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Editorial

Identification of Agro-Climatic Twins Based on Climatic and Agri-Ecological Similarities for the Sharing of Agricultural Technologies: Insights from Indian Punjab

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ABSTRACT

Climate twin regions are geographically distant areas that share very similar climatic conditions. The climatic parameters, such as temperature patterns, rainfall levels, and seasonal cycles, are statistically comparable in these regions. Owing to these shared climatic parameters, such regions often exhibit analogous agroecosystems, biotic communities, and socio-economic practices. Subsequently, these regions provide a basis for the potential transferability and adaptive application of crop species, land-use practices, and livelihood strategies under similar environmental conditions. The purpose of studying these climate twins is to help scientists and planners understand how a region's climate might change in the future. For example, in scenarios where a region is projected to experience increased temperatures and reduced precipitation, researchers can examine its present-day climate analogue to infer potential environmental responses and agricultural impacts. In simple terms, climate twin regions act like real-world previews of future climate conditions, helping societies prepare for climate change more effectively. The climate of a region is the outcome of several factors, such as latitude, altitude, distance from water bodies, soil type, etc., and its agri-eco-resources determine its agricultural productivity. With this hypothesis, we analysed to identify *agro-climatic twins* of Punjab with similar climate and agri-eco-resources and to understand whether they too are as highly agri-productive.

Keywords: Climate, Punjab, Latitude, Altitude, China, Australia, Rainfall, Temperature, Agroclimatic twins, Agric-ecology,

The climate of a given region is primarily characterized by its latitude, altitude, and distance from the sea and mountains. The natural vegetation type in a region is determined by its climate, soil and water availability. Different regions of the world with similar types of climates can be referred to as "*Climatic Twins*". However, the crops cultivated in those "*Climatic Twins*" may not be similar, as crops grown in a region are characterised by climate, soil, and the availability of irrigation water, and the food habits of the inhabitants (Ungar *et al.,* 2011; Bastin *et al.,* 2019). In some cases, the same crop grown in those "*Climatic Twins*" may have different yield levels. The yield gap may be due to cultivar type or crop management techniques. Therefore, identification of "*Agro-Climatic Twins*" is important from an agricultural viewpoint (Bos *et al.,* 2015; Georgakopoulos *et al.,* 2016). In one such interesting study, Licker *et al.,* (2010) compared yield patterns for the 18 most dominant crops within regions of similar climates and identified the regions and management practices for increasing the present yield levels to the climatic potential.

Identification of Agro-Climatic Twins: A Case Study for Punjab, India

The state of Punjab in India has a geographical area of 50,362 sq. km., but it is a major producer of cereal crops. Post-independence, during the late 1940's, one of the major challenges faced by India was feeding the masses. During the 1960s, the *Green Revolution* was ushered into the country by the introduction of high-yielding variety seeds, irrigation, pesticides, and fertilizers. The Punjab state facilitated the nation's food sufficiency goal with its favourable climatic conditions, irrigation water and agro-technological convergence piloted with the dedicated efforts of scientists and farmers alike

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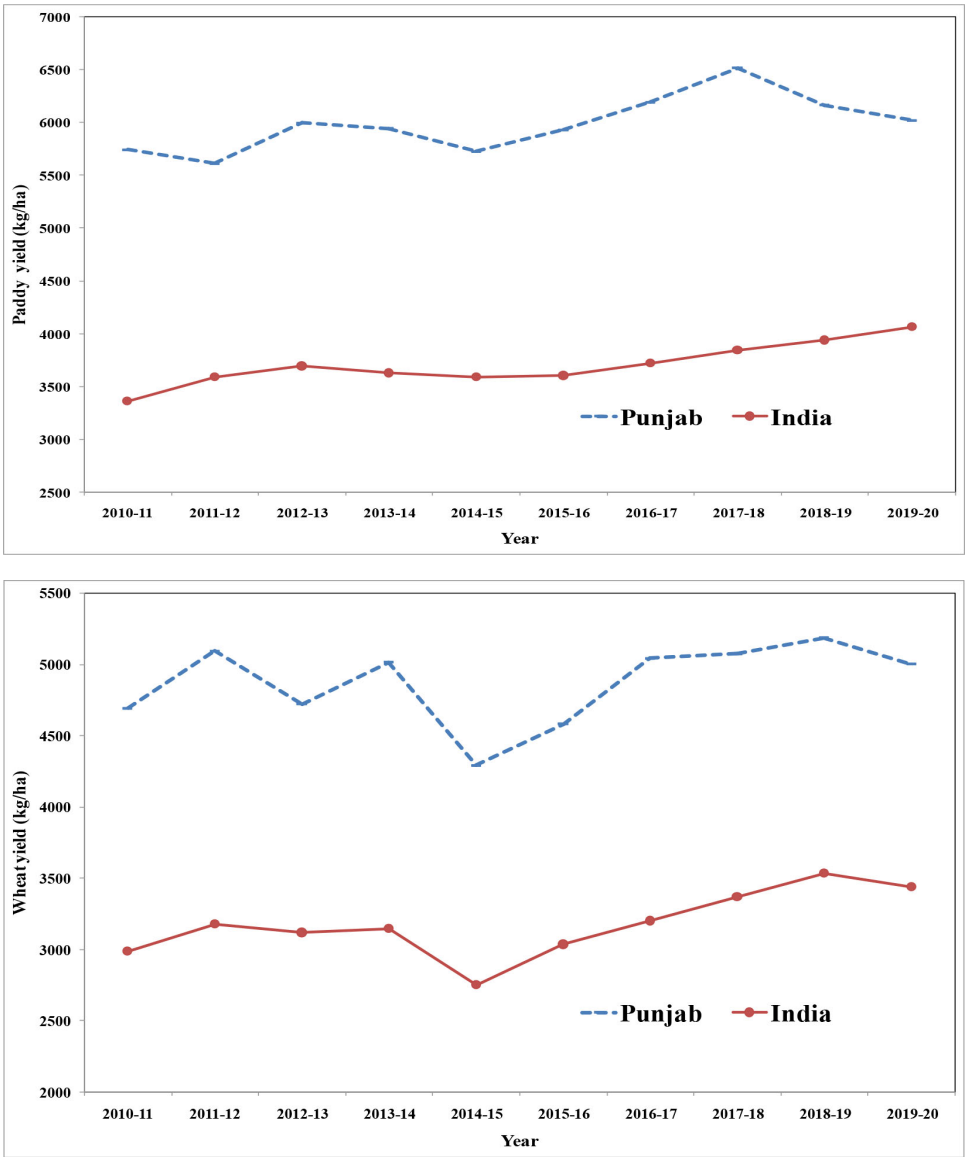


