PREDICTING FUTURE TEMPERATURE AND PRECIPITATION OVER PAKISTAN IN THE 21ST CENTURY

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ABSTRACT

The objective of this study was to analyze projections of changes in mean annual temperature and precipitation over Pakistan for mid-century (2040–2069) and end century (2070–2099) time periods. An open source web tool namely "climate wizard" was used to obtain temperature and precipitation departures projected by three different GCMs under A1B, B1 and A2 emission scenarios. To ensure the maximum possible spatial coverage, a total of 16 climatic stations in Pakistan were selected. Results indicated a temperature departure in the range of 1.3-2.7°C for the mid century period, and a temperature departure in the range of 2.3-5.3°C for the end century period. Among different provinces of Pakistan, Gilgit Baltistan, Northern and Southern Punjab, Khyber Pakhtunkhwa and central Balochistan are likely to be subjected to greatest temperature rise in the coming decades. The projections of precipitation changes over Pakistan by different models show greater variability compared to temperature changes. An increase in precipitation in the range of (1-11%) was projected over Pakistan for the mid century. However, central Balochistan and southern Punjab showed negative precipitation departures ranging from -1 to-11%, thus increasing the likelihood of droughts in these regions. For the end century, positive precipitation departures were projected throughout the country, except Balochistan, Gilgit Baltistan and Southern Punjab, which showed negative departures of (-1 to -19%). With the projected rise in mean annual temperature through Pakistan, several sectors such as agriculture, energy, water supply and health will face serious challenges in the second half of the 21st century. Therefore, preventive and remedial measures are required to minimize the impacts of projected warming by formulating long-term management and control policies for all sectors.

Keywords: *Temperature, precipitation, Departure, GCM, Climate wizard*

INTRODUCTION

Climate change caused by higher concentration of greenhouse gases (GHG) has been considered as a serious threat to the inhabitants of earth. It has affected every component of environment which has clearly been demonstrated through studies carried out in different parts of the world. Such studies were two dimensional and the aim was to identify historical trends in observed climatic parameters as well as make future projections under different combinations of global climate models (GCMs) and emission scenarios. The choice of using a particular GCM for making future projections depends on its ability to represent both past and present trends effectively and model should be calibrated before carrying impact assessment study as suggested by Kundzewicz et. al.,[1]. A climate model that works well in colder region may not be capable to accurately predict future climate in a warmer region and the same is true for dry and wet regions. Further, a model capable to make accurate temperature projections may not be able to project precipitation patterns adequately as demonstrated by Turnpenny et. al.,[2]. From their study it was concluded that HadRM2, the model used in their study, simulated temperature well as compared to precipitation across United Kingdom. McSweeney et. al.,[3] developed a methodology for selecting from the available CMIP5 models to be used in regional climate studies for various regions such as Africa, Europe and Southeast Asia.

The fifth assessment report of IPCC[4] revealed that a rise of 0.85°C occurred in average global air surface temperature from 1880 to 2012, and this increasing trend in temperature is very likely to continue. Considered as a whole, the IPCC[4] stated that the range of published evidence indicates that the net damage costs of climate change are very likely to be significant and to increase over time. For the purpose of projecting future climate in any region of the world, IPPC[5] has identified six different scenarios each representing different levels

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of emission rates of greenhouse gases and associated temperature rise for future (Table 1). The A1 and B1 storylines are focused on global development, while A2 and B2 emphasis on regional solutions. The A1 and A2 predict greater cumulative emissions, whereas B1 and B2 predict that emissions will level off with time.

Table 1: Scenarios and associated temperature change in 2090-2099 relative to 1980-1999

Scenario	Mean and Likely range (°C)
Constant year 2000 concentration	0.6 (0.3-0.9)
B1*	1.8 (1.1-2.9)
A1T	2.4 (1.4-3.8)
B2	2.4 (1.4-3.8)
A1B*	2.8 (1.7-4.4)
A2*	3.4 (2.0-5.4)
A1FI	4.0 (2.4-6.4)

Different studies have been conducted to predict possible changes in various meteorological variables in different parts of the world[2,3]. A study carried out in Pakistan by Farooqi et. al.,[6] in which Climate Scenario generator MAGIC and Regional Climate Model RegCM2 were used for projecting future rainfall and temperature during 2000-2050. Based on their results it was found that temperature will continue to rise during 2000-2050 throughout Pakistan not exceeding the threshold temperature of 2°C. Further that the middle and southern parts of country will suffer more as compared to northern hilly areas.

A study for predicting future temperature rise was conducted by Sharif[7] in Saudi Arabia using six different GCMs and three emission scenarios namely A1B, B1 and A2. Analysis of projected temperatures was carried out for two future time periods: mid-century (2040–2069) and end (2070–2099). Jeremy et. al.,[8] focused on finding answer to the question "When and where temperature will exceed threshold temperature (2°C)" rather than what might happen in future. The answer to this question is crucial for mitigation and adaptation strategies. Based on their study, they predicted that the 2°C threshold will probably be exceeded over large parts of Eurasia, North Africa and Canada by 2040 in the absence of mitigation strategies. Liu and Smedt[9] analyzed the impacts of climate change on stream flow in one of the basins in Western Europe by using A2 scenario with HadCM3. Annual temperature and precipitation anomalies relative to 1961-90 were calculated over the basin and the future trends were represented with a five year moving mean. David et. al.,[10] analyzed model performance to represent crop response to extreme heat (higher temperatures above 34°C) in Northern India. They used nine years data of wheat growth to monitor rates of wheat senescence following exposure to temperatures greater than 34°C. Simulations with two process-based crop models indicated that existing models underestimated the effects of intense heat on senescence. They further concluded that crop models underestimated yield losses for 2°C by as much as 50% for some sowing dates. It was deduced from study results that warming presents an even greater challenge to wheat growth and its adaptation ability depend on its resistance to higher temperatures and extreme heat.

The major objective of the present research is to analyze projections of surface temperature and precipitation over Pakistan in 21st century for different combinations of GCMs and emission scenarios, a unique and new work that has not been done in Pakistan till date. The outputs of three different GCMs, namely in combination with A1B, B2, and A2 scenarios were analyzed for two different time scales: mid century (2040-2069) and end (2070-2099). Projected anomalies were computed relative to baseline period 1961-1990. The intent behind the analysis carried out herein was to identify locations in Pakistan where the projected temperature change could exceed the threshold of 2°C in the coming decades.

Study Area

Pakistan is one of the important countries located in South Asia which comprises of five provinces namely Khyber Pakhtunkhwa, Sindh, Punjab, Gilgit Baltistan, Balochistan and FATA (Federally administered Tribal area) as shown in Figure 1. The country has diverse climatic and geological features including tallest mountain ranges (Himalaya, Karakoram and Hindukash), longest rivers and vast plains. It is stretched along the latitude located between Arabian Sea in south and China in north side. The northern side is covered by tallest snow covered peaks (K-2, Nanga Parbat) and longest glaciers (Siachin) of the world. These glaciers ensure perennial flow in rivers throughout the year thus fulfilling most of irrigation water demands. The total area of Pakistan is 79.6 million hectares in which only 29% is being cultivated (Pakistan Bureau of Statistics[11]). Thus the total cultivable area is 23.08 million hectares in which 80% area is irrigated by canals in Pakistan. Nearly 58% of the total country area comprises mountains and 41% make plains. Majority of the population (70%) live in rural areas and they depend on agriculture for their livelihood (Pakistan Bureau of Statistics[11]).

