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A Statistical Modeling for spatial-temporal variability analysis of solar energy with respect to the climate in the Punjab Region

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Abstract

The purpose of this study was to assess the Spatio-Temporal effects of changing solar radiation on climate. Climate change in the world has gained public attention because it is one of the most important aspects of human survival. One particular climatic impact of changing solar insolation that has been overlooked by most researchers is the change in the atmosphere's carbon dioxide holding capacity. Changes in biochemical cycles and climate on a global, regional, and local scale have resulted from this change. The main goal of this study is to measure solar and climatic variability trends in the study area over the time period of 1990 to 2018. Making a connection between these factors has always been overlooked in Pakistan. To measure the relationship between variables, ordinary least squares methods were applied to solar variables and climatic variables for the regions of Bahawalpur, Islamabad, and Lahore. In the study area, a linear relationship was discovered between climatic variables and solar variables. The relationship between solar insolation and climatic variables (maximum temperature, minimum temperature, and precipitation) can be clearly observed using statistical analysis.

Keywords: Ordinary Least Squares, Solar Insolation, Climate Change

INTRODUCTION

The periodic solar variability with periods ranging from 11 years for sunspots to 2000 years for cycles, could be the cause of global temperature cycles (Ehrlich, 2007; Song et al., 2019). The influence of solar activity on the climate system is spatially and temporally selective, and is often more substantial at the regional scale (Song et al., 2019). This research explores the influence of solar insolation on regional climate of Punjab Province in recent decades using statistical techniques and solar radio flux (SRF) data. Changes in solar insolation flux cause significant fluctuations in summer and winter temperatures, precipitation, and air circulation across Punjab Province. Solar activity is partly responsible for natural climatic fluctuation (Tzanis, Benetatos, & Philippopoulos, 2022).

The goal of this research is to get a better knowledge of the impact of solar variability on the Earth's climate system and how solar radiation works with carbon dioxide I determining the climate. For this it is very imperative to understand how Carbon Dioxide absorption works with different bands of solar radiation. The atmosphere is made up of various constituents, the majority of which are selective absorbers. Similarly, this implies that they absorb more radiations in some wavelengths than others by absorbing less shortwave and more longwave radiation, as shown in Fig 1. All of this contributes to the greenhouse effect, which is responsible for global climate change. As a result, in the case of carbon dioxide, it is critical to determine where the CO2 absorption bands are located in relation to the Earth's emission spectrum and the amount of carbon dioxide that is already present in the atmosphere. (Marsh, 2007). Carbon dioxide has three absorption bands with wavelengths of 4.26, 7.52, and 14.99 microns (micrometers).

If the earth is thought to be a black body that has no atmospheric absorption, then its emission spectrum ranges between 15 to 20 micrometers. As the wavelength decreases, so does the emission spectrum. As a result, the absorption bands of carbon dioxide at 4.26 and 7.52 micrometers absorb a negligible amount of thermal radiation in comparison to the band at 14.99 microns. (Marsh, 2007). Similarly, CO2 is that gas that is naturally present in atmosphere with such large amount which make the atmosphere opaque at the center of band 14.9 33 mm over short distances(Marsh, 2007) However, band saturation can increase CO2 concentration that has an effect on the band's edge. This marginal impact, changes in carbon dioxide concentrations cause changes in solar forcing (Marsh, 2007). As a result, it is concluded that changes in carbon dioxide concentrations have little effect on Earth's temperature that becomes drastic when combined with a specific band of solar radiation.

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A very strong base of this research could be analyzed by the fact that on Equator there is no season as Sun shines vertically on the equator two times in a year.

That is the reason the general climate of equatorial countries if marked by high temperatures. As we move from the equator towards the pole the sun rays become slanting and temperature also start decreasing from equator towards pole. According to the IPCC, as quoted by (Marsh, 2007) (Usoskin, Solanki, Schüssler, Mursula, & Alanko, 2003) studied that current situation of solar activity can affect the terrestrial atmosphere. They found a general resemblance what they drawn in their study between sunspot recreation and temperature variations that

- Both showed moderate diminishing pattern prior to 1900, that was following a sharp rise during last era.
- Decline in sunspot data was seen together with high level of activity (between 1100 and 1300) and cooling off periods compared with the Medieval Warm Period.

Solar Radiation Management for Climate Change

Because of the sensitivity of solar flux and changing temperature, Atmospheric relief concerns have revived the discussion about solar radiation management. According to the studies related to modelling, world temperature can stabilize by managing solar radiation but by doing so global precipitation would be reduced. (Ricke, Morgan, & Allen, 2010). A study found that some minor technical and scientific variability to reduce the solar energy can be ignored for a uniform decrease in insolation that is capable of neutralizing regional surface warming caused by artificial CO2. (Matthews & Caldeira, 2007). The radiation comes on the surface can be reduce through Solar Radiation Management (SRM) (Allen et al., 2013). The reduced albedo that is balanced through incoming radiations can cool down the mean temperature of the world, but it will ultimately affect the hydrological cycle and different climatic impacts regionally (Govindasamy, Caldeira, & Duffy, 2003; Irvine, Ridgwell, & Lunt, 2010; Matthews & Caldeira, 2007; Ricke et al., 2010; Robock, Oman, & Stenchikov, 2008).