Fig. 1: Comparison of paddy and wheat yield in Punjab and India during the recent decade

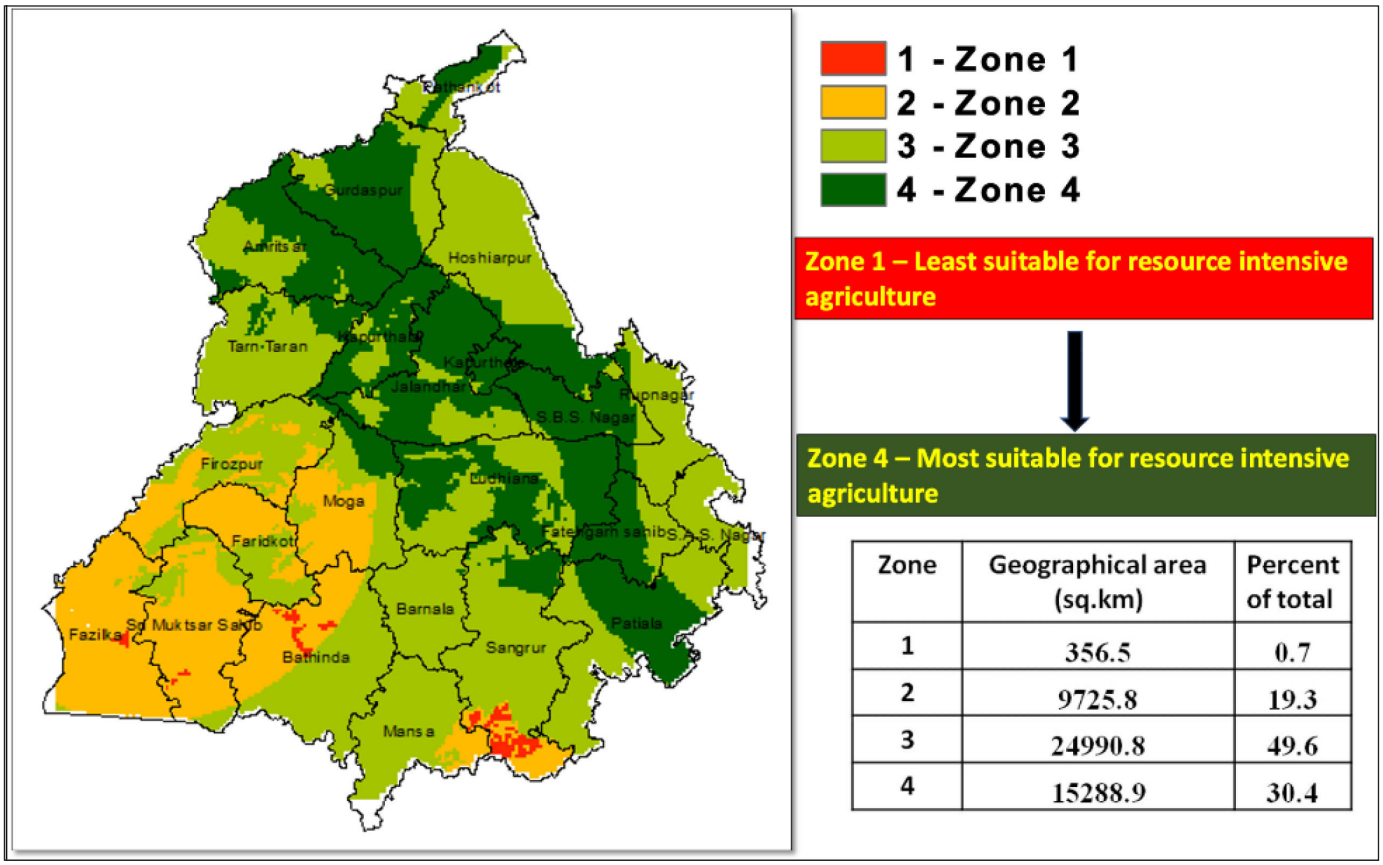
(Randhawa, 1977). Rice and wheat are the major cereal food crops of the Indian population. Over the recent decade (2010-11 to 2019-20), the average paddy and wheat productivity in Punjab was >60 per cent above the average productivity of the country (Fig. 1). Recently, during 2023-24, the state contributed 46.8% wheat and 22.7% rice towards the food grain pool of the country (Anonymous 2024). So, the question that arises is how this small state, having a geographical area of merely 1.53% of the country as a whole, can produce so many food crops? To understand this, we have tried to review and present the uniqueness of the state and then locate its climatic twins across the globe.

Topographical description of the Punjab state of India

Punjab state is located in the northern plains of India. It occupies 1.54% (50,362 sq. km) of the total geographical area of India, extending from 29.30° to 32.32° North latitude and 73.55° to 76.50° East longitude. It is part of the Indo-Gangetic plains formed due to alluvial deposits by rivers and tributaries. The climate of Punjab is semi-arid, hot, and subtropical monsoon-type, with cold winters and hot summers. It comprises three major seasons, i.e. summer season (mid-April to the end of June), rainy season (July to September) and winter season (December to February). The transitional seasons in Punjab are the post-monsoon season (mid-September to the end of November) and the post-winter season (March to mid-April).