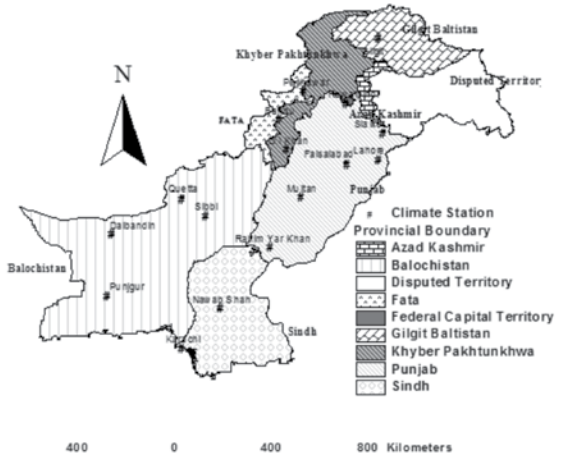


Figure 1. Map of Study area (Pakistan) showing provinces, FATA and climatic stations

A large segment of population lives around river deltas in plains and is highly vulnerable to extreme flood events caused by higher expected temperatures in future. With respect to climate most area of Pakistan falls in the category of arid to semi arid environments except northern part where humidity and snow covers are dominant. Monsoon winds that arise from the Bay of Bengal and Arabian Sea cause Monsoon rainfall which contributes 59% of the total rainfall in the country. Though Monsoon rainfall is a vital source of groundwater recharge during summer season, it often causes flood in major rivers within the country. So far these floods have caused great financial and human losses in the absence of effective water management policy. El Nino phenomena suppress monsoon rainfall activity over Pakistan while a La Nina phenomenon has a negative impact on winter precipitation over Pakistan (Azmat[12]).

Historical data of mean annual temperature and precipitation for the period 1950-2001 indicated positive temperature trends throughout the study area (0.018°C/year) and decreasing precipitation trend as reported by Climate wizard tool and shown in Figures 2a and 2b respectively. These figures show trend lines of mean annual temperature and precipitation over time based on regression equation. These findings are in agreement with the results of Salma et. al.,[13] which stated that precipitation had negative trend (-1.18mm/year) over the country during the period 1960-2010. Similar increasing trend in mean annual temperature over Punjab province (Pakistan) at the rate of 0.013°C/year was identified by Khattak et. al.,[14] while Farooqi et. al.,[6] predicted decreasing trend of rainfall in future (2000-2050). Maida and Ghulam[15] found that throughout Pakistan extreme events of both maximum and minimum temperature are increasing particularly in Punjab, Northern areas, Balochistan, and Azad Kashmir. Thus Pakistan is observing positive trends in mean annual Temperature and negative trends in mean annual precipitation based on historical records though their spatial distribution is not uniform. Since the frequency of depressions and Cyclones has also increased over Bay of Bengal and the Arabian Sea it may greatly affect the monsoon belt in Pakistan in future as mentioned by Nessa et. al.,[16]. Pakistan is among top ten countries which are affected most by climate change hazards like floods, wind storms, droughts and higher temperatures (PMD[17]).

Currently the nation is facing energy crises due to few water storage structures and dams though there is plenty of flowing water in rivers. Its canal-irrigation system established by the British is the largest in the world.

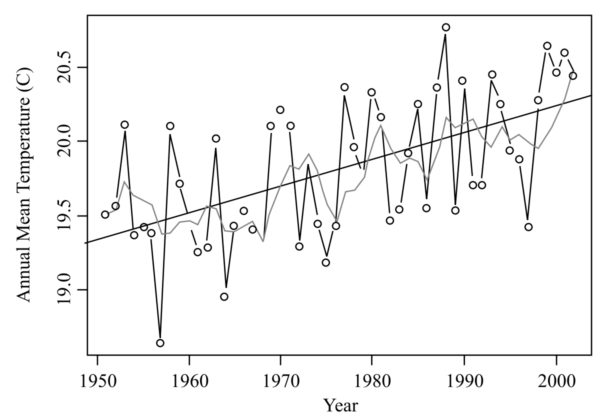


Figure 2a: Trend in mean annual temperature over Pakistan during the period 1950-2001 Source (www.Climatewizard.org)

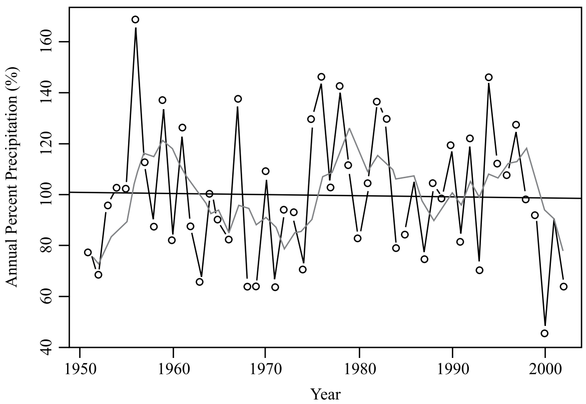


Figure 2b: Trend in mean annual precipitation over Pakistan during the period 1950-2001 Source (www. Climatewizard.org)

Wheat and cotton are the most grown crops including rice, sugarcane, corn, oilseeds, pulses, vegetables, and fruits such as citrus (Pakistan Bureau of Statistics[11]). Because of the poor water management and lack of water storage structures the country often faces both floods and energy crises during summer. Floods cause intense damage to standing crops and large population segments in plain areas resulting in great financial losses. The energy shortfall reaches its peak in hot summer creating a general sense of displeasure among the entire nation. A large area is still barren and uncultivated as irrigation system has not been fully utilized and extended to far flung areas. Thus self sufficiency in agricultural products is yet to be achieved.

DATA AND METHODOLOGY

Temperature and precipitation projections of three GCMs under three emission scenarios and their "Ensemble Average" were obtained using the Climate Wizard tool to analyze future trends in these parameters at the provincial and national level. The two time periods 2040–2069 and 2070–2099 that most accurately describes the predicted conditions for the mid-century and the end of the 21st century, were used in the present study relative to 1960-1990 period. All stations were analyzed along the latitude moving from North to South so that future predicted climate over various provinces in Pakistan is clearly visible in North-South direction. The primary purpose of using average of all model outputs called "Ensemble Average" (EA) was to remove uncertainties that might exist in various model outputs. This average takes into account both smaller and greater temperature departure predicted by various models used in this study. EA being the combined output of all GCMs can be considered as the best approximation for predicting future temperature and precipitation. The fact that none of the single model can predict both temperature and precipitation changes with greater accuracy throughout study area, was recognized leading to the use of three different models and their average (EA). This led us to rely more on the results of EA than considering outputs of individual GCM. Different numbers of stations were selected to facilitate adequate spatial coverage and better predictions of future climate within provinces as well.

For future projections of spatial changes in mean annual temperature and precipitation over Pakistan, an interactive web based "Climate wizard tool" was used which is available at www.climatewizard.org. The tool can perform two types of tasks based on available data. First climate data of any variable for a particular period can be compared with baseline data (already available in tool) to find climate departures. Second it can calculate statistic of interest (mean temperature, maximum temperature) using trend analysis. It is capable to make various graphs and tables which represent changes in climatic parameters based on historical record. A unique practical advantage of Climate Wizard Tool is that it provides high-resolution climate data sets created using downscaling techniques that utilize information from finer resolution climate data sets of past observations. Thus on the whole it gives a clear picture of historical trend in a certain parameter and predicts its future values based on model selection and scenario. In this study three important scenarios have been used namely A2, A1B, and B1 each representing different levels of emission rates of greenhouse gases and associated temperature (IPCC[18]). Complete details regarding how to extract climatic projections are available on respective website in the form of tutorials (www.climatewizard.org).