SRM implementations may have an impact on the carbon cycle due to carbon-climate feedback that means solar insolation has a major role in influencing the role of carbon dioxide as a global warming gas. SRM, for example, can increase land carbon uptake by mitigating the negative climate change effects on carbon basins. (Matthews & Caldeira, 2007). Solar radiation directly affect the CO2, so the decrease in solar radiation can lessen the global CO2 (Allen et al., 2013).

A study did experiments of large-ensemble in which study analyze the 54 scenarios for global temperature adjustment and presented the results of local climatic differences that were modified by solar radiation management. The study resulted that decrease in solar radiation will ultimately reduce the global temperature and precipitation variation when compared to unrestricted greenhouse gas outflows.

As long as the greenhouse gases are not in control, this is not possible to balance the rising temperature and precipitation variation, but with solar radiation management it is possible to delay the climate change at some extent (Ricke et al., 2010). A Study by Govindasamy et al., 2003 demonstrated that how decrease in solar radiance can help to mitigate the quadrupling effects of carbon dioxide content. This means that the 3.6% decrease in solar luminosity can reduce the earth temperature by 4.09º C from "4 x CO2" state that can compensate the change to some extant caused by CO2 quadrupling.

STUDY AREA

The Punjab province is Pakistan's easternmost province consist of 36 districts that cover the area of 205, 345 km2 approximately.

It is the most populated province of the country with population of 73.621 million people(Tahir, Jamil, Zaidi, Arif, & Ahmed, 2005). Islamabad, the capital city if the province located in the north of Punjab province is chosen as one of the study sites for the Solar Radiation Values. The two other city selected for the study are Lahore and Bahawalpur located in the center east and south of the Punjab province respectively. Shown in Figure 2.

Material and METHOD

General Approach

For measuring solar flux, this research has utilized satellite data from NASA because when the distance between stations exceeds 34 kilometers interpolation between measurement stations is not as accurate as data from satellites, that is why the focus of this research is on NASA satellite data of 2m resolution for a better understanding and comprehensive explanation. (Stökler, Schillings, & Kraas, 2016)

Datasets

For the selected study years, NASA Surface Meteorology and Solar Energy Project data for downward thermal infrared (longwave) radiative flux and sky insolation incident on a of these scatter plots demonstrated the linearity of the data.

Methods

Ordinary Least Squares (OLS) has been used in this research. OLS is a statistical technique that demonstrates the link between dependent and independent variables. Depending on the kind of data, it displays linear or multiple regressions. The linear regression model has three stages:
Examining the correlation and directionality of data.
Estimating the model (fitting the line), and
Evaluating the model's validity and usefulness.

For applying Ordinary Least Squares determining the linearity of the data is must that can be calculated by finding relationship between one independent (Insolation on Horizontal Surface) and one dependent (maximum temperature) from 1990 to 2018 that is assessed by fitting a straight-line equation along the observations. Simple Linear Following assumption that were necessary before applying OLS has been applied in the datasets.

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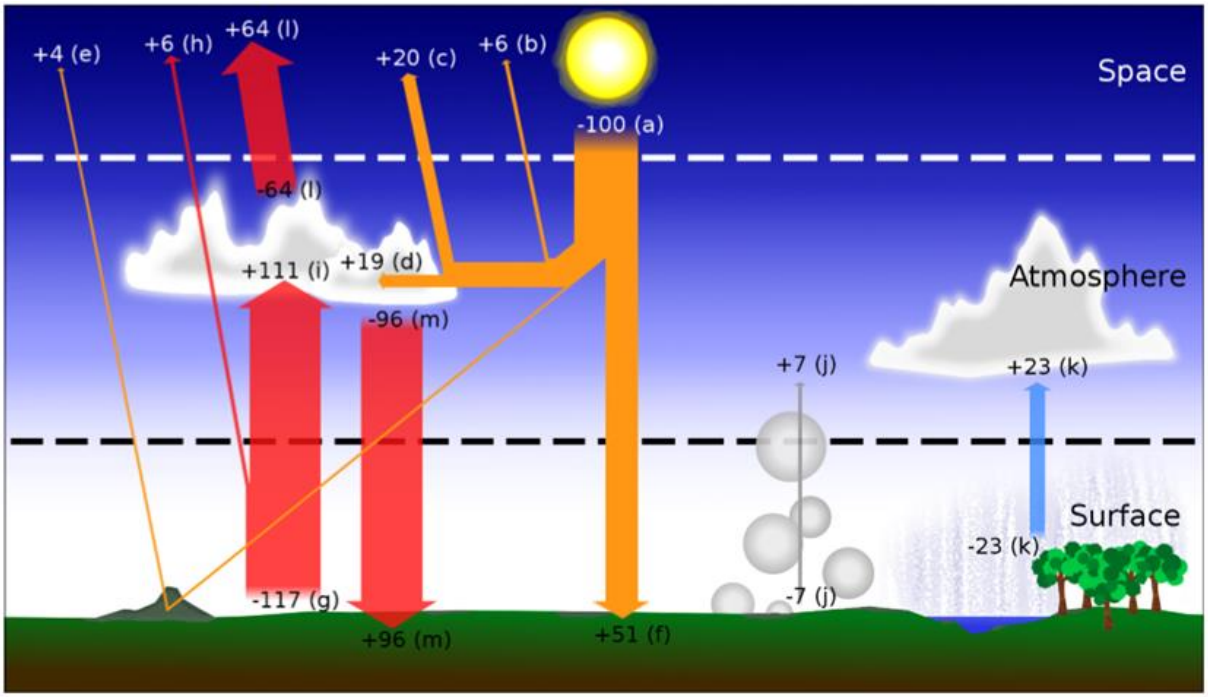

Fig 1. The annual energy balance of Earth's surface and atmosphere, showing equal input and output of energy in each zone. Source: Adapted from (Ahrens, 2009)

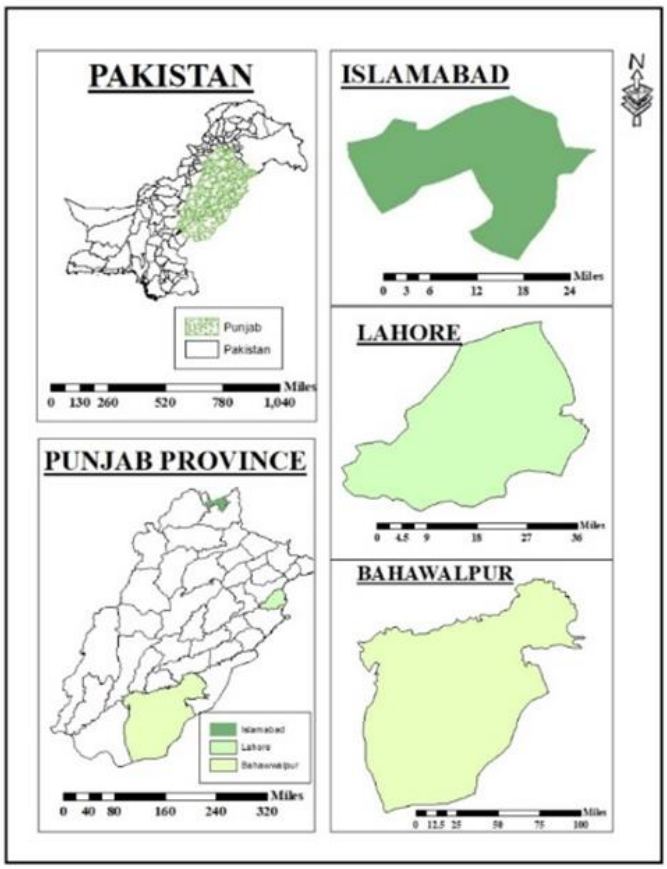

Fig 2. Study Area Map

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Assumption# 1 Linear Relationship between both Variables

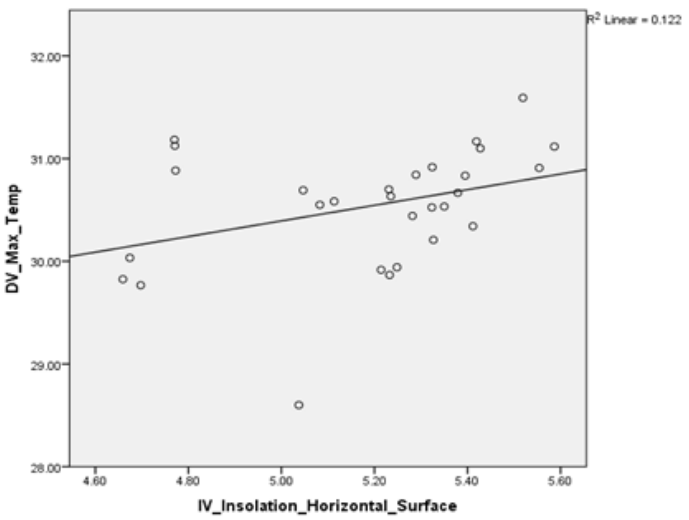

Fig.3 Linear Relationship Between both variables

According to fig 3, the relationship between insolation and maximum temperature from 1990 to 2018 is linear. Scatter plot diagram indicates that the 1st assumption for simple linear regression has been met.

Assumption# 2 Residuals should be Uncorrelated

According to table 1, the correlation (R) between the insolation and maximum temperature are positively correlated. The R-value .350 indicates a low positive correlation. The R2 value .122 indicates that change in insolation will change the maximum temperature positively by 12%. As per the third assumption of the regression model the observations should be independent or residuals should be uncorrelated. Results indicate the Durbin Watson value 1.567 lies within the critical range 1.5 < DW< 2.5 therefore this assumption has been met because the obtained value is close to 2.

RESULTS AND DISCUSSION

A lot of attention has been given to the potential relationship of mainstream variation on the Earth's attractive field and environmental change; the changes in the sun with atmosphere are thought to interface by using the following instruments;

- The change in the radiance, based on sunlight can become a cause of variation in the contribution of lower air warmth.
- Changes in the ozone fixation combined with solar UV radiations can warm the stratosphere,that collaborates with troposphere and Lower environment.

Different cycles like variations in sunspot action occurred due to Changes in the Earth's circle around the Sun and variation in sun based global radiation (Dergachev, Vasiliev, Raspopov, & Jungner, 2012).

Relationship between Solar and Climatic Variables 1990-2018

In the study of three selected regions, the changes between variables are observed for linear relationship but the pattern remained consistent except for Bahawalpur region where a positive relation was found between minimum temperature and radiation. In Bahawalpur region both positive and negative relation was found between two variables (maximum temperature and rainfall) that were almost negligible as shown in Figure 4.

Table. 1 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.350[a]	.122	.090	.57119	1.567

a. Predictors: (Constant), IV_Insolation_Horizontal_Surface

b. Dependent Variable: DV_Max_Temp

In the other two (Lahore and Islamabad) selected regions the relationship between the radiation and dependent variables was discernible. Fig 5 and 6 clearly show the positive linear relation between the min-max temperature of different years and radiations. While the rainfall data in both regions observed in opposite direction that indicate less rainfall during high insolation, which help to make prediction that low radiation on earth surface will result in high rainfall and vice versa.

Outlier in the Data

In regression analysis the outliers show a negative relation and reduced the regression equation impact that is used to predict dependent variable values, which ultimately affect the predictive results. In Figures 7 and 8 outliers extracted from the data are showed for the study area. There were no outliers in the temperature data for any of the three regions. Rainfall and radiation data in Bahawalpur had outliers that were corrected accordingly. Similarly, the only outlier in the radiation data was found in Islamabad region, and data was quite symmetric and not outlier is observed in Lahore region.

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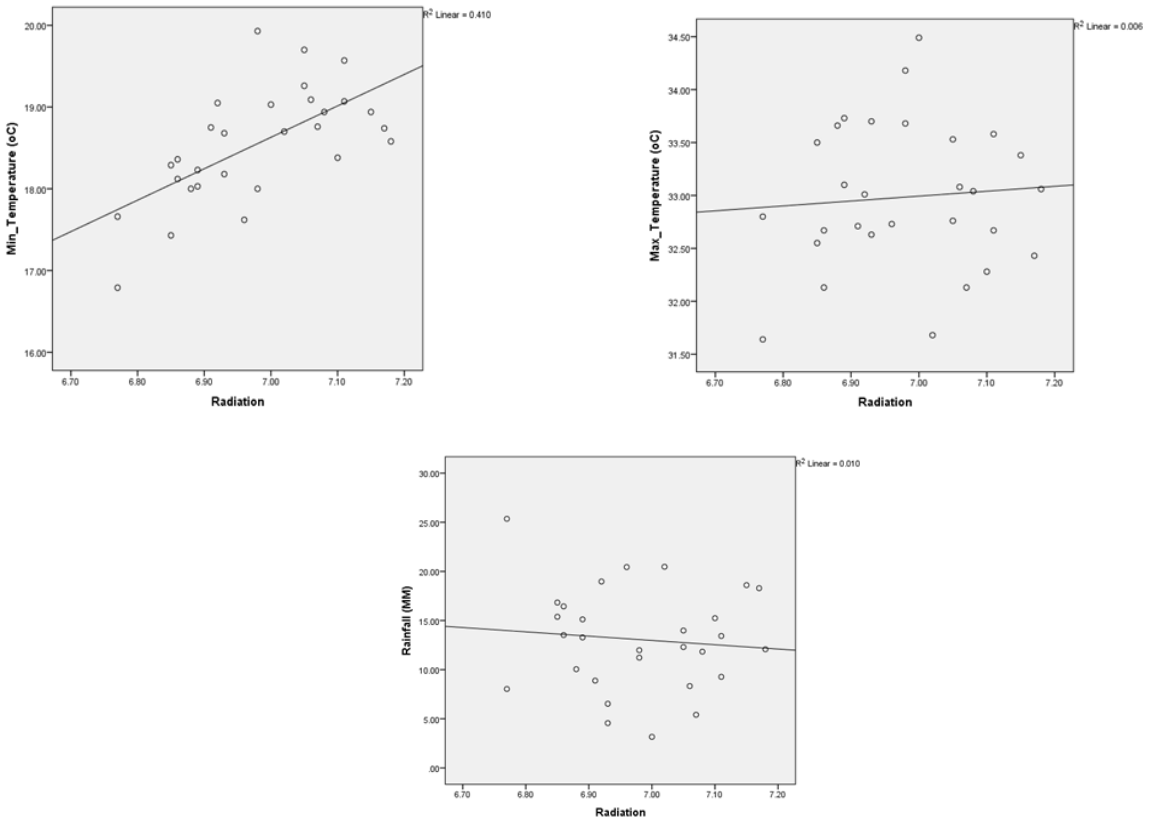

Fig 4. Linear Relationship of the Data (Bahawalpur)

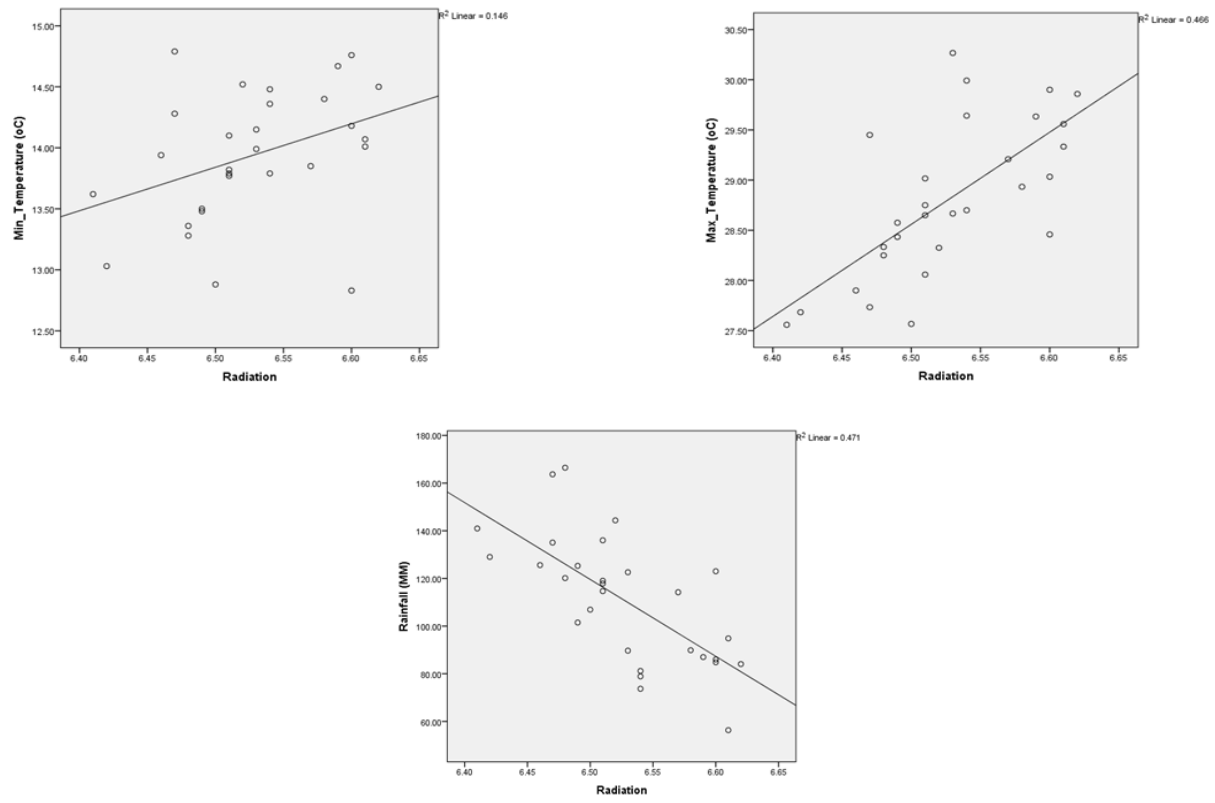

Fig 5. Linear Relationship of the Data (Lahore)

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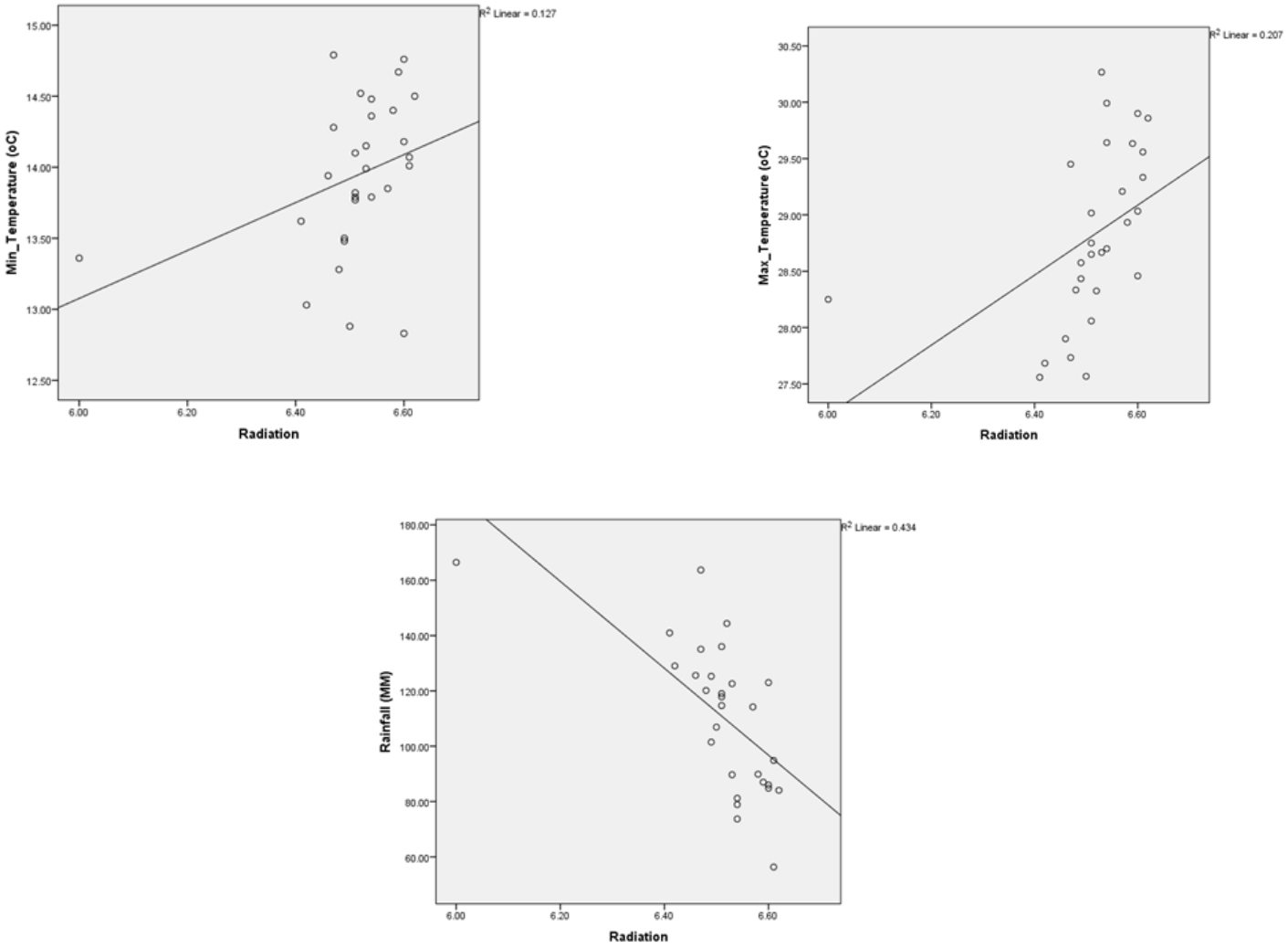

Fig 6. Linear Relationship of the Data (Lahore)

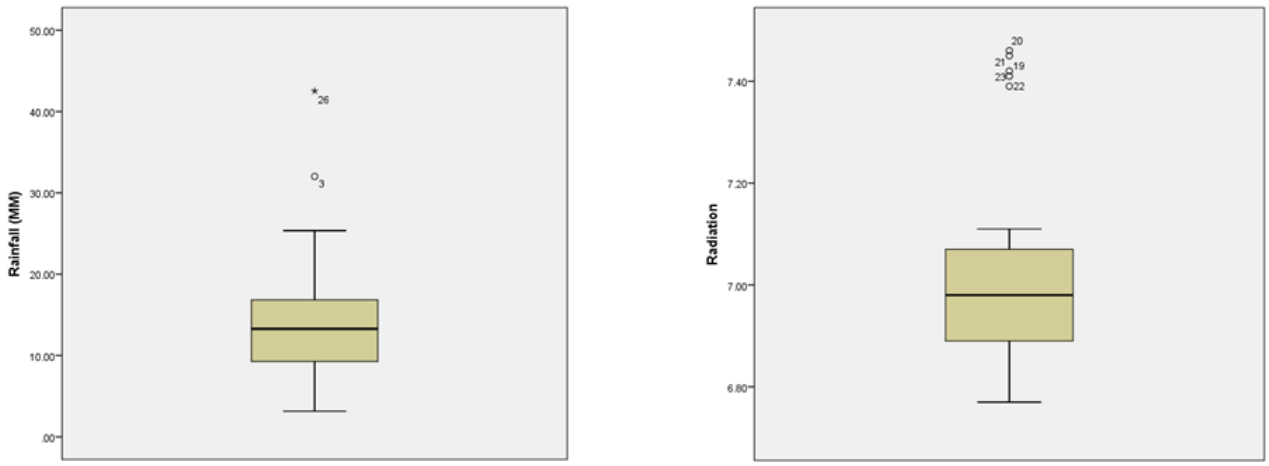

Fig 7. Outliers in Bahawalpur Data

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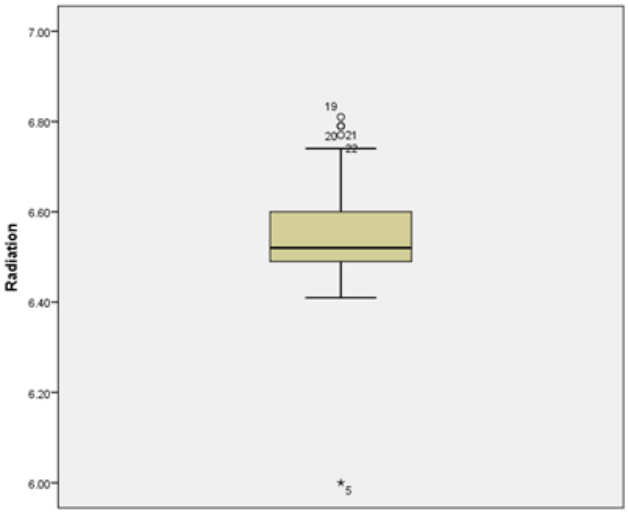


Fig 8. Outliers in Islamabad Data

Homoscedasticity Test

For OLS regression analysis the final step is to authenticate and homoscedasticity of the data that is a classical assumption test in regression models. Scatter plot diagram for the Prediction of values between independent variables ZPRED and residue ZPRED is working principle of heteroscedasticity. (Opposite of homoscedasticity). In Figure 8, result showing no clear pattern. On scatter plot dots are irregular and far away that indicate there is no heteroscedasticity problem found in data. As there is no heteroscedasticity found in data it is concluded that data is homoscedastic and is suitable to perform the OLS regression analysis.

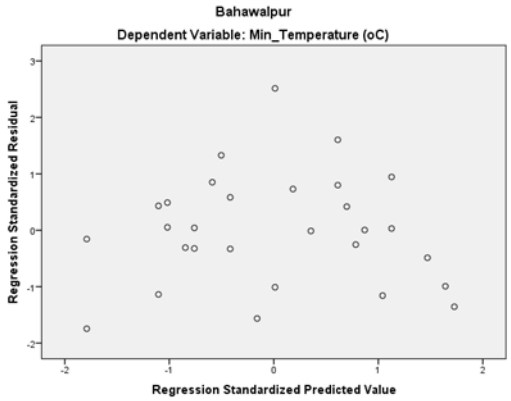
Ordinary Least Squares

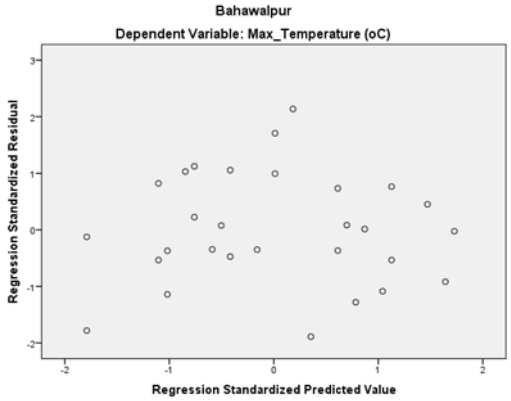
The results of regression analysis are shown in Tables 3, 4, and 5 for the selected regions Bahawalpur, Islamabad, and Lahore, respectively.

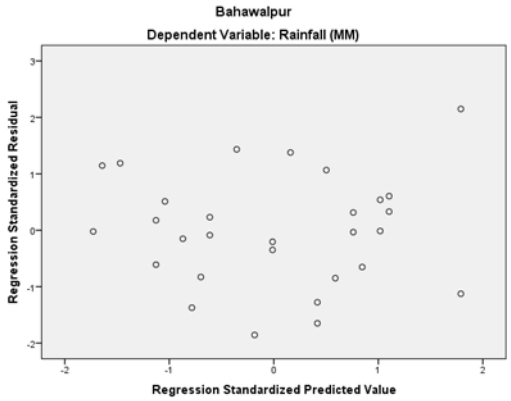
In Table 3, the regression analysis for Bahawalpur region are showing positive relationship (B=1.479) between radiation which is an independent variable and Min temperature that indicate per unit change in radiation value will change 1.479 units of the min temperature.

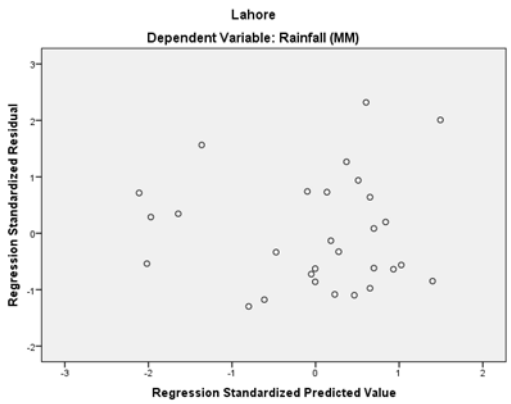
Max temperature and rainfall showed negative relationship B= -0.127 and -1.29, respectively while other two independent variables showed positive relationship.

Thus "Sig" showed a significant relationship between radiation and the mini temperature is found which indicates that null hypothesis only for min temperature can be accepted and it will be rejected for max temperature and rainfall as they do not have any relation with independent variable.









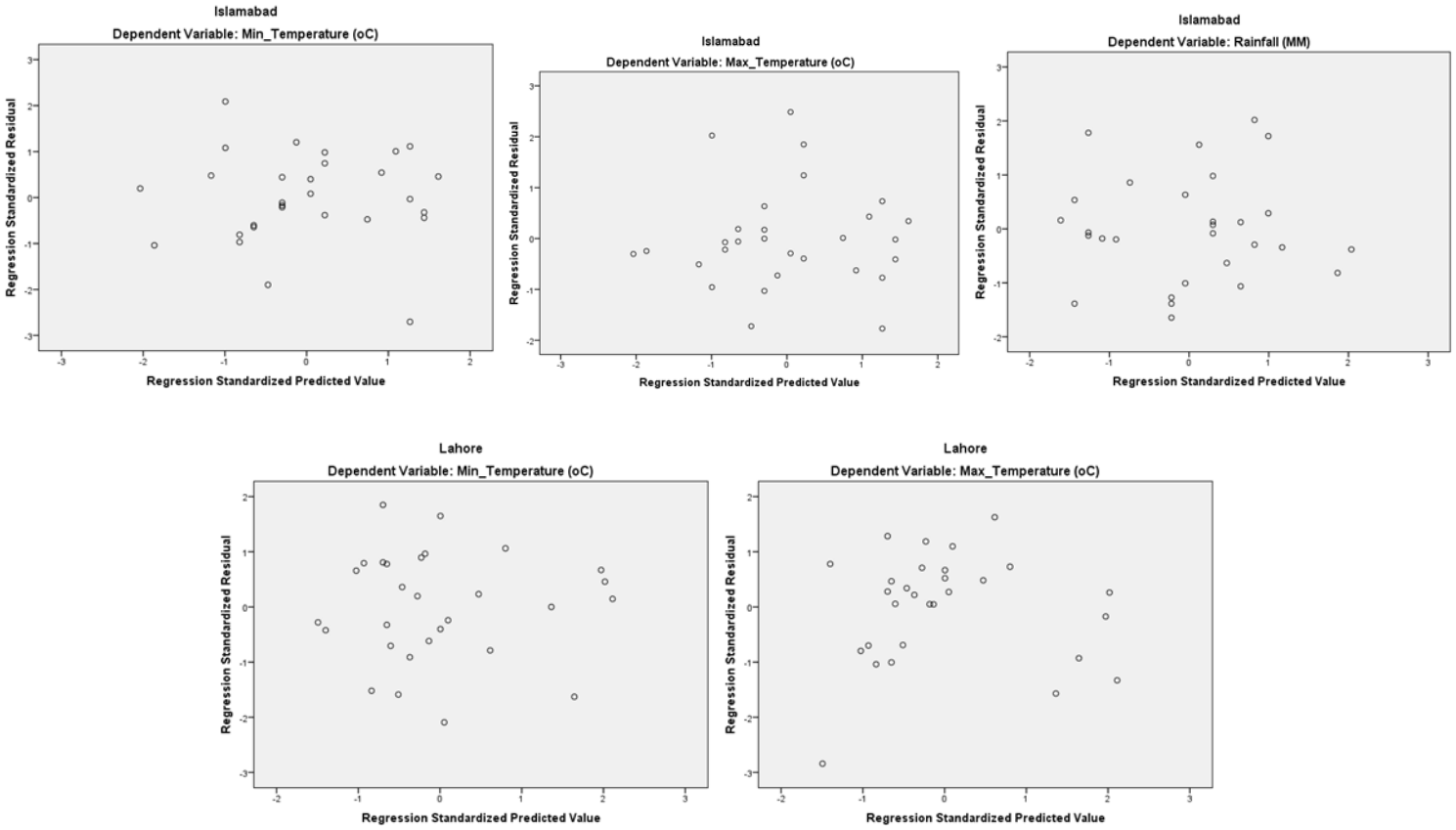


Fig 9. Homoscedasticity Test Results

Table 3: Linear Regression Analysis Bahawalpur Region

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.155	4.165		1.958	0.061
	Radiation	1.479	0.592	0.433	2.496	0.019
a. Dependent Variable: Minimum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	33.873	4.55		7.445	0
	Radiation	-0.127	0.647	-0.038	-0.2	0.846
a. Dependent Variable: Maximum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23.53	54.03		0.436	0.667
	Radiation	-1.29	7.685	-0.032	-0.17	0.868
a. Dependent Variable: Rainfall (MM)						

The Min-max temperature and rainfall forecast for Bahawalpur can be develop by using the regression equations 1,2,3 respectively.

Min Temp = Radiation*1.5+8.2 **(1)**
Max Temp= Radiation*-0.127+33.9 **(2)**
Rainfall= Radiation*-1.3+23.5 **(3)**

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Table 4: Linear Regression Analysis Islamabad Region

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.774	4.034		1.183	0.247
	Radiation	1.4	0.616	0.401	2.272	0.031
a. Dependent Variable: Minimum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15.544	5.806		2.677	0.012
	Radiation	2.027	0.887	0.403	2.285	0.03
a. Dependent Variable: Maximum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	874.084	165.894		5.269	0
	Radiation	-116.632	25.342	-0.663	-4.602	0
a. Dependent Variable: Rainfall (MM)						

The regression analysis results for Islamabad in Table 3 are showing positive results between dependent variables (min-max temperature) and independent variable (radiation) while rainfall has negative relationship with radiations that indicate 116.632 units of change in rainfall in the opposite direction with every per unit increase in radiation

Results for Islamabad region showed strong relation between temperature, rainfall and radiation in Islamabad region. A regression equation 4, 5 and 6 are developed to forecast the dependent variables on the basis of independent variables.

Min Temp = Radiation * 1.4 + 4.8 **(4)**
Max Temp = Radiation * 2.03 + 15.5 **(5)**
Rainfall = Radiation * -116.6 + 874.1 **(6)**

Table 4 showing the results of regression analysis for Lahore region and it is observed that Lahore region has similarities with Islamabad. Temperature (minimum and maximum) had a positive relationship with the independent variable radiation.

Table 5: Linear Regression Analysis Lahore Region

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.266	8.422		0.388	0.701
	Radiation	2.293	1.215	0.341	1.887	0.07
a. Dependent Variable: Minimum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	17.154	7.017		2.444	0.021
	Radiation	1.931	1.013	0.345	1.907	0.067
a. Dependent Variable: Maximum Temperature (ºC)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	568.246	205.994		2.759	0.01
	Radiation	-73.965	29.724	-0.432	-2.488	0.019

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a. Dependent Variable: Rainfall (MM)

According to a regression analysis performed on Lahore data, rainfall acted as a contrarian to radiation. In terms of temperature, for every unit increase in radiation, the minimum and maximum temperatures will rise by 2.293 and 1.931 units, respectively. Rainfall, on the other hand, will decrease by 73.965 units for every unit increase in radiation in the Lahore region. The regression analysis results showed strong relationship between dependent and independent variables as shown in the fig 4 scatter plot of these variables. The regression equation 7, 8, 9 given below can use to predict rainfall and temperature in Lahore.

Min Temp = Radiation * 2.3 + 3.3 **(7)**
Max Temp = Radiation * 1.9 + 17.2 **(8)**
Rainfall = Radiation * -74.0 + 568.2 **(9)**

CONCLUSION

It is concluded from the research that solar radiations are not constant and it varies with passage of time. The sun output also experiences changes that effect the earth's climate and weather conditions. The temperature and sunspot activity are directly proportional to each other that determine whether it reflects genuine physical association or it require more in-depth investigation. In statistical analysis, even when the data meets all the assumptions of the analysis it is not necessary that the data will give statistically significant results. Even the results indicated the positive value of "B" that meant increase in insolation will increase the maximum temperature but the p value .063 was greater than 0.05 of the value therefore, we failed to reject the null hypothesis. It is recommended that study area should be investigated more and future studies can develop on after effects of this research and outcomes can be further refine by focusing on solar management and planning. It is suggested that after the investigation of area wise solar output the solar based project to run different machinery can be started in Pakistan.

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