Agro-climatic description of the Punjab state of India

Punjab has been divided into six agro-climatic zones based on homogeneity, rainfall pattern, distribution, soil texture, cropping patterns, etc. (Table 1). The first five zones are land areas i.e. northeastern regions (agro-climatic zone I & II) having sub-mountain and undulating plain regions (covering 18.5% of available land area and having rainfall >800-900 mm), central and western plain regions (agro-climatic zone III & IV –



Zone	Geographical area (sq.km)	Percent of total
1	356.5	0.7
2	9725.8	19.3
3	24990.8	49.6
4	15288.9	30.4

Fig. 2: Agro-eco-resource zones for crop cultivation in different districts in Punjab, India

(Prabhjyot-Kaur et al., 2024)

covering 55% of available land area and having rainfall 500-800 mm) and southwestern region (agro-climatic zone V – covering 20% of available land area and with rainfall <200mm). The sixth zone is the flood plains region with four separate components - the Ghaggar, the Sutlej, the Beas and the Ravi floodplains. The floodplains are locally known as *Bet*. The area covered by the floodplains is about 3500 sq. kilometres, which is about 7% of the total area of Punjab.

In a recent study by Prabhjyot-Kaur *et al.,* (2024), the agro-eco-resource zonation was done for Punjab based on climate (maximum and minimum temperature and rainfall), soil (organic carbon, texture and pH) and groundwater depth and its fluctuations. They divided the state into four zones based on suitability for resource-intensive cropping patterns. They reported that resource-intensive cropping patterns could be practiced in zone IV, having 30% area, followed by zone III, having 50% area, zone II, having 19% area, and zone I, having <1% area, which was suitable for only climate-resilient crops (Fig. 2).

Hypothesis of the study

The present study's hypothesis was to first identify the "*Agro-climatic twins*" of regions in the world. Thereafter, an attempt was made to investigate whether:

i) Those regions in the world with comparable agroecological environments also have similar types of agri-productivity.

ii) Similar types of crops are also grown in those regions.

MATERIAL AND METHODS

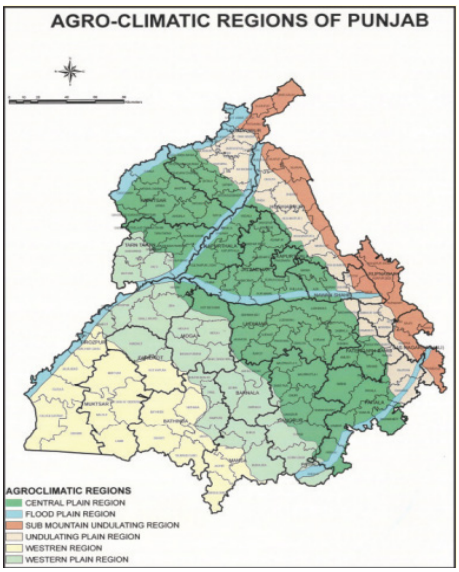
Methodology adopted and data source used

The Food and Agriculture Organization (FAO 2024) has defined agroecological zones as land regions with similar types of climates, soil, and landforms with a specific range of potential and land-use constraints. The climate is a primary driver for determining the suitability of crop types to be grown in a region and depends upon many factors, such as position on the globe (latitude), altitude, distance from the sea, etc. The Köppen climate classification is an efficient way to describe climatic conditions and has been widely used to map the geographic distribution of long-term mean climate and associated ecosystem conditions. As per this classification, the state of Punjab has the following two types of climate systems (Table 2). The Cwa (Dry winter humid subtropical) and BSh (Hot semi-arid) climate types in which Punjab agro-climatic zones I, II, III, IV, and V, respectively, fall are depicted for areas across the globe in the Köppen-Geiger climate map (Fig. 3).

To identify regions in the world with a similar climate

Table 1: Description of Agro-climatic zones of Punjab

S. No.	Agro-climatic Zones	Districts Covered	Area/ Per cent	Average rainfall (mm)	Major Crops Grown
1	Sub-mountain undulating zone	Pathankot, Gurdaspur and Hoshiarpur	4,800 sq. km / 9.5%	>900	Wheat, paddy, sugarcane, Mango, Litchi
2	Undulating plain zone	Rupnagar and SBS Nagar	4,600sq.km / 9%	800-900	Wheat, paddy, sugarcane, Mango, Litchi, citrus, guava
3	Central plain zone	Amritsar, Tarn Taran, Kapurthala, Jalandhar, Ludhiana, Fatehgarh Sahib, Sangrur and Patiala	18,000 sq.km / 36%	500-800	Wheat, paddy, sugarcane, oilseed pear, guava
4	western plain zone	Firozpur and Faridkot	9,500 sq.km / 19%	300-500	Wheat, paddy, cotton, gram, barley
5	Western zone	Moga, Bathinda, Mansa, Muktsar, Sangrur and Barnala	10,000 sq.km / 20%	<200	Wheat, paddy, cotton, gram, oilseeds, barley



Source: https://www.yourarticlelibrary.com/india-2/punjab/top-6-agro-climatic-regions-of-punjab-india/88924

