

Impacts of climate change on selected agricultural crops in Tehran city region

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ABSTRACT

This paper addresses the literature gap in analyzing the impacts of climate change on peri-urban agriculture, with a focus on the Tehran city region, a critical agricultural hub in Iran that is vulnerable to climate variability. The objective was to quantify the impacts of climate change on the yields of key crops—wheat, barley, apples, walnuts, grapes, cucumbers, watermelons, cotton, and alfalfa—using quantile regression models (0.25, 0.50, and 0.75) to capture heterogeneous yield responses. The models, applied to crop yield records from 1994 to 2014 and climatic data from five synoptic stations, are robust to outliers and estimate conditional quantiles of yield distributions. Impacts were projected for three time slices (2030s, 2060s, and 2080s) under IPCC RCP4.5 and RCP8.5 scenarios. Results reveal that climate variability has a significant but non-monotonic impact on major crop yields. The highest positive and negative impacts are on walnuts and apples, respectively. These results have many implications for planners and other stakeholders involved in peri-urban agriculture and can provide important insights for place-specific adaptation and mitigation measures. Several adaptation strategies can be implemented to mitigate negative impacts and capitalize on potential benefits, including modifications to crop cultivars and planting schedules, the development of institutional frameworks and infrastructure to address water scarcity and enhance food security, and the education of farmers on climate-related challenges and the adoption of advanced agricultural technologies.

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1. Introduction

Global food insecurity remains a critical challenge, particularly in developing countries, where 720 million people are chronically undernourished and over two billion face micronutrient deficiencies, despite increased food production over the past five decades (United Nations, 2014; von Grebmer et al., 2014; FAO, IFAD, UNICEF, WFP and WHO, 2025). Although conventional food systems have greatly raised the food availability (Feenstra, 2002; Fanzo and Miachon, 2023) in light of technological and logistical developments as well as economies of scale, these developments have had significant costs (Donald et al., 2010). Many authors stress that contemporary food systems have contributed to soil depletion, biodiversity loss, global climate change, and air and water

pollution, (Foster and Magdoff, 2000; Pirog et al., 2001; Weis, 2010; Holden et al., 2018; Çakmakçı et al., 2023; Fanzo and Miachon, 2023). Furthermore, current agro-food systems have supplanted traditional livelihoods, threatened the subsistence of small-holder families (Hines, 2000; Menezes, 2001; Singh, 2009) and led to prevalence of diet-related diseases (WHO, 2002; Nestle, 2007; Drewnowski et al., 2020). Since the 1980s exacerbation of those challenges and problems as well as the widespread and growing public concerns has led to the emergence of agro-food movements such as ‘Slow Food’, ‘Local Food’, ‘community food-security movement’ and ‘Organic Food’. Moreover, the topic has received a great deal of attention from



academics in the various disciplines (planning, architecture, geography, the environment), and they are scrambling to incorporate food issues in their responsibilities (Pothukuchi and Kaufman, 1999, 2000; Maxwell, 1999; Campbell, 2004; Morgan and Sonnino, 2010; Matooane et al., 2025). Nowadays, food policy obtained special position in urban planning and management agenda, and considered as a one of the main preconditions to achieve sustainable development in many cities in North America, Europe and Australia. In this context, locally or regionally based food production is one of the core principals of alternative food movements. Alternative advocates believe that local food reduces the environmental impact, provides opportunities for physical activity, supports the local economy, increases the consumption of healthy and fresh foods, provides culturally appropriate foods, increases social justice and equity, supports the local economy, leads to self-reliant, and strengthens communities (DuPuis and Goodman, 2005; Kneen, 1992; Hines, 2000; Papargyropoulou et al., 2024). It should be noted that local food production can contribute to sustainable food systems and urban food security, if it be based on true comparison of ecological impacts of local and imported products through comprehensive analyses such as 'life cycle analysis' (Born and Purcell, 2006; Mariola, 2008). On this basis, many planners and policy makers attempt to enhance urban food security and to support urban agriculture through appropriate land use planning and regulations, development of farmer markets, social learning processes, providing effective transport links and food storage facilities, and water and waste management (Feenstra, 2002; Howe, 2002; Clancy, 2004; APA, 2007; Mendes et al., 2008; Redwood, 2012).

However, there is a gap in the literature regarding the impacts of climate change on peri-urban agriculture and, more importantly, on related adaptation and mitigation strategies at the city and city-region scales. Although climate change is one of the major challenges facing the agriculture sector in the coming decades (Parry et al., 2004; IPCC, 2007; FAO, 2008; Wiebelt et al., 2013), its impacts at urban and city-region scales have been largely neglected. Whilst the impacts of climate change on food security and agriculture have been examined and simulated extensively at the national and global scales (Karimi et al., 2018;

Shahvari et al., 2019; Pakrooh and Kamal; 2023; Ghamghami and Beiranvand, 2022), the urban and city-region scales have been largely neglected. In Iran, the availability of freshwater and fertile soils has determined the location of human settlements, with main cities situated in the heart of fertile plains. Major agricultural activities are thus located in peri-urban areas and metropolitan regions. However, climate change poses a significant threat to urban agriculture in Iran due to heightened vulnerability and low coping capacity. The exposure of Iran's agriculture to climate hazards has increased over recent decades due to changes in the amount and distribution of precipitation, significant rises in temperature, dust storms, aggravated flooding, and more intense and frequent droughts, particularly in the Tehran city region (Keramat et al., 2011; Mosammam et al., 2016; Dastorani and Poormohammadi, 2012; Roshan and Grab, 2012; Ehteramian et al., 2012; Ghamghami and Beiranvand, 2022; Pakrooh and Kamal., 2023). Accordingly, this paper examines the impacts of climate change on key crops—wheat, barley, apples, walnuts, grapes, cucumbers, watermelons, cotton, and alfalfa—in the Tehran city region, a vital hub for peri-urban agriculture in Iran. The region, encompassing two provinces namely Tehran and Alborz, spans approximately 199,517 hectares of farmland situated in the semi-arid foothills of the Alborz Mountains. It plays a central role in ensuring local food security and sustaining economic stability. Similar to agricultural systems worldwide, this region faces mounting pressures from climate variability, compounded by the urbanization of poverty, shifting dietary patterns, unsustainable resource use, biofuel production, market volatility, and regional conflicts (Ravallion, 2002; Norberg-Hodge, 2002; Pollan, 2006; World Bank, 2008; Morgan and Sonnino, 2010; FAO, 2015b). This analysis provides critical insights for place-specific adaptation and mitigation strategies aimed at safeguarding urban food systems under evolving climatic conditions.

