Preliminary Results of Correlation Analysis between Sunspot Number and Annual Precipitation in Saudi Arabia

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This study investigates the correlation between precipitation data and sunspot number (SSN) and galactic cosmic ray (CR) flux, at seven sites in Saudi Arabia over a 35-year period (1985-2019). The analysis includes annual, quarterly, and monthly mean precipitation data to investigate the relationships between rainfall and SSN and CR for all solar cycles together and for each individual cycle. The study finds that the strength, magnitude, proportion, and statistical significance of the relationship between precipitation and the two variables varied between stations, cycles, seasons, and months. Positive correlations between mean rainfall and SSN were observed in certain stations, seasons, and cycles, while negative correlations between mean rainfall and CR were found in others. The study discusses potential causes of terrestrial and extra-terrestrial factors that may affect the strength and magnitude of the results. These findings provide valuable insights into the potential role of solar activity in climate change and can inform the forecasting of future meteorological phenomena. However, the physical mechanism underlying the observed correlations remains poorly quantified.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

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1. Introduction

The Sun's influence on the Earth's environment is a topic that has been studied extensively across various fields. Even minor changes in solar outputs can have significant impacts on meteorological and climate variables, including rainfall. Solar activity can affect rainfall through several mechanisms, such as changes in the Earth's upper atmosphere that alter atmospheric circulation patterns and affect rainfall in the tropics and subtropics [1-2]. Another proposed mechanism is the modulation of primary cosmic rays in the heliosphere, which can ionize atmospheric molecules and affect cloud formation, precipitation, ozone production, and atmospheric aerosols [3-4]. However, the relationship between solar activity and rainfall is not fully understood, and other factors, such as ocean currents, geographical locations, and atmospheric pressure systems, can also play a role. Given the critical importance of reliable rainfall for agriculture and water resource management, further research is necessary to better understand these relationships, particularly in regions like Saudi Arabia where little research has been conducted on this topic. The aim of this study is to investigate the relationship between solar activity and cosmic rays and rainfall in Saudi Arabia.

2. Data and methodology

Monthly mean rainfall data from seven weather stations in Saudi Arabia provided by the Ministry of Environmental Protection were utilized for the purpose of this study (figure 1). The selected stations were chosen based on their location, topography, and historical record, covering a wide area of the country from east to west and north to south. However, the southeast Rub al Khali desert was excluded due to the lack of a rain gauge in that area.

The seven selected stations included Abha and Gizan, which were chosen for their high rainfall compared to other stations and their location near the equatorial low-pressure region in the southern region of the country, which increases rainfall rates. Riyadh, Hail, and Rafha were also selected, with the latter two located in the north and experiencing the lowest rainfall. AL-Ahsa and Jeddah were chosen as coastal regions with high humidity, but their location near the sub-tropical highs suppresses rainfall by blocking warm air from rising to higher altitudes and forming clouds.

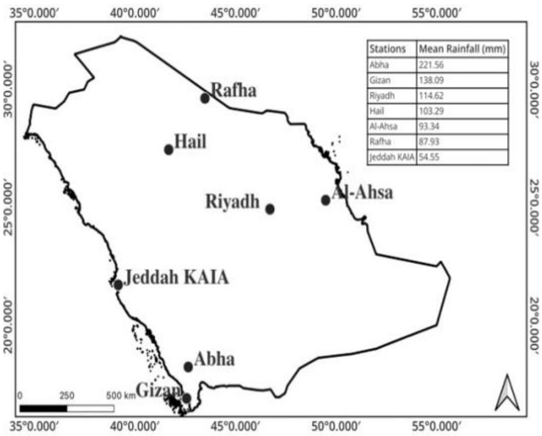

Figure 1. shows the geographical coordinates of the sites considered in this study. The range of the Mean annual precipitations is indicated.

The mean monthly values from the selected stations were averaged to obtain annual and seasonal rainfall data. The data underwent quality control procedures, including the nonparametric Kruskal-Wallis test to assess data homogeneity and eliminate random errors found in the original data. Linear interpolation methods were used to fill gaps caused by missing data. Sunspot numbers for the study period were obtained from the National Oceanic Atmospheric Administration, the National Geophysical Data Centre, and the National Space Weather Prediction Centre in the USA. Cosmic ray count (CR) data for the study period were obtained from the Sodankyla Geophysical Observatory of the University of Oulu (http://cosmicrays.oulu.fi/) neutron monitor station.

3. Results and discussions

3.1 Correlation results for the whole study period

Figure (2) depicts an example that demonstrates the inter-annual variability of mean rainfall and sunspot number (SSN) along with the 12-month running mean. The data reveals distinct 11-year cyclic patterns in the SSN, with peaks during the maximum of solar cycles and a minimum during quiet periods. In contrast, the rainfall variations during the study period exhibited variability from cycle to cycle. Notably, during the maximum of cycle 23, the region experienced a decrease in rainfall compared to the average. These observations underscore the influence of solar activity on the variability of climate patterns, particularly with regards to precipitation.

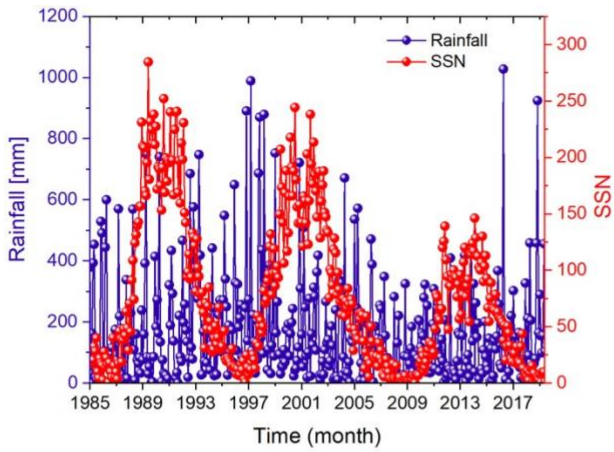

Figure 2. Displays a time series of the monthly mean values of rainfall data over Saudi Arabia and sunspot number (SSN) from January 1985 to December 2019.

Figure (3) is an example of a scatter plot between the mean monthly values of rainfalls in Abha station in winter and summer and SSN and CR during the study period. While there is a spread in the data, the figure indicate that the CR from both data sets are correlated with Abha summer and anti-correlated with Abha winter , with different degrees of dependence.

Table (1) provides a detailed breakdown of the correlation coefficients between annual and seasonal rainfall and solar activity (SSN) and cosmic rays (CR) for the selected stations.

The results indicate that the correlations between rainfall and sunspot numbers or cosmic rays are generally weak or variable, with some exceptions showing significant correlations.

For annual rainfall, there is a weak positive correlation with SSN for Hail (0.26) and a weak negative correlation with SSN for Riyadh (-0.14). Meanwhile, there is a weak negative correlation between annual rainfall and CR for Abha (-0.14) and a weak positive correlation for Gizan (0.18). However, for other seasons and stations, the correlations are weak or non-existent. For instance, there are no significant correlations between spring rainfall and either SSN or CR, except for a weak negative correlation between spring rainfall and CR for Abha. For winter rainfall, there is a significant positive correlation with SSN for Abha (0.42) and a significant negative correlation with CR for Abha (-0.54**). Hail and Riyadh also show weak positive correlations with SSN, while having weak negative correlations with CR. For spring rainfall, there are no significant correlations with either SSN or CR, except for a weak negative correlation between spring rainfall and CR for Abha (-0.1).

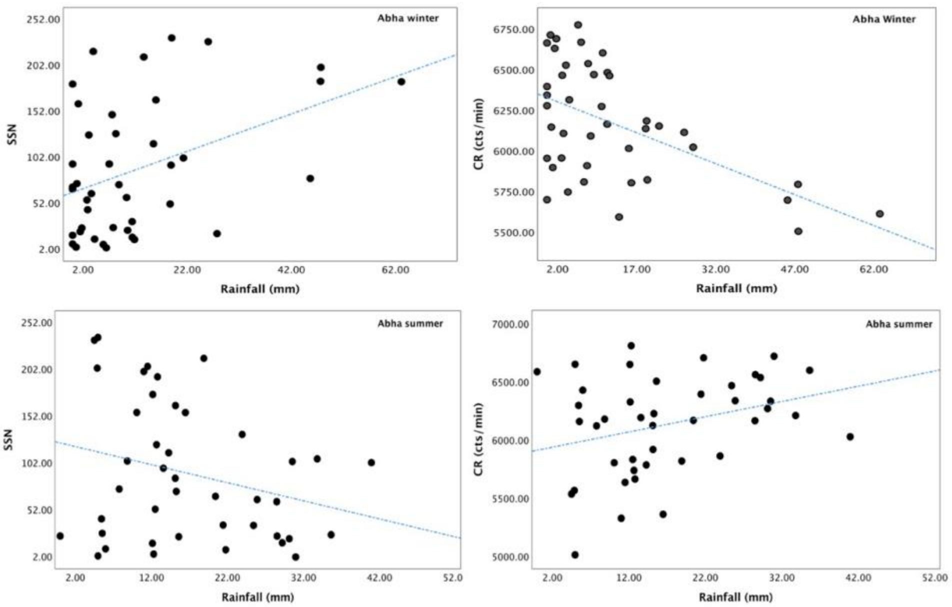

Figure 3. Scatter plots between winter and summer rainfall over Abha sites versus SSN and CR. The blue dashed line is the linear fitting of the data points.

Table 1. correlation coefficients between annual and seasonal rainfall and SSN and CR for the seven stations.

	Annual		Winter		Spring		Summer		Fall	
	SSN	CR	SSN	CR	SSN	CR	SSN	CR	SSN	CR
Abha	0.09	-0.14	0.42**	-0.54**	0.00	-0.10	-0.27	0.31*	0.06	0.06
Al-Ahsa	-0.12	0.05	0.18	-0.32	-0.26	0.18	-0.04	0.03	-0.12	0.26
Gizan	-0.09	0.18	0.16	0.00	0.16	-0.25	-0.26	0.30	-0.10	0.21
Hail	0.26	-0.42**	0.27	-0.29	0.31*	-0.26	-0.11	0.11	-0.08	-0.16
Jeddah KAIA	-0.09	0.22	0.13	0.12	-0.07	0.03	-0.08	0.20	-0.21	0.17
Rafha	-0.10	-0.01	0.10	-0.19	-0.12	0.06	0.03	-0.08	-0.16	0.09
Riyadh	-0.14	0.09	0.24	-0.38*	-0.18	0.04	-0.16	0.18	-0.15	0.27

*** trend at $\alpha = 0.001$ level of significance; ** trend at $\alpha = 0.01$ level of significance.* trend at $\alpha = 0.05$ level of significance; + trend at $\alpha = 0.1$ level of significance.

For summer rainfall, there is a significant negative correlation with SSN for Hail (-0.27) and a significant positive correlation with CR for Hail (0.31*). There are also weak positive correlations between summer rainfall and CR for Gizan and Jeddah. For fall rainfall, there are weak positive correlations with CR for Al-Ahsa (0.26), Gizan (0.21), and Riyadh (0.27). Meanwhile, there is a weak negative correlation between fall rainfall and SSN for Hail (-0.08) and Jeddah KAIA (-0.21). The positive and negative correlations suggest that different factors may be influencing the relationship between meteorological variables and cosmic ray observations at each station and during each season.

3.2 Cycle to Cycle correlations

Table (2) presents the correlation coefficients between annual and seasonal rainfall and sunspot number (SSN) and cosmic ray (CR), for seven weather stations in Saudi Arabia during the 22nd to 24th solar cycles.

Table 2. Correlation coefficients between annual and seasonal rainfall and SSN and CR for the seven stations from cycle to cycle (22nd - 24th solar cycles). [.c] refers to one of the variables is constant, correlation coefficient could not be computed.

		Annual		Winter		Spring		Summer		Fall	
		SSN	CR	SSN	CR	SSN	CR	SSN	CR	SSN	CR
1987 -1996	Abha	0.20	-0.25	0.43	-0.51	0.33	-0.41	**-0.55***	0.53	-0.04	0.11
	Gizan	-0.32	0.36	0.36	-0.26	0.04	0.01	-0.52	0.44	-0.37	0.51
	Rafha	**-0.64***	**0.62***	-0.27	0.21	-0.41	0.52	.c	.c	-0.38	0.37
	Hail	-0.16	0.15	0.09	-0.17	0.10	-0.02	-0.47	0.35	**-0.61***	**0.57***
	Riyadh	-0.47	0.45	-0.10	0.07	-0.50	0.44	.c	.c	**-0.65***	**0.59***
	Al-Ahsa	-0.49	0.44	-0.14	0.07	**-0.57***	0.47	-0.15	0.20	**-0.79****	**0.73****
	Jeddah KAIA	-0.36	0.39	0.12	-0.12	0.41	-0.29	-0.03	0.06	-0.46	0.45
1997 -2008	Abha	-0.23	0.41	0.17	-0.07	-0.36	0.47	-0.15	0.18	**0.59***	-0.23
	Gizan	0.07	0.11	0.30	-0.10	0.10	-0.25	-0.05	0.05	0.02	0.23
	Rafha	-0.03	0.09	0.00	0.01	-0.14	0.08	-0.11	0.25	-0.01	-0.01
	Hail	**0.66****	-0.37	-0.13	0.23	0.41	-0.07	0.04	0.12	0.40	**-0.54***
	Riyadh	-0.16	0.16	0.34	**-0.59***	-0.07	-0.06	.c	.c	-0.16	0.35
	Al-Ahsa	-0.18	0.06	0.24	-0.46	-0.47	0.40	0.04	0.12	-0.16	0.32
	Jeddah KAIA	0.46	-0.29	0.27	-0.07	-0.14	0.05	0.10	0.05	0.17	-0.41
2009 -2019	Abha	-0.05	0.04	-0.07	0.24	0.05	-0.08	-0.31	0.22	0.49	-0.23
	Gizan	-0.36	0.31	-0.19	0.04	-0.10	0.12	-0.33	0.25	-0.19	0.16
	Rafha	0.02	-0.10	0.20	-0.21	0.29	-0.10	.c	.c	-0.22	0.04
	Hail	0.15	-0.06	0.46	-0.35	0.05	0.10	-0.13	0.18	0.03	-0.02
	Riyadh	0.25	-0.27	**0.64***	-0.43	-0.28	0.23	-0.19	0.20	-0.11	-0.01
	Al-Ahsa	0.35	-0.34	0.14	-0.19	0.17	-0.06	-0.19	0.20	0.25	-0.28
	Jeddah KAIA	-0.46	**0.60***	-0.19	0.40	-0.23	0.25	0.07	0.00	-0.36	0.42

The results show that the correlations between rainfall and solar activity or cosmic rays are generally weak and vary between cycles, stations, and seasons. For example, for annual rainfall, there is a weak positive correlation with SSN for Abha during the first cycle and a weak negative correlation with CR for the same station during the first and third cycles. However, for other stations and cycles, the correlations are weak or non-existent.

Looking at the results, we can see that the correlation coefficients between rainfall and SSN are mostly negative, indicating an inverse relationship between the two variables. However, the strength and significance of the correlation vary across stations and seasons. For example, for the

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period of 1987-1996, Al-Ahsa showed a strong negative correlation between annual rainfall and SSN (-0.488), while Riyadh showed a moderate negative correlation (-0.473). In contrast, Gizan showed a weak negative correlation (-0.323), and Jeddah KAIA showed a weak negative correlation (-0.362).

For winter rainfall, there are significant positive correlations with SSN for Abha during the first and second cycles, and significant negative correlations with CR for Abha during the first and third cycles. Hail also shows a significant negative correlation with SSN during the second cycle and a significant positive correlation with CR during the first cycle. Riyadh and Al-Ahsa show a significant negative correlation with SSN during the second cycle as well.

For summer rainfall, there is a significant negative correlation with SSN for Hail during the first and second cycles, and a significant positive correlation with CR for the same station during the first and third cycles. Gizan and Jeddah KAIA also show weak positive correlations with CR during the first cycle.For fall rainfall, there are weak positive correlations with CR for Al-Ahsa and Riyadh New during the second cycle, and a weak negative correlation with SSN for Hail during the second cycle as well.

3.3 Discussions

The results of this study suggest that solar activity, as measured by SSN and CR, may have some influence on rainfall patterns in Saudi Arabia, but the relationship is complex and varies by station and season. While the correlations between annual rainfall over Saudi Arabia and both SSN and CR have low correlation coefficients, the obtained results are consistent with some previous studies [e.g., 5-9]. However, the strength, magnitude, and significance of the correlations presented here are affected by several factors, including terrestrial and extra-terrestrial sources. Terrestrial factors include variations in atmospheric circulation, geographic location, and topological characteristics, as well as spatiotemporal changes in atmospheric aerosols [10–13]. Extreme precipitation events and the length of the study period may also affect the correlations [14]. Extra-terrestrial factors that affect the correlations include the effects of meteor showers, lunar cycles, and solar radiation [15-16]

The exact mechanism of the relationships between solar activity, CRs, and rainfall is still uncertain and remains poorly quantified. However, previous studies have suggested that ionization from CRs can influence the microphysical properties of clouds and the formation of precipitation by enhancing the formation and growth of cloud condensation nuclei, or by creating an electrical charge separation that can enhance precipitation.

4. Conclusion

In this study, annual, quarterly, and monthly mean precipitation data from seven sites in Saudi Arabia were analyzed to investigate their correlations with sunspot number (SSN) and galactic cosmic ray (CR) flux over 35 years (1985-2019). The results indicate that the strength, magnitude, proportion, and statistical significance of the relationship between precipitation and the two variables varied between stations by season and month. The correlations between rainfall and solar activity or cosmic rays were generally observed, but were found to vary between cycles, stations, and seasons.

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These findings provide insights into the potential role of solar activity in climate change and could improve the forecasting of future meteorological phenomena, even though the physical mechanism behind the observed correlations remains poorly quantified. However, it is important to note that the results presented in this study are preliminary, and more detailed investigations are recommended to understand the complex relationships between solar activity, CRs, and rainfall in Saudi Arabia. Further research is needed to identify the physical mechanism behind the observed correlations and to better understand the potential role of solar activity in climate change.

Acknowledgments

We would like to thank King Abdulaziz University (KAU) for supporting this work.

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