Global Climate-Change Impact Studies Centre (GCISC)
(A Body Corporate established under the GCISC Act 2013)

YEAR BOOK (2023-24)
(in pursuance of Rule 25 of Rules of Business 1973)

1. INTRODUCTION

The Global Climate-Change Impact Studies Centre (GCISC) was initially established as a developmental initiative in April 2002, with the mission to conduct research on climate change, its impacts, and potential solutions. Later, GCISC's status was formalized with the enactment of the GCISC Act 2013 by the Parliament, officially recognized through the Gazette of Pakistan on March 26, 2013, as Act No. XVII of 2013, amended in 2023. According to the Act, GCISC is designated as a corporate entity governed by a Board of Governors (BoG), presided over by the Federal Minister responsible for the relevant Ministry overseeing climate change matters.

The Centre is mandated to undertake scientific investigations of the phenomenon of climate change at regional and sub-regional levels and study its impacts on various sectors of socio-economic development in order to prepare the country to meet threats to its water resources, agriculture, ecology, energy, health, bio-diversity etc.

2. ROLES & FUNCTIONS

GCISC, under the Act, is tasked with three functions, namely research, capacity building, outreach and awareness:

a. **Research**: the research program is driven by national policy goals, namely protecting people against the impacts of climate change, promoting economic growth and sustainable development in a climate-constrained future, and honoring Pakistan's international commitments. To these ends, research is organized in three groups:

   - **Climatology and Environment**: using climate system models to predict future climate behavior in Pakistan, including monsoons, temperature, precipitation, and climate extremes.
   - **Water Resources and Glaciology**: using glacio-hydrological and water models to assess future behavior of glaciers, aggregate and seasonal flows in the Indus River System, and changes in the hydrological extremes across the country.

- ***Agriculture, Forestry & Land Use**:* use of crop simulation models to predict the impact of projected changes in temperature, precipitation, and water availability on agriculture and food security of the country and to assess the impacts on Forestry, Land Use.

b. **Capacity building**: imparting technical and communication skills to GCISC staff as well as students and climate scientists at other national research organizations and universities.

c. **Dissemination of research findings**: to the scientific community, planners, policymakers, and to the public at large, in order to raise awareness of climate change among policymakers as well as the citizenry.

3. ACTIVITIES

RESEARCH

The key research activities of the Research Sections revolve around following themes:

I. Climatology & Environment Section

The Climatology & Environment Section research areas focus on key aspects of climate variability and change, which can be summarized as follows:

- To assess historical climate trends over Pakistan and its regions;
- Climate profiling of Pakistan based on IPCC future climate scenarios (RCPs, SSPs etc.;
- To generate up-to-date information on changes in near to long term climate extremes and to study associated impacts;
- Study variations in summer monsoon patterns for impact assessments;
- High resolution climate information for future urban climate issues
- Intra seasonal to inter decadal climate predictions;
- Integrated modeling of air pollution and greenhouse gas emissions;
- Development & updating of GHG inventory of Pakistan for energy & industrial processes sectors;

II. Water Resources & Glaciology Section

- Application of Machine Learning and Artificial Intelligence (AI) techniques to model Indus River System (IRS) flows;
- Climate change analysis for the high-elevation Hindukush-Karakoram-Himalaya (HKH) region;

- Application of different hydrological and cryospheric models to assess the water availability and variability (quantitatively) in space and time in the Indus River System (IRS) under the latest socio-economic and climate projections;
- Analysis of climate impact on the frequency and intensity of hydrological extreme events at seasonal and sub-seasonal scales;
- Drought prediction in the Indus Basin as a climate adaptation strategy;
- Plausible Adaptation strategies in line with national Climate change and Water policies to ensure the country's water security;
- Research dissemination (International and national scientific journals and books, newspaper articles, policy briefs, etc.);
- Capacity building, awareness raising and collaboration among National and International institutions, researchers and academicians
- Identification of location and time-specific climate extremes (dry and warm) for related impacts on water availability and variability from different sources (surface water and groundwater)

III. Agriculture, Forestry and Land Use Section

- Assess impacts of projected climate change on productivity of key agricultural crops in different climatic zones using crop models;
- Assess impacts on related areas, including productivity of forestry, grasslands, rangelands and fragile ecosystems (i.e., mountains, wetlands, coasts, and arid areas); livestock; and land degradation and deforestation, insect-pest infestation dynamics;
- Assess food security in the face of future climate change and especially under reduced availability of irrigation water;
- Devise adaptation measures, including smart agriculture;
- Studies on water, food, energy nexus;
- Updating GHG emissions from agriculture, forestry and land use and waste sectors.
- Research dissemination (International and national science journals and books, newspaper articles and policy briefs etc.)
- Capacity building and awareness raising

4. GOALS & TARGETS

Throughout the year, GCISC made notable advancements in the international scientific literature concerning climate change and its associated effects, while also offering substantial inputs to various research projects. Additionally, the organization conducted several workshops and seminars aimed at disseminating information and raising awareness on pertinent issues:

The following is a summary of the accomplishments in 2023-24:

- Publication of key research findings in scientific journals = 17
- Contribution towards technical reports = 10
- Organization of scientific activities/workshops/seminars for information dissemination and awareness = 20
- Scientific contributions/ presentations and effort on capacity building of GCISC young scientists through academic and specialized trainings and participation in online conferences, workshops etc. at International level (Nos) = 25
- Effort on capacity building of GCISC young scientists through academic and specialized trainings and participation in conferences, workshops etc at National Level (Nos) = 85
- Scientific Contributions and Presentations in National Conferences and Workshops = 48
- Provision of training to university students across Pakistan in the field of climate change through GCISC internship program = 27
- Responses to NA/Senate starred questions and provided inputs (presentations/ briefs) for NA Standing Committee on Climate Change on the aspects of Climate Change = 13
- Muhammad Arif Goheer, Principal Scientific Officer/ Head- Agriculture and Coordination contributed to UNFCCC's Consultative Group of Experts (CGE) activities.
- Shahbaz Mehmood, Head Climatology & Environment delivered key note speech and participated as a panelist at a seminar titled "Current Affairs & Climate Change and its Impacts on Pakistan", organized by Karachi Council on Foreign Relations (KCFR).
- Contributions to Pakistan's 1st Biennial Update Report submitted to UNFCCC in 2022.
- GCISC provided technical inputs in the preparation of National Adaptation Plan.
- GCISC in collaboration with LUMS Energy Institute organized a one-day stakeholder workshop at the LUMS, Lahore under TNC Project. Two GCISC scientists delivered lectures, and participated as panelist in the event.
- GCISC successfully conducted stakeholders' consultation across the country for data collection and reconciliation required for the preparation of National GHG Inventory to be reported in the Third National Communication of Pakistan to streamline the data providers, sectoral experts and reviewer in the GHG inventory process for future reporting to the UNFCCC.
- Reports on Subnational Climate Risk Profiles for Punjab and KP provinces of Pakistan under GIZ's Strengthening Climate Adaptation and Resilience (SAR) Program.

- GCISC has been awarded a contract by the Ministry of Climate Change & Environmental Coordination (MoCC&EC) to contribute in various chapters of Third National Communication (TNC).
- Development of MRV platform for GHG Inventories & MRE platform for Adaptation tracking in Agriculture (Pilot basis).
- GCISC co-organized a one-day capacity building seminar on Climate Change Impacts, Air Pollution, and Climatic Extremes for faculty members and students at the University of Sargodha. Three scientists from Climatology & Environment Section delivered talks and had focused meetings on climate change curriculum with faculty members of various departments.
- One Water Section Scientist is working as a Co-PI in "Flash Floods Harnessing for the Prosperity of Arid and Resource-stressed Neglected Agro-based Communities (ProNAC)" approved by Higher Education Commission (HEC) in National Research Program for Universities (NRPU) (Ongoing).
- Global Climate-Change Impact Studies Centre (GCISC) is leading a project on Climate Risk Assessments under GIZ's Strengthening Adaptation and Resilience (SAR) Programme. Water section taking the lead as Expert Working Group Coordinator to perform Climate Risk Assessment (CRA) related to the Water Sector.

5. ACHIEVEMENTS & SALIENT RESEARCH FINDINGS

A) Research

a. The projections over the Upper Indus Basin at 1.5 °C and 2.0 °C temperature increase:

This study investigates future water availability in the Upper Indus Basin (UIB) of Pakistan for the time horizons when the global and/or regional warming levels cross Paris Agreement (PA) targets. The GCMs data is obtained from the 5th Phase of Coupled Model Inter-Comparison Project under two Representative Concentration Pathways (RCP4.5 and RCP8.5). Based on the five best performing GCMs, we note that global 1.5°C and 2.0°C warming thresholds are projected in 2026 and 2047 under RCP4.5 and 2022 and 2036 under RCP8.5 respectively while these thresholds are reached much earlier over Pakistan i.e. 2016 and 2030 under RCP4.5 and 2012 and 2025 under RCP8.5 respectively. Interestingly, the GCMs with the earliest emergence at the global scale are not necessarily the ones with the earliest emergence over Pakistan, highlighting spatial non-linearity in GCMs response. The emergence of 2.0°C warming at global scale across 5 GCMs ranges from 2031 (CCSM4) to 2049 (NorESM) under RCP8.5. Precipitation generally exhibits a progressive increasing trend with stronger changes at higher warming or radiative forcing levels. Hydrological simulations representing the historical, 1.5°C and 2.0°C global and region warming time horizons indicate a robust but seasonally varying increase in the inflows. The highest inflows in the baseline and future are witnessed in July. However, the highest future increase in inflows is projected in October under RCP4.5 (37.99% and 65.11% at 1.5 °C and 2.0 °C) and in April under RCP8.5 (37% and 62.05% at 1.5 °C and 2.0 °C). These hydrological changes are driven by increases in the snow and glacial melt contribution, which are more pronounced at 2.0 °C warming level. These findings should help for effective water management in Pakistan over the coming decades.