Table 2: Koppen's Climate classification with representative regions in Punjab

Climate classification type	Description	Regions of the Punjab state
Cwa *(See fig 2a)*	Dry winter humid subtropical climate ▫ Monsoon-influenced humid subtropical climate. ▫ The average temperature of the coldest month should be >0 °C ▫ At least one month's average temperature should be >22 °C ▫ For at least four months, the average temperature should be >10 °C ▫ The wettest month should receive at least ten times more rain than the driest month.	Zone I: Sub-mountain undulating Region *(District: Pathankot, Gurdaspur, Hoshiarpur)* Zone II: Undulating plain regions *(District: Rupnagar, Nawanshahar, Mohali)*
BSh (See fig 2b)	Hot semi-arid climate ▫ The mean annual temperature of at least 18° C ▫ Mean temperature greater than 0° C in the coldest month. ▫ Precipitation is less than potential evapotranspiration but not as low as desert climate	Zone III: Central Plain region *(District: Amritsar, Tarn Taran, Jalandhar, Kapurthala, Ludhiana, Fatehgarh Sahib, Patiala, Sangrur)* Zone IV: Western plain region *(District: Fazilka, Faridkot, Firozpur)* Zone V: Western Region *(District: Moga, Mansa, Bathinda, Muktsar, Barnala)*

to Punjab, the first two representative cities from each agro-climatic zone of Punjab were shortlisted. Then, a comparison of climate data for different regions was done using the climate database available from https://en.climate-data.org/. The site data for the locations on this website is based on data obtained from the OpenStreetMap project (https://www.openstreetmap.org), which is open-source data, licensed under the Open Data Commons Open Database License (ODbL). All the climatic data comes from a climate model that has more than 220 million data points and a resolution of 30 arc seconds. The model uses weather data from thousands of weather stations spread all over the world for 1982 and 2012.

The soil properties of the corresponding regions were obtained from Harmonized World Soil Database (HWSD) v 1.2 (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/ harmonized-world-soil-database-v12/en/). This database is a 30-arc-second raster database with over 15,000 different soil mapping units that combine existing regional and national updates of soil information worldwide. The use of such a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters. These parameters included organic carbon (O.C.), soil pH, soil water storage capacity, soil depth, cation exchange capacity of the soil, clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage,

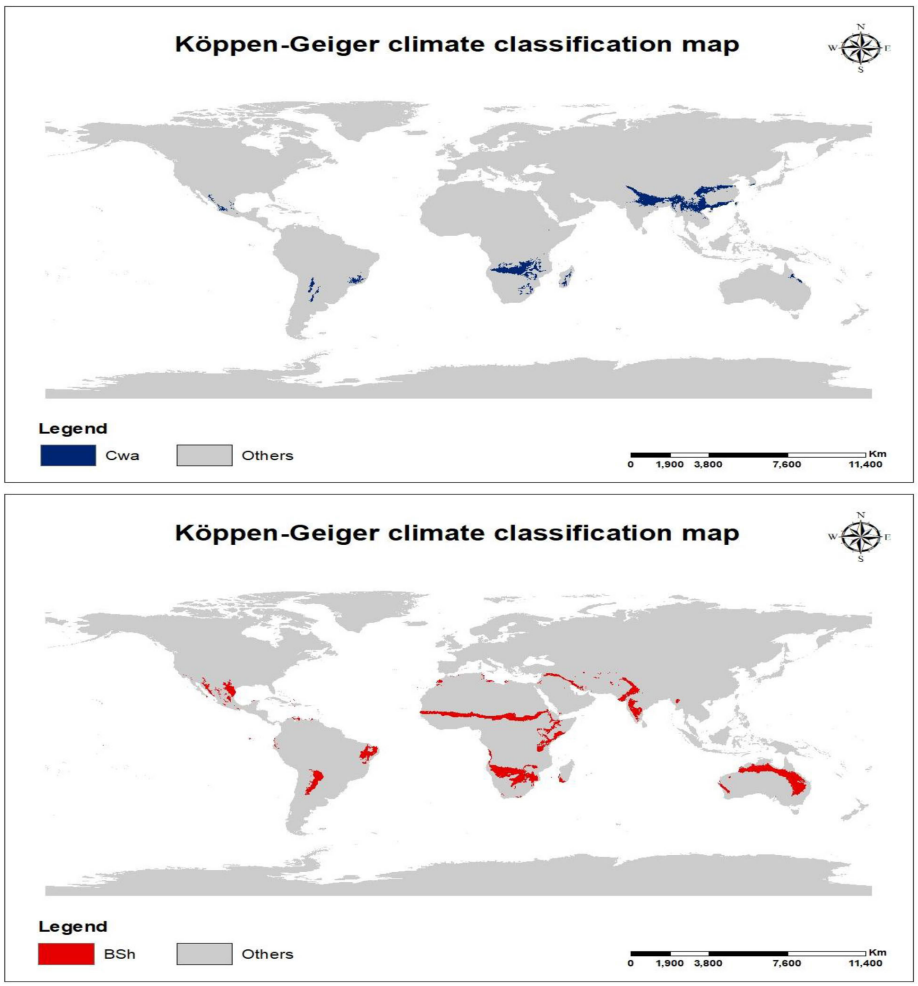


Fig. 3: Köppen-Geiger climate map depicting the distribution of Cwa and BSh climate types across the world map

salinity, textural class, and granulometry. The information on crops grown in the selected regions was collected from different open-source databases.

Criterion adopted for comparison of the climatic twin regions/ locations

The selected regions across the world were then further shortlisted based on the following parameters:

1. Latitude
2. Elevation in meters (from a.m.s.l.)
3. Average annual rainfall (mm)
4. Temperature range (^{C})
5. Day Length range
6. Distance from sea (km)
7. Soil type
8. Major crops grown

The Cwa: Dry winter humid subtropical climate type

The Cwa type of climate is found in the agro-climatic zones (ACZ) I and II of Punjab and in several parts of the globe (Fig. 3). As per the 7 criteria adopted in the study, the closest match was with Sichuan province in southwestern China. For comparison, the Hoshiarpur and Gurdaspur districts in ACZ I, the Nawanshar and Mohali districts in ACZ II and Nanchong city in the northeast of Sichuan were selected. The descriptive summary of information is presented in Table 3. The soil type in the Punjab region is coarse loamy and fine loamy, while in Nanchong is a loamy type. Like ACZ I and II in Punjab, agriculture is the mainstay of Nanchong's economy (https://en.wikipedia.org/wiki/Nanchong). In Sichuan province, silkworm rearing forms the basis for the silk industry. In the Punjab region, vegetables (peas, potatoes, etc.) and fruits (Kinnow/orange, guava, litchi, mango, etc.) are important components of its agricultural economy. The major similar crops grown in both regions are rice and horticultural fruits, i.e. oranges.