Over the last few decades, (peri)urban agriculture has attracted considerable attention among researchers, international organizations, and policymakers worldwide. Urban agriculture, as a multidimensional and dynamic concept, refers to farming activities, livestock rearing, beekeeping, and aquaculture at all scales—from commercial and intensive

agriculture to small-scale hobby gardening and agrotech parks—within or on the fringe of a city or metropolis (Garnett, 1996; Mwalukasa, 2000; Orsini et al., 2020; Teng, 2020, 2024). In addition to production, urban agriculture includes interrelated activities such as processing and marketing of food and non-food products, largely using human and natural inputs and services available in and around cities, and in turn supplying goods and services primarily to those cities (Drescher and Iaquina, 1999; Mougeot, 2000). According to Smit et al. (1996) and Gundel et al. (2000), about 800 million urban residents worldwide are engaged in some form of urban agriculture, and 200 million produce for local and global markets. In the Tehran city region, for example, peri-urban agriculture supports the cultivation of key crops such as wheat, apples, and grapes, contributing to local food security and economic stability. The reviewed literature reveals that urban agriculture provides numerous socio-economic and environmental benefits, ultimately enhancing the overall quality of life in urban areas. From an economic perspective, it has significant potential to generate employment, particularly for poor urban residents with limited skills and capital. It contributes substantially to local economies by transforming vacant land into productive spaces and stimulating the development of micro-enterprises such as agricultural input production, food processing, transportation, and marketing (Maxwell, 1995; Mougeot, 2000; Zeeuw et al., 2000; RUA Foundation, 2017). Socially, urban agriculture improves food and nutrition security, strengthens coping capacities of low-income households, and thus alleviates urban poverty and food-related health challenges (Maxwell et al., 1998; Orsini et al., 2013). It also promotes social inclusion, reduces gender inequalities, helps prevent social problems such as drug use and crime, and provides recreational and educational opportunities (Gonzalez Novo and Murphy, 2000; Smit and Bailkey, 2006; Orsini et al., 2013). Ecologically, urban agriculture enhances waste recycling (Furedy et al., 1999; Cofie et al., 2006), improves biodiversity and air quality (Konijnendijk and Gauthier, 2006; Orsini et al., 2013), supports favorable microclimates (Konijnendijk et al., 2004), and contributes to climate change adaptation (UN-HABITAT, 2009).

Like agriculture in rural areas, urban agriculture is one of the most vulnerable sectors to climate change because it directly depends on natural resources. The effects of climate change on urban agriculture can be both direct and indirect. Direct impacts include changes in climatic variability and extreme events (e.g., heatwaves, droughts, hail, and floods), elevated CO₂ concentrations, altered rainfall patterns and amounts, rising average temperatures, and sea-level rise (IPCC, 2007; Parry et al., 2007; Schmidhuber and Tubiello, 2007; Bates et al., 2008; Bryngelsson et al., 2016; Chari and Ngcamu, 2022; Naazie et al., 2024). Indirect impacts occur through shifts in crop nutrition, water availability, fodder quantity and quality, resource prices (e.g., feed and energy), crop suitability, degradation of soil and other resources, as well as increased occurrence of weeds, pests, and diseases (Nearing et al., 2004; Bindi and Olesen, 2010; Thornton and Gerber, 2010; Olesen et al., 2011; Chari and Ngcamu, 2022; Naazie et al., 2024). Moreover, water-related challenges such as competition for land and water, conflicts, and migration further exacerbate vulnerabilities (Reuveny, 2007; Lotze-Campen et al., 2008). Climate change also has economic consequences for farm profitability, agricultural supply and demand, trade, and price stability (Kaiser and Drennen, 1993; Bozzola et al., 2023). Climate change profoundly impacts agriculture in Tehran and Alborz Provinces by altering the hydrological regimes of the Karaj, Latian, and Mamlu dam watersheds, primarily through temperature increases and variable precipitation patterns (Naderi et al., 2025).

Rising temperatures in city regions like Tehran may shorten crop growth periods, reduce sugar content, lower storage stability of fruits and vegetables, increase weed and pest prevalence, and diminish soil fertility, all of which result in yield reductions (Adams et al., 1996; Shah et al., 2021; Bhat, 2021; Chachar et al., 2023). They also affect water availability and seasonality, reduce forage quality and quantity in peri-urban grasslands, suppress livestock appetite, and ultimately lower weight gain (Adams et al., 1998; Barnett et al., 2005). Higher temperatures increase the need for cooling and refrigeration in food production and storage, and exacerbate wildfire risks in urban and peri-urban gardens and forests. In coastal cities, sea-level rise threatens agricultural land through salinization, reduces

fish populations, and damages infrastructure critical to urban agriculture.

Precipitation intensity and variability in city regions may deteriorate surface and groundwater quality, reduce soil moisture, accelerate erosion (Nearing et al., 2004; Amparo-Salcedo, 2025), alter river flow regimes, and increase flooding and drought risks. These disruptions adversely affect production, processing, transport, and storage facilities, ultimately reducing agricultural productivity (Reilly et al., 2003; Falloon and Betts, 2006; Alcamo et al., 2007; Ziervogel and Frayne, 2011). Shifts in temperature, rainfall, and CO₂ levels are also expected to increase irrigation demand and alter species composition and ecosystem dynamics (Fischer et al., 2007; McKeon et al., 2009; Jones & Thornton, 2009; Thornton and Gerber, 2010; Izaurralde et al., 2011). Although higher CO₂ concentrations may enhance plant growth and water-use efficiency (CO₂ fertilization) (Gedney et al., 2006; Long et al., 2006; Betts et al., 2007), these benefits are likely to be offset by the adverse effects of rainfall variability, extreme weather, and shifts in runoff regimes (Bates et al., 2008).

Food production in city regions is also influenced by climate change through disruptions in urban food demand, interruptions in input supplies, and challenges faced by urban-based service providers to farmers (Satterthwaite et al., 2010). Climate-driven volatility in agricultural markets, alongside rising costs of energy, fertilizers, and other inputs, further undermines resilience (Bryan et al., 2009; Jackson et al., 2012). Accordingly, analyzing and estimating the potential impacts of climate change on all dimensions of (peri)urban agriculture—including production, processing, packaging, transport, and marketing—can provide critical insights for urban planners and policymakers, while also informing place-specific adaptation and mitigation strategies.

Adaptation and mitigation measures in agriculture are critical for addressing climate change impacts and for sustaining productivity and enhancing food system resilience (Malhi et al., 2021). These include the adoption of drought- and heat-resistant crop varieties, timing adjustments in planting and harvest, and conservation agriculture practices, collectively reducing yield losses and supporting food security (Malhi et al., 2021). Climate-smart

agriculture (CSA) practices—such as crop diversification, optimized water management, and minimal tillage—help mitigate climate-induced stress while enhancing economic and environmental sustainability (Muench et al., 2024). Mitigation efforts, including reducing fossil fuel use in farm machinery and increasing renewable energy integration, can significantly lower greenhouse gas emissions. Moreover, applying biofertilizers and better managing agricultural residues can improve soil health and reduce environmental impacts, thereby increasing yields with a lower carbon footprint (Malhi et al., 2021). Subsequent sections will explore place-specific adaptation and mitigation strategies to address these challenges and enhance the resilience of Tehran's urban food systems.