The GCMs (Global Circulation Model) utilized in this study are UKMO-HADCM3.1, NCAR-CCSM3-0.1, and GFDL-CM2-1.1 along with "Ensemble Average". This is because UKMO-HADCM3.1 (Recommended by UK meteorological Office) has been successfully used to predict temperature and precipitation changes in UK which has considerable climatic similarity with the northern areas of Pakistan though terrain is different in both regions. The UKMO-HADCM3.1 was selected as its regional version (HadRM2) has shown greater accuracy in representing temperature changes in Upper Indus Basin, a work soon to be published. We rely more on the simulations of UKMO-HADCM3.1 under A2 as fast upward trends in mean annual temperature (0.013°C/Year) and rainfall (3.23mm/year) over Punjab were noticed by Khattak et.al.,[14]. Except the Northern parts most of the area in Pakistan receives rainfall mostly in spring and summer therefore we selected NCAR-CCSM3-0.1 as well as it was used by Charabi[19] in Oman. The southern districts of Punjab, Khyber Pakhtunkhwa and Balochistan have similar meteorological characteristic as that of Oman i.e. mostly dry and hot. Because of this climatic similarity NCAR-CCSM3-0.1 was preferred, which is capable to simulate future climate in dry hot regions of Pakistan. Our analysis and discussions were more focused on the output of EA though other models were used for a broader picture of possible future climate. EA was utilized to remove uncertainties that might exist, an approach used by Sharif[7] for predicting temperature changes in Saudi Arabia. GFDL-CM2-1.1 in general predicts extreme values of various meteorological parameters and therefore greatly affects the "Ensemble Average" as observed by Sharif[7].

Departures in mean annual temperatures and precipitations over 16 selected stations were analyzed resulting in greater spatial coverage (Fig.1). Based on the values of temperature departures stations were identified where projected temperatures might exceed the threshold value (2°C) as done by Manoj et. al.,[20]. This enabled us to recognized stations that might suffer to a considerable extent in future. Projected changes were analyzed to see trend of future changes along latitude in North South direction.

RESULTS AND DISCUSSIONS

4.1 Temperature Projections for Mid century (2040-2069)

Initial examination of temperature projections revealed that under all emission scenarios UKMO-HADCM3.1 and EA were close in terms of magnitude of results. Further that NCAR-CCSM3-0.1 projected least values among all models and GFDL-CM2-1.1 projected greatest changes in mean annual temperature. Thus we concluded that GFDL-CM2-1.1 exhibits extreme values of departures, NCAR-CCSM3-0.1 predicts least changes while UKMO-HADCM3.1 and EA predicts moderate future temperature changes. Among all provinces of Pakistan Gilgit Baltistan (GB), Northern and Southern Punjab, Khyber Pakhtunkhwa (KPK) and Central Balochistan will be subjected to greatest temperature changes, the Northern provinces of Pakistan being most affected.

Temperature departures of UKMO-HADCM3.1 (under B1) for mid century revealed that extreme northern areas of Pakistan (Gilgit, Peshawar), Northern and southern districts of Punjab and Central Balochistan will suffer more as compared to the other climatic stations as shown in Figure 3a. On the whole we conclude that under very moderate scenario (BI) Gilgit Baltistan, Central districts of Khyber Pakhtunkhwa (KPK), Central Balochistan and Northern Punjab will touch the threshold value (2°C) during 2050s (Figure 3a). Human survival will be possible in all parts of Pakistan during mid century only if B1 scenario is implemented before 2020, a situation that is difficult to prevail after the construction of China-Pakistan Economic Corridor (CPEC) in 2030. NCAR-CCSM3-0.1 under B1 predicted same trend of future temperature as that of UKMO-HADCM3.1, with all values less than 2°C at all climatic stations. Temperature departures of EA were close to the results of Ukmo-hadcm3.1 but it was more affected by the outputs of GFDL-CM2-1.1. Under BI all model results predicted moderate temperature changes for mid century throughout the country except GFDL-CM2-1.1.

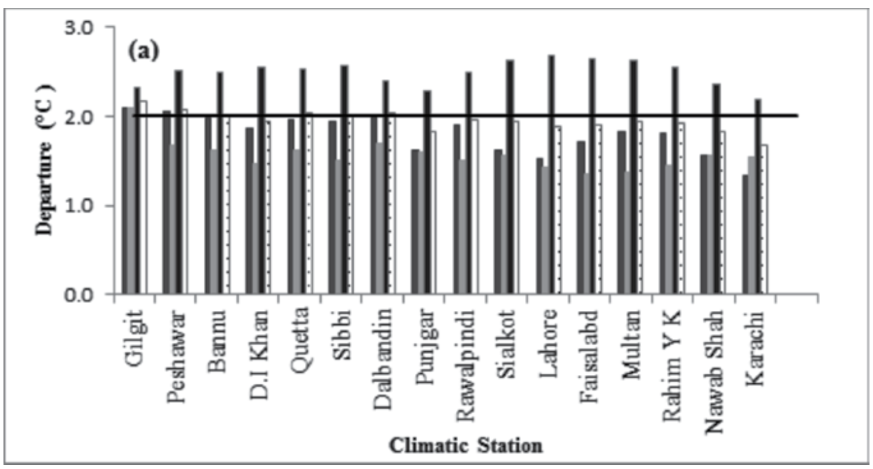
Under A1B scenario all models predicted temperature departures exceeding 2°C at all climatic stations during 2050s (Figure 3b). Under AIB extreme temperature departures (greater than 2.2°C) were predicted by UKMO-HADCM3.1 for all climatic stations except Karachi. Projected temperatures had same latitudinal trend across various provinces like B1 scenario i.e. Gilgit Baltistan, Central plain districts of Khyber Pakhtunkhwa (KPK), Central Balochistan and Northern Punjab will observe greatest changes in mean annual temperature as shown in Figure 3b.

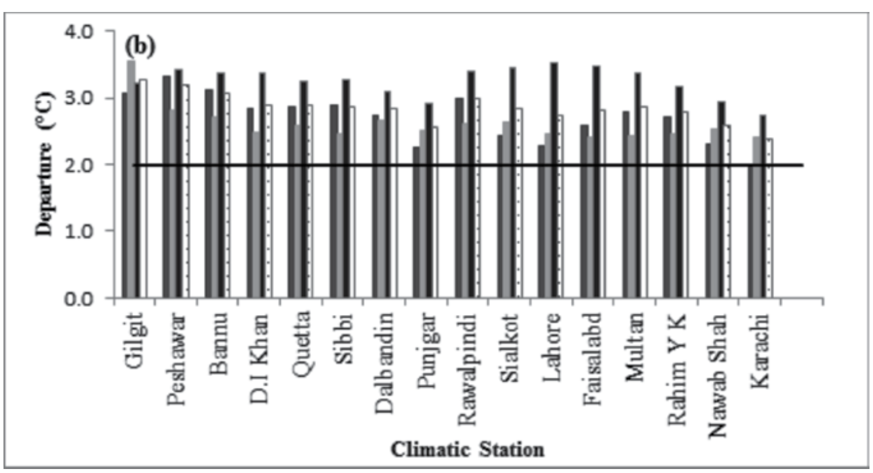
All models (under A2) predicted temperature departures less in magnitude as compared to A1B scenario. This means that A1B showed greater temperature changes in Pakistan as compared to A2. Except Lahore and Karachi all stations exceeded the allowable temperature rise (2°C) as predicted by UKMO-HADCM3.1 as shown in Figure 3c. A greater temperature change will be focused more on Central plain areas of Khyber Pakhtunkhwa, Southern and Northern Punjab, Gilgit Baltistan and central Balochistan. On provincial level Gilgit Baltistan, Khyber Pakhtunkhwa and Balochistan will suffer to greater extent as compared to other areas. Spatial distribution of projected departures in mean annual temperature (°C) for mid century (2040-2069) at all climatic stations of Pakistan according to EA using various scenarios have been shown in Figure 4. It is worth noticing that ever increasing population, irregular urbanization and poor land management may cause early temperature changes. Effective and well balanced distribution of land and water resources is highly needed to counter balance adverse effects of regional warming. The need is to not only frame strict constitutional laws but also reinforce them effectively. Promotion of greenery among masses and avoiding use of coal may prove good mitigation strategies. Every effort must be made to keep environment clean and minimize emissions of Greenhouse gases to atmosphere.