The BSh: Hot semi-arid climate type

The BSh type of climate is found in the agro-climatic zones (ACZ) III, IV and V of Punjab and several parts of the globe (Fig. 3). As per the 7 criteria adopted in the study, the closest

match was with regions located in Australia. For comparison, locations in the ACZ III (Ludhiana and Amritsar districts) and in Dubbo, New South Wales, Australia, were selected. The descriptive summary of information is presented in Table 4. The soil type in the Punjab region is sandy, clayey/course/ fine loam, while in Dubbo is sandy loam to loam type. In Dubbo, New South Wales, livestock (beef, sheep), wheat, barley, sorghum, cotton, and canola form the mainstay of its economy (https://www.dpi.nsw.gov.au/data/assets/pdf_file/0007/1275379/Central-West-Slopes-and-Plains-Snapshot.pdf). However, in the fertile plains of Dubbo, wherever irrigation is available, especially on farmlands near the rivers, vegetables (cauliflower, cabbage, carrot) are also cultivated. In the Punjab region, rice, wheat, sugarcane, potato, peas, etc., are important constituents of its agricultural economy. Wheat is a common winter-season crop in both regions.

In the case of ACZ IV, locations (Faridkot and Ferozpur districts) in Punjab and Cobar in New South Wales, Australia, were selected. The descriptive summary of information is presented in Table 5. The soil type in the Punjab region is coarse loam to loam, while in Cobar is sandy loam to loam type. In Cobar, New South Wales, the mining of metals is the mainstay of its economy (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1275381/Western-Plains-Snapshot.pdf). However, livestock (beef, sheep) and lesser water-requiring crops (sorghum, cotton, maize and green gram) are the main entities of its agriculture sector. In these regions of Punjab state, wheat, cotton, rice, green gram, gram, and barley form the major mainstay of their agriculture sector. The low water-requiring cotton and wheat are the common crops in both regions.

In the case of ACZ V, locations (Bathinda and Muktsar districts) in Punjab and Cunnamula (Queensland, Australia), Kalgoorlie (Western Australia) and Bourke (New South Wales, Australia) were selected. The descriptive summary of information is presented in Table 6. The soil type in the Punjab region is loam to sandy loam, while at locations in Australia is sandy clay loam to loam type. In general, the mainstay of the economy in these regions in Australia is the mining of metals. However, in Cunnamulla, Queensland, (https://outthebackaustralia.com/ destinations/cunnamulla/industry), Kalgoorlie, Western Australia (https:// www.agric. wa. gov. au/sites/gateway/files/Report%20card%20on%20sustainable%20natural%20resource%20use%20in%20agriculture%20-%20full%20report%20-%2025MB.pdf) and Bourke, New South Wales (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1275381/Western-Plains-Snapshot.pdf) livestock (sheep, cattle, goats), wheat, cotton, sorghum and green gram are the main entities of their agriculture sector. In these semi-arid regions of Punjab, wheat, cotton, mustard, rice, sorghum, chickpea, green gram, etc., are important constituents of its agricultural economy. Wheat and cotton are the major similar crops in both regions.

RESULTS AND DISCUSSIONS

Comparison of the crop productivity levels in the selected agro-*climatic twin regions/ locations*

In the Punjab state, the Green Revolution was initiated during the 1960s to feed the population of India. The core element of this phenomenon was the adoption of high-yielding dwarf varieties of wheat and rice along with a shift to irrigated, high-input crop management practices (Randhawa, 1977). During 2022-23, the state recently contributed 46.24% of wheat and 21.43% of rice to the central pool. Earlier, the contribution was as high as 55% wheat and 42% of rice (Anonymous 2024).

Rice production in the CWa climate-type regions of Punjab and China

Rice is the common crop cultivated in the two regions of Punjab and China. In Punjab, in the recent two years, the six districts falling in ACZ I and II contributed 22% to the total rice production in the state (Anonymous, 2024). The Sichuan province in southwestern China contributes 7% to the total main rice production in the country, as rice is cultivated as a main and ratoon crop (Table 7) in the province (https://ipad.fas.usda.gov/countrysummary/Default.Aspx? id=CH&crop=Rice). In Sichuan, the average productivity of the main crop is 6-9 t ha^{-1}, while the ratoon crop is 3-4 t ha^{-1} (Jiang *et al.*, 2023). In Punjab, the CWa type of climate districts have an average rice productivity of 4-6 t ha^{-1} (Anonymous 2024a, 2024).

Wheat and cotton production in the BSh climate-type regions of Punjab and Australia

Wheat and cotton are the common crops cultivated in the two regions of Punjab and Australia. In Punjab, wheat is the major winter-season cereal cultivated over a 3.5 Mha area. The average wheat productivity ranges between 4.0 and 4.5 t ha^{-1} (Anonymous 2024b). The average productivity of the wheat in New South Wales, Queensland, and Western Australia is 1.93, 1.49 and 1.73 t ha^{-1}, respectively (https://research.csiro.au/ digiscape /digiscapes-projects/wheat-yield-forecasts /#: ~: text=New%20South%20Wales%20Wheatcast%E2%84%A2,the% 2015%2Dyear%20NSW%20 average).