2. Materials and methods

2.1. Setting

The study was carried out in Tehran city region, Iran. The Tehran city region—defined here as the broad geographic region containing two provinces namely Tehran and Alborz—is the largest metropolitan region in Iran, home to just over 15.98 million people (Statistical Center of Iran, 2016). The Tehran city region, situated within a fertile plain, is characterized by rich soils, grasslands, and semi-humid ecosystems in its southern section, transitioning to mountainous ecosystems in the north (Fig. 1). This region provides a compelling context for examining the impacts of climate change on urban and peri-urban agriculture, owing to its diverse agricultural production and pronounced climate variability over the past three decades. The climate is semi-arid, with a mean annual precipitation of 326 mm over the past 50 years, approximately two-thirds of which occurs during autumn and winter. Over the same period, the mean annual temperature is 13.4 °C (IRIMO, 2014). Within this context, agriculture remains a critical component of the Tehran city region's economy and livelihoods. More than 199,517 ha are currently used for agricultural production, providing employment for approximately 104,022 people (Statistical Center of Iran, 2011). According to the Ministry of Agricultural Jihad (2015), more than 14.15 million tons of food crops were produced in the region. In addition, 17.85 thousand tons of meat, 289.6 thousand tons of

milk, 83.58 thousand tons of chicken, and 0.71 thousand tons of honey were produced in 2013 (Agriculture Jihad Organization of Alborz, 2012; General Directorate of Economic Affairs and Finance of Tehran, 2014). Agriculture in the Tehran city region therefore plays a significant role in the national macroeconomy, contributing an estimated \$1.2 billion in annual value added (Agriculture Jihad Organization of Alborz, 2012; General Directorate of Economic Affairs and Finance of Tehran, 2014). Between 1994 and 2013, agricultural patterns in the Tehran and Alborz regions shifted significantly, reflecting adaptations to resource constraints and market demands (Table 1). Cereal crops saw substantial declines in cultivated area and production: for example, irrigated wheat area decreased from 96,482 ha to 48,366.3 ha, and irrigated barley area dropped from 65,917 ha to 45,317.3 ha. High-

value fruit crops showed improved yields despite stable or slightly reduced areas: irrigated apples increased yield from 15,725 kg/ha to 28,082.5 kg/ha, and irrigated cherries improved from 10,495.6 kg/ha to 13,359.7 kg/ha. Vegetable crops experienced reduced areas but maintained high yields: irrigated tomatoes decreased from 7,994 ha to 5,699.2 ha with yield rising to 39,444.2 kg/ha. Perennial crops declined in productivity: irrigated walnuts saw yield fall from 5,991.5 kg/ha to 2,672.8 kg/ha. Fodder crops expanded significantly: irrigated forage corn surged from 4,556 ha to 30,777 ha with yield increasing to 48,744.6 kg/ha, and irrigated alfalfa doubled from 7,000 ha to 15,085.3 ha. These trends indicate agricultural intensification, a shift toward livestock-supporting crops, and responses to environmental pressures, necessitating sustainable adaptive strategies.

Table 1. Changes in Area, Production, and Yield Performance of Selected Crops in the Tehran City Region, 1994–2013.

products	1994			2013		
	Area (Ha)	Production (Tonnes)	Yield Performance (Kg/per Ha)	Area (Ha)	Production (Tonnes)	Yield Performance (Kg/per Ha)
Rainfed wheat	6825.0	4513.7	661.4	2000.5	1053.5	526.6
Irrigated wheat	96482.0	389341.7	4035.4	48366.3	152159.6	3146.0
Rainfed barley	1493.0	774.4	518.7	60.0	30.0	499.8
Irrigated barley	65917.0	250432.4	3799.2	45317.3	134033.4	2957.7
Irrigated cucumbers	11543.0	337289.1	29220.2	2945.4	65917.6	22379.8
Irrigated tomatoes	7994.0	292103.4	36540.3	5699.2	224800.2	39444.2
Irrigated watermelons	2456.0	48371.4	19695.2	719.2	28411.9	39504.9
Irrigated apple	16682.0	262324.0	15725.0	15526.0	436009.0	28082.5
Irrigated cherries	8150.0	85539.0	10495.6	9064.0	121092.4	13359.7
Irrigated walnuts	3297.0	19754.0	5991.5	2821.0	7540.0	2672.8
Rainfed grape	0.0	0.0	0.0	21.5	70.6	3285.7
Irrigated grape	12937.0	182099.0	14075.8	8060.0	108825.0	13501.9
Irrigated pomegranate	3929.0	49358.0	12562.5	1148.0	10888.0	9484.3
Irrigated potatoes	5329.0	123702.5	23213.1	2899.4	78054.1	26920.8
Rainfed chickpea	10.0	3.1	310.0	9.0	6.3	700.0
Irrigated chickpea	34.0	41.2	1211.8	42.9	16.7	389.3
Irrigated beans	423.0	679.4	1606.1	222.1	143.0	643.9
Irrigated Cotton	11197.0	28538.1	2548.7	639.9	1451.0	2267.5
Rainfed alfalfa	137.0	682.5	4981.8	0.0	0.0	0.0
Irrigated alfalfa	7000.0	90597.3	12942.5	15085.3	215663.2	14296.2
Irrigated forage corn	4556.0	196692.6	43172.2	30777.0	1500213.3	48744.6

Like other regions of Iran, the Tehran city region is projected to undergo significant climatic changes by the end of the 21st century. Data presented in Figs 1-2, generated via the KNMI Climate Explorer platform (<https://climexp.knmi.nl/start.cgi>), illustrate the multi-model mean of projected changes in near-surface temperature and precipitation across Iran under the Representative Concentration Pathway (RCP) scenarios 4.5 and 8.5, derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble. The CMIP5 ensemble, comprising outputs from numerous global climate models, provides

robust projections by capturing a wide range of climate responses and minimizing model-specific uncertainties (Taylor et al., 2012; IPCC, 2014). According to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2014), relative to the 1986–2005 baseline, mean annual precipitation in Iran is projected to decline marginally by 0.033% under RCP4.5 and 0.058% under RCP8.5, while mean annual temperature is expected to increase substantially, by 2.6 °C under RCP4.5 and 5.9 °C under RCP8.5, by 2100. The synergistic impacts of rising temperatures and reduced

precipitation are projected to pose significant challenges for the Tehran city area, particularly impacting water resources and agricultural productivity. Elevated temperatures are expected to intensify evapotranspiration rates, escalate irrigation requirements, and heighten

the risk of diminished crop yields, thereby jeopardizing regional food security and the sustainability of water resources. Location and land use of Tehran city region in shown in Fig. 3.

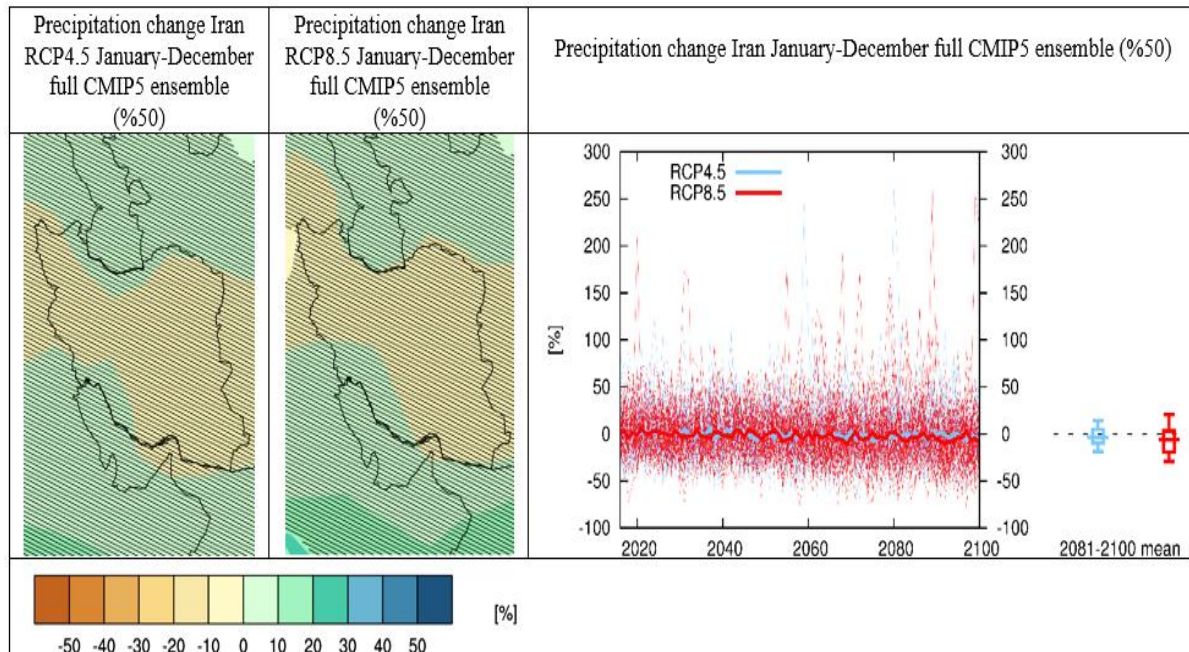


Fig. 1. (Top right) Relative Precipitation change Iran relative to 1986–2005 full CMIP5 ensemble. On the left, for each scenario one line per model is shown plus the multi-model mean, On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2016–2100 in the two RCP scenarios. (Top left) Maps of relative precipitation change Iran in 2016–2100, with respect to 1986–2005 in the RCP4.5 and RCP8.5 scenarios. The hatching represents areas where the signal is smaller than one standard deviation of natural variability.

