

Possible Association between Space Weather Variables, and the World's COVID-19 Cases

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Abstract

This study aims to investigate the influential role of space weather parameters on the transmission of COVID-19. Solar radio flux, interplanetary magnetic field, Dst index, sunspot number, and solar wind speed were utilized to represent the space weather variables. The association of the considered variables to the number of the confirmed COVID-19 cases worldwide along with five geographical categories, *i.e.* Asia, Europe, Africa, South, and North America, were investigated for a period ranging from 20 January 2020 to 5 August 2021 using Pearson linear tests as well as the non-parametric Spearman's and Kendall's rank correlation tests. Pearson linear tests showed that the number of confirmed COVID-19 cases worldwide and the chosen geographical categories have a significant correlation to interplanetary magnetic strength, solar radio flux F10.7, and sunspot number. When the confirmed COVID-19 cases reported in the Asia continent were excluded, the solar wind speed correlated significantly with the number of COVID-19 cases reported elsewhere in the world and the other geographical categories. The non-parametric Kendall and Pearson tests showed that the world's COVID-19 cases and the other geographical categories had significant correlations with the interplanetary magnetic field, radio flux F10.7, sunspot number, and the solar wind speed, but not with the Dst index.

Keywords

COVID-19, Infectious Diseases, Solar Activity, Magnetic Field, Solar Wind

1. Introduction

The spread of epidemics and pandemics depends on several factors including individual, social, economic, physiological, or immunological factors, as well as environmental and meteorological factors [1]-[7].

The first known identified confirmed case of COVID-19 was reported in December 2019 (WHO, 2019) [8]. Since then, Coronavirus (COVID-19) has spread across the world and developed into a full-scale global pandemic that has become one of the most significant global health threats of this century.

Subsequently, several research studies were conducted around the world to investigate the association between COVID-19 and a wide range of factors to understand their contribution to the spread of COVID-19 and to reduce the ongoing threat of the COVID-19 pandemic. These include the population density, social-economical, and health system, as well as the effects of meteorological conditions on the spread of COVID-19 in several places of the world [9]-[14].

Since the Sun plays an enormous and effective role in influencing the Earth and in turn, our lives, any slight change in the Sun's activity will impact the Earth depending on the strength and intensity of this change [15] [16] [17].

Factors that are affected by solar disturbances such as geomagnetic activity and related Earth's ionosphere-geomagnetic disturbances, as well as variations in cosmic ray intensity may affect human health and contribute to the appearance, severity, and spread of infectious diseases. Somehow, these factors, directly or indirectly, influence the nature of the virus, acquired hosts, virus-host interactions, and stability of the virus causing infectious diseases ([1] and references therein [18]-[24]). Over the past 20 years, numerous heliobiological studies have been conducted to provide evidence that suggests that space weather activities may have caused a broad range of adverse effects on human health, including the spread of infectious disease [5] [23] [25] [26] [27] [28].

The relationship between influenza pandemics and the sunspots, which is one of the solar activity indices, was first noticed by Alexander Chizhevsky [29], and later confirmed by Hope-Simpson [30], who observed the same correlation between influenza pandemics and sunspot maximums. Yeung [31] established that the seven pandemics that occurred between the years 1700 and 2000 coincided with increased solar activity.

Though the interrelation of data between infectious diseases and solar activity may appear unrealistic, these obvious relationships, which were observed by different researchers, must be explored and cannot be dismissed easily. Although the exact mechanisms behind these disturbances affecting the human health may not yet be established, there are speculations about the reality of such relationships, and the results obtained in this field have attracted scientific communities from different research areas and encouraged them to conduct more research in this field to search for mechanisms that can explain such relationships [19] [26] [27].

It is important to explore the potential effects of extraterrestrial factors, particularly, solar activity and the associated disturbances, on the nature of the current COVID-19 virus.

This study aims to explore the potential influences of space weather factors on COVID-19. This will help researchers such as epidemiologists to add more knowledge to the understanding of the effects of space weather factors on the

transmission of infectious diseases including COVID-19.

2. Material and Method

2.1. Data

The data used in this study covers a period from 20 January 2020 to 5 August 2021 and comprises the number of confirmed COVID-19 cases worldwide, along with space weather indices.

The data of COVID-19 cases were procured from the website: Our World in Data. It collects available information that is published by official sources that include national authorities—usually governments, ministries of health, or centers for disease control, as well as the data published by Johns Hopkins University (JHU) on a regular basis and processes it on a daily basis. Due to the availability of data, the data that is collected includes more than 92% of the world's population taken from more than 136 countries. In this study, the total confirmed cases of the world and of the five geographical categories were utilized. The categories chosen were Asia, Africa, South and North America, and Europe.

The five space weather variables used, here, were the solar wind speed (SWS), Dst index, sunspot number (SSN), interplanetary magnetic field (B_t), and solar radio flux at 10.7 cm ($F_{10.7}$). Daily mean values of these variables were obtained from the OMNI NASA database (<http://omniweb.gsfc.nasa.gov>).

The Dst index monitors variations in the globally symmetrical ring current that revolves around the Earth close to the magnetic equator in the Van Allen (or radiation) belt of the magnetosphere. The 10.7 cm solar radio flux ($F_{10.7}$) is one of the most widely used indices of solar activity. It measures the total emission from all sources present on the solar disk at a wavelength of 10.7 cm. The solar wind is a stream of charged particles with the solar magnetic field embedded in it that continuously flow outward from the solar corona, and consists of electrons, protons, and alpha particles in plasma. The solar wind varies in density, temperature, and speed depending on the time and solar latitude and longitude, and its mean speed values range between 250 and 750 kilometers per second. Sunspots appear as dark areas in the solar disk as they are cooler than their surroundings. Sunspots are caused by disturbances in the Sun's magnetic field. They usually appear in pairs of opposite magnetic polarity and their numbers vary according to the approximate 11-year solar cycle. The interplanetary magnetic field (IMF) is a part of the Sun's magnetic field that is carried into interplanetary space by the solar wind. In this study, the B_t value that indicates the total strength of the interplanetary magnetic field was used.

2.2. Statistical Tests

In this study, the relationships between the considered variables were examined using the Pearson linear test as well as the Spearman and Kendall rank correlation tests.

The Pearson correlation coefficient is used to measure the strength of a linear

association between two sets of data.

On the other hand, Spearman and Kendall rank correlations (e.g., [9] [11]) are used for nonparametric tests to examine the strength of the association between two variables and it is calculated using Equations (1) and (2), respectively.

Spearman rank correlation can be estimated with the following equation:

$$\rho = 1 - 6 \times \frac{\sum d_i^2}{n(n^2 - 1)} \quad (1)$$

ρ is the Spearman rank correlation coefficient, d_i is the difference between the ranks of corresponding values x_i and y_i and n is the number of x and y pairs.

Kendall rank correlation can be estimated with the following equation:

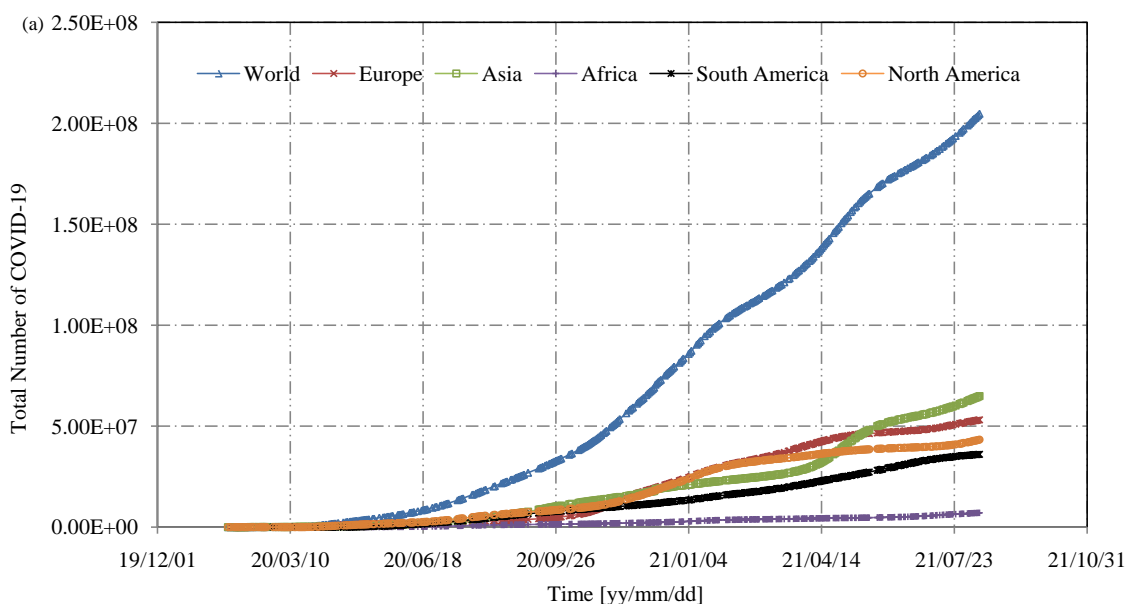
$$\tau = \frac{n_c - n_d}{\frac{1}{2}n(n-1)} \quad (2)$$

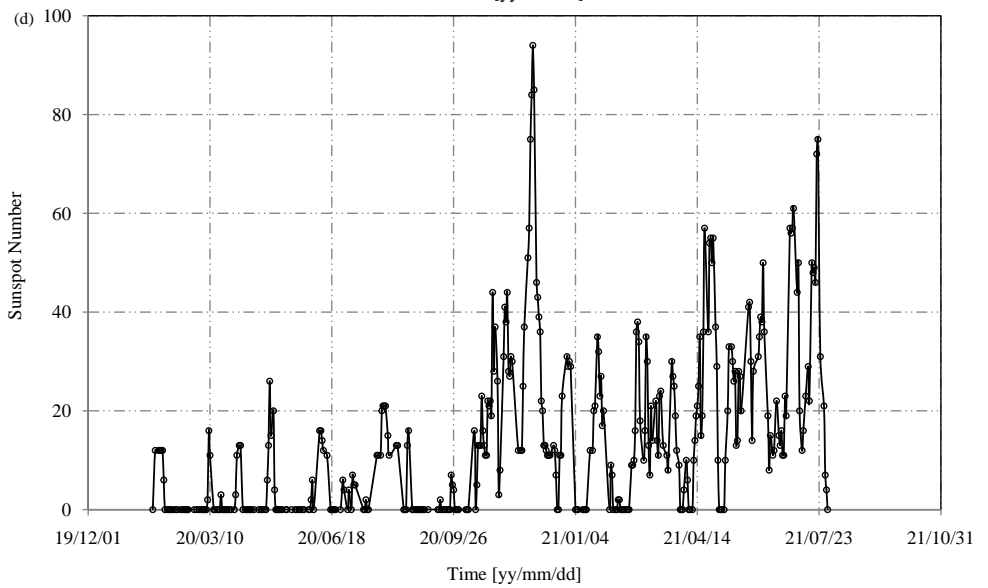
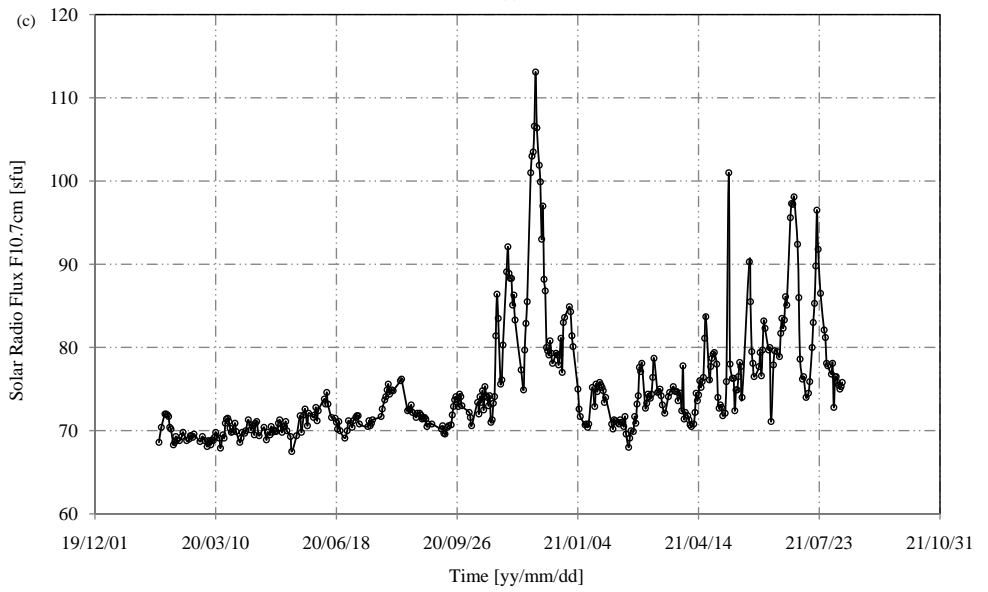
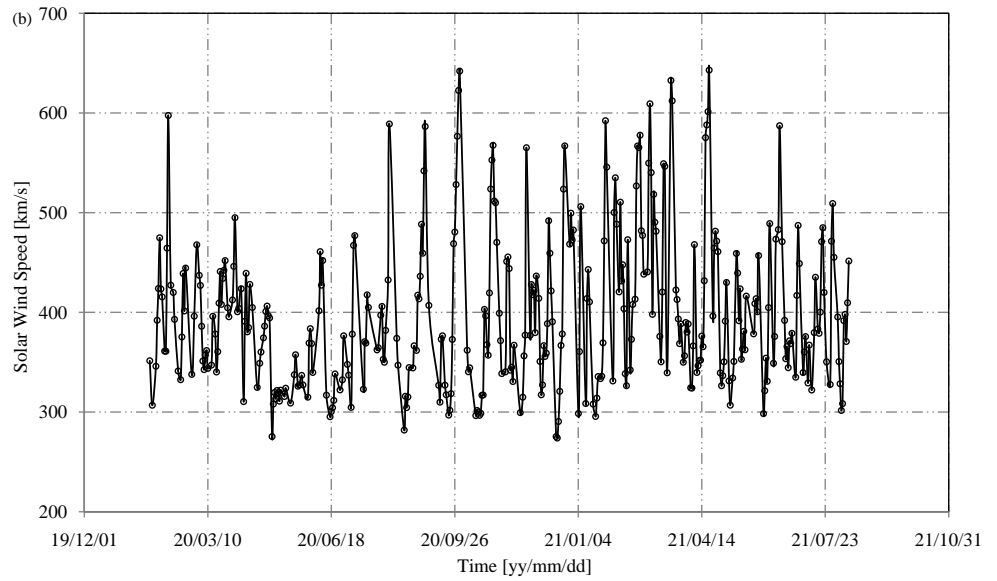
τ is the Kendall rank correlation coefficient, n_c and n_d represent the number of concordant and discordant pairs, respectively. The n represents the number of pairs. In case significant differences were observed in both statistical tests, to combat the same, factors that affect COVID-19 were taken into consideration.

3. Results and Discussions

The COVID-19 epidemic was caused by a coronavirus called SARS-COV-2, which first broke out in Wuhan, China, followed by a surge in confirmed cases. It has infected about 210 million, and has caused about 4.5 million deaths. All of this was included within our study period, which was from 20 January 2020 to 5 August 2021.

Figure 1 shows the daily values of the confirmed COVID19 cases and the variations of the solar activity parameters during the considered study period.





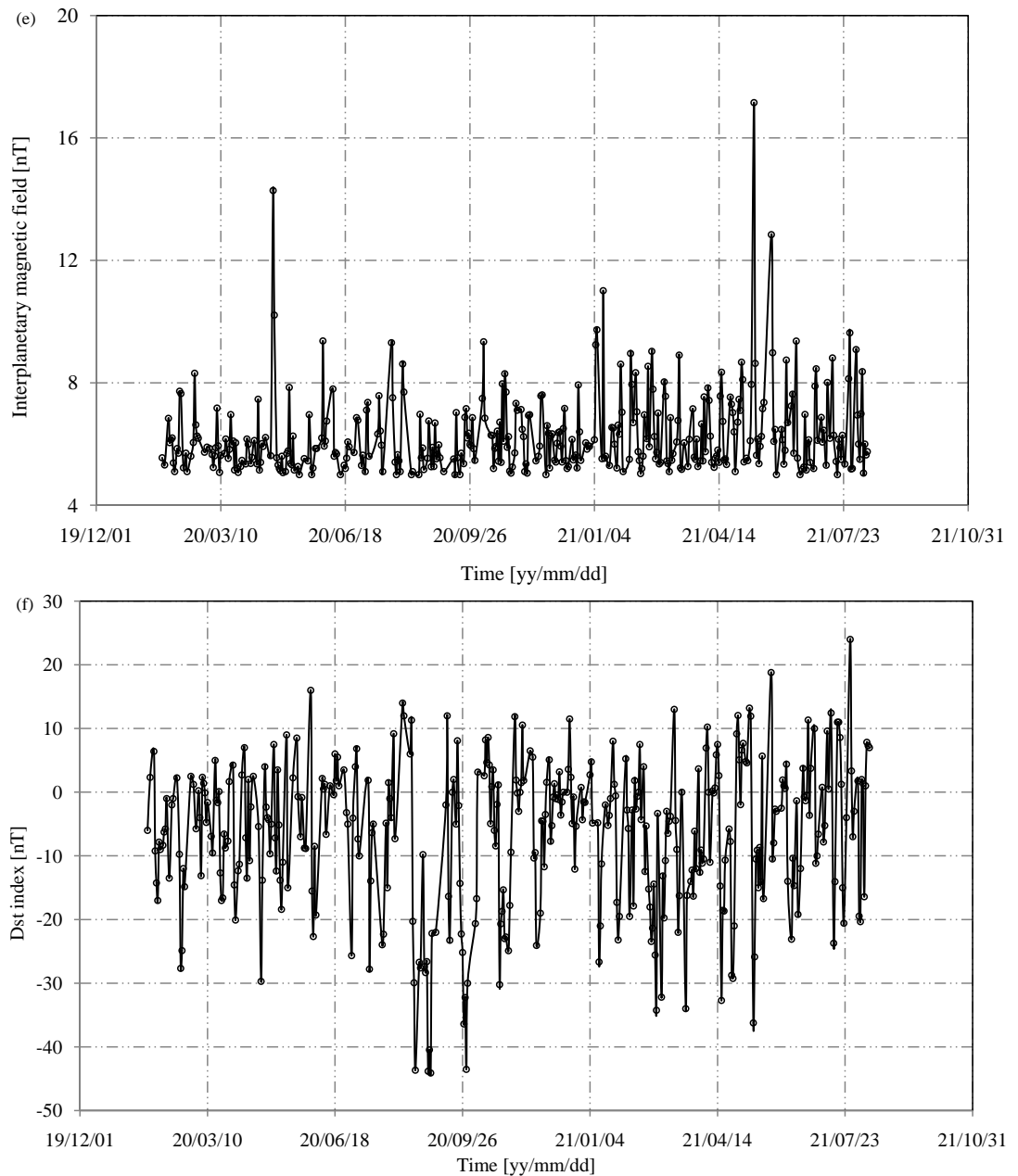


Figure 1. The time series of the daily values of (a) the number of cases of COVID-19; (b) solar wind speed (SWS); (c) solar radio flux at 10.7 cm; (d) Sunspot Number; (e) interplanetary magnetic field; and (f) Dst index; during the study period.

The considered variables covered a wide range of values experienced during the study period. The Solar wind speed ranged between 640 and 270 with a mean of 398, the F10.7 had a maximum value of 113, a minimum value of 67, and a mean value of 75.5. Interplanetary magnetic field had a mean value of 6.82 and ranged between 17 and 5. Sunspot number reached a maximum of 94 and a minimum of 0 and had a mean of 14.

Tables 1-3 summarize, respectively, the results of Pearson, Kendall and Spearman correlation tests on the association of daily COVID-19 cases in the

Table 1. Summary of the Pearson linear correlation results between COVID-19 in the world, the five geographical categories, and the five space weather parameters (20 January 2020-5 August 2021).

Category	Tests	B _t	Dst	F10.7	SSN	SWS
World	Pearson Correlation Coefficient	0.159**	0.098	0.123*	0.357**	0.135**
	Sig. (2-tailed)	0.002	0.054	0.015	0.000	0.008
	N	385	385	385	385	385
Europe	Pearson Correlation Coefficient	0.161**	0.101*	0.123*	0.320**	0.145**
	Sig. (2-tailed)	0.002	0.048	0.016	0.000	0.004
	N	384	384	384	384	384
Africa	Pearson Correlation Coefficient	0.149**	0.086	0.108*	0.399**	0.164**
	Sig. (2-tailed)	0.004	0.097	0.038	0.000	0.002
	N	370	370	370	370	370
Asia	Pearson Correlation Coefficient	0.153**	0.116*	0.126*	0.411**	0.095
	Sig. (2-tailed)	0.003	0.023	0.013	0.000	0.064
	N	385	385	385	385	385
North America	Pearson Correlation Coefficient	0.163**	0.075	0.117*	0.294**	0.170**
	Sig. (2-tailed)	0.001	0.142	0.021	0.000	0.001
	N	385	385	385	385	385
South America	Pearson Correlation Coefficient	0.152**	0.087	0.115*	0.376**	0.136**
	Sig. (2-tailed)	0.004	0.097	0.029	0.000	0.010
	N	364	364	364	364	364

*Correlation is significant at the 0.05 level (1-tailed). **Correlation is significant at the 0.01 level (1-tailed).

Table 2. Summary of nonlinear Kendall correlation results between COVID-19 in the world, the five geographical categories, and the five space weather parameters (20 January 2020-5 August 2021).

Category	Tests	B _t	Dst	F10.7	SSN	SWS
World	Kendall Correlation Coefficient	0.105**	0.052	0.507**	0.442**	0.078*
	Sig. (2-tailed)	0.006	0.131	0.000	0.000	0.022
Europe	Kendall Correlation Coefficient	0.105**	0.052	0.505**	0.441**	0.077*
	Sig. (2-tailed)	0.006	0.132	0.000	0.000	0.025
Africa	Kendall Correlation Coefficient	0.104**	0.052	0.491**	0.445**	0.096**
	Sig. (2-tailed)	0.008	0.143	0.000	0.000	0.006
Asia	Kendall Correlation Coefficient	0.105**	0.052	0.507**	0.442**	0.078*
	Sig. (2-tailed)	0.006	0.131	0.000	0.000	0.022
North America	Kendall Correlation Coefficient	0.105**	0.052	0.507**	0.442**	0.078*
	Sig. (2-tailed)	0.006	0.131	0.000	0.000	0.022
South America	Kendall Correlation Coefficient	0.117**	0.040	0.476**	0.435**	0.100**
	Sig. (2-tailed)	0.003	0.266	0.000	0.000	0.005

*Correlation is significant at the 0.05 level (1-tailed). **Correlation is significant at the 0.01 level (1-tailed).

Table 3. Summary of nonlinear Spearman correlation results between COVID-19 in the world, the five geographical categories, and the five space weather parameters (20 January 2020-5 August 2021).

Category	Tests	B	Dst	F10.7 cm	R	SWS
World	Spearman Correlation Coefficient	0.139**	0.077	0.678**	0.600**	0.127*
	Sig. (2-tailed)	0.006	0.132	0.000	0.000	0.013
Europe	Spearman Correlation Coefficient	0.140**	0.076	0.676**	0.598**	0.125*
	Sig. (2-tailed)	0.006	0.135	0.000	0.000	0.015
Africa	Spearman Correlation Coefficient	0.139**	0.077	0.656**	0.602**	0.155**
	Sig. (2-tailed)	0.007	0.140	0.000	0.000	0.003
Asia	Spearman Correlation Coefficient	0.139**	0.077	0.678**	0.600**	0.127*
	Sig. (2-tailed)	0.006	0.132	0.000	0.000	0.013
North America	Spearman Correlation Coefficient	0.139**	0.077	0.678**	0.600**	0.127*
	Sig. (2-tailed)	0.006	0.132	0.000	0.000	0.013
South America	Spearman Correlation Coefficient	0.155**	0.060	0.641**	0.590**	0.160**
	Sig. (2-tailed)	0.003	0.257	0.000	0.000	0.002

*Correlation is significant at the 0.05 level (1-tailed). **Correlation is significant at the 0.01 level (1-tailed).

world with the five geographical categories and the solar parameters during the study period.

According to Pearson correlation tests, the numbers of the confirmed COVID-19 cases in the world and all the considered categories have a significant correlation with interplanetary magnetic strength, solar radio flux F10.7 cm, and sunspot number. Solar wind speed correlated significantly with the number of COVID-19 cases in the world and all the categories, except cases reported in Asian countries.

Moreover, the numbers of the reported cases in the world, South America, North America, and African countries have no correlations with the Dst index. Whereas, the number of COVID-19 cases in Asia and European countries is significantly correlated with the Dst index according to Pearson tests. Sunspot number indicated the strongest Pearson correlation coefficient with the number of the reported cases. The correlation ranged between 0.411 and 0.29.

Kendall and Spearman tests indicated significant correlations between the world's COVID-19 cases and the other geographical categories, with the interplanetary magnetic field, radio flux F10.7 cm, sunspot number, and the solar wind speed. However, the strength and the type of the association differed from one variable to another. Contrary to these values, the two tests showed no significant correlations of the number of COVID-19 with the Dst index.

The Kendall and Spearman correlations between the number of the COVID-19 cases and F10.7 cm were strongest for all the categories, followed by the sunspot number. In the case of Kendall, the correlation coefficients ranged between 0.507 and 0.476, while for Spearman, the correlation coefficients ranged between 0.678 and 0.641. For the correlations between sunspot and the con-

firmed cases, Kendall correlations ranged between 0.445 and 0.435, while Spearman coefficient ranged between 0.602 and 0.590.

Both tests indicated low, but significant, correlations between the number of COVID-19 cases and interplanetary magnetic fields and solar wind speed. The results of the Kendall and Spearman tests indicated that the correlation coefficients between the F10.7 cm and the number of the COVID-19 cases worldwide were between 0.507 and 0.678, respectively.

Confirmed COVID-19 cases for all the categories and interplanetary magnetic field showed Kendall values between 0.15 and 0.117, and Spearman coefficients ranging between 0.155 and 0.140, wherein both cases the highest correlations were observed with the COVID-19 confirmed cases reported in South America.

For the relationship between solar wind speed and COVID-19 confirmed cases for all the categories, the Kendall coefficients ranged between 0.100 and 0.077, and Spearman coefficients ranged between 0.160 and 0.124.

The number of confirmed COVID-19 cases in South American countries showed the highest Kendall (0.117) and Spearman (0.155) correlations with interplanetary magnetic fields. On the other hand, the confirmed cases of COVID-19 in this geographical category showed the lowest correlation coefficients *i.e.*, Kendall had a value of 0.476 and Spearman had a value of 0.641, when correlated with the F10.7 radio flux. COVID-19 confirmed cases found in Asia, Europe, NAM countries, and the entire world showed the highest Kendall and Spearman correlation coefficients with the F10.7 radio flux. The number of COVID-19 confirmed cases in African countries showed a Kendall correlation coefficient of 0.445 and a Spearman correlation coefficient of 0.602, which were the highest among the other categories.

4. Discussions and Conclusions

In this study, the relationships between space weather variables and the number of the COVID-19 cases worldwide that was recorded on a daily basis for the period from 20 January 2020 to 5 August 2021 was investigated using Pearson linear, and non-linear tests of Spearman and Kendall rank correlations. The space weather variables considered here were the solar radio flux at 10.7 cm, Dst index, interplanetary magnetic field, sunspot number, and solar wind speed. The numbers of the COVID-19 cases were further divided into five geographical categories namely, Asia, North America, South America, Africa, and Europe.

The linear Pearson tests showed that:

- 1) The numbers of the confirmed COVID-19 cases in the world and the other categories have a significant correlation with interplanetary magnetic strength, solar radio flux F10.7, and sunspot number.
- 2) Solar wind speed correlated significantly with the number of COVID-19 cases in the world and all the categories, except cases reported in Asian countries.
- 3) The number of COVID-19 cases in Asian and European countries is signif-

icantly correlated with the Dst index.

4) The number of the reported COVID-19 cases in the world, and South American, North American, and African countries have no correlations with the Dst index.

The non-parametric Kendall and Spearman tests showed that:

5) Significant correlations were realized between the COVID-19 cases for all the geographical categories and all the considered space weather indices (inter-planetary magnetic field, radio flux F10.7, sunspot number, and the solar wind speed)

6) No significant correlations were observed between the number of COVID-19 cases and the Dst index.

Despite above findings showing significant influences of space weather variables on the number of the COVID-19 cases, the exact mechanism that explains this relationship is not yet clear.

Heliobiological investigations conducted in the last two decades have shown that solar activity and its subsequent disturbances may, directly or indirectly, affect human health and life on Earth including the spread and outbreak of infectious diseases, which can be expected for the current COVID-19 pandemic as well [24] [30] [31].

The variability of the space weather can influence the environment, atmospheric, and climatic variability. These include the changes in the ionization levels of the atmosphere caused by the cosmic rays and the magnetosphere-ionosphere interactions caused by solar winds [32] [33]. The environmental and climatological variations caused due to solar activity and its associated disturbances may have a potential impact on the nature of the genetic transformation of the virus, acquired hosts, and virus-host interactions [33]. For instance, the interactions of the solar wind with the Earth's magnetosphere cause magnetosphere-ionosphere interactions that may have a pronounced impact on the health and physiological function, due to the subsequent variations in the ultra-low frequency [32]. The modulation of cosmic rays due to the solar activity may affect the cloud and aerosols formations that may have a direct effect on the environment or an indirect effect on the human health, including their effects on the immune system of animals and humans, as well as reducing the ability of the organisms to resist viruses [23] [26] [27] [33] [34] [35] [36].

Since this threat of COVID-19 virus will not be the last to cause a large outbreak leading to worldwide panic and death, it is important for the scientists and researchers to consider and understand the possible impacts of space weather activities on the environmental conditions and its subsequent impact on the spread of this pandemic and other infectious diseases [36] [37] [38].

The present study contributes additional knowledge to understanding the effects of the Sun on the transmission of COVID-19 and can be useful for epidemiologists to understand the behavior of the virus when compared to these factors and can conduct long-term control strategies against disease outbreaks. Although interesting results were found, there were several limitations noted in

our study. For instance, the infected cases may have been impacted by several additional factors such as social behavior, economics, epidemiology, and terrestrial environmental factors.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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