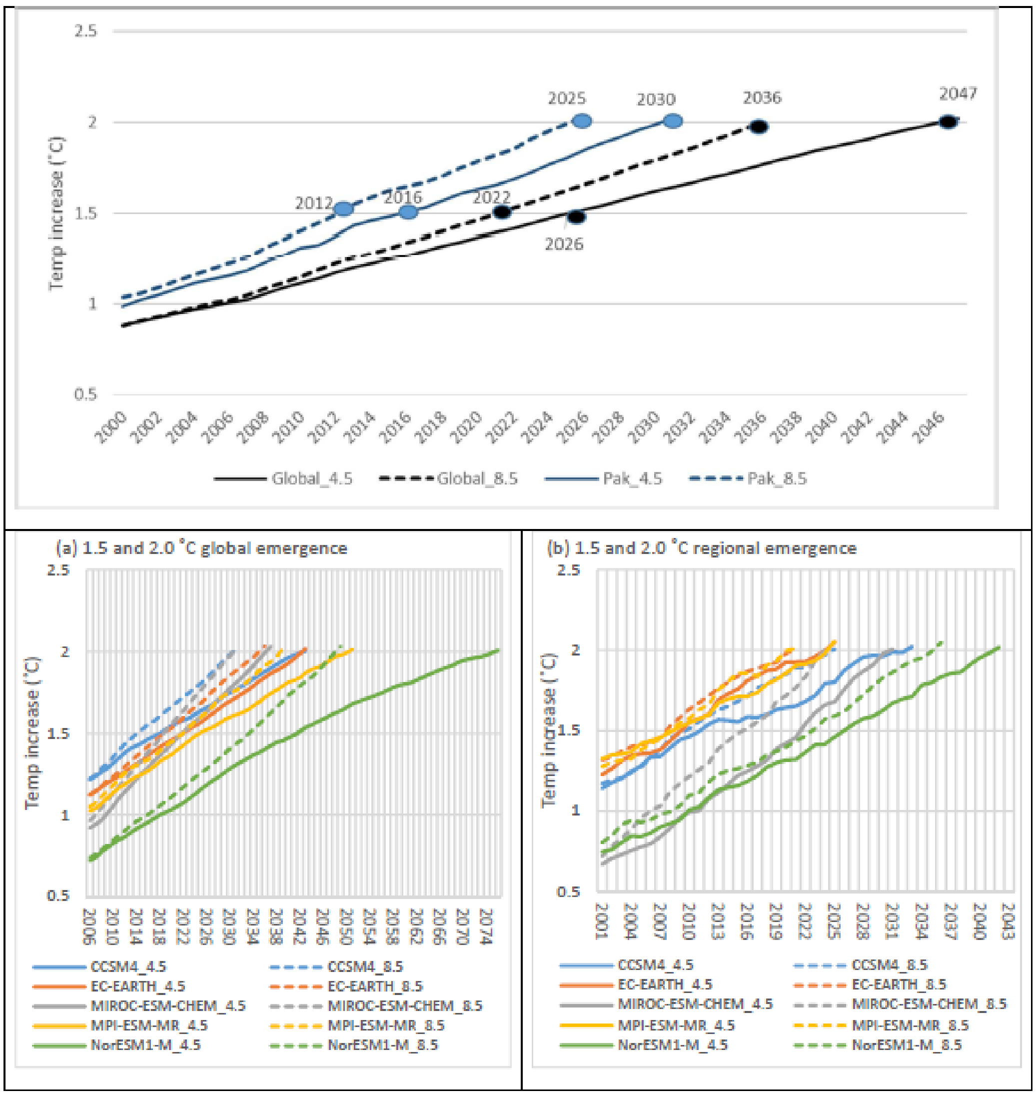


Figure 01: *Emergence of 1.5 and 2.0˚C warming over Globe and Pakistan relative to pre-industrial period (1851-1880) projected by ensemble of 5GCMs (upper panel) and individual GCMs (lower panel) (a) emergence of 1.5 and 2.0˚C at global scale, (b) emergence of 1.5 and 2.0˚C at regional scale under RCP4.5 (solid line) and RCP8.5 (dotted lines).*

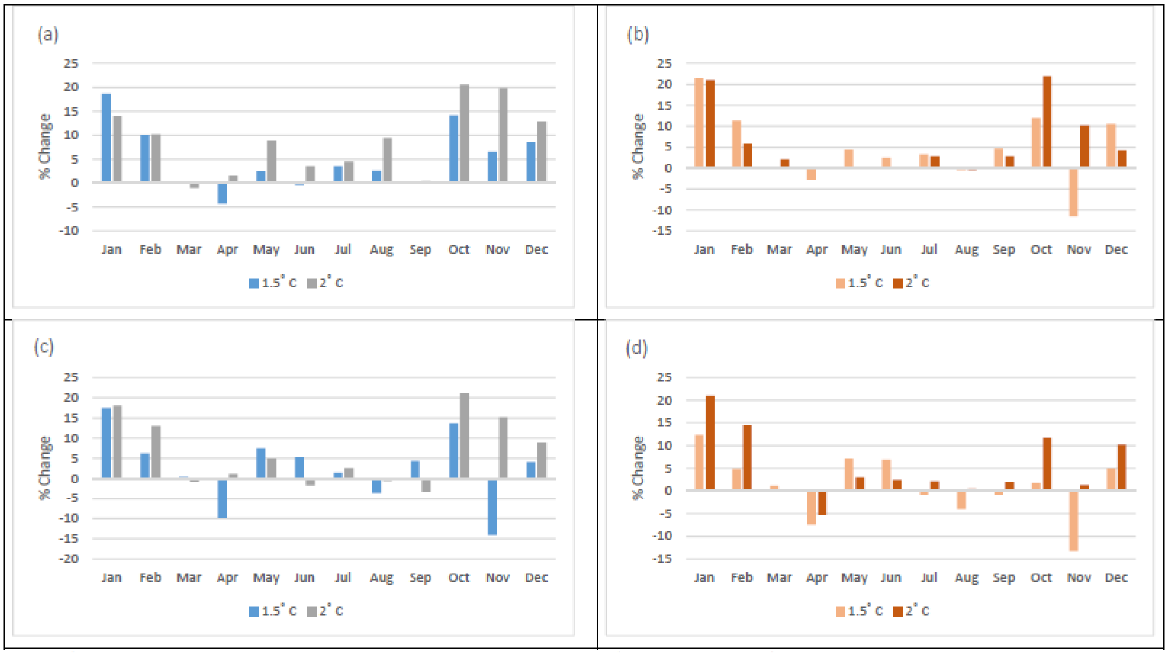


Figure 02: *Percent change in precipitation compared to historical period (1976-2005) over UIB under 1.5 and 2.0°C warming at Global level (a,b) and at Pakistan (c,d) relative to preindustrial period (1851-1880) under RCP4.5 (left) and RCP8.5 (right)/*

b. Black carbon emissions inventory and scenario analysis for Pakistan:

Black carbon (BC) emissions, resulting from the incomplete combustion of carbonaceous fuels, have been extensively linked to adverse impacts on air quality, climate change, and public health. This study aims to present a comprehensive evaluation of Pakistan's BC emissions inventory for the year 2021, along with projections until 2050, utilizing two distinct scenarios: the reference emission scenario (RES) and the accelerated reduction scenario (ARS). To derive these estimates, we employ the GAINS integrated assessment model, which accounts for technology-specific characteristics in sources and regions. Notably, this study goes beyond conventional approaches by addressing the often overlooked sources of BC emissions, including kerosene lighting, bricks production, diesel generator sets, and natural gas flaring. Our analysis reveals that Pakistan's total BC emissions in 2021 amounted to 180.8 thousand tons (kt), with domestic-residential combustion being the predominant contributor, accounting for more than half (105.7 kt) of the total emissions. The transport, industry, waste, agriculture, power plants, and fuel conversion sectors contributed 26.1 kt, 20.1 kt, 10.7 kt, 8.9 kt, 6.0 kt, and 0.9 kt, respectively. Projecting ahead, we anticipate that the total BC emissions in Pakistan will reach 200.9 kt by 2050 under the RES, while the ARS predicts a significant reduction to 40.6 kt. The ARS achieves more rapid and substantial BC reductions by emphasizing the adoption of cleaner fuels, improved biomass stoves, high-efficiency emission control technologies, and ban on open burning of uncollected waste and crop residue. This study underscores the considerable potential for reducing BC emissions across various sectors in Pakistan over the next three decades.

Table 01: *Projected reductions in BC EFs for various source categories*

Scenarios	Sector	Fuel activity	EF reduction compared to 2021	Year achieved
Reference Emission Scenario	Domestic	-	-	-
	Transport	-	-	-
	Industry (combustion)	-	-	-
	Industry (processes)	-	-	-
	Power	-	-	-
	Natural gas flaring	-	-	-
	Fuel conversion	-	-	-
	Agriculture	-	-	-
	Waste	-	-	-
Accelerated Reduction Scenario	Domestic	Fuelwood cooking	67%	2035
		Fuelwood heating	68%	2035
		Kerosene lighting	100%	2025
	Transport	Heavy-duty diesel buses & trucks	94%	2045
		Diesel rail	100%	2040
		Diesel agriculture machinery	98%	2040
		Gasoline non-road machinery	53%	2040
		Heavy-duty gas buses & trucks	65%	2035
		Motorcycles gas 2-stroke	51%	2050
		Motorcycles gas 4-stroke	64%	2050
	Industry (combustion)	Heavy fuel oil boilers & other combustion	100%	2025
	Industry (processes)	Cement production	100%	2025
		Glass production	100%	2025
		Lime production	100%	2025
		Bricks production	85%	2050
	Power	Furnace oil existing & new power plants	100%	2025
	Natural gas flaring		-	-
	Fuel conversion		-	-
	Agriculture	Agriculture waste burning	100%	2040
	Waste	MSW open burning	100%	2035

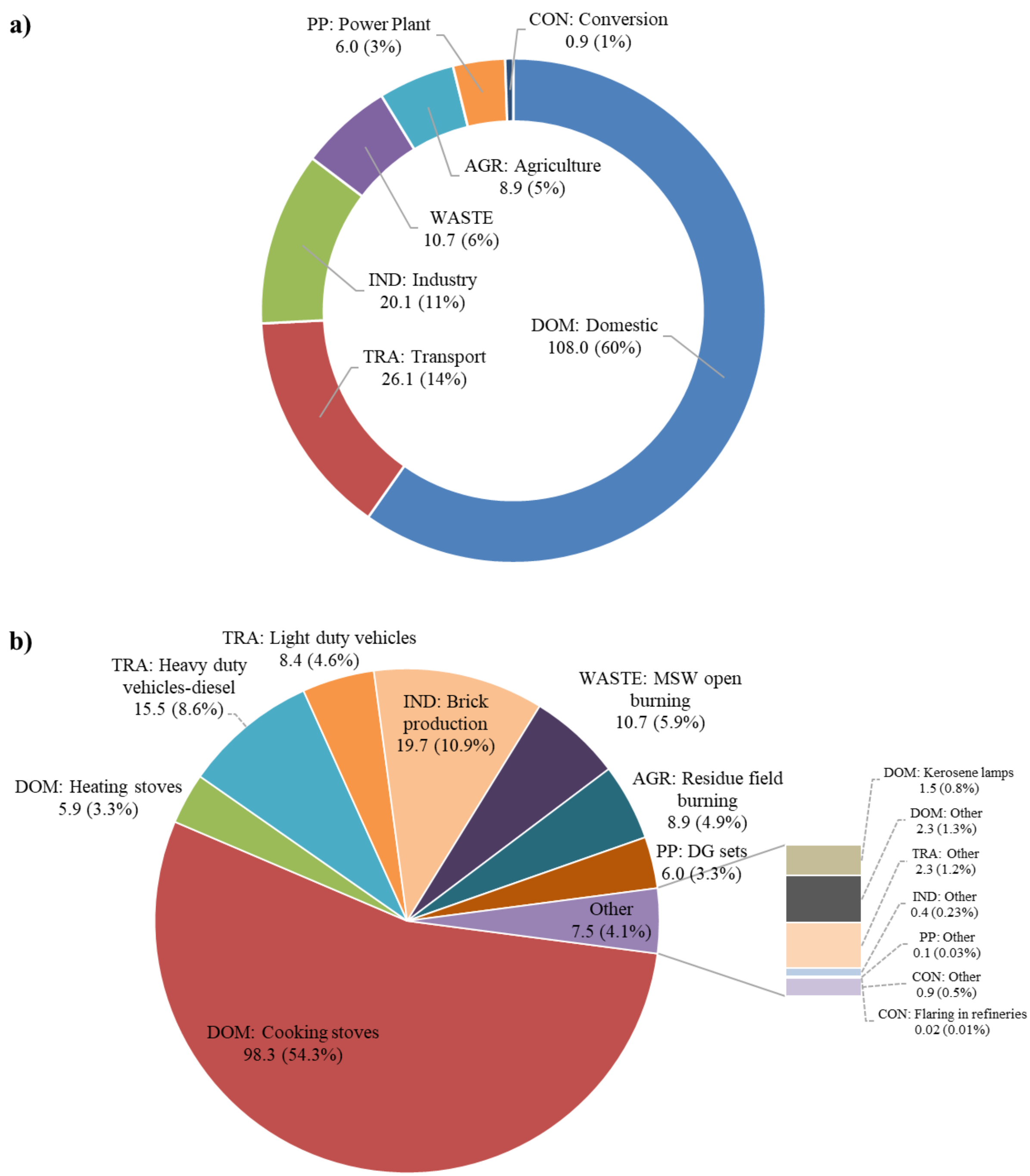


Figure 03: *BC emissions in kilotons (kt) and the sectoral (a), sub-sectoral (b) contributions in percent (%) in Pakistan for the year 2021.*