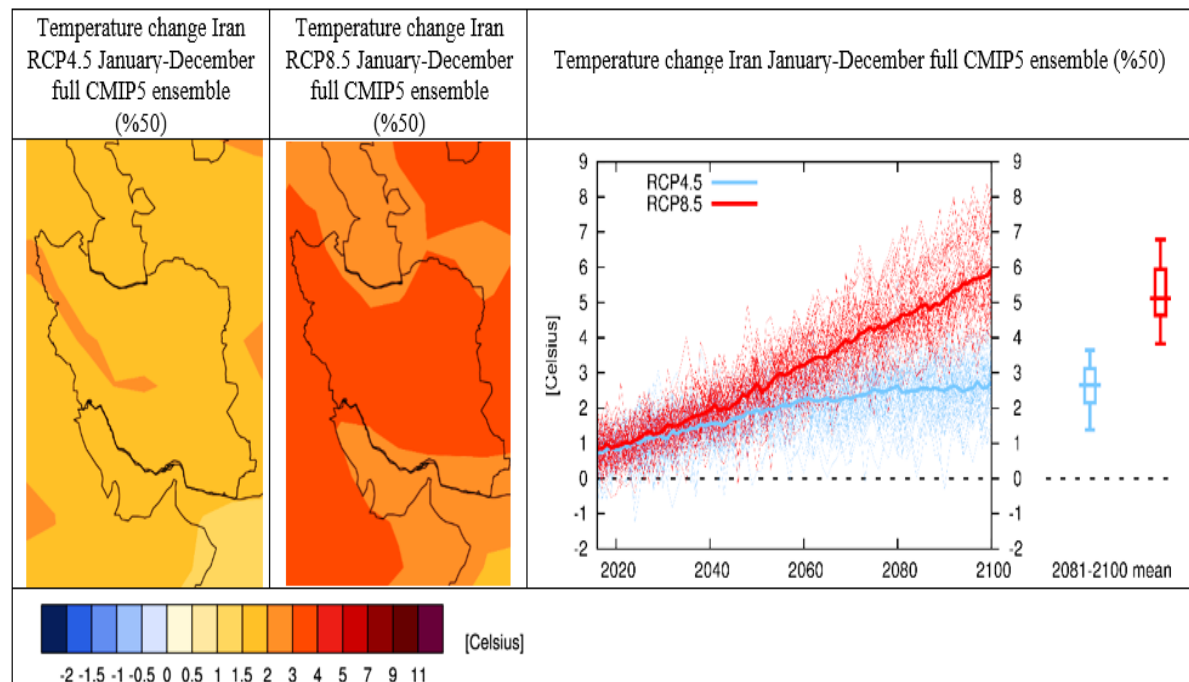


Fig. 2. (Top right) Temperature change Iran Jan-Dec wrt 1986–2005 full CMIP5 ensemble. On the left, for each scenario one line per model is shown plus the multi-model mean, on the right percentiles of the whole dataset: the box extends from 25% to 75%, the whiskers from 5% to 95% and the horizontal line denotes the median (50%). (Top left) Maps of mean RCP4.5 temperature 2016–2100 minus 1986–2005 Jan-Dec full CMIP5 ensemble. The hatching represents areas where the signal is smaller than one standard deviation of natural variability.

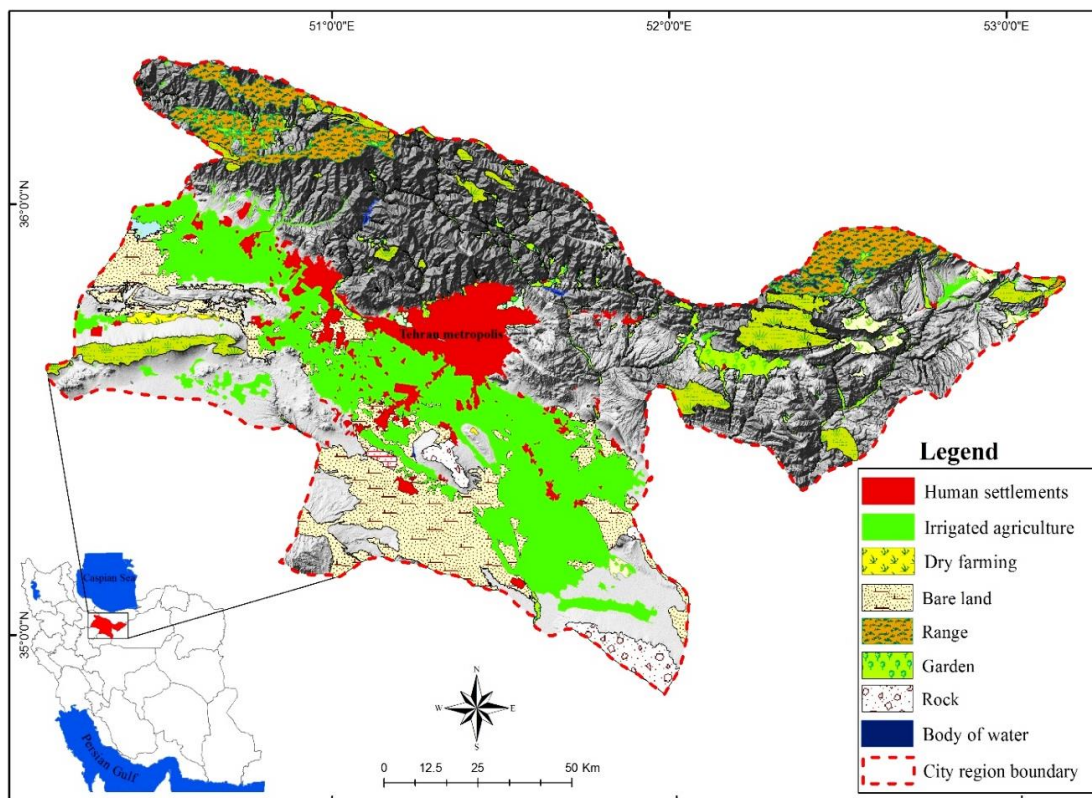


Fig. 3. Location and land use of Tehran city region.