We classified temperature departures in four distinct categories for ease of understanding so that agricultural scientists, health managers and water management experts may identify regions which are highly vulnerable to negative impacts of global warming. The four distinct ranges are T>4°C, 3<T≤4°C, 2<T≤3°C and 1<T≤2°C (Allowable temperature rise) which will enable better understanding of projected temperature changes in future in various regions of Pakistan.

4.2 End century temperature projections (2070-2099)

Temperature departures of UKMO-HADCM3.1 under





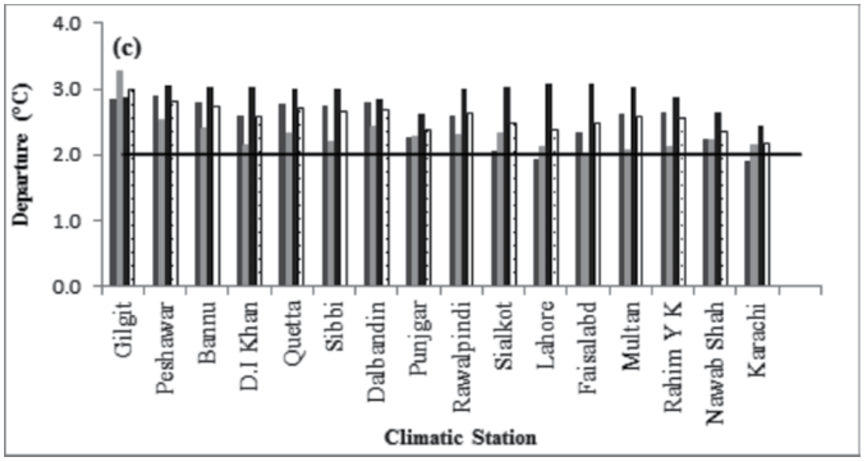


Figure 3: Departures (°C) in mean annual temperature at climatic stations under (a) B1 (2) A1B and (3) A2 scenarios by various models for mid century (2040-2069).The Black bold line indicates Threshold value (2°C) of temperature rise within which human survival is manageable.

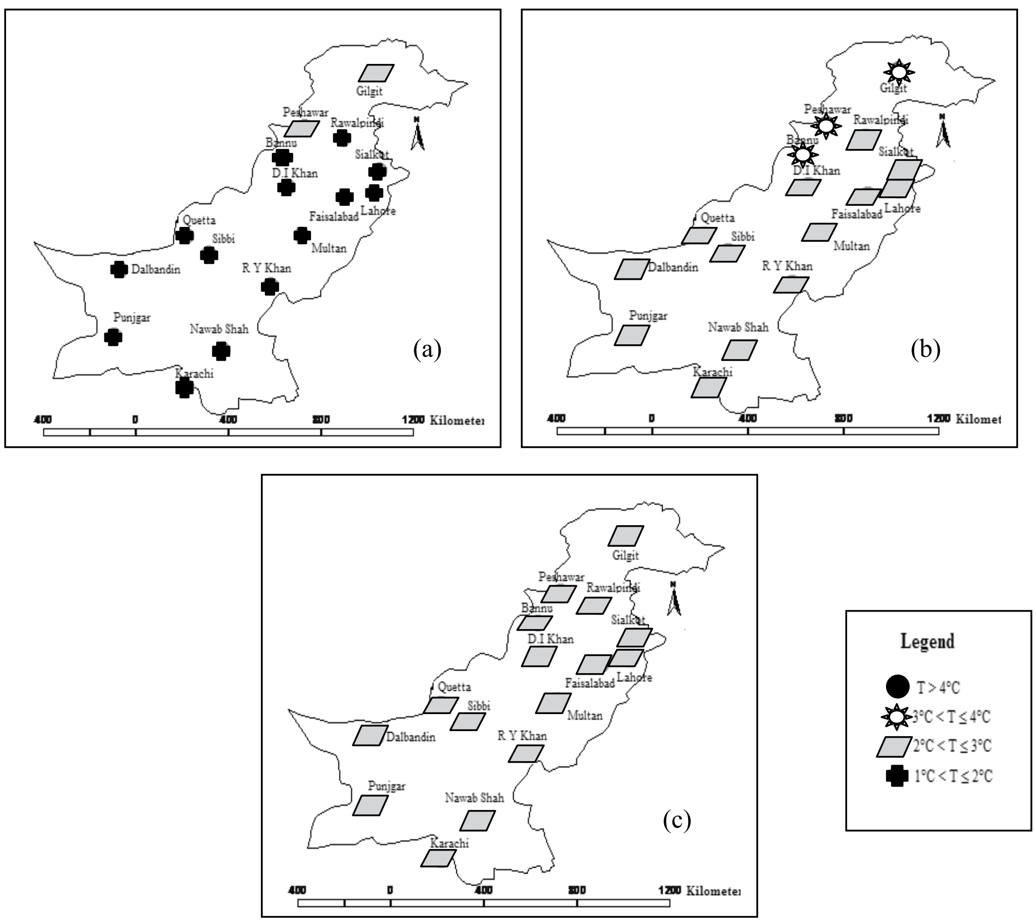


Figure 4: Spatial distribution of projected departures (°C) in mean annual temperature for climatic stations of Pakistan under (a) B1 (b) A1B and (c) A2 scenario for mid century (2040-2069) as predicted by "Ensemble Average". The green circle indicate moderate temperature rise (Threshold value of 2°C) which allow human survival with ease while others indicate values exceeding the upper limit (2°C).

B1 for end century revealed that mean annual temperature will rise by 2.3°C at all stations in Pakistan except Karachi as shown in Figure 5a.Thus within provinces temperature rise in future will be different at various locations i.e. Non uniform spatial distribution within provinces. Under very moderate scenario (BI) mean annual temperature in Gilgit Baltistan, Central Khyber Pakhtunkhwa (KPK), Northern and Southern districts of Punjab and Central Balochistan will exceed 2.5°C during end century. Thus under B1 all model results (except NCAR-CCSM3-0.1) revealed a temperature rise of 2.5°C during 2080s at all stations of Pakistan (Except Lahore and Rahim Yar Khan).

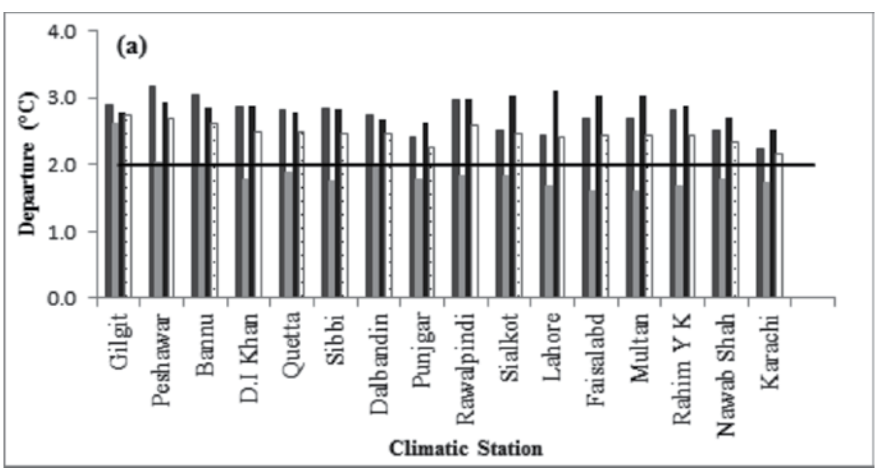
All models predicted temperature departures exceeding 2.8°C at all climatic stations of Pakistan during 2080s under A1B. Under this scenario UKMO-HADCM3.1 predicted a rise of greater than 4°C in mean annual temperature at all stations of KPK, Central Balochistan and Gilgit Baltistan as shown in Figure 5b. Thus human survival will be very difficult at stations where predicted mean annual temperature will exceed 4°C excluding the hilly areas of Pakistan. This is because the mean annual temperature of Northern hilly areas of Pakistan (Gilgit) is less than the other parts and rise up to 4°C will allow human survival only in these colder areas. For the rest of Pakistan tolerating a predicted rise of 3.5- 4°C will be very difficult, a very alarming situation. EA revealed same predicted values with a very slight difference in magnitude.