In Punjab, the southwestern districts with a BSh climate are the traditional cotton-growing belts, with an average cotton productivity of 0.437 t ha^{-1} (Anonymous 2024). In Australia, nearly 66% of cotton is grown in New South Wales, while the remaining 33% is cultivated in Queensland (https://cottonaustralia.com.au/industry-overview#:~:text=Approximately% 2066% 25%20of%20Australia's%20cotton,NSW%20and%2033%25%20in%20Queensland). Cotton productivity in these regions in Australia is as high as 1.78 to 2.04 t ha^{-1} (https://www.dpi.nsw.gov.au/about-us/publications/pdi/2023/cotton).

Constraints and strengths of agro-climatic twins of Punjab

The concept of "*agro-climatic twins*" of Punjab allows us to understand specific features of those regions where, despite the climatic features and soil types being similar, the productivity levels of common crops are not the same. In this study, we have identified the regions in Sichuan Province in China and regions in Australia having comparable agri-ecological characteristics to those observed in Punjab.

Table 3: Descriptive summary of the region with Cwa (Dry winter humid subtropical climate type) and agro-ecological features similar to agro-climatic zones I and II of Punjab

Characterization parameters	Agro-climatic Zone of Punjab				Sichuan, China
	Zone I: Sub Mountain undulating Region *(Pathankot, Hoshiarpur and Gurdaspur)*		Zone II: Undulating Plain Region **(***Rupnagar, Nawanshahar and Mohali)*		Nanchong
	Hoshiarpur	Gurdaspur	Nawashahar	**Mohali**	
Latitude	*31.51°N*	*32.04°N*	*31.12°N*	*30.70°N*	*30.83°N*
Elevation from mean sea level (m)	*296*	*264*	*261*	*324*	*338*
Average annual rainfall (mm)	*991*	*959*	*857*	*940*	*1003*
Average annual temperature (°C)	*23.7*	*23.5*	*24.2*	*24.1*	*17.7*
Minimum temperature variation (°C)	*6-27*	*5-26*	*6-27*	*7-26*	*4-24*
Maximum temperature variation (°C)	*19-41*	*18-41*	*20-41*	*20-40*	*9-33*
Day length range (Hr)	*10.16 to 14.13*				*10.15 to 14.15*
Distance from sea (km)	*1200*				*1500*
Distance from Punjab, India (km)	-	-	-	-	*2300*
Soil Type	*Coarse loamy and fine loamy Soils*				*Loamy*
Vegetation/ Crops	*Wheat, basmati rice, maize, sugarcane, kinnow/ orange, potato, peas*	*Wheat, basmati rice, maize, mango*	*Wheat, rice, maize, mustard, peas, guava*	*Wheat, rice, maize, mustard*	*Rice, sweet potato, hemp, orange*

CWa climate-type regions of Punjab and China

Punjab region

The regions with the CWa climate type have sub-mountainous undulating topography as they fall in the foothills of the Shivalik ranges, so they have a diversified agricultural pattern. Rice cultivated in this region (Pathankot and Gurdaspur district) is primarily aromatic basmati rice, which has lower yield potential than the parmal rice grown in the state. Hence, comparable rice productivity in the Punjab region (4-6 t ha^{-1}) is lower than in the Sichuan province (main crop: 6-9 t ha^{-1}, ratoon crop: 3-4 t ha^{-1}) in China. The other crops cultivated in this region in Punjab include wheat, maize, sugarcane, potato, peas, kinnow, guava, mango, litchi, etc (Table 7). Silkworm rearing as a cottage industry is done in some sub-mountainous areas in Gurdaspur, Pathankot, Hoshiarpur, and Ropar districts. The rearing of milch animals (cow, buffalo) is another important component of the agri-economy of the Punjab region.

Sichuan Province in China

This is mainly an agricultural province with ~46% of its permanent population residing in rural areas (Dai *et al.,* 2022). The Dujiangyan Irrigation System (DIS) is this province's major crop water source. The DIS is a natural control over the floodwater of the Minjiang River without building dams. It distributes water for agricultural purposes in the fertile plains of Chengdu in Sichuan (Cao *et al.,* 2010). Hence, the farmers can grow multiple crops of rice (main and ratoon) during the year. The region is famous for its silk industry, and silkworm rearing forms a major part of its economy (https://www.statista.com/statistics/242915/silkworm-cocoon-production-in-china-by-province/). Other crops cultivated include sweet potato, corn, beans, potato, hemp, and orange. Piggery is another important component of the agri-economy of the Sichuan province in China.

BSh climate-type regions of Punjab and Australia

Punjab region

The regions with the BSh climate type have plain topography as they are nurtured by the floodplain regions of three rivers, i.e. Ravi, Beas, and Sutlej. Before the last decade of the 20th century, the region had a diversified agricultural pattern. In the northeastern parts of this region (Amritsar, Tarn Taran, Jalandhar, and Kapurthala), sugarcane, maize, wheat, mustard, vegetables, and fruits were grown, while in the southwestern region cotton, mustard, wheat, chickpea, bajra, barley, etc were grown. The central region was mainly dominated by rice, wheat, mustard, vegetables, fruits, etc. However, rice (~3.1 Mha) is presently followed by wheat (~3.5 Mha), forming the major cropping system of these three regions. The other crops cultivated in this region in Punjab include mustard, sorghum, barley, chickpea, green gram, potato, pea, pear, etc (Table 8). The comparable cotton productivity in the southwestern districts (Muktsar, Mansa, Fazilka, Firozpur) of Punjab is 0.436 t ha^{-1}, which is lower than in the Australian regions, where it is as high as 2.88 t ha^{-1}. The lower cotton productivity in Punjab districts may be attributed to poor quality (saline) water and light-textured soils. On the other hand, in the BSh climate regions of Punjab, wheat productivity is as high as 4.0 to 4.5 t ha^{-1} as compared to low wheat productivity (1.49 to 1.93 t ha^{-1}) in Australian regions. The rearing of milch animals (cow, buffalo) is another important component of the agri-economy of the Punjab region.

Table 4: Descriptive summary of the region with BSh (Hot arid climate type) and agro-ecological features similar to agro-climatic zone III of Punjab

Characterization parameters	Agro-climatic zone III: Central Plain Region (*TarnTaran, Kapurthala, Jalandhar, Fatehgarh Sahib, Sangrur and Patiala)*		New South Wales, Australia
	Ludhiana	Amritsar	
Latitude	*30.9°N*	*31.63°N*	*32.23°S*
Elevation from mean sea level (m)	*247*	*232*	*265*
Average annual rainfall (mm)	*726*	*703*	*639*
Average annual temperature (°C)	*24.3*	*23.3*	*17.2*
Minimum temperature variation (°C)	*5-27*	*4-26*	*3-18*
Maximum temperature variation (°C)	*20-41*	*18-41*	*15-33*
Distance from sea (km)	*1200*	*1200*	*350*
Distance from Punjab, India (km)	-	-	*10,400*
Soil Type	*Sandy, clayey loam, alkaline in nature.*	*Coarse loamy and fine loamy soils*	*Sandy loam to Loam*
Vegetation/ Crops	*Wheat, rice, potato, green gram*	*Wheat, rice, sugarcane, pea, potato, pear.*	*Wheat, canola, barley, sorghum, cotton, vegetables*

Table 5: Descriptive summary of the region with BSh (Hot arid climate type) and agro-ecological features similar to agro-climatic Zone IV of Punjab

Characterization parameters	Agro-climatic zone IV: Western Plain Region		New South Wales, Australia
	Faridkot	Ferozpur	Cobar
Latitude	*30.67°N*	*30.92°N*	*31.49°S*
Elevation from mean sea level (m)	*207*	*200*	*242*
Average annual rainfall (mm)	*445*	*484*	*417*
Average annual temperature (°C)	*24.1*	*24*	*18.6*
Minimum temperature variation (°C)	*5-27*	*5-27*	*4-20*
Maximum temperature variation (°C)	*19-42*	*19-41*	*15-34*
Distance from sea (km)	*1000*	*1000*	*650*
Distance from Punjab, India (km)	-	-	*10,000*
Soil Type	*Coarse loam to loam*	*Coarse loam to loam*	*Sandy loam to loam*
Vegetation/ Crops	*Wheat, cotton, rice, green gram*	*Wheat, cotton, rice, green gram, gram, barley*	*Sorghum, cotton, maize, green gram*

Australia states

In Australian states with a BSh-type climate, the low annual rainfall of <600 mm, high evaporation rates, and mediocre soil types are the major constraints. The irrigation systems are strictly monitored, and irrigation water is expensive in water-scarce regions of Australia. However, water-efficient cultivation of cotton has made the country a leader on a global scale. In Australia, the average water productivity is 1.08 bales/ML, which is nearly 2.25 times the global average of 0.48 bales/ML (https://www.insidecotton.com/identifying-trends-and-drivers-water-productivity-australian-cotton-through-benchmarking-includes). The crops are irrigated by surface, sprinkler and drip systems in laser levelled fields. The other crops cultivated include canola, maize, barley, sorghum, chickpea, oats, and green gram. Cattle and sheep rearing is another important component of the agri-economy of these states in Australia.

CONCLUSION

The present study was conducted to identify the *agro-climatic twins* of Punjab, which is one of the most agriculturally productive states of India. The criteria for selection of the regions across the globe were latitude, elevation, average annual rainfall, temperature range, day length range, distance from sea, soil type, and major crops grown (Heinz *et al.,* 2024). The state has two main climate types, i.e. Cwa (Dry winter humid subtropical climate type) and BSh (Hot semi-arid climate type). The analysis conducted revealed that:

i) The climatic twin of agroclimatic zones I and II of Punjab, with the Cwa climate type were the Sichuan province in south western China. The major similar crop is rice, and the productivity levels in Sichuan are higher due to the availability of a better irrigation system. However, this region in Punjab is growing aromatic basmati rice, which, though it has a lower yield, is globally recognized for its superior aromatic and cooking traits. Both regions are cultivating vegetables and fruit crops. Silkworm rearing is also a similar agri-industry in the two regions.

ii) The climatic twin of agroclimatic zones III, IV and V of Punjab with BSh climate type were Queensland, Western Australia and New South Wales regions in Australia.

Table 6: Descriptive summary of the region with BSh (Hot arid climate type) and agro-ecological features similar to agro-climatic zone V of Punjab

Characterization parameters	Agro-climatic zone V: Western Region *(Moga, Mansa, Sangrur and Barnala)*		Queensland, Australia	Western Australia	New South Wales, Australia
	Bathinda	Muktsar	Cunnamulla	Kalgoorlie	Bourke
Latitude	*30.21 ˚N*	*30.47 ˚N*	*28.08 ˚S*	*30.74 ˚S*	*30.08 ˚S*
Elevation from mean sea level (m)	*208*	*200*	*189*	*382*	*106*
Average annual rainfall (mm)	*421*	*384*	*375*	*257*	*372*
Average annual temperature (°C)	*24.5*	*24.4*	*20.5*	*18.2*	*20.1*
Minimum temperature variation (°C)	*5-27*	*5-27*	*6-22*	*5-17*	*5-21*
Maximum temperature variation (°C)	*20-42*	*19-41*	*18-36*	*18-34*	*18-36*
Distance from sea (km)	*1100*	*1100*	*800*	*350*	*750*
Distance from Punjab, India (km)	-	-	*9,900*	*8,400*	*10,000*
Soil Type	*Loam to Sandy Loam*	*Sandy Loam*	*Sandy clay loam to Loam*	*Sandy to clay mainly sandy dominated*	*Sandy loam to Loam*
Vegetation/ Crops	*Wheat, cotton, rice, potato, mustard*	*Wheat, cotton, rice, mustard*	*Wheat, sorghum, chickpeas, green gram, cotton*	*Wheat, barley, canola, oats*	*Sorghum, cotton, maize, green gram*

Table 7: Comparison of agricultural features of the Cwa (Dry winter humid subtropical) climate type in Punjab (India) and Sichuan (Nanchong, China)

Agri- features	ACZ I and II in Punjab (India)	Sichuan province (Nanchong, China)
Irrigation System	• Canal irrigation • Tubewell irrigation	• Dujiangyan ancient irrigation system *(*Method of channelling and dividing the water of the River Min (a tributary of the River Yangtze) instead of simply channelling it to avoid floods)
Productivity of a common crop	• Rice: 4-6 t ha^{-1} (Anonymous, 2024)	• Main crop rice: 6-9 t ha^{-1} (Jiang *et al.,* 2023) • Ratoon rice: 3-4 t ha^{-1}
Major Constraints	• Climate change and its variability • Depleting groundwater resources	• Limited environmental resources • Climate change and its variability
Salient Features	• Resource-intensive crop management practices • Mechanized cultivation practices	• Main season and ratoon rice crop • Terrace farming • Well-equipped with modern technologies used for agriculture
Agricultural Institute nearby	• Punjab Agricultural University, Ludhiana	• Sichuan Academy of Agricultural Sciences • China Agricultural University
Other crops/ livestock	• Wheat, rice, maize, sugarcane, potato, peas, Kinnow / orange, mango, litchi, guava, milch animals (cow, buffalo)	• Rice, orange, sweet potato, hemp, silkworm, pork

Wheat and cotton are the two common crops. The average productivity of wheat in Punjab is very high compared to Australian regions. However, the productivity of cotton is very high in the Australian regions. The irrigation network in Australia is very well monitored, and water-efficient cultivation of cotton in the region is commendable. In these regions of Punjab, irrigation is by canal and tubewell irrigation. Both regions are following mechanized farming practices. The other common crops include canola/mustard, barley, sorghum, chickpea, and green gram.

So, the results of the analysis showed that the *climatic twins* of Punjab are also cultivating a similar type of crops. However, the productivity levels were not similar due to the inherent crop management techniques of each of these regions.

Table 8: Comparison of agricultural features of the BSh (Hot arid climate type) in Punjab (India) and Australia

Agri- features	ACZ III, IV and V in Punjab (India)	Australia
Irrigation System	• Canal irrigation • Tubewell irrigation	• Surface, sprinkler and drip irrigation • Southwest irrigation area (Harvey water scheme) • Dam irrigation • Preston Valley irrigation scheme (Dam to rivers)
Productivity of a common crop	• Wheat – 4.0 to 4.5 t ha^{-1} • Cotton- 0.436 t ha^{-1}	• Wheat – 1.49 to 1.93 t ha^{-1} • Cotton- 2.88 t ha^{-1}
Major Constraints	• Climate change and its variability • Depleting groundwater resources • Saline underground water • Light textured soil	• Drought • Rising costs of water, reduced water allocation (privatisation of the irrigation system) • Environmental regulations • Shortage of labour
Salient Features	• Resource-intensive crop management practices • Mechanized cultivation practices	• Water-efficient cultivation of cotton • Organic beef production due to prevailing dry conditions • Mechanized cultivation of crops in laser-levelled fields • Drones for crop monitoring
Agricultural Institute nearby	• Punjab Agricultural University, Ludhiana	• Yanco Agricultural Institute, New South Wales, Australia • Wagga Wagga Agricultural Institute, New South Wales, Australia • The University of Queensland, Brisbane, Australia
Other crops/ livestock	• Rice, mustard, sorghum, barley, chickpea, green gram, potato, pea, pear, milch animals (cow, buffalo)	• Canola, maize, barley, sorghum, chickpea, oats, green gram, cattle, sheep

WAY FORWARD

Two geographically distant regions are "*analogues*" or "*twins*" if they exhibit statistically similar climate conditions (temperature, rainfall, seasonality, extremes). When the crop cultivation and their productivity levels are to be compared, then it is extended to include agro-ecological factors like soil, elevation, distance from water bodies, and cropping systems. By locating these "*agro-ecological mirrors*", agricultural development can be accelerated through the following applications:

i) Augmented technology transfer

The major benefit of identifying such twins is the ability to bypass years of local trial and error. If a specific drought-tolerant wheat variety or a water-saving irrigation technique (like Direct-Seeded Rice) succeeds in one region, it is highly likely to succeed in its agro-climatic twin. So, the farmers can adopt new technologies with higher confidence, knowing they have been "field-tested" in a comparable environment.

ii) Yield Gap Analysis

If two regions have the same climate but the productivity of the same crop is distinctly different, then the difference is likely due to management, policy, or infrastructure. This helps governments identify non-climatic barriers to success.

iii) Validation of Predictive Modelling

Dynamic crop simulation models such as DSSAT, APSIM, etc., are described as "site-specific" and require thorough calibration and validation before use in a new region. So, this agro-ecological twinning solves this by providing out-of-sample validation.

iv) Germplasm Exchange and Biodiversity

Agro-climatic twins provide a roadmap for the exchange of genetic resources. Breeders can outsource wild relatives of crops from twin regions, ensuring the traits (like heat tolerance or pest resistance) are already synchronised with the target abiotic stressors. If a specific pest outbreak occurs in one region, its *agro-climatic twin* can be put on high alert, as the same pest may thrive in that region too.

v) Utilising Analogues in climate change impact assessment

As a way forward, *Agro-climatic twinning* is a powerful tool for climate change predictions. Researchers can use this technique to help locate a region (say B) for a region (say A) that is presently having the predicted climate for region A. Hence, if region A's projected climate for the year 2050 matches the current climate of region B, then the present time climate of region B becomes the "*future climatic twin*" of region A. So, by studying the crops and water management strategies currently used in the future twin, the target region can begin adapting decades before the climate fully shifts.

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