2.2. Data set and climate model

City region level yield data series of major food crops (wheat, barley, apples, walnuts, grapes, cucumbers, watermelons, cotton, and alfalfa) encompassing both irrigated and rainfed systems, were obtained from the Ministry of Agriculture Jihad for the period 1994–2014. These crops, selected as dependent variables, were chosen based on their product categories, area under cultivation, production volume, and consistent cultivation history (Table 2). Monthly climate data, including mean and standard deviations of maximum and minimum temperature, rainfall, solar radiation, and relative humidity, were sourced from the Islamic Republic of Iran Meteorological Organization (IRIMO) for five synoptic stations (Abali, Firouzkouh, Karaj, Semnan, and Tehran-Mehrabad) covering the Tehran city region during the same period (IRIMO, 2018). These variables were included to capture both average climatic conditions and variability, which critically influence crop yield responses to climate change (Lobell and Gourджи, 2012). Aggregate-level monthly data were spatially averaged across the five stations to represent the regional climate, ensuring

comprehensive coverage of the Tehran metropolitan area. The stations were selected for their spatial distribution across the region’s diverse topography (e.g. elevations ranging from 1190.8 m at Tehran-Mehrabad to 2465.2 m at Abali), high-quality long-term records, and consistent data availability (Table 2). The inclusion of standard deviations of temperature and precipitation in analytical models captures climate variability alongside mean climatic conditions. Numerous studies have demonstrated that variability in temperature and precipitation significantly influences crop growth, physiological stress responses (e.g., heat and water stress), and yield outcomes, often independently of mean climatic values (Lobell et al., 2011; Ray et al., 2015; Asseng et al., 2015; Lesk et al., 2016; Zhao et al., 2017; Shew, 2020). By incorporating standard deviation as a measure of climate variability, models can account for both central tendencies and fluctuations, enabling a more robust and comprehensive assessment of climate impacts on agricultural productivity.

Table 2. Detailed information on selected synoptic stations.

Station	Latitude	Longitude	Elevation
Abali	35° 45' N	51° 53' E	2465.2 M
Tehran Mehrabad	35° 41' N	51° 19' E	1190.8 M
Firouzkooh	35° 55' N	52° 50' E	1975.6 M
Jeophysics Tehran	35° 44' N	51° 23' E	1418.6 M
Semiran	35° 48' N	51° 29' E	1549.1 M
Karaj	35° 47' N	50° 52' E	1292.9 M

Source: I.R Of Iran Meteorological Organization (Irimo), 2018

To ensure data reliability, yield and climate data underwent rigorous quality control, including cross-verification against secondary sources, outlier detection using statistical thresholds, and standardization to address missing or inconsistent records. Future climate projections were derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble under Representative Concentration Pathway (RCP) scenarios 4.5 (stabilization) and 8.5 (rising radiative forcing), accessed via the KNMI Climate Explorer

platform (<https://climexp.knmi.nl/start.cgi>) (Taylor et al., 2012; IPCC, 2014). Specific variables extracted included mean near-surface temperature, precipitation, and their standard deviations for three-time horizons (2030s, 2060s, 2080s), enabling assessment of long-term climate impacts. Historical (IRIMO) and projected (CMIP5) data were integrated using statistical downscaling techniques to reconcile differences in spatial resolution, aligning coarse-resolution CMIP5 outputs with finer-scale station data to ensure consistency in the analysis.

Table 3. Selected food crops in Tehran city region in 2014 by products categories.

Categories/products		Area (Ha)		Production (Tons)		Yield Performance (Kg/per Ha)	
		2014		2014		2014	
		Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Cereals	Wheat	2000.5	48366.3	1053.5	152159.6	526.61	6816.5
	Barley	60	45317.3	30	134033.4	499.83	2957.7
Vegetables and melons	Cucumbers	0	2945.4	0	65917.6	0	46695.8
	Watermelons	0	719.2	0	28411.9	0	81313.5
Fruit and nuts	Apples	0	15526	0	436009	0	51500
	Walnuts	0	2821	0	7540	0	5999.2
	Grape	21	7906	108825	69	3,285.7	15217.4
Other crops	Cotton	0	639.9	0	1451	0	2244
	Alfalfa	0	15085.3	0	215663.2	0	13279.8

Table 4. CMIP5 full ensemble mean of projected seasonal changes in near-surface temperature and precipitation for three time slices (2016–2045, 2046–2075, and 2076–2100, namely 2030s, 2060s, and 2080s) relative to 1986–2005 under RCP4.5 and RCP8.5 scenarios (IPCC, 2014).

Month	2016–2045 (2030s)				2046–2075 (2060s)				2076–2100 (2080s)			
	Temperature °C		Precipitation %		Temperature °C		Precipitation %		Temperature °C		Precipitation %	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
DJF	1.39	1.48	-0.0015	-0.012	2.1	3.36	-0.035	0.035	2.33	3.85	-0.009	-0.0036
MAM	1.2	1.6	-0.016	-0.02	2.17	3.4	-0.053	-0.052	2.55	4.99	-0.052	-0.14
JJA	1.55	1.87	-0.019	-0.034	2.6	4.06	-0.09	-0.014	2.89	5.7	-0.074	-0.018
SON	1.5	1.7	0.03	-0.004	2.33	3.85	-0.0036	-0.0092	2.7	5.3	-0.0085	-0.0043

DJF= Dec, Jan, Feb.; MAM= Mar, Apr, May; JJA= June, Jul, Aug.; SON= Sep, Oct, Nov.

2.3. Research method

Our research focuses on the production side of urban agriculture, defined here as encompassing the cultivation of foodstuffs, including fruits and vegetables, across all scales—from commercial and extensive farming to small-scale family farms—in the Tehran city region. The crops analyzed include irrigated alfalfa, apple, barley, beans, cherries,

chickpea, cotton, cucumbers, forage corn, grape, pomegranate, potatoes, tomatoes, walnuts, watermelons, and wheat, as well as rainfed alfalfa, barley, chickpea, grape, and wheat. Although data were collected over consecutive years (1994–2014), our investigations show no significant time-series autocorrelation. The Ljung-Box test, applied with up to 12 lags to account for monthly data, yielded p-values indicating no autocorrelation

(Box and Pierce, 1970; Koenker, 2005). Consequently, we proceeded under the assumption of independence. Initially, a traditional multivariate regression model was used to estimate the effects of climate change on major food crop productivity. This method, widely adopted in climate change impact studies (Iglesias et al., 2000; Alexandrov and Hoogenboom, 2000; Neuwirth and Hofer, 2013; Bawayelaazaa Nyuor et al., 2016; Sitienei et al., 2017; Kukul and Irmak, 2018), takes the matrix form (Eq. 1):

$$Y = X\beta + \varepsilon \tag{1}$$

where Y is a vector of responses, β is a vector of parameters, X is design matrix and finally ε is a zero-mean vector of independent normally distributed errors. The least squares method, $(X'X)^{-1}X'Y$ used to estimated unknown parameters so the predicted values are $\hat{Y} = Xb$. However, conditional mean models like multivariate regression have limitations, including sensitivity to outliers and assumptions of homoskedasticity. In this paper, quantile regression was employed because it provides a more comprehensive perspective on the relationships between response and predictor variables, does not impose distributional assumptions on the error term, and accommodates potential heteroskedasticity. Quantile regression has received relatively less attention in the climate change literature. Originally developed by Koenker and Bassett (1978) as an alternative to mean regression, this approach does not require the assumption of normally distributed residuals in regression models. Quantile regression estimates are less sensitive to outliers in the response variables compared to standard linear regression. While multivariate regression models the relationship between predictor and response variables using the conditional mean function, quantile regression characterizes this relationship through the conditional quantile function. The τ -th

