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On the Relationship between Meteorological Variables, Dst Index, Solar Wind Speed, Solar Radio Flux, and Cosmic Rays and COVID-19 Cases

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Abstract

This study aims to determine the influential role of the meteorological, solar, and geophysical factors and cosmic rays on the transmission of COVID-19 in Riyadh, Saudi Arabia. The meteorological factors were air temperature, relative humidity, wind speed, and atmospheric pressure. The solar radio flux, Dst index, and solar wind speed were utilized as representatives of the solar and geophysical variables. The association between these variables and the COVID-19 pandemic cases from 3 April 2020 to 1 August 2021 was investigated using the Spearman and Kendall rank correlation tests. The obtained results showed that the air temperature and average wind speed are positively associated with the daily number of reported COVID-19 cases. On the other hand, the mean values of relative humidity and atmospheric pressure are inversely correlated with the number of COVID-19 cases in Riyadh. Moreover, the results showed that the Dst index and cosmic rays are positively correlated with the COVID-19 cases. Contrarily, solar wind speed and radio flux at 10.7 cm have negative correlations with the COVID-19 cases. The obtained results will help the epidemiologists to understand the behavior of the virus against meteorological, solar, and geophysical variables and can be considered as a useful supplement to help national and international organizations and healthcare policymakers in the process of strategizing to combat COVID-19.

Keywords

COVID-19, Solar Activity, Meteorology, Space Weather, Cosmic Rays

1. Introduction

The spread of epidemics and pandemics depends on several factors, such as individual, social, economic, physiological or immunological, as well as environmental influences such as meteorological and/or cosmo-geophysical factors (e.g., [1] [2]).

Since the first known identified case was reported in Wuhan, China, in December 2019, the Coronavirus (COVID-19) disease has spread worldwide and developed into a global pandemic, becoming one of the most significant global health threats in a century (WHO, 2020) [3].

Immediately afterward, several research studies around the world were conducted to investigate the association between COVID-19 and a wide range of factors to understand their influence in contributing to the spread of COVID-19 and to reduce the ongoing threat of the pandemic. These include the population density, socio-economic factors, healthcare, and the like (e.g., [4] [5]).

Furthermore, a large number of investigations have been conducted to investigate the effects of meteorological conditions on COVID-19 transmission in several places in the world (e.g., [6]-[11]).

Given the large and effective role that the sun plays in influencing the Earth and thus, our lives, any slight change in the sun's activity will have an impact on the Earth depending on the strength and intensity of this change or event [12] [13]. Extraterrestrial factors mainly affected by solar disturbances, such as the fluctuation of the Earth's magnetic field (Earth-ionosphere cavity/Schumann resonances), geomagnetic activity, variation of cosmic ray (CR) intensity, and electromagnetic changes, contribute to the nature of the virus, acquired hosts, virus-host interactions, and spread of infectious diseases outbreaks (e.g., [1] [14] and references therein).

Over the last 20 years, numerous studies have been carried out, and the evidence suggests that space weather activity has a broad range of adverse effects on human health [15]-[23].

It is imperative to explore the potential effects of these factors on the current COVID-19 pandemic to help national and international organizations and healthcare policymakers in the process of strategizing to combat COVID-19. To the best knowledge of the authors, there is no study that examines the relationship between solar, CRs, geophysical parameters, and the spread of COVID-19 cases.

The aim of this study is twofold: firstly, it will investigate the impact of the meteorological variables measured in Riyadh, Saudi Arabia. Secondly, the study will fill the research gap and explore the potential influences of solar, CRs and geophysical variables on COVID-19. Detailed material and methods regarding data source and statistical models are described in Sect. 2. The analysis results are explained in Sect. 3. Finally, the discussions and conclusions are given in Sect. 4.

2. Material and Methods

2.1. Data

The data used in this study covers the period from 3 April 2020 to 1 August 2021 and comprises the number of confirmed COVID-19 cases, surface meteorological variables, CR observations, and solar and geophysical indices.

The data for the COVID-19 cases were taken from reports on the official website of the Saudi Ministry of Health.

Daily average data of the air temperature, relative humidity, atmospheric pressure, and wind speed were collected from the KACST weather station installed at the roof of the radiation detector lab (latitude: 24˚43'; longitude: 46˚40'; altitude: 613 m; vertical cut-off, Rc = 14.4 GV), Riyadh, Saudi Arabia. The station is equipped with sensors that all continuously monitor several weather parameters. Detailed explanations about these sensors are described in several research papers [24].

Pressure-corrected CR observations for CR neutrons and muons were obtained from the KACST neutron detector and CARPET detectors located at the same location as the weather sensors: the KACST main building.

The neutron monitor consists of an outer paraffin wax reflector (9.5 cm) surrounded by a lead producer. The inner two-cm-thick paraffin wax moderator was also surrounded by a neutron producer made of lead. The multiplied and decelerated neutrons reach the 63 cm-long LND2043 counter, filled with BF_3 gas at a pressure of 933 hPa. An interface unit was developed for logging and storing the data at a resolution of 1 ms.

The CARPET detector consists of 120 Geiger counters (type STS-6) located on a platform of ~1.5 × 1.5 m. The 120 counters were divided into groups of 60 upper and 60 lower counters, separated by an aluminum absorber with a thickness of 7 mm. The detector records data from three channels with a time resolution of 1 ms, (Up, Down, and Telescope or Tel). The CR muons are recorded by the telescope channel that registers the total number of particles that simultaneously cross the Up and Down layers of the counters. In this study, CR muons recorded by telescope channel will be used.

The technical details and calibration procedures of the detectors have been discussed in several research articles [25] [26].

Three solar and geophysical variables were used in this study: the solar wind speed, Dst index, and solar radio flux at 10.7 cm. The daily mean values of these variables were obtained from the OMNI NASA database (http://omniweb.gsfc.nasa.gov).

The Dst index monitors the variations of the globally symmetrical ring current, which encircles 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 emissions at a wavelength of 10.7 cm from all sources present on the solar disk.

The solar wind is a stream of charged particles with the solar magnetic field embedded in it; it continuously flows outward from the solar corona and consists of electrons, protons, and alpha particles in a state known as plasma. The solar wind varies in density, temperature, and speed over time and over solar latitude and longitude.

2.2. Statistical Tests

In this study, the relationships between the considered variables were examined according to the Spearman and Kendall