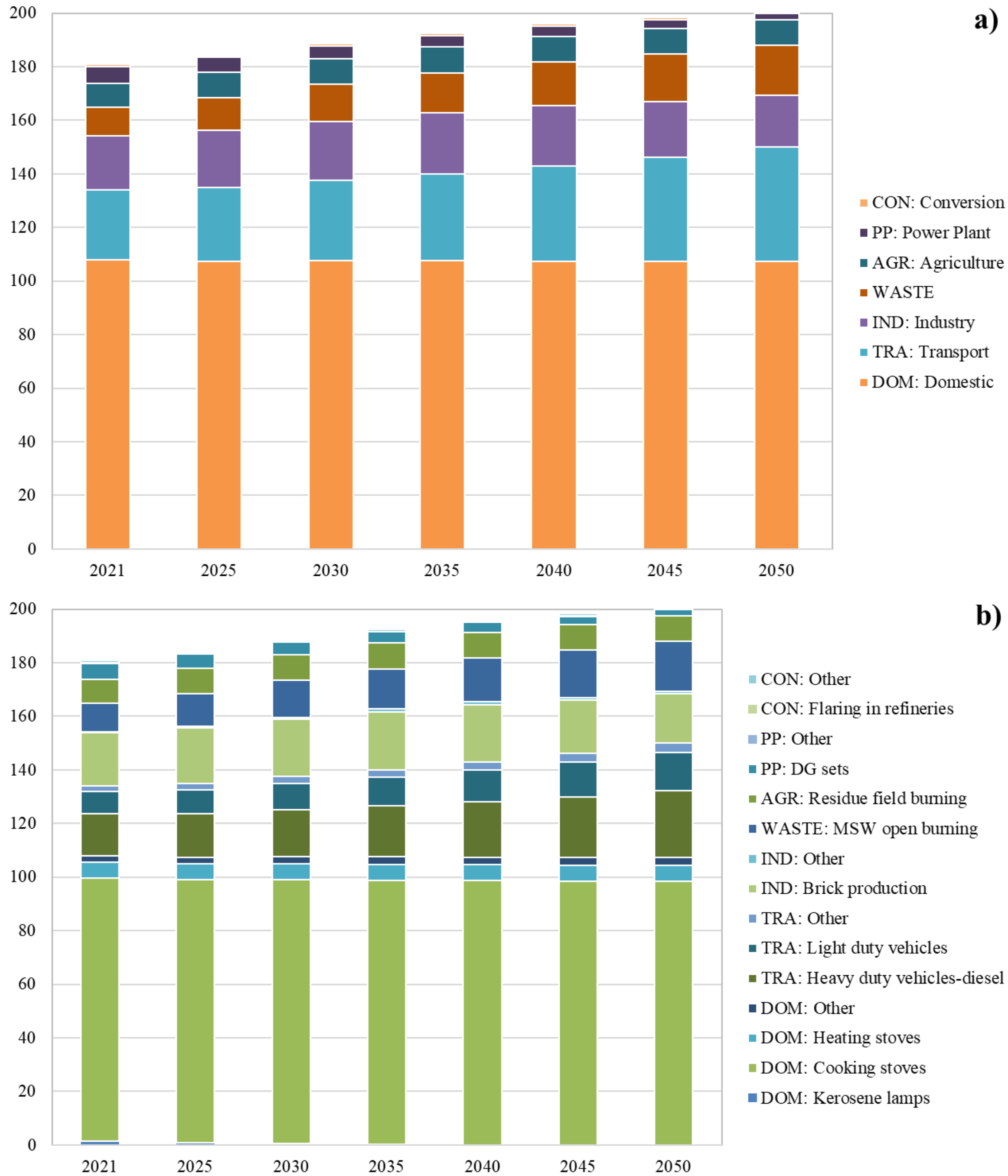


***Figure 04:** BC emissions in kilotons (kt) by key sectors (a) and sub-sectors (b) in Pakistan under the RES, from 2021 to 2050*

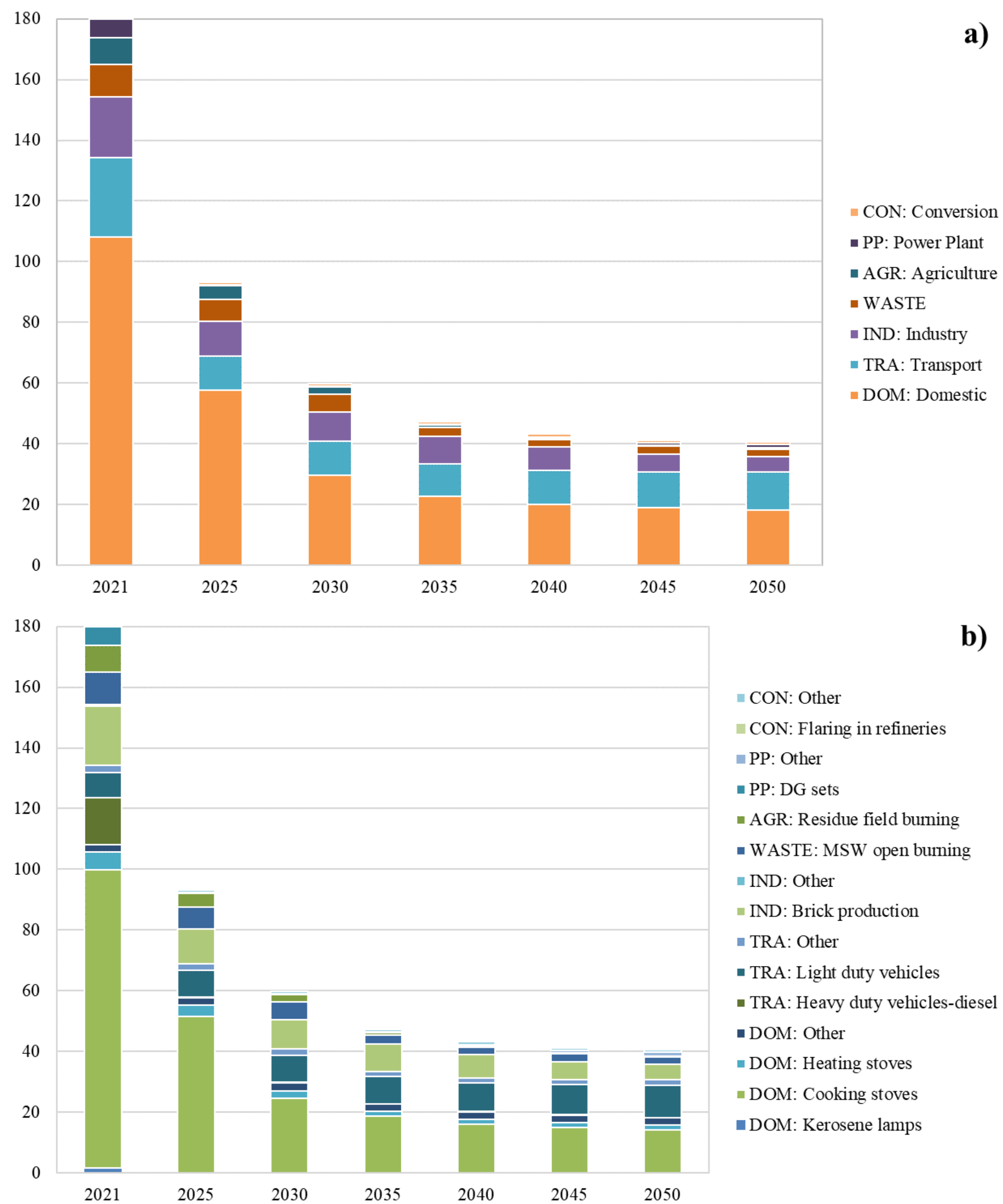


Figure 05: *BC emissions in kilotons (kt) by key sectors (a) and sub-sectors (b) in Pakistan under the Reference scenario, from 2021 to 2050*

Table 02: *BC reduction in the ARS and contributions of changes in fuel consumption and reductions in EFs*

Year	Sectors	Total reductions (kt)	Contribution of changes in fuel consumption (%)	Contribution of reductions in EFs (%)
2030	Domestic	78.1	7	93
	Transport	18.8	9	91
	Industry	12.3	21	79
	MSW open burning	7.8	0	100
	Agricultural waste burning	7.2	0	100
	Power plant	4.7	40	60
	Fuel conversion	0.0	5	95
	Total	128.9	12	88
2050	Domestic	89.1	14	86
	Transport	30.3	26	74
	Industry	14.34	33	67
	MSW open burning	16.08	0	100
	Agricultural waste burning	9.1	0	100
	Power plant	1.32	79	21
	Fuel conversion	0.0	6	94
	Total	160.24	32	68

c. A 5-km gridded product development of daily temperature and precipitation for Bangladesh, Nepal, and Pakistan from 1981 to 2016:

Many efforts have been made by the scientific community to produce gridded datasets with high spatial resolution because they are essential for climate change assessment, impact studies, decision-making, etc. This study fits into this context and describes the methods used to prepare a 5-km gridded product of precipitation and minimum and maximum temperatures by merging observed data from meteorological stations, from 1981 to 2016, of Bangladesh, Nepal, and Pakistan with ERA5 reanalysis. The step-by-step methods for station data quality control and the development of the 5-km gridded data are presented. Additionally, we use the 5-km dataset to show the main climate features of the three countries, which facilitate comparison with other data sources in the literature.

d. Modelling the impact of climate change on dengue outbreaks and future spatiotemporal shift in Pakistan:

Climate change has a significant impact on the intensity and spread of dengue outbreaks. The objective of this study is to assess the number of dengue transmission suitable days (DTSD) in Pakistan for the baseline (1976–2005) and future (2006–2035, 2041–2070, and 2071–2099) periods under Representative Concentration Pathway (RCP4.5 and RCP8.5) scenarios. Moreover, potential spatiotemporal shift and future hotspots of DTSD due to climate change were also identified. The analysis is based on fourteen CMIP5 models that have been downscaled and bias-corrected with quantile delta mapping technique, which addresses data stationarity constraints while preserving future climate signal. The results show a higher DTSD during the monsoon season in the baseline in the study area except for Sindh (SN) and South Punjab (SP). In future periods, there is a temporal shift (extension) towards pre- and post-monsoon. During the baseline period, the top ten hotspot cities with a higher frequency of DTSD are Karachi, Hyderabad, Sialkot, Jhelum, Lahore, Islamabad, Balakot, Peshawar, Kohat, and Faisalabad. However, as a result of climate change, there is an elevation-dependent shift in DTSD to high-altitude cities, e.g. in the 2020s, Kotli, Muzaffarabad, and Drosh; in the 2050s, Garhi Dopatta, Quetta, and Zhob; and in the 2080s, Chitral and Bunji. Karachi, Islamabad, and Balakot will remain highly vulnerable to dengue outbreaks for all the future periods of the twenty-first century. Our findings also indicate that DTSD would spread across Pakistan, particularly in areas where we have never seen dengue infections previously. The good news is that the DTSD in current hotspot cities is projected to decrease in the future due to climate change.