conditional quantile function is defined as Eq. 2:

$$Q(\tau|x) = x'\beta(\tau) \tag{2}$$

Where $\tau \in (0,1)$ and $\beta(\tau)$ is the quantile coefficient vector depending on τ . Next define the quantile regression model of Eq. 3:

$$y_i = x'_i\beta(\tau) + \varepsilon_i(\tau) \tag{3}$$

Where $P(\varepsilon_i(\tau) < 0) = \tau$. $\beta(\tau)$ can be estimated by minimizing Eq. 4:

$$\sum_{i=1}^n \rho_{\tau}(y_i - x'_i\beta) \tag{4}$$

Where the asymmetric quantile loss function is defined as Eq. 5:

$$\rho_{\tau}(u) = u(\tau - I(u < 0)) \tag{5}$$

$I(.)$ is the indicator function. The package `quantreg` available in R software is used to estimate and make inferences about quantile regression. In our modeling strategy, the response variables are crop yields (kg per hectare), and the independent variables include monthly average rainfall, maximum and minimum temperature, relative humidity, and solar radiation. For each food crop, significant independent variables were selected based on the available data, and a quantile regression model was fitted accordingly. Given the large number of food crops in this study, it is not feasible to include all fitted models in the paper. Therefore, we report only the fitted quantile regression models with $\tau = 0.25, 0.50,$ and 0.75 for rainfed wheat (Table 5).

Limitations of quantile regression include its assumption of linearity in quantile relationships, which may not fully capture complex non-linear interactions, and its sensitivity to data quality, particularly with respect to spatial variability and the 20-year temporal coverage of the dataset. These constraints may restrict the ability to detect subtle climate–yield relationships or the influence of non-climatic factors such as soil management practices and genetic improvements. Nevertheless, quantile regression offers distinct advantages by revealing heterogeneous climate impacts across the yield distribution, insights that are often obscured by mean-based approaches.

Table 5. Coefficients of fitted quantile regression with $\tau = 0.25, 0.50$ and 0.75 for rainfed wheat.

	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Intercept	3715.814	1901.441	1900.417
JAN.Mean_Rain	7.659	1.792	1.791
JULYMean_Rain	2.505	4.187	4.188
AUG.Mean_Rain	15.178	12.934	12.932
OCT.Mean_Rain	-3.157	-3.163	-3.163
NOV.Mean_Rain	1.866	1.578	1.578
DEC.Mean_Tem	0.595	-81.411	-81.398
JAN.Max_Tem	33.849	-10.012	-10.016
OCT.Max_Tem	-13.777	24.349	24.363
MAR.Min_Tem	-40.283	-26.869	-26.869
MAYMin_Tem	79.464	46.691	46.694
JUNEMin_Tem	15.504	3.409	3.399
JULYMin_Tem	-56.132	5.698	5.706
DEC.Min_Tem	11.212	30.177	30.169
APR.Humidity	11.432	0.911	0.909
MAYHumidity	-15.821	-5.380	-5.374
NOV.Humidity	-20.634	-7.259	-7.257
FEB.Sunshine	4.842	-2.924	-2.924
MAYSunshine	-11.413	-2.303	-2.302

3. Results and discussion

3.1. Estimating potential effects of climate change on major crops

Major food crops, including irrigated and rainfed alfalfa, barley, chickpea, grape, and wheat, as well as irrigated apple, beans, cherries, cotton, cucumbers, forage corn, pomegranate, potatoes, tomatoes, walnuts, and watermelons, were selected to assess the impact of climate change on crop yields in the Tehran city region from 1994 to 2014, using quantile regression models. With 21 years of available data, the number of candidate covariates (e.g., mean rain, mean temperature, maximum temperature, minimum temperature, relative humidity, and solar radiation for each month) exceeded the number of observations, presenting a high-dimensionality challenge. Quantile regression was selected for its robustness in capturing heterogeneous yield responses across quantiles (0.25, 0.5, and 0.75) and its computational efficiency and interpretability in small-sample agronomic studies (Koenker, 2005). To address the high-dimensionality challenge, a correlation-based variable selection method was implemented, excluding covariates with absolute correlation coefficients below 0.3. This threshold, widely adopted in agronomic studies to balance model parsimony and predictive power (Lobell et al., 2012; Ray et al., 2019), ensured the retention of climatically relevant variables while mitigating overfitting. The selection was validated through simple linear regressions, where retained covariates demonstrated the highest coefficients of determination (R^2 , ranging from

0.38 to 0.62 for significant covariates, Tables 8–9). For instance, January means temperature was strongly negatively correlated with apple yield ($r = -0.62$, Table 8), while June and October relative humidity ($r = 0.51$) and September maximum temperature ($r = -0.48$) were key drivers for walnut yield (Table 9). Cross-validation using a leave-one-out (LOO) approach confirmed the robustness of the correlation-based covariate selection, with retained predictors consistently enhancing model fit, yielding an average R^2 improvement of 0.15–0.20. Alternative variable selection strategies were systematically evaluated. These included LASSO regressions (Tibshirani, 1996), which penalizes regression coefficients to induce sparsity, and principal component analysis (PCA) (Jolliffe, 2002), which transforms correlated predictors into orthogonal components to reduce dimensionality. Both methods were ultimately not adopted due to the limited sample size (21 observations), which could compromise the stability of LASSO coefficient estimates and reduce interpretability of PCA-derived components in an agronomic context. These methods were not adopted due to the small sample size (21 observations), which risks unstable LASSO estimates (e.g., high variance in coefficient selection) and PCA components that obscure the agronomic interpretability of climatic drivers (e.g., temperature, humidity). Stepwise regression was also considered but rejected due to its sensitivity to multicollinearity among monthly climatic variables, which could inflate variance in this dataset. The correlation-based approach was

prioritized for its transparency, reproducibility, and alignment with the study’s focus on interpretable climate-yield relationships.

Quantile regression models were fitted across the 0.25, 0.5, and 0.75 quantiles without additional regularization techniques, relying on the correlation-based selection to manage model complexity. This approach ensured robust estimation of heterogeneous yield responses while preserving interpretability for agronomic applications. Model performance was evaluated using quantile-specific R² and pseudo-R² metrics, with values indicating moderate to strong explanatory power (e.g, R² = 0.45–0.60 for apple and walnut at the 0.5 quantile, Tables 8–9). The absence of regularization was justified by the effective reduction of covariates (from 72 to approximately 15–20 per crop) through the 0.3 threshold, which minimized overfitting while maintaining statistical power in the small-sample context (Koenker, 2005).

Yield projections were generated under RCP4.5 and RCP8.5 climate scenarios for the 2030s, 2060s, and 2080s (Tables 6–7, Figs 4–5). The results reveal a non-monotonic response of major crops to projected climatic changes. Irrigated wheat, barley, alfalfa, and walnuts are projected to experience yield increases, with walnuts showing the largest gains (from 3,227

kg/ha in 1994–2014 to 4,645 kg/ha and 6,003 kg/ha under RCP4.5 and RCP8.5, respectively, by the 2080s, representing 44% and 86% increases; Table 4). Irrigated wheat yields are projected to increase from 4,076 kg/ha to 5,013 kg/ha under RCP8.5 by the 2080s (23% increase, Table 7). Conversely, irrigated apple, grape, cucumber, watermelon, cotton, and rainfed wheat are projected to experience declines, with apple yields decreasing from 19,269 kg/ha to 12,912 kg/ha (33%) and 7,087 kg/ha (63%), cucumber yields from 22,633 kg/ha to 13,073 kg/ha (42%), and grape production from 113,718 tons to 73,247 tons (36%) under RCP8.5 by the 2080s (Tables 6–7). Key correlations include a strong negative association between apple yield and January mean temperature (r = -0.62, Table 8), a positive correlation between walnut yield and June/October relative humidity (r = 0.51), and a negative correlation with September maximum temperature (r = -0.48, Table 9). Positive yield trends for wheat, barley, and alfalfa may be moderated by extreme weather conditions and shifts in seasonal runoff, highlighting the complexity of climate impacts. Note that Figures and tables do not include all crops analyzed in this study, focusing only on key crops with significant climate impacts.