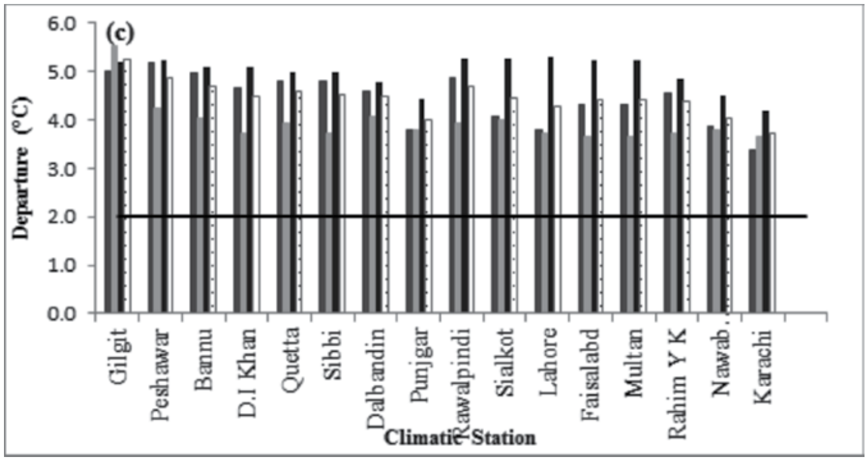
Under A2 all models predicted departures in mean annual temperature exceeding 3.4°C at climatic stations of Pakistan during 2080s. Under this scenario UKMO-HADCM3.1 predicted a rise of greater than 4°C in mean annual temperature at all stations except Lahore and Karachi as seen in Figure 5c. EA predicted temperature departures exceeding 4.3°C at all stations of Pakistan except Lahore. Overall it can be concluded that end century will be warmer in Pakistan as compared to mid century. Spatial distribution of projected departures in mean annual temperature (°C) for end century (2040-2069) at all climatic stations of Pakistan according to "Ensemble Average" using various scenarios have been shown in Figure 6.

4.3 Mid century precipitation projections (2040-2069)

Departures of mean annual precipitations were examined and analyzed to locate stations which will be subjected to scarcity of precipitation during mid and end of twenty first stations. Results of UKMO-HADCM3.1 and EA were analyzed which takes into account all model outputs.

UKMO-HADCM3.1 revealed positive precipitation departures throughout the country except Quetta and Dalbandin (Central Balochistan) in the period 2040-2069 (under B1) as shown in Figure 7a. Greatest positive precipitation departures were observed at Karachi (Sindh)





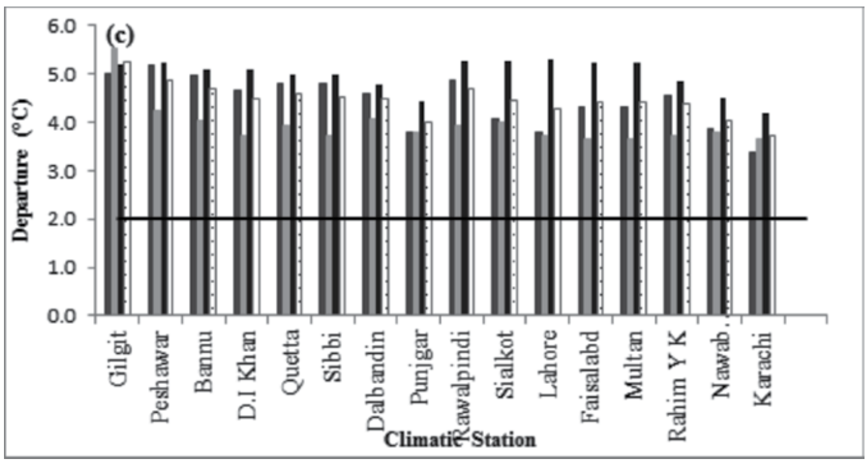


Figure 5: Departures (°C) in mean annual temperature at climatic stations under (a) B1 (b) A1B and (c) A2 scenario by various models for End century (2070-2099). The Black line indicates Threshold value (2°C) of temperature rise within which human survival is manageable.

and Lahore (central Punjab) i.e. exceeding 26%. It means that among all provinces of Pakistan central Punjab and Sindh along with its coastal areas will receive maximum rainfall during 2050s. EA predicted positive precipitation departures (None exceeding 14%) at all provinces except entire Balochistan and southern Punjab where departures were negative. On the whole we concluded that under very moderate scenario (BI) precipitation amount will increase throughout Pakistan except central Balochistan and southern Punjab where droughts are highly expected under B1. Under AIB scenario UKMO-HADCM3.1 exhibited positive precipitation departures throughout the country except central Balochistan and Southern Punjab where negative departures were seen (Figure 7b). Central Punjab and Sindh along with its coastal belt demonstrated greatest departures among all and their magnitudes were higher as compared to predicted under B1. EA predicted same changes in mean annual precipitation with the addition of negative departure in Gilgit Baltistan i.e. GB will receive very little precipitation. Overall under AIB scenario precipitation amount will increase throughout Pakistan except central Balochistan and southern Punjab where rainfall will be rare. Central Punjab and entire Sindh will receive maximum precipitation among all which may cause damage to infrastructures in mid century (2040-2069). Precipitation departures under A1B are greater in magnitude suggesting extreme events of precipitation (Droughts and rainstorms) in coming decades.

Positive and greatest departures (among all scenarios) were exhibited by UKMO-HADCM3.1 throughout Pakistan during mid century (2040-2069), all exceeding 20% under A2.Among all provinces Gilgit Baltistan, Southern Khyber Pakhtunkhwa, Central Punjab and Sindh