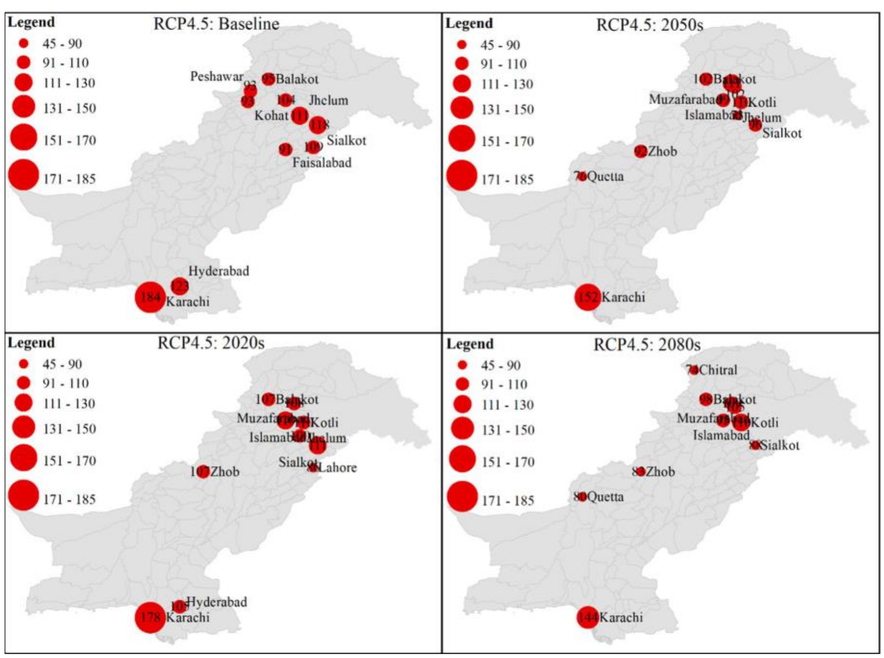


Figure 06: *Hotspots cities of dengue transmission based on climate suitability of Pakistan for baseline (1976–2005) and future periods 2020s, 2050s, and 2080s under RCP4.5*

e. **Wavelet coherence of monsoon and large-scale climate variabilities with precipitation in Pakistan:**

Monsoon and its teleconnection with earth system internal processes affect the spatiotemporal distribution of precipitation and water resources. In this paper, the wavelet coherence analysis has been utilized, a time and frequency domain methodology for comparing the spectral features of two independent time series superior to linear approaches. This technique is used to capture the significant modes of variabilities in the Indian Summer Monsoon Index (ISMI) and large-scale climate indices (CIs) between ocean-atmosphere oscillations, like Indian Ocean Dipole (IOD), El Nino Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO) and Arctic Oscillation (AO) over Pakistan. Precipitation time series during 1960–2016 revealed significant inter-annual coherences with ISMI, whereas, the remaining CIs (IOD, ENSO, PDO, SOI, NAO, AMO and AO) revealed inter-annual, decadal and inter-decadal coherences. However, AO revealed strongest coherences in R-II, III and VI at inter-decadal scales among all CIs. Overall, the inter-annual cysles on ISMI are 2.8 years, IOD 1–5.3 years, PDO 0–5.3 years, SOI 1–5.3 years, NAO 0–5 years, AO 0–5 years and AMO 0–8.3 years. Whereas, the remaining CIs shared inter-decadal coherences over particular regions. The ISMI displayed coherences (except in the UIB) with the large-scale CIs over various homogenous regions on an inter-annual scale. The dominant influence of ISMI is observed in R-II and III; the significant coherences in R-II ranged from ~8–32 months (~0.8–2.8 years). The IOD and NAO have major coherences than the remaining large-scale CIs ranging from ~16–64 months (1.3–5.3 years). The AO has the most significant coherences observed in R-II, III, and VI on the decadal/ interdecadal scale from 128 months and above (almost 10–15 years). On a 1.0-year time scale, all homogenous regions demonstrated strong intermittent coherence with ISMI, IOD, ENSO, PDO, SOI, NAO, AMO and AO. These findings have substantial implications for decision-makers and scientists in Pakistan looking to enhance water resource planning and operations in the face of future climate uncertainties.

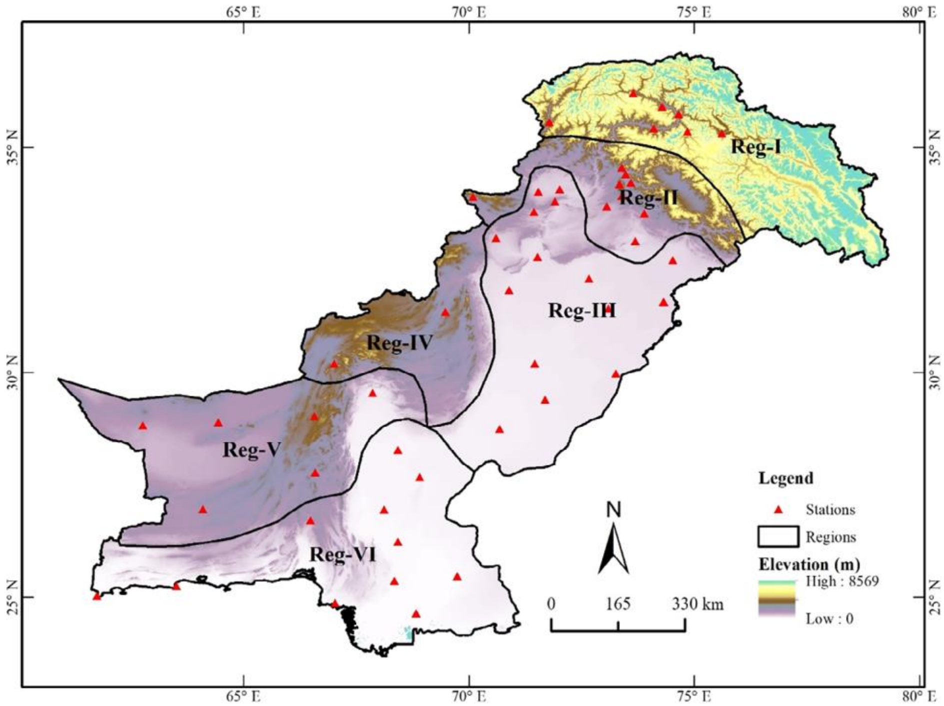


Figure 07: *Distribution of meteorological stations in precipitation homogenous climatic regions of Pakistan*

f. Comparative Analysis of Selected Glaciers of Hunza Basin, Pakistan since 1972–2018: Varied Responses to Climate Change

Snow and glaciers are very sensitive to changing climate. Glaciers in the central Karakoram, western Himalaya and eastern Hindukush mountain ranges are not responding to global warming in the same manner as their counterparts around the world. Glaciers in this region are behaving differently. Some are retreating, while others are stable or surging. It is important to monitor these changes to protect downstream communities from the negative consequences. This study is conducted to monitor the state of the selected glaciers of Hunza River Basin, such as Batura, Passu, Ghulkin, Gulmit, Baulter, Barpu, Samaiyar Bar, Muchu har, and Shishper glaciers were analysed using Digital Elevation Model and satellite images for 1972, 1979, 1990, 1998, 2008 and 2018. A semi-automatic approach was adopted to delineate the glacier boundary sup plemented by manual editing. These glaciers show different fluctuations over the last fifty years. The Batura glacier showed surge in the 1970s and then retreated followed by quiescence. There is no prominent change in Ghulkin, Barpu, and Samaiyar Bar glaciers while almost 40 m per year retreat was observed in Passu and Gulmit glaciers but Muchuhar retreated at a faster rate. The surge of Shishper results in the formation of glacier-dammed lake which has so far triggered four Glacial Lake Outburst Floods (GLOFs). Overall, area of nine glaciers decreased from 596.54 ± 31.02 km2 in 1972 to 568.52 ± 8.51 km2 in 2018, which accounts for

4.8% decrease in area. This decrease will affect landscape development, regional hydrology and people living downstream.

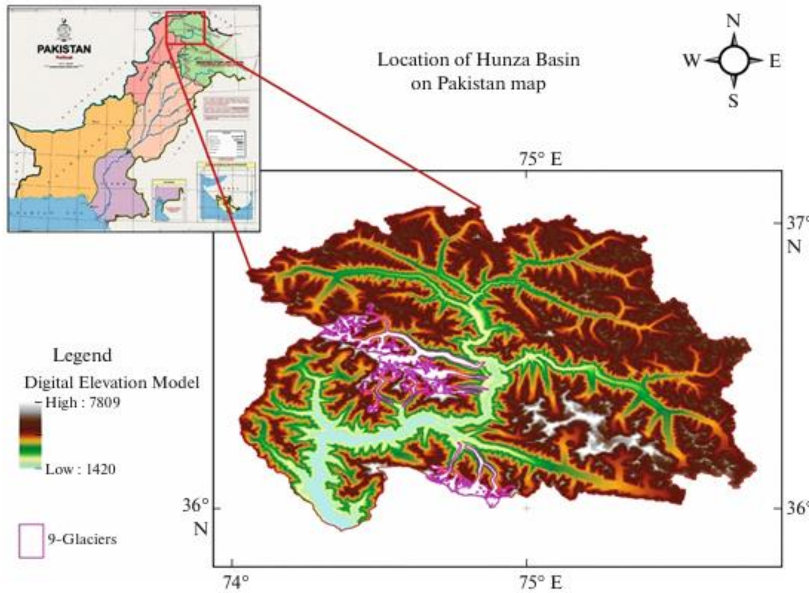


Figure 08: *Location map of the Hunza Basin*

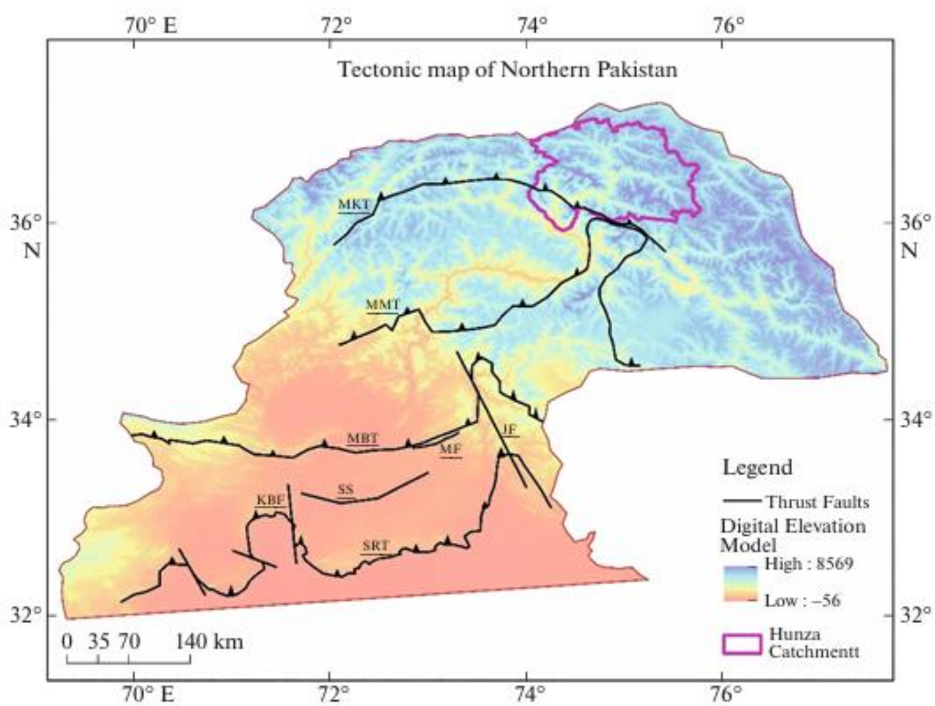


Figure 09: *Tectonic map of Northern Pakistan.*

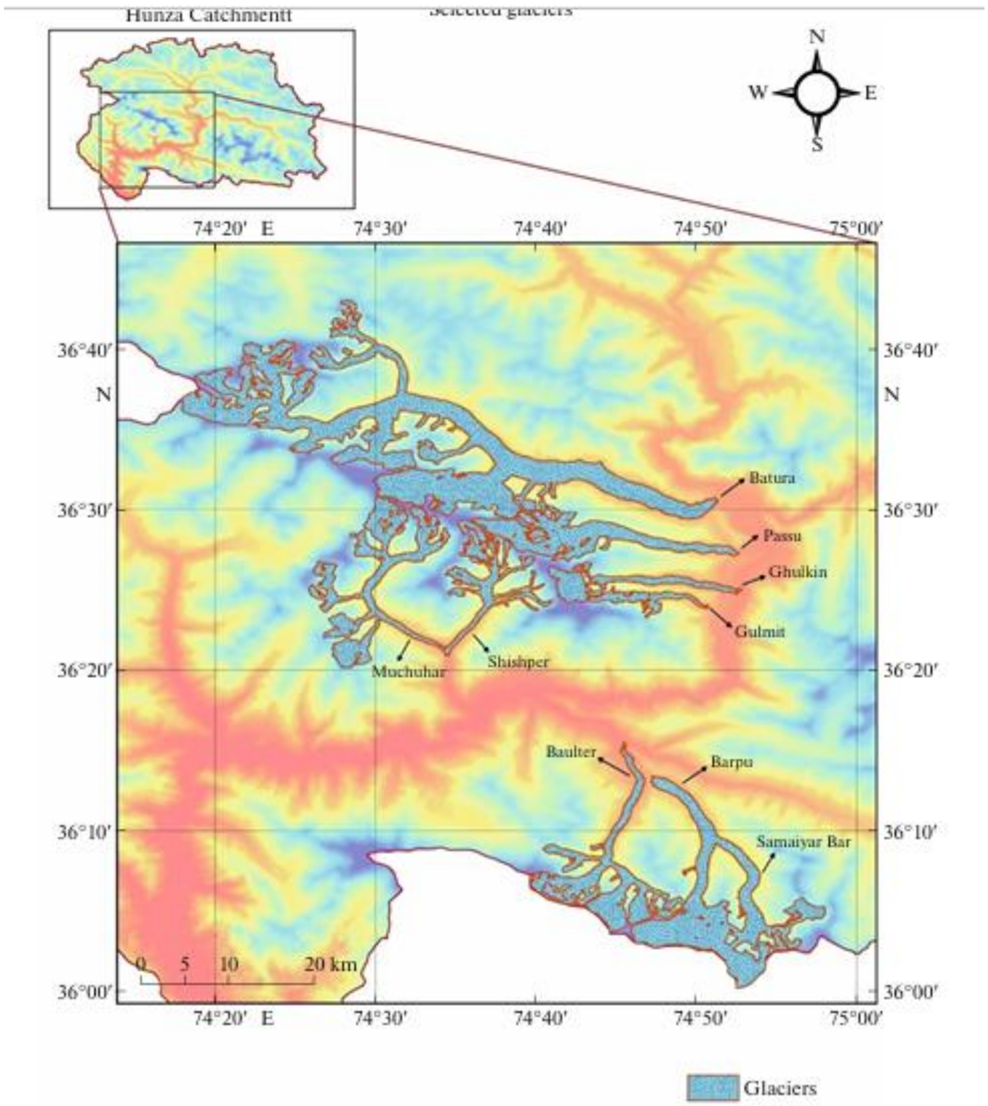


Figure 10: *Digitization of glaciers.*

Name of glacier	Elevations (m)					% change in area (km^2) 1972–2018
	2200–3200	3200–4200	4200–5200	5200–6200	6200–7200	
Barpu/Samaiyar Bar	NW	N	N	N	N	+6.53
Batura	SE	E	SE to E	SE	SE	−4.16
Baulter	N	N	NE	NE	N	−0.41
Ghulkin	E	E	E	NE	NE	−7.41
Gulmit	SE	E	E	E	Nil	−11.44
Muchuhar	SE	SW to SE	S	S	S	−14.68
Passu	E	E	E	NE	SE	−8.04
Shishper	SW	S	SE	Nil	Nil	−17.82

Table 03: *Aspect and percentage area change of glaciers.*

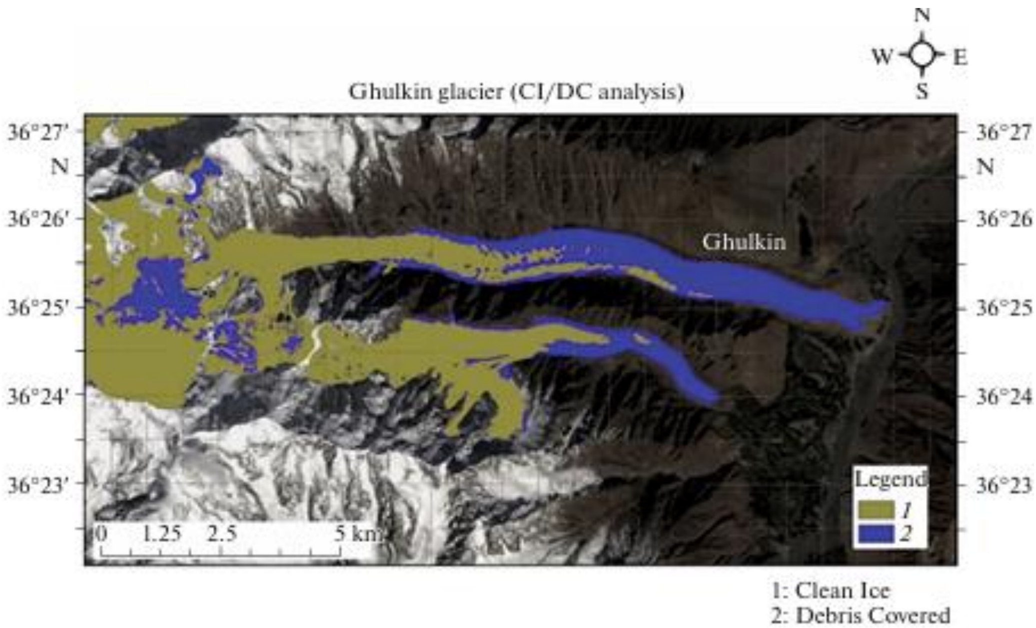


Figure 11: *Ghulkin glacier (CI/DC analysis).*

g. Optimized irrigation scheduling as an adaptation option to support Wheat production in the Indo-Gangetic Plain (IGP) of South Asia:

Increased climate variability and growing populations in the Indo-Gangetic Plain (IGP) of South Asia exacerbate pressures on existing natural resources. In the IGP, agriculture is the primary source of livelihood and is responsible for ~ 90% of total freshwater consumption. Water availability and demand in the region are highly variable within and between the years, posing threats to sustained water use for food production. To address this concern, we investigated supplemental irrigation as an adaptation strategy by determining the effects of optimal irrigation scheduling, including quantity and time, during critical crop growth stages of wheat using the Crop Kites concept. Crop kites investigate the relationship between water use and yield, showing that this can change substantially between locations and years. This study explores the potential of increasing water productivity in irrigated fields with supplemental irrigation. Specifically, we investigate the potential of maximally reducing irrigation while minimally reducing yield. This analysis assumes perfect information on the best irrigation schedule a priori, estimating an upper limit on the yield potential and water savings of investing in supplemental irrigation practices and infrastructure. Additionally, we focus on the added benefits of supplemental irrigation regarding irrigation water productivity. The hydrology and vegetation model, Lund Potsdam Jena managed Land (LPJmL), is used to simulate crop yields of 16 rainfed crops with 20,000 different irrigation schedules in India at 30 arcminute resolution (around 50 km at the equator) under two irrigation scenarios. Our modelling results show that the same total irrigation amount distributed differently can produce significantly different outcomes. For example, in our study, the Crop kite for a specific location but for a different year showed 60% of the previous maximum, with a slight increase in water use. Our results of crop water productivity under the prioritizing irrigation water productivity scenario show that by using 4% of the total irrigation water, we maintain 56% of the full irrigation harvest. Furthermore, our other statistical analysis results under maximizing irrigation water productivity show that by using 23% of the irrigation water, 84% of the full irrigation harvest is maintained. Our study outcomes suggest that an optimal distribution of supplemental irrigation is a promising adaptation measure to help increase water productivity and yields and buffer climatic variability with limited water availability.

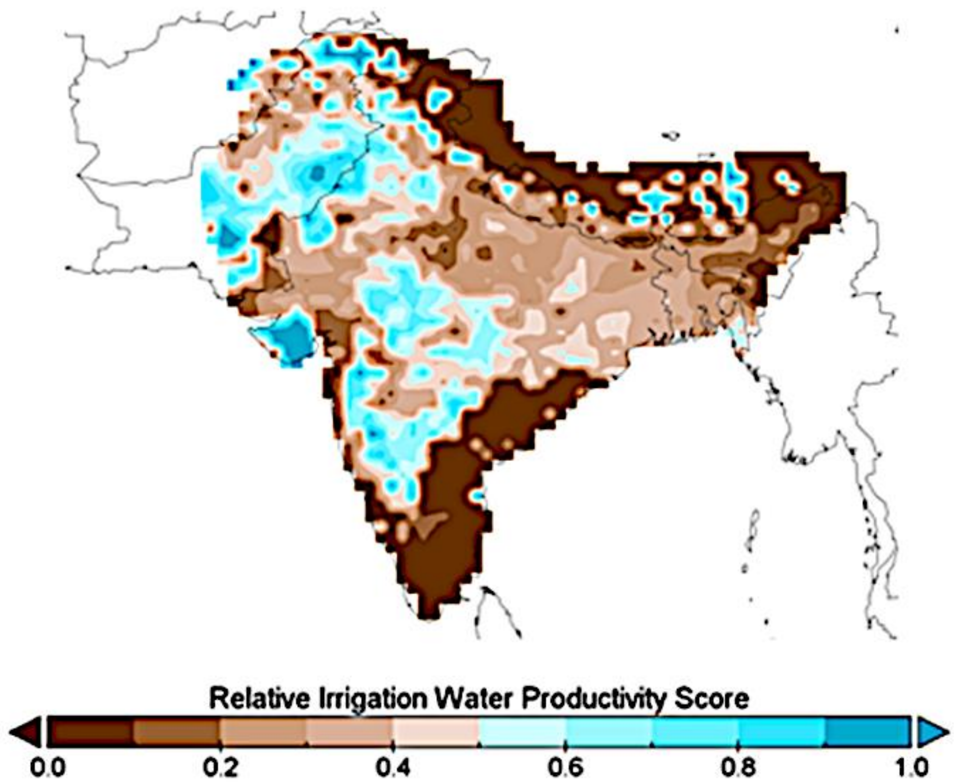
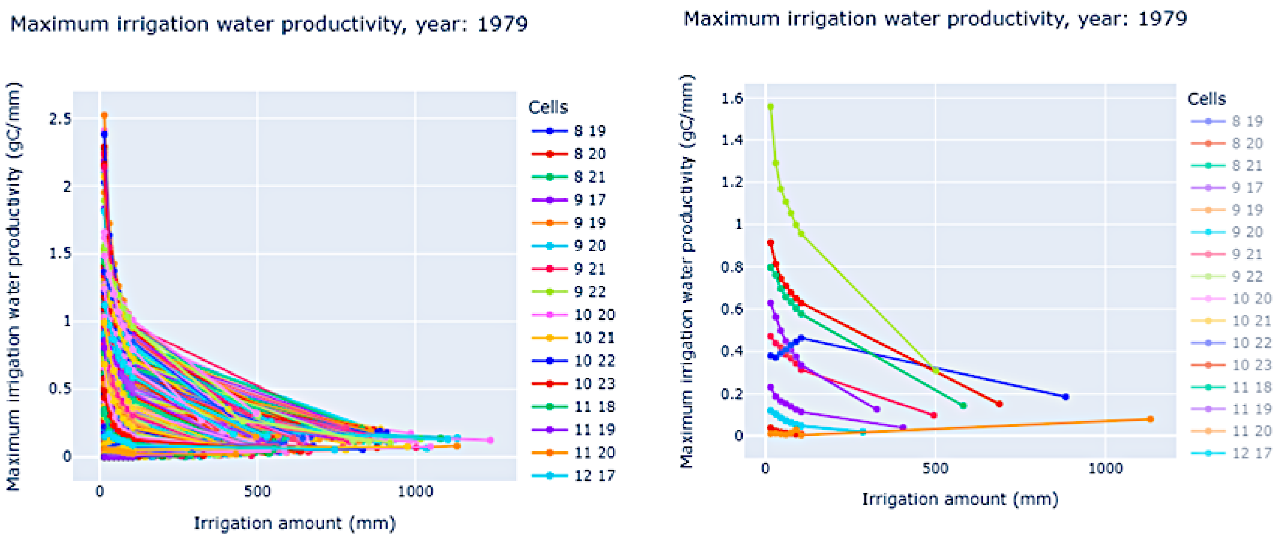


Figure 12: *Irrigation water productivities for the same crop over the whole study domain for 2000 over most of south Asia.*



(a) (b)

***Figure 13:** Maximum irrigation water productivity*

The relationship between crop water use (evapotranspiration) and crop yield is complex and is influenced by climate, soil, and irrigation management. The space of water use and crop yield relationships is referred to as a Crop kite. Crop kites show the relationship between water use and crop yield for a specific crop, location, and season. The lines in **Fig. 13(a)** and **13(b)** represent the top line of the bonus yield irrigation Crop kites, illustrating the solution space between irrigation water use and bonus yield. These top lines represent the highest bonus yield irrigation water productivity simulated for each total irrigation amount. **Fig. 14** shows two different crop kites for two locations in the same year (2000).

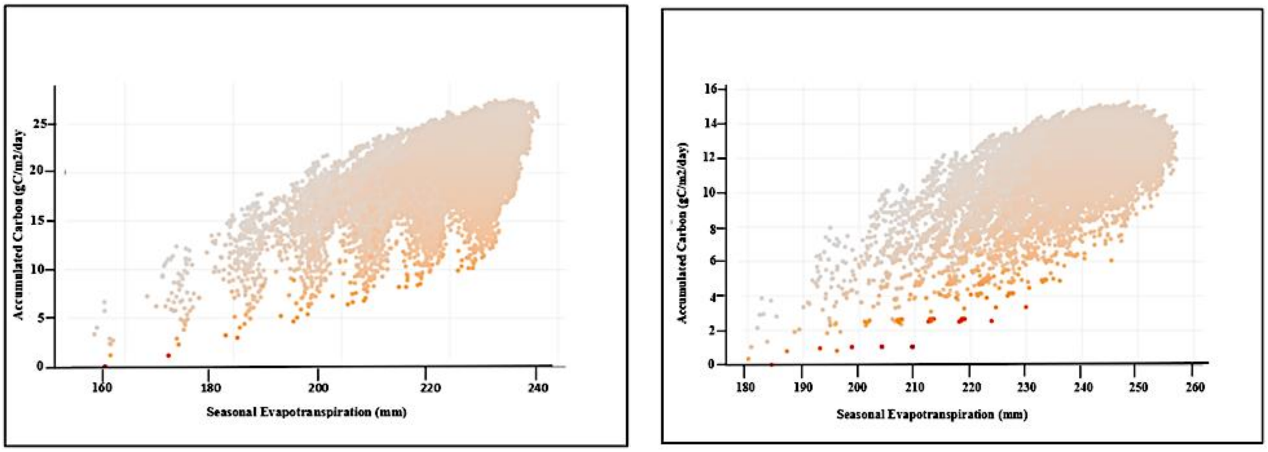


Figure 14: *Crop kite. The x-axes represent seasonal evapotranspiration (mm), and the y-axis represents accumulated carbon (gC m^{-2} d^{-1}). Each panel represents a Crop kite for a different location (grid cell). Each point results from at least one simulation of a different irrigation scheduling for a specific year, crop, and location. Notice that the left figure has much higher y-values (yield) than the figure on the right but with the same amount of evapotranspiration.*

It is also observed that the same amount of evapotranspiration can result in strikingly different yields. The crop kite for a specific location can change similarly in shape, with maximum yield and evapotranspiration levels. To understand the importance of location-specific irrigation application, we have overlapped the two Crop kites of wheat, representing the relationship between crop water use and yield for a different year (**Fig. 15**).

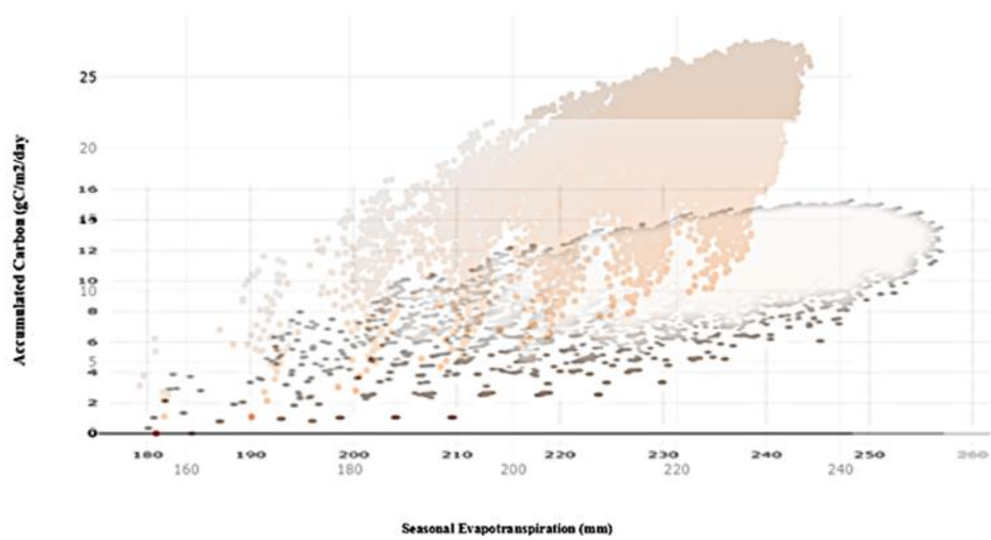


Figure 15: *Crop kites for different years, at the exact location and both for wheat. The x-axes represent seasonal evapotranspiration (mm), and the y-axis represents accumulated carbon (gC m^{-2} d^{-1}), a proxy for yield.*

Table 04: *Values used under Prioritising irrigation water productivity Scenario*

Variable	*Amount*	*variable estimated*

Rainfed harvest	6053	gC/m2* Irr_frac (H)
Optimised Irrigated harvest	7624	gC/m2* Irr_frac (H)
Optimised Irrigation bonus harvest	1571 = 7624 - 6053	gC/m2* Irr_frac (H)
Optimised Irrigation application	2303	mm/m2* Irr_frac (W)
Optimised Irrigation WP	0.68 = 1571/2303	gC/mm* Irr_frac (WP)
Irrigated harvest	13591	gC/m2* Irr_frac (H)
Irrigation bonus harvest	7538 = 13,591 - 6053	gC/m2* Irr_frac (H)
Irrigation application	53,674	mm/m2* Irr_frac (W)
Irrigation WP	0.14 = 7538/53,674	gC/mm* Irr_frac (WP)

Irrigation water application decreases 96% = (53,674 – 2303)/ 53,674 compared to the full irrigation application amount (drops to 4% = 2303/53,674 of the full irrigation amount), while irrigation bonus harvest decreases 79% = (7538-1571)/7538 from the harvest from full irrigation application amount (drops to 21% = 1571/7538 of the harvest from full irrigation).

h. Sub-National Climate Risk Profile:

Sub-national risk profiles for Punjab and KPK have been developed by the Global Climate-Change Impact Studies Centre (GCISC) with the assistance of BMZ, Germany through GIZ Pakistan

CRP DATA Details:

CMIP6 RCP-SSP Scenario Framework

13 GCM Ensembles Downscaled and Bias Corrected GCM at 0.25 degree

Baseline (1974-2015), Future (F1: 2021-2060) & (F2: 2061-2100)

Provincial Climate Risk Profiling is performed on a seasonal (Summer and Winter) scale. This CRP is divided into the following three main sections:

Climate Projections/ Trends: (Spatial and Temporal):

Climate Extreme Indices (CEI):

- Seasonal temperature and Precipitation Extremes
- Frequency and Intensity of Warm, Dry, Wet and Cold Extremes
- Very hot days, Very Cold days
- Growing Degree days
- Impacts of Climate Change on the following Sectors:
- Agriculture, Water Resources, Infrastructure, Ecosystem, Health

Major Findings of CRA-CRP Project:

- The seasonal temperature changes show diverse patterns over different areas in Punjab. Summer temperatures show an increase of 3.5 °C in the North with the largest increase of 4 °C in the South. During winter, there is more warming expected with a higher increase above 4 °C across the whole Punjab under extreme climate scenarios.
- Precipitation trends are uncertain and show distinct patterns in future across seasons in the province. Summer precipitation is projected to increase significantly (150 mm to 300 mm) in upper Punjab during the late century period under RCP-SSP 585. Future dry and wet periods are likely to become more extreme.
- In the Punjab agricultural sector, the environmental indicators, including extreme precipitation and temperature, are no longer conducive to the current cropping patterns and intensities across the province. This situation necessitates the redistribution of cropping zones based on altered climate variables and adaptation measures.

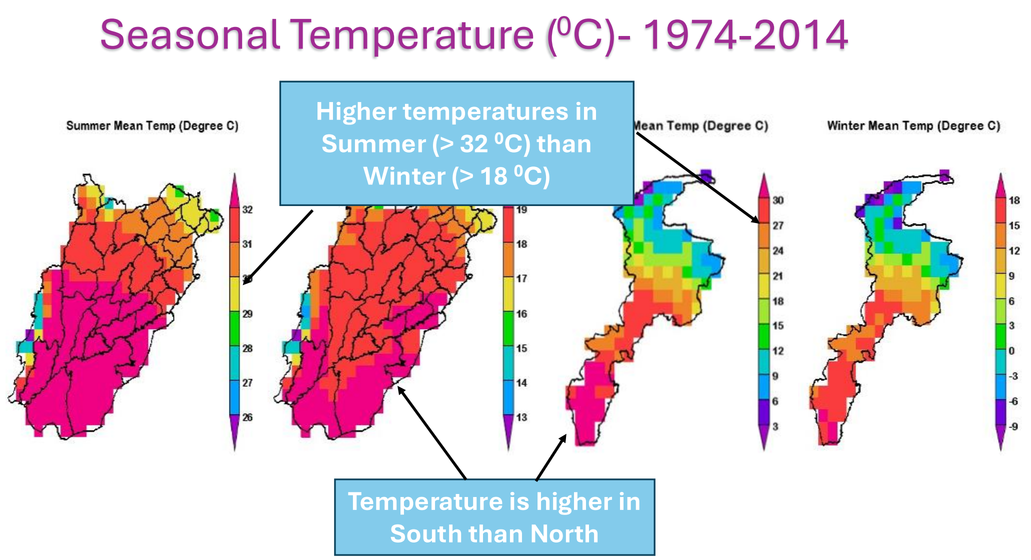


Figure 16: *Seasonal Temperature (°C) – 1974-2014*

Seasonal Precipitation (mm)-1974-2014

Higher precip in Punjab than KPK

Precipitation is higher in Northern parts of Punjab and Central parts of KPK (> 400mm)

Summer precip higher in Punjab and winter precip in KPK

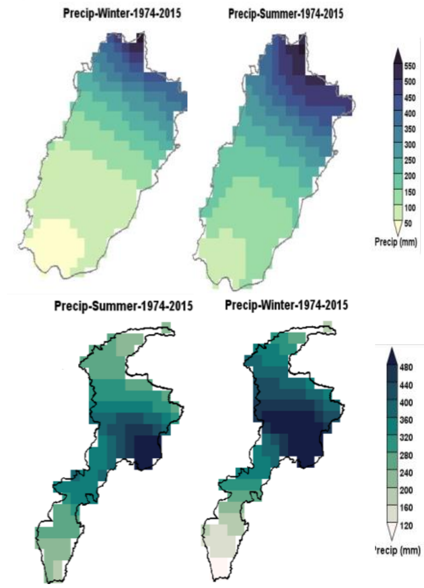


Figure 17: *Seasonal Precipitation (mm) – 1974-2014*

Future Changes in Spatial Distribution of Temperature-Punjab

Large variation in Spatial distribution of Temperature is observed in seasons, locations and periods under both RCP-SSP scenarios

Positive change in Temperature (^{0}C) is higher in Southern parts with larger changes during Winter

The largest increase in Temperature (>4.2 ^{0}C) is observed under RCP-SSP585 scenarios during F2 (2061-2100)

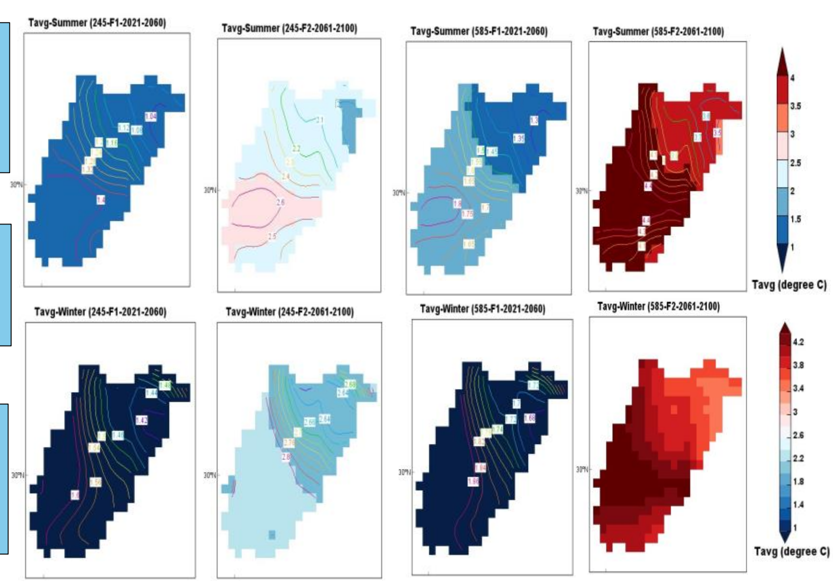


Figure 18: *Future Changes in Spatial Distribution of Temperature-Punjab*

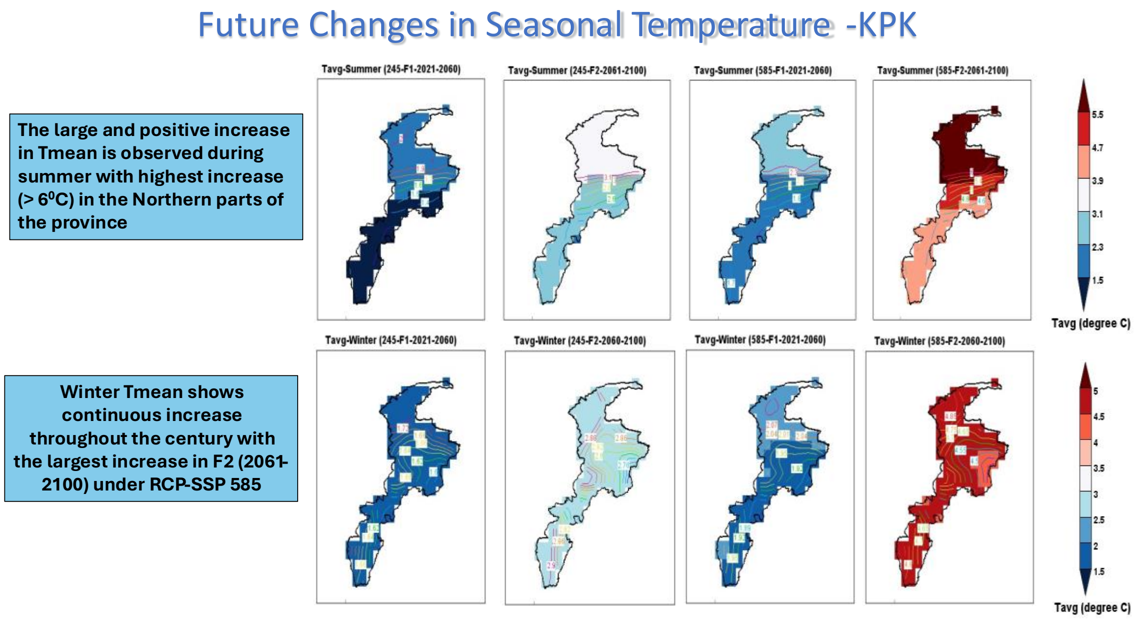


__Figure 19:__ Future Changes in Seasonal Temperature - KPK

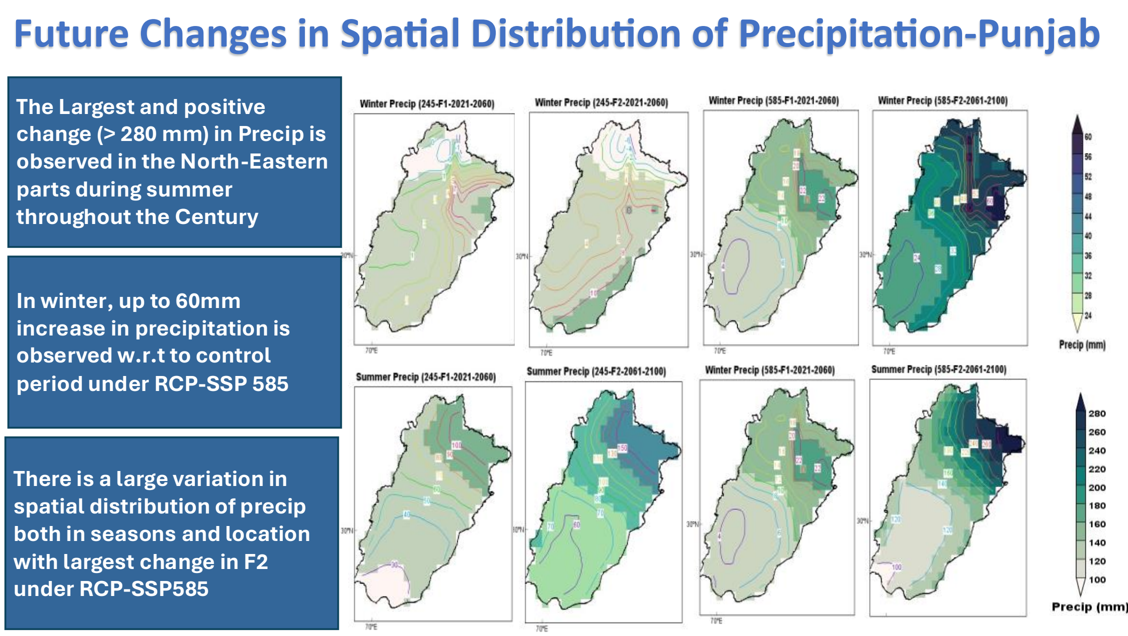


__Figure 20:__ Future Changes in Spatial Distribution of Precipitation – Punjab

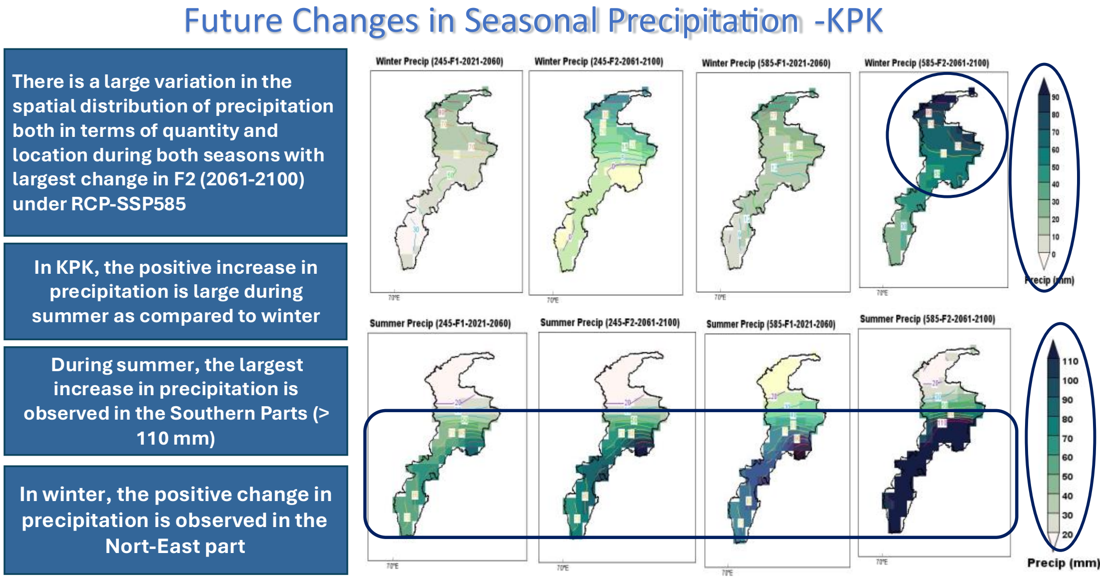


Figure 21: *Future Changes in Seasonal Precipitation - KPK*

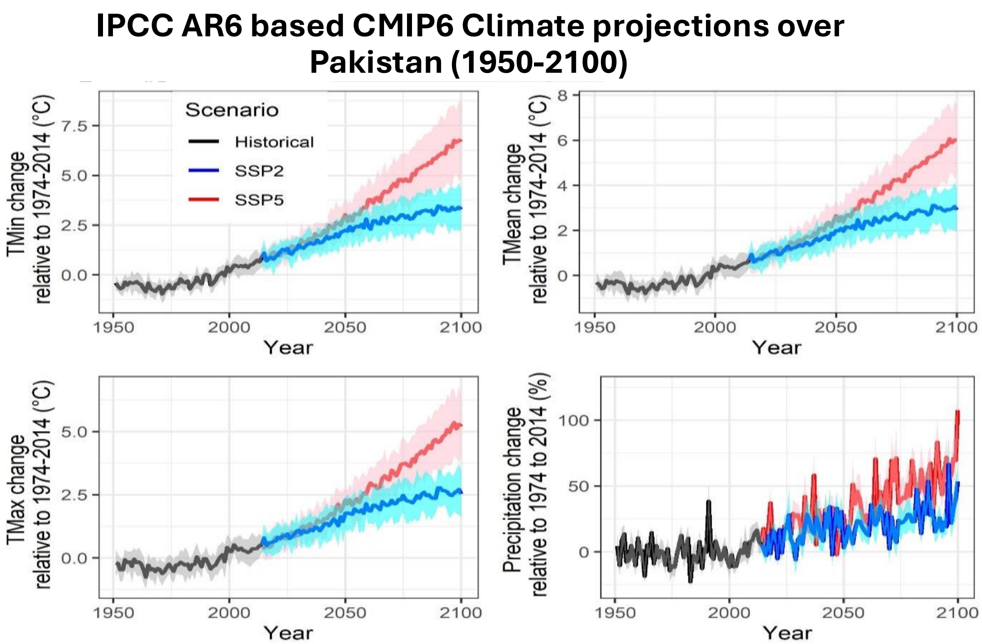


Figure 22: *IPCC AR6 based CMIP6 Climate Projections over Pakistan (1950-2100)*

Frequency and Intensity of Temperature Extremes over Punjab

The frequency and intensity of warm extremes (Tmax P99) are continuously increasing in both seasons with a larger increase in summer

Cold extremes (Tmax P10) shows non-significant change both seasons

The frequency and intensity of warm extremes are larger under RCP-SSP 58 with largest increase during F2 (2061-2100)

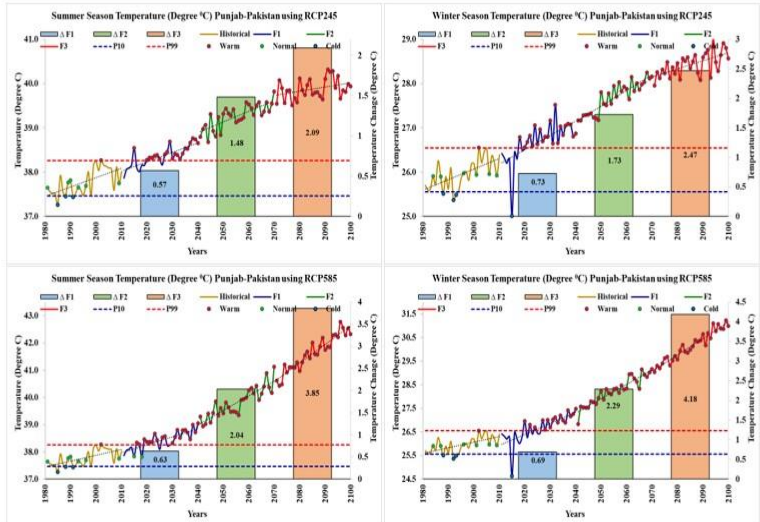


Figure 23: *Frequency and Intensity of Temperature Extremes over Punjab*

i. Emission profile of waste sector in Pakistan:

The substantial increase in greenhouse gas (GHG) emissions from waste sector by rapid population growth and urbanization, emphasizes on the need for mitigation actions to meet commitments of Paris Agreement (PA). The sector emitting high methane (CH_4) emissions has potential to meet emission reduction targets. Detailed segregated information of waste related activities responsible for emissions is highly needed for accurate estimation of emissions and placing mitigation actions thereafter. The present study aims to provide an in-depth analysis of all such source activities with associated emissions in one place, needed for tracking progress on the sector waste since country's nationally determined contributions (NDCs) submission and exploring opportunities for mitigation actions. In this study, emission estimations for 2019-20 were carried out in accordance Intergovernmental Panel on Climate Change (IPCC) revised 1996 guidelines for national GHG inventories. The results showed that waste sector emitted 26.94 million tons (Mt) of carbon dioxide equivalent (CO_2e) emissions in the inventory year, of which 23.88 Mt were methane (CH_4), 2.67 Mt were nitrous oxide (N_2O) and 0.39 Mt were CO_2 emissions. Solid waste disposal (SWD) with 14.30 (53.1) Mt of CO_2e emissions was the major emitting category, followed by wastewater handling & discharge (11.43 Mt; 42.4%) and waste incineration & open burning (1.21Mt; 4.5%). Given the highest share of solid waste to the total GHG emissions from waste sector, the results of this study suggest to focus on solid waste more seriously. The current scenario of waste generation, collection and disposal strengthens the case for improved data management and mitigation technologies in deciding waste management options.

Table 05: *Emission profile of waste sector in Pakistan (Mt of CO_2e)*

Source Category	Emissions (CO_2e)			
	CO_2	CH_4	N_2O	Total
Waste	**0.39**	**23.88**	**2.67**	**26.94**
Solid Waste Disposal		14.30		14.30
Waste Incineration and Open Burning	0.39	0.64	0.18	1.21
Wastewater Handling and Discharge		8.94	2.49	11.43

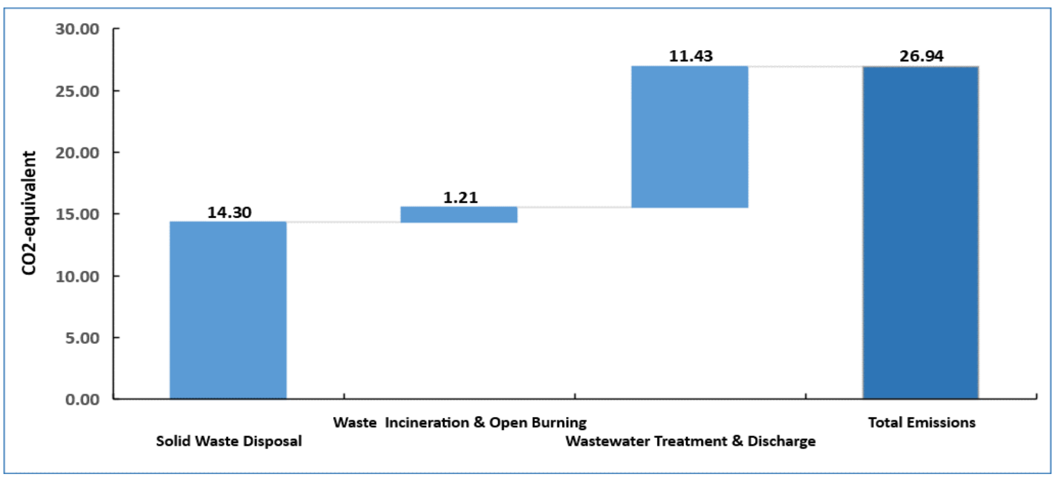


Figure 24: *Emission profile of waste sector (Mt of CO_2e)*

B. Capacity Building:

Capacity building constitutes a crucial element of GCISC's endeavors, given the continuous evolution of climate science. Given the frequent emergence of novel concepts, tools, and methodologies for impact assessment, it is essential to equip the Center's researchers and other institutions with the latest technologies and skills to ensure high-quality research and effective action.

Throughout 2023-24, scientists at the Center actively participated in numerous national and international training workshops, acquiring expertise in a broad spectrum of areas, including climate science, climate modeling, seasonal forecasting, early warning systems, drought monitoring and assessment, hydrological modeling, crop simulation, water management, water surface runoff analysis, water-food-energy nexus, earth observation systems, space technology, and remote sensing/geographic information systems (RS/GIS) tools. These newly acquired skills are being effectively utilized in both ongoing and planned research endeavors at the Center. Additionally, GCISC's scientists contributed as resource persons in workshops and seminars organized by various entities.

Furthermore, twenty-seven students from prominent institutions such as the National University of Science and Technology (NUST), Islamabad, Bahria University, Islamabad, PMAS-Arid Agriculture University Rawalpindi, University of Agriculture, Faisalabad, and University of Engineering & Technology (UET) Peshawar participated in internships at GCISC for periods ranging from 2 to 3 months. During their tenure, the Center's researchers provided them with orientation lectures on climate science, modeling, and other analytical skills. These interns were supervised by GCISC researchers and assigned various studies by their university teachers and GCISC mentors, enabling them to gain practical experience and contribute to ongoing research initiatives.

C. Mass Awareness / Media Appearance:

The scientists at the Center disseminated numerous articles across prominent national newspapers, covering diverse facets of climate science and its implications for water resources, agriculture, and forestry. Additionally, these experts engaged in interviews and offered insights into pressing matters such as heatwaves, glacier retreat, monsoon disruptions, food insecurity, challenges in wheat production, efficient irrigation practices, and other related concerns linked to climate change.

D. Inputs for parliamentary Business

The GCISC, serving as the research division under the Ministry of Climate Change & Environmental Coordination (MoCC&EC), regularly offers expert insights on climate change, its effects, and potential mitigation measures to support parliamentary activities. This includes furnishing answers to inquiries from the National Assembly and Senate and actively participating in the discussions of standing committees addressing climate change issues.

E. Administrative Matters

The Centre, serving as the research division under the MoCC&EC, providing technical comments on the most immediate letters of MoCC & EC and also on other Govt. Departments / Private / NGOs etc., on the following official business;

- Technical input on Pakistan foreign affairs matters with other countries on bilateral, interministerial, joint commission, joint sessions, SDGs, MoUs, Technical Cooperation Agreements, Strategic Partnership, Globalization etc., and PM visits;
- Submission of responses on technical / non-technical inquiries on Material for Economic Survey of Pakistan, Annual Progress Reports, Year Books, Performance Monitoring, Principle of Policies, PMDU Portal inquires etc.,