Table 6. Impacts of projected climate change on major crops in Tehran city region under the RCP4.5 and RCP8.5 scenarios, where Y.Kg/H means Yield (Kg/Ha) and P/T means Production (Tone).

Period	Scenario	Irrigated Apple		Irrigated Cotton		Irrigated Cucumbers		Irrigated Grape		Irrigated Walnuts	
		Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T
Current (mean) (1994-2014)		19269	279367	3051	12673	22633	78258	12134	113718	3227	11816
2030s	RCP4.5	15754	230593	2966	12321	19460	66588	10864	101813	3980	14269
2060s	RCP4.5	13629	199501	2907	12077	17776	60827	9962	93359	4518	16196
2080s	RCP4.5	12912	188999	2862	11890	17394	59519	9666	90583	4645	16650
2030s	RCP8.5	15202	222526	2940	12215	19190	65665	10520	98584	4129	14800
2060s	RCP8.5	10249	150025	2800	11634	14932	51094	8730	81809	5196	18628
2080s	RCP8.5	7087	103732	2666	11074	13073	44734	7816	73247	6003	21521

Table 7. Impacts of projected climate change on major crops in Tehran city region under the RCP4.5 and RCP8.5 scenarios, where Y.Kg/H means Yield (Kg/Ha) and P/T means Production (Tone)

Period	Scenario	Irrigated Wheat		Irrigated Alfalfa		Irrigated Barley		Irrigated Watermelons		Rainfed Wheat	
		Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T	Y.Kg/H	P/T
Current (mean) (1994-2014)		4076	235986	12314	118299	3584	139466	36869	28202	739	1665
2030s	RCP4.5	4453	254215	12156	117429	3805	149067	32577	26539	724	1641
2060s	RCP4.5	4592	262127	12151	117377	3929	153910	29902	24360	706	1599
2080s	RCP4.5	4644	265135	12272	118548	3997	156583	28854	23506	713	1615
2030s	RCP8.5	4467	255032	12218	118025	3843	150558	31953	26031	721	1634
2060s	RCP8.5	4968	283599	12134	117215	4176	163596	25673	20915	716	1621
2080s	RCP8.5	5013	286160	12732	122986	4391	172030	20510	16708	715	1620

Table 8. Correlation between irrigated grape and different covariates for each month of the year

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
Mean rain	-0.22	-0.06	-0.4	-0.33	-0.27	-0.13	-0.06	0.08	-0.11	0.17	0.1	-0.18
Mean temperature	-0.22	-0.29	0.19	0.11	-0.13	-0.3	-0.25	-0.71	-0.32	-0.41	-0.37	-0.15
Max temperature	-0.09	-0.21	0.19	0.13	0.11	0.11	0.32	0.02	0.1	0.32	-0.39	0.05
Min-temperature	-0.47	-0.36	0.05	0.11	0.29	-0.03	-0.36	-0.42	-0.36	-0.32	0.11	-0.12
Relative humidity	0	0.02	-0.36	-0.35	-0.38	-0.25	-0.28	-0.15	-0.07	-0.07	0.09	-0.11
Solar-radiation	-0.05	-0.1	0.14	0.13	-0.1	-0.09	-0.19	-0.36	-0.2	-0.12	-0.1	0.16

Table 9. Correlation between irrigated cucumber and different covariates for each month of the year

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
Mean rain	0.17	0.18	0.11	-0.14	0.39	0.23	-0.24	-0.03	-0.19	0.18	0.31	-0.26
Mean temperature	0.09	-0.08	-0.19	0.07	-0.03	-0.06	0.21	0.33	-0.26	-0.25	0.12	-0.33
Max temperature	0.21	0.01	-0.18	0.1	-0.12	-0.36	0.12	0.43	-0.48	-0.37	0.1	-0.34
Min-temperature	0.22	-0.09	0.23	-0.07	0	0.04	0.26	0.3	-0.15	-0.11	-0.17	-0.4
Relative humidity	-0.03	0.13	0.11	0.06	0.45	0.51	0.12	-0.09	0.08	0.51	-0.16	-0.06
Solar-radiation	0.22	-0.05	0.06	0.07	-0.29	-0.11	0.46	0.19	-0.22	-0.35	0.11	0.1