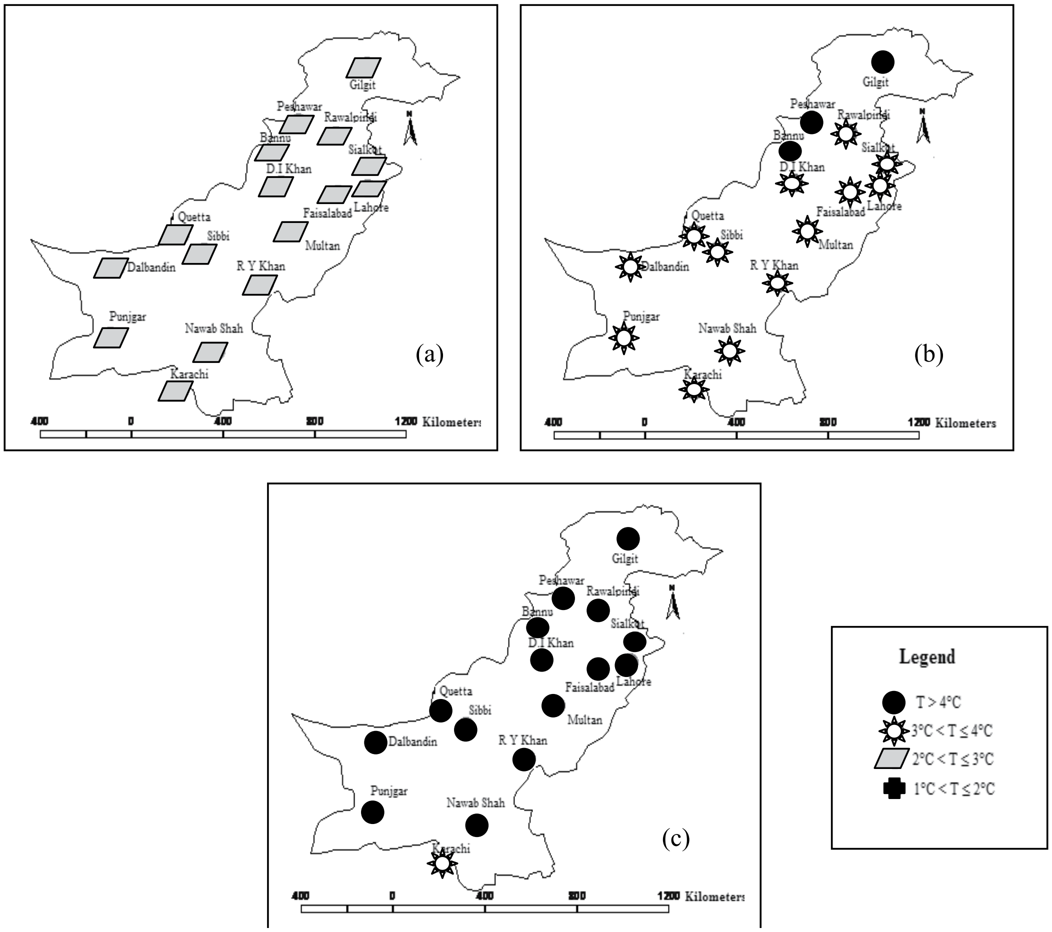


Figure 6: Spatial distribution of projected departures (°C) in mean annual temperature for climatic stations of Pakistan under (a) B1 (b) A1B and (c) A2 scenario for End century (2070-2099) as predicted by "Ensemble Average". The green circle indicate allowable temperature rise (Threshold value of 2°C) which allow human survival with ease while others indicate values exceeding the upper limit (2°C).

(Karachi) showed greatest precipitation departures, all exceeding 26% (Figure 7c). Same positive departures in precipitation were also predicted by EA though the magnitude of increase was small as compared to Ukmo-hadcm3.1. These results indicated extremely wet summers which will increase the degree of mugginess in hot summers during 2050s. Spatial distribution of projected departures in mean annual precipitation in percentage for mid century (2040-2069) at all climatic stations of Pakistan according to EA using various scenarios have been shown in Figure 8.

We divided departures in precipitation into 3 distinct ranges such that (1) 35%>PPT>20% (High) (2) 20%≥PPT>10% (Medium) and (3) 10% ≥PPT>0% (Low) in order to give a clear picture of change in precipitation amount in various regions of Pakistan. This will help in identifying areas where extreme events of precipitation and drought are highly possible as predicted by EA.

4.4 End century precipitation projections (2070-2099)

UKMO-HADCM3.1 predicted positive precipitation departures throughout the country in the period 2069-2099 under B1 (Figure 9a). Greatest positive departures among all were observed at coastal belt of Sindh (Karachi) and central Punjab i.e. exceeding 27%. These areas will

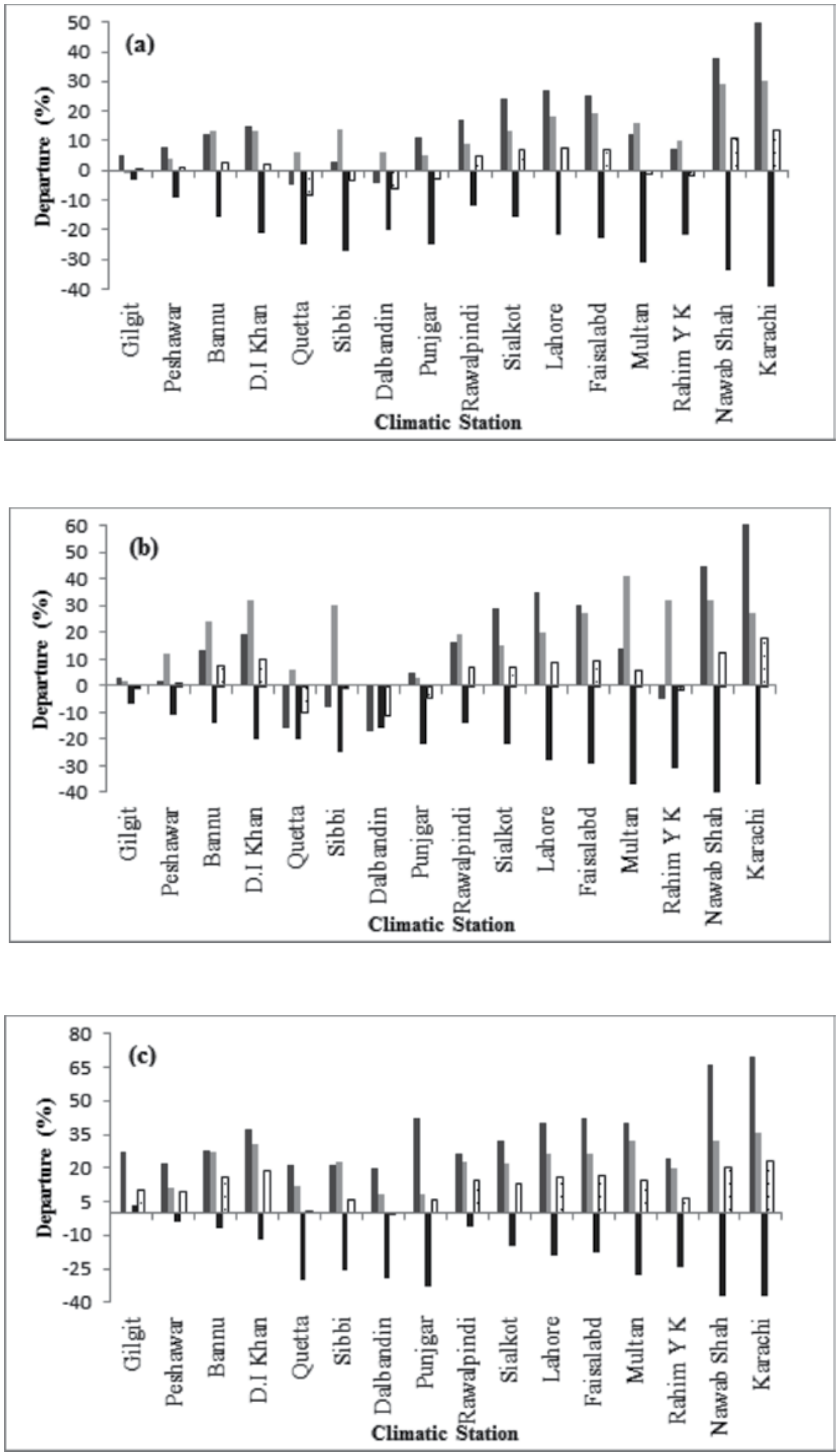


Figure 7: Projected departures (% change) in mean annual precipitation at climatic stations under (a) B1 (b) A1B and (c) A2 scenarios predicted by various models for mid century (2040-2069).

