20.86	0	0.9	0.5	
Sugarcane	11.92	11.92	11.92	0.8	1.25	1.0
Bajra	0	0	5.15			0.9
Wheat & other winter crops	0	23.836	0		0.9	
Sesame	0	0	7.25			0.75
Fallow land	0.00	2.98	31.02			
Total Agric Land	59.59	59.59	59.59			
Total Basin area :	423.00					
Basin's equivalent upward water flux coefficient (K_{be})				0.79	0.57	0.39

from June 1st to October 31st, November 1st to February 15th and February 16th to May 31st, respectively. This seasonal categorization was applied to all weather-related (temperature), hydrological (rainfall, runoff) and agro-meteorological (ET_o and ET_c) variables.

RESULTS AND DISCUSSION

The results of the analysis conducted on the time series data for seasonal averages of day maximum temperature, day minimum temperature and day mean temperature along with seasonal rainfall, runoff, reference evapotranspiration (ET_o) and evapotranspiration (ET_c) from vegetation during different seasons for the periods 1951-2000, 2001-2050 and 2051-2100 are presented in Table 2.

Day maximum temperature

In the study area, the day maximum temperature showed an increasing trend over time. During 1951-2000, the average day maximum temperature ranged from 31.9°C in the monsoon to 32.7°C in summer, with an annual average of 31.9°C. In the period of 2001-2050, these values increased to 32.9°C, 32.5°C, 35.0°C and 33.4°C, respectively. Furthermore, during 2051-2100, the average day maximum temperature rose to 34.0°C, 33.8°C, 36.2°C and 34.6°C, respectively. These findings indicate a warming trend in day maximum temperatures, both in the past and projected for the future, consistent with global observations.

Analyzing the trends, during 1951-2000, the seasonal average of day maximum temperature showed a significant increase of 0.29 °C/decade and 0.2 °C/decade respectively in summer and annual periods, while the trends in monsoon and winter were not statistically significant. From 2001-2050, the seasonal average of day maximum temperature exhibited significant increases of 0.29°C, 0.32°C, 0.53°C and 0.35°C/decade in monsoon, winter, summer and annual periods, respectively. However, in the latter half of the 21st century (2050-2100), the trends showed insignificant decreases across all seasons. This suggests that the rate of warming due to day maximum temperature will be higher in the first half of the 21st century compared to the latter half of both the 20th and 21st centuries.

Day minimum temperature

The day minimum temperature showed a warming trend in the past and is projected to continue in the future, similar to global observations. From 1951-2000, the average day minimum temperature ranged from 22.6°C in the monsoon to 18.4°C annually. In the period of 2001-2050, these values increased to 25.3°C, 13.7°C, 20.7°C and 20.5°C, respectively. Furthermore, during 2051-2100, the average day minimum temperature further rose to 28.2°C, 15.3°C, 22.8°C and 22.8°C, respectively. Analyzing the trends, during 1951-2000, the seasonal average of day minimum temperature exhibited significant increases of 0.43°C, 0.44°C and 0.27°C/decade in the monsoon, summer and annual periods, respectively, while the trend in winter was not statistically significant. From 2001-2050, the seasonal average of day minimum temperature showed significant increases of 0.59°C, 0.34°C, 0.48°C and 0.52°C/decade in monsoon, winter, summer and annual periods, respectively. During 2051-2100, a 5% significant level increase of 0.29°C/decade was observed in the monsoon period and 0.12°C/decade was observed annually. Insignificant decreasing and increasing trends were found in the winter and summer seasons, respectively. The rate of warming due to day minimum temperature is expected to be higher in the first half of the 21st century compared to the latter half of both the 20th and 21st centuries, similar to the trend observed for day maximum temp8erature.

Day mean temperature

During the period of 1951-2000, the average day mean temperature ranged from 26.5°C in the monsoon to 24.4°C annually. Subsequently, from 2001-2050, these values increased to 28.5°C, 22.8°C, 27.4°C and 26.5°C, respectively. Furthermore, in the period of 2051-2100, the average day mean temperature further rose to 30.0°C, 24.2°C, 28.6°C and 27.9°C, respectively. Significant increases were observed in the seasonal average of day mean temperature during 1951-2000, with rates of 0.14°C/decade in the monsoon, 0.24°C/decade in summer and 0.14°C/decade annually at significant levels of 5%, 1% and 1%, respectively. However, no statistically significant trend was observed for winter. In the subsequent period of 2001-2050, a significant increase of 0.44°C/decade in the monsoon, 0.38°C/decade in winter, 0.35°C/decade in summer and 0.4°C/decade annually was observed at a 1% significant level. Conversely, in the latter half of the 21st century (2050-2100), insignificant increasing trends were observed in the monsoon, summer and annual periods, while a decreasing trend was noted for winter. These findings suggest that the rate of warming due to day mean temperature will be higher in the first half of the 21st century compared to the latter half of both the 20th and 21st centuries.

The region has experienced a warming trend, and this trend is expected to be more pronounced in the day minimum temperature compared to the day maximum temperature. The similar results were also found by Anonymous, 2017, Rank *et al.,* (2020), Lunagaria *et al.,* (2015) and Pandey (2023). The warming trend has not been uniform worldwide, as the upward temperature trend globally indicates that more areas are experiencing warming than cooling (NOAA, 2023).

Rainfall

The seasonal rainfall data for the years 1951 to 2100 were analyzed, showing an increasing trend in the monsoon season. The average monsoon rainfall for the periods of 1951-2000, 2001-2050 and 2051-2100 were recorded as 913mm, 1123mm and 1336mm, respectively, indicating a progressive rise in rainfall over time. However, within each 50-year period, there were insignificant decreases during the second half of the 20th century (-27 mm/decade) and increases during the first (29 mm/decade) and second (99 mm/decade) halves of the 21st century. Although the average rainfall increased by 23.0% in the first half and 46.3% in the second half of the 21st century compared to the second half of the 20th century, these trends were not statistically significant within each 50-year period. Similar findings were also discussed by Anonymous, (2017) and Balu et al., (2023).

Runoff

The analysis of monsoon seasonal runoff revealed an increase to 615mm and 781mm during the first and second halves of the 21st century, respectively, compared to 419mm during the second half of the 20th century. This increase in runoff during the 21st century may be attributed to the occurrence of more extreme rainfall events. These findings align with previous studies that emphasize the significant influence of rainfall on future runoff changes (Yazawa and Shoji, 2023). Specifically, the trend in runoff showed an insignificant decrease of -15.65 *mm/decade* during the second half of the 20th century, while increasing by 27.97 *mm/decade* and 73.4 *mm/decade* during the first and second halves of the 21st century, respectively, over 50-year periods. The runoff exhibited substantial increases of 46.78% and 86.40% during the first and second halves of the 21st century, respectively, in comparison to the second half of the 20th century. These increases surpassed the corresponding rainfall increases of 23.00% and 46.33%. The changes in runoff can be attributed to the combined effects of increased precipitation and rising temperatures. The results are comparable to findings by Anonymous, (2017), Balu *et al.,* (2023) and Yazawa and Shoji, (2023).

Reference evapotranspiration (ET_o)

The time series analysis of seasonal and annual reference evapotranspiration (ET_o) was conducted for the period 1951-2100. The results, presented in Table 2, indicate a decreasing trend in average annual ET_o from 1772 mm during 1951-2000 to 1747 mm during 2001-2050, and further to 1657 mm during 2051-2100. The average annual ET_o is projected to decrease by -1.41% and -6.5% during the periods 2001-2050 and 2051-2100, respectively, compared to 1951-2000. In the monsoon season, ET_o decreased from 709 mm to 640 mm (-9.73%) during 1951-2000 to 2001-2050 and further to 553 mm (-22%) during 2051-2100. However, in the winter season, ET_o increased from 476 mm to 498 mm (+4.62%) between 1951-2000 and 2001-2050, remaining stable thereafter. Similarly, the summer ET_o increased from 587 mm to 609 mm (+3.75%) during 1951-2000 to 2001-2050 and remained unchanged during 2051-2100.

In the past period (1951-2000), the winter season experienced a significant increase (at the 1% level) in seasonal evapotranspiration (ET_o) of 6.85 *mm/decade*, primarily due to warming trends in day mean temperature. However, ET_o showed insignificant decreases during the monsoon season and increases during summer and annually. The increase in warming nights and their frequency contributed to the rise in ET_o during winter. The insignificant decrease in ET_o during the monsoon season may be attributed to increased humidity resulting from more wet days and higher rainfall amounts (Lunagaria *et al.,* 2015). In the first half of the 21st century (2001-2050), there was a significant decrease in seasonal ET_o of 15.2 *mm/decade* during the monsoon season, and a significant increase of 7.66 *mm/decade* during the summer season, both at the 5% and 1% significance levels, respectively. However, there were insignificant changes observed during winter and annually. In the latter half of the 21st century, there was a significant decrease in ET_o during the monsoon and annual seasons at rates of 15.2 *mm/decade* and 14 *mm/decade*, respectively, while changes in winter and summer seasons were insignificant. The decrease in ET_o during the monsoon season can primarily be attributed to an increase in rainfall despite rising temperatures. These findings align with the results reported by Anonymous (2017), Chattopadhyay and Hulme, (2023) but contradict those of Roderick and Farquhar (2004).

Evapotranspiration (ET_c) from vegetation

The values of K_{be} were computed as 0.79, 0.57 and 0.39 for the monsoon, winter, and summer seasons, respectively. It can be

Table 2: Maan-Kendall and Sens slope statistics of the temperature, ET_o and water fluxes for the different periods and seasons.

Periods	1951-2000			2001-2050			2051-2100		
Seasons	Ave (mm)	MK (Z)	Sens Slope (mm/ decade)	Ave (mm)	MK (Z)	Sens Slope (mm/ decade)	Ave (mm)	MK (Z)	Sens Slope (mm/ decade)
Max Temp									
Monsoon	31.9	1.37	0.17	32.9	2.46	0.29*	34.0	-0.45	-0.07
Winter	31.0	1.69	0.17	32.5	2.21	0.32*	33.8	-0.22	-0.03
Summer	32.7	2.61	0.29*	35.0	4.68	0.53**	36.2	0.54	0.04
Annual	31.9	2.46	0.20*	33.4	4.42	0.35**	34.6	-0.25	-0.02
Min Temp									
Monsoon	22.6	2.71	0.43**	25.3	4.92	0.59**	28.2	2.24	0.29*
Winter	12.3	-0.10	-0.01	13.7	3.65	0.34**	15.3	-1.04	-0.11
Summer	18.4	3.70	0.44**	20.7	4.62	0.48**	22.8	1.89	0.15
Annual	18.4	3.13	0.27**	20.5	6.04	0.52**	22.8	2.17	0.12*
Mean Temp									
Monsoon	26.5	1.799	0.14*	28.5	4.233	0.44**	23.0	0.57	0.06
Winter	19.8	0.728	0.08	22.8	3.597	0.38**	24.2	-0.70	-0.06
Summer	26.0	3.154	0.24**	27.4	4.835	0.35**	28.6	1.07	0.06
Annual	24.4	2.568	0.14**	26.5	5.755	0.40**	27.9	0.74	0.05
ET_o									
Monsoon	709	-0.92	-3.80	640	-2.58	-15.2*	553	-2.01	-15.2*
Winter	476	3.03	6.85**	498	1.92	5.80	497	0.27	0.44
Summer	587	0.60	1.32	609	3.21	7.66**	607	-0.74	-3.18
Annual	1772	1.77	11.41	1747	0.59	3.21	1657	-2.07	-14.0*
Rainfall									
Monsoon	913	-0.37	-27.11	1123	0.52	28.86	1336	1.44	98.97
Runoff									
Monsoon	419	-0.57	-15.65	615	0.70	27.97	781	1.54	73.40
ET_c									
Monsoon	560	-0.92	-3.00	506	-2.58	-12.0*	437	-2.01	-12.0*
Winter	270	3.03	3.89**	283	1.92	3.29	282	0.27	0.25
Summer	230	0.60	0.52	239	3.21	3.0**	238	-0.74	-1.25
Annual	1061	1.32	6.24	1027	-0.92	-4.16	957	-2.09	-12.1*

*5% level of significance **1% level of significance

observed from Table 2 that the ET_c in the monsoon season decreased from 560mm in the later half of the 20th century to 506mm and 437mm in the first and latter half of the 21st century, respectively. However, in the winter season, it increased from 270mm to 283mm from 1951-2000 to 2001-2050 and remained stable thereafter. Similarly, the summer ET_c increased from 230mm to 239mm from 1951-2000 to 2001-2050 and slightly decreased to 238mm in 2051-2100. These results indicate potential climate change impacts on summer ET_c. The average annual ET_c showed a decreasing trend, with values of 1061mm, 1027mm and 957mm for the periods 1951-2000, 2001-2050 and 2051-2100, respectively.

During the latter half of the 20th century (1951-2000), the seasonal ET_c showed a significant increase of 3.89 *mm/decade* (1% significance level) in the winter season, primarily attributed to the warming trends in the day mean temperature. However, there was an insignificant decrease in ET_c during the monsoon season and an increase during the summer and annual seasons. The increase in ET_c during winter could be attributed to the rise in warming nights and their frequencies. The insignificant decrease in ET_c during the monsoon season may be influenced by increased humidity resulting from higher rainfall amounts. In the first half of the 21st century (2001-2050), significant decreases of 12.0 *mm/decade* in ET_c during the monsoon season and increases of 3.0 *mm/decade* during the summer season were observed at a 5% and 1% significance level, respectively. However, there were insignificant increases in ET_c during the winter season and insignificant decreases in ET_c during the summer season. In the latter half of the 21st century, significant decreases in ET_c of 12.0 *mm/decade* during the monsoon season and 12.1 *mm/decade* in the annual season were found at a 5% significance level. There were insignificant increases in ET_c during the winter season and insignificant decreases in ET_c during the summer season.

According to the data presented in Table 2, there is a projected decrease in crop water requirement (ET_c) during the monsoon season and throughout the year. A decrease of -9.64% and -21.93% in the monsoon season and -3.2% and -9.8% annually is expected during the first and second half of the 21st century, respectively, compared to the second half of the 20th century. Nevertheless, there will be an increase of 4.81% and 4.44% in the winter season, as well as 3.91% and 3.48% in the summer season during the first and second half of the 21st century, respectively, compared to the second half of the 20th century.

In the Shingoda basin, it is expected that the crop water requirement (ET_c) will increase due to a rise in the average day mean temperature by 3.0°C and 1.4°C in the winter season, and 1.4°C and 1.3°C during the first and second half of the 21st century, respectively, compared to the second half of the 20th century. This decrease can be attributed to the increased rainfall amount, which leads to higher relative humidity as supported findings by Anonymous, (2017) and Rajabi *et al.,* (2022). These projections emphasize the need for robust management measures to address the imminent impacts of climate change.

CONCLUSION

A warming trend was detected in the Shingoda basin which was more due to increasing trend of night temperature rather than day temperature. The warming trend was more during 1st half as compared to 2nd half of 21st century. Similarly, the rainfall increased by 23.0 % and 46.33 % while runoff increased by 46.78 % and 86.40%. However, annual ET_o decreased by -1.41% and -6.5% and ET_c by -3.2 % and -9.8% during 1st and 2nd half of 21st century in comparison to 2nd half of 20th century. The downward water flux (rainfall) was found deficit by -16.10% during 1st half of 20th century but surplus by 8.46% and 28.37% in comparison to upward flux (ET_c). The higher amount of upward water flux as compared to downward during past was evidenced by depleting groundwater water table and sea water intrusion in the study area. This indicates that climate change impacts would be positive during monsoon season while negative during winter and summer season in context to water usage by agriculture and forest ecosystems in water scared region. However, the increased in rainfall during the 21st century can be the hope to meet the water demands for sustaining the agriculture and forest ecosystems.

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