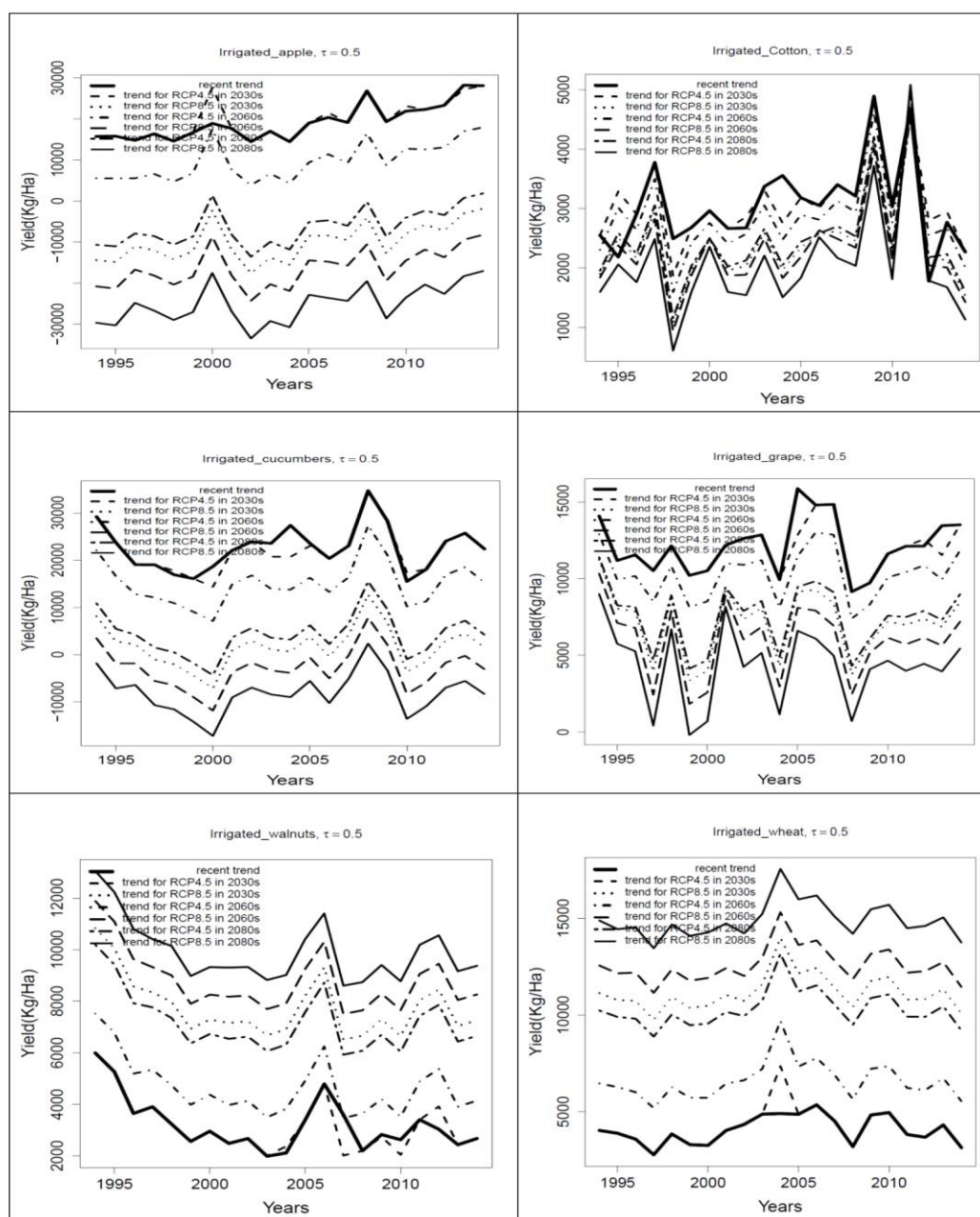


Fig. 4. Impacts of projected climate change on major crops in Tehran city region under the RCP4.5 and RCP8.5 climate change scenarios, where Y.Kg/H means Yield (Kg/Ha) and P/T means Production (Tone).

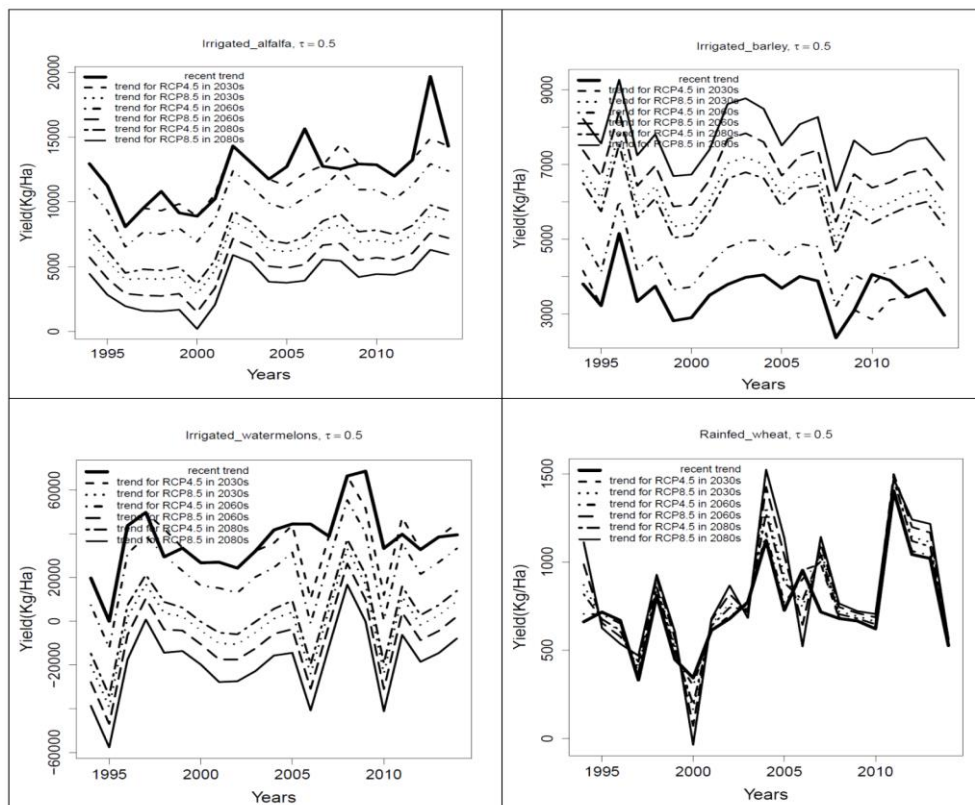


Fig. 5. Impacts of projected climate change on major crops in Tehran city region under the RCP4.5 and RCP8.5 climate change scenarios, where Y.Kg/H means Yield (Kg/Ha) and P/T means Production (Tone).

4. Conclusion

This paper quantifies the impacts of climate variability and long-term climate change on (peri)urban agricultural production in the Tehran metropolitan region, focusing on yields of major food crops, including both irrigated and rainfed systems. Notably, irrigated wheat, barley, alfalfa, and walnuts are projected to experience yield increases, with walnuts showing the highest gains (up to 86% under RCP8.5), whereas irrigated apple, grape, cucumber, watermelon, and cotton face significant declines, with apple yields projected to decrease by 63% under RCP8.5 by the 2080s. These results illustrate heterogeneous crop responses to changing climate, emphasizing that climate impacts are neither uniform nor monotonic across crops. Compared with global or rural-focused studies, this research contributes a crop-specific, peri-urban perspective in a semi-arid region, complementing prior work (e.g. Lobell et al., 2011; Wheeler and von Braun, 2013; Vishwakarma et al., 2025). By employing quantile regression, the study captures variability across the yield distribution, revealing heterogeneous crop responses and the impacts of climate extremes, which are often

overlooked by mean-based approaches. Vishwakarma et al. (2025) highlight that lower quantile of wheat yield anomalies are strongly associated with extreme weather and socioeconomic drivers, emphasizing the value of quantile-based methods for understanding global yield shocks. Our study extends these insights to a peri-urban, semi-arid context, demonstrating the importance of crop-specific adaptation strategies under changing climatic conditions. The study’s findings are highly relevant for urban planners, policymakers, and stakeholders, offering guidance for place-specific adaptation in peri-urban agriculture. Adaptive strategies, such as adjusting planting dates, are cost-effective measures that optimize crop phenology, enhancing productivity and food security, particularly for vulnerable crops like apple and grape. Developing climate-resilient crop varieties suitable for warmer and more variable conditions represents a scalable and economically efficient solution compared with large-scale infrastructure investments. Strengthening institutional frameworks to promote water-efficient technologies, such as drip irrigation, and integrating agricultural priorities into urban land-use planning can further enhance resilience. Additionally,

building climatic literacy through social learning empowers farmers and supports adaptive capacity. Despite these insights, several limitations must be acknowledged. The analysis focuses exclusively on crop production, excluding livestock, processing, transport, and marketing. The 20-year temporal scope (1994–2014) may limit detection of long-term trends, and variable selection due to high-dimensional predictors may reduce model robustness. Quantile regression, while robust to outliers, assumes linearity in quantile relationships and is sensitive to data quality, particularly regarding spatial variability and temporal coverage. These constraints may limit detection of subtle climate–yield interactions and the influence of non-climatic factors such as soil management or genetic improvements. Weak correlations between climate variables and yields suggest that non-climatic drivers, including advanced crop management and fertilizer use, significantly influence outcomes. Nevertheless, the study provides valuable insights into heterogeneous climate impacts and advances understanding of urban and peri-urban agricultural responses under changing climates. Future research should expand the scope to include livestock, supply chains, and other agricultural dimensions, and evaluate the long-term efficacy of adaptation measures. Coordinated policy interventions are crucial, including incentives for sustainable irrigation, regulatory frameworks to prevent groundwater overuse, and urban planning reforms to support climate-resilient agriculture. Such efforts are essential for sustaining urban food systems, ensuring food security, and fostering resilient peri-urban economies under intensifying climate challenges.

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