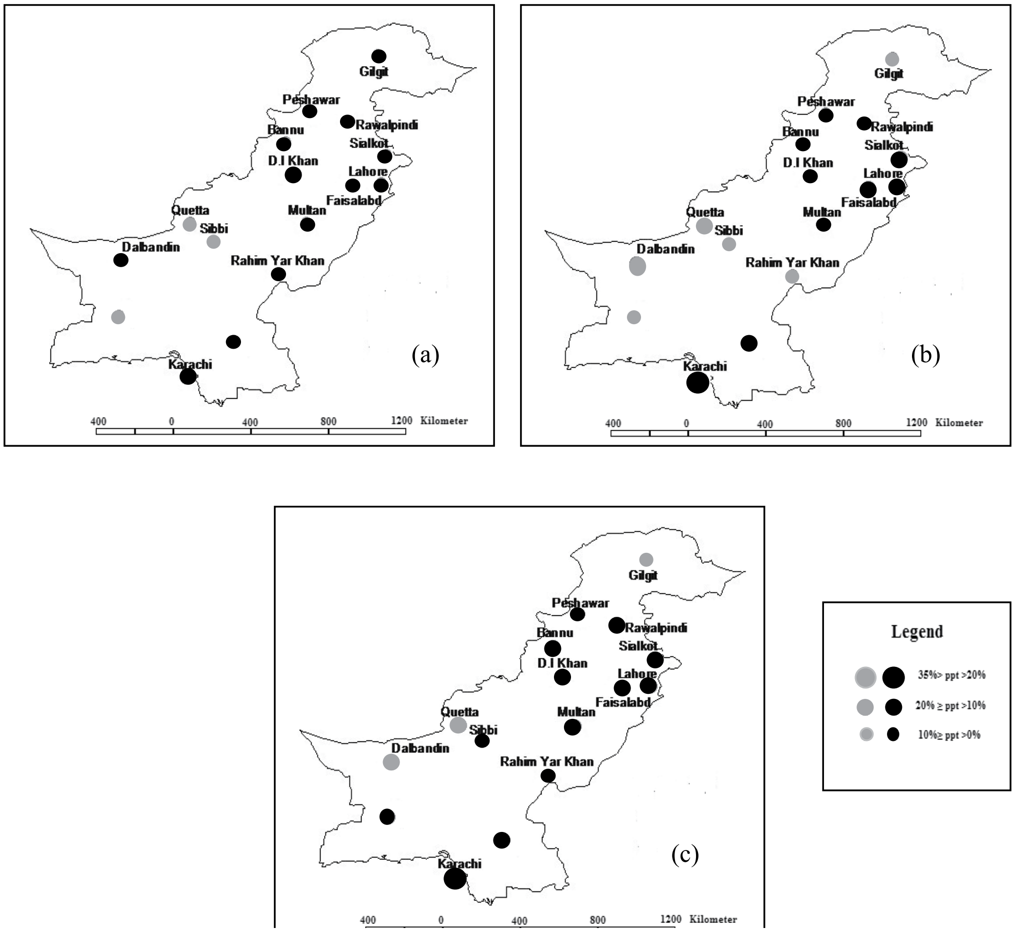
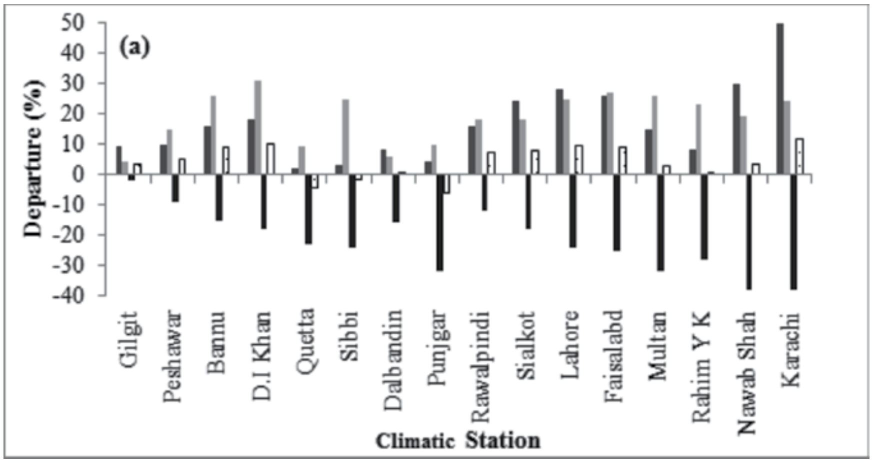


Figure 8: Spatial distribution of projected departures (%) in mean annual precipitation for climatic stations of Pakistan under (a) B1 (b) A1B and (c) A2 scenario for mid century (2040-2069) as predicted by "Ensemble Average". The Blue circles indicate positive departures (increasing trend) while Red circle represent negative departures (drying tendency) in mean annual precipitation.

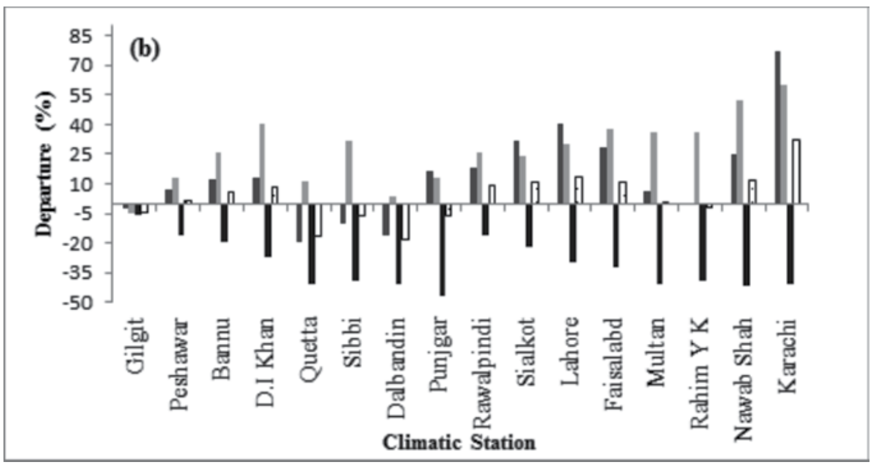
be subjected to very wet summers during end century (2080s). Results of EA also demonstrated same pattern of changes with slight difference in magnitude. On the whole it was noticed that entire Sindh and central Punjab will be vulnerable to greatest amount of rainfall under B1 scenario. Balochistan will face scarcity of rainfall which may result in population shift to other parts of Pakistan.

UKMO-HADCM3.1 (under AIB) revealed positive precipitation departures throughout the country except central Balochistan, GB and Southern Punjab. Among all greatest positive departures were seen at Sindh and central Punjab i.e. all exceeding 24% (Figure 9b). Thus both central Balochistan and southern Punjab will be highly vulnerable to extreme events of droughts during 2080s. Ensemble average predicted same changes in mean annual precipitation with the addition of negative departure in GB as well. So it can be concluded that under AIB scenario precipitation amount will increase throughout Pakistan during end of twenty first century except Balochistan and southern Punjab where rainfall may disappear completely. Magnitude of predicted changes in precipitation amount during end century was greater as compared to mid century.

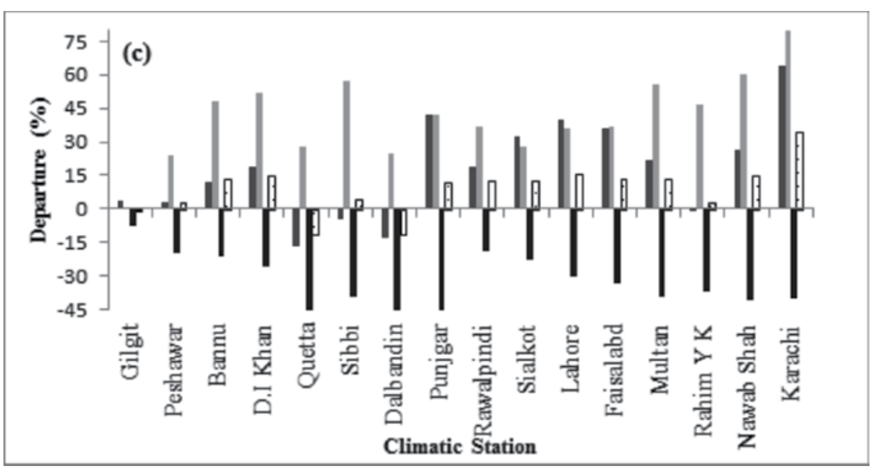
Both UKMO-HADCM3.1 and EA (under A2) predicted precipitation departures slightly less than predicted under A1B (Figure 9c). Both revealed greatest positive departures in entire Sindh and Central Punjab while Gilgit Baltistan, Southern Punjab and Balochistan will be subjected to decreasing precipitation events during 2080s. Latitudinal trend of predicted precipitation departures



(a)



(b)



(c)

Figure 9: Departures (% change) in mean annual precipitation at climatic stations under (a) B1 (b) A1B and (c) A2 scenarios by various models for end century (2070-2099).

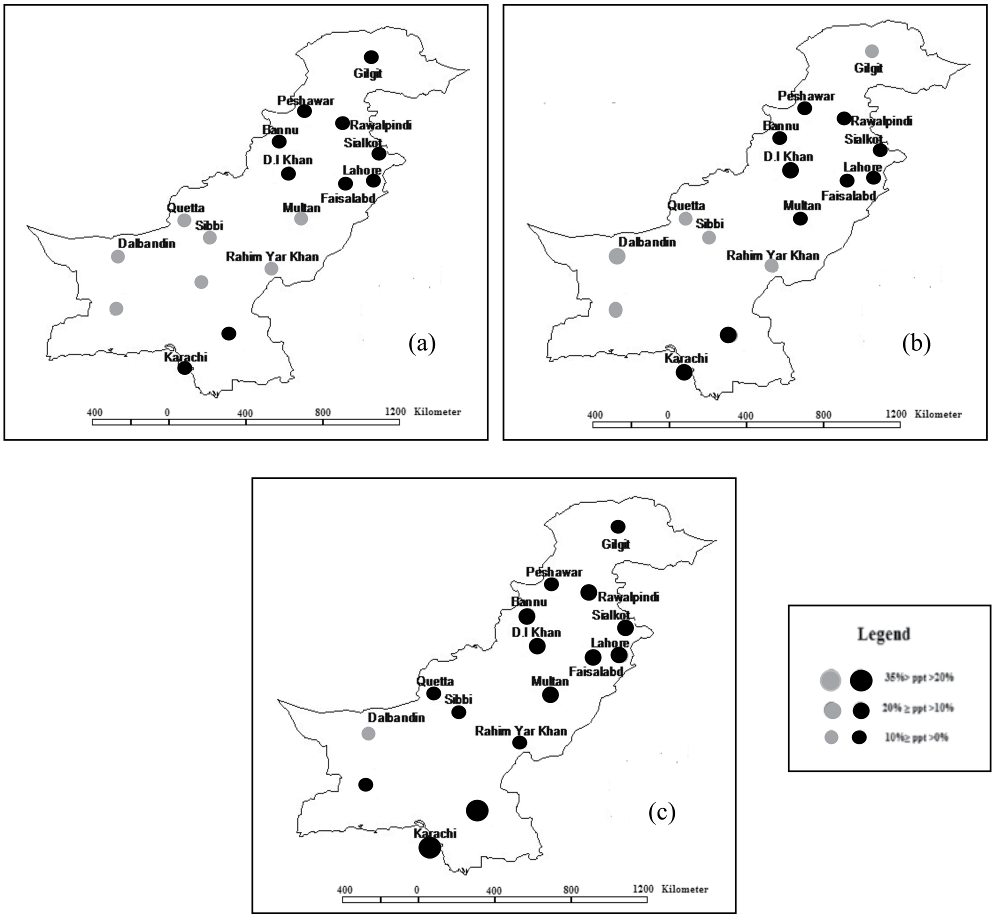


Figure 10: Spatial distribution of projected departures (%) in mean annual precipitation for climatic stations of Pakistan under (a) B1 (b) A1B and (c) A2 scenario for end century (2070-2099) as predicted by "Ensemble Average". The Black circles indicate positive departures (increasing trend) while Silver circle represent negative departures (drying tendency) in mean annual precipitation.

throughout the country under A2 was very similar to that of A1B. Overall it is concluded that AIB predicted greater changes in precipitation for end century while for mid century A2 predicted extreme changes. All scenarios and models predicted higher changes in precipitation for end century as compared to mid century i.e. Seasons will be wetter during End century in Pakistan as compared to mid century. On the whole both time slices observed wet climate with slight differences in magnitude throughout Pakistan. Balochistan and southern Punjab seems to be greatly affected by droughts in coming decades while Sindh and central Punjab will have plenty of water if managed well. Precipitation may cause floods and losses if occur in the form of severe storms. Spatial distribution of projected departures (%) in mean annual precipitation for mid century (2040-2069) at all climatic stations of Pakistan according to "Ensemble Average" using various scenarios have been shown in Figure 10.

Temperature and precipitation changes directly impact agriculture, energy and health sectors, water supply demands, environment and ecology in any region. Adaptations to the negative impacts of climate change are very important for the sustainable agriculture and food security of any region. Both temperature and precipitation projections should be incorporated in planning and policy making. Addressing the issue of climate change is critical to predict reliable future climate changes which will facilitate researchers and planners across Pakistan to analyze climate change on regional scale. The results of the present research have good potential to motivate stakeholders to use best practices for conservation of water supplies both for irrigation and domestic purposes. Overall the results presented in this study will help in the understanding of climate change and assist policy makers to take precautions for future. Rather than discussing various problems caused by climate change it is necessary to formulate mitigation strategies for effective implementation as soon as possible.

CONCLUSIONS

This study predicted departures in mean annual temperature and precipitation for mid (2040-2069) and end of twenty first century (2070-2099) with respect to baseline period (1960-1990) for 16 climatic stations of Pakistan covering all provinces. Trends of projected temperature and precipitation along the latitude (North-South) were also analyzed. Three GCMs and their average output under three scenarios were analyzed and this data was extracted from open source namely climate wizard (www.climatewizard.org). The predicted temperature rise throughout Pakistan in next decades may be attributed to regional climate changes, global warming and local land use. It is strongly recommended that water resource planners, agricultural experts and health managers must consider these changes in policy making.

Following specific conclusions derived from this study are:

Model results for mid century showed that projected temperature rise will be in the range of 1.3-2.7°C mostly affecting Plains of KPK, Punjab and Balochistan. However this temperature rise is considered.

For end century model outputs revealed that throughout the country rise in mean annual temperature will be in the range of 2.3-5.3°C making human survival difficult.

Analysis for mid century revealed that mean annual precipitation amount will increase throughout Pakistan (1-50%) except central Balochistan and southern Punjab (-1 to-11%) where droughts might prevail due to negative departures.

All models exhibited positive precipitation departures (end century) throughout Pakistan (1-77%) except central Balochistan where they were negative (-1 to -19%). Central Balochistan, Gilgit Baltistan and Southern Punjab would observe decrease in predicted precipitation and the rest of Pakistan will be subjected to increasing precipitation amount by the end of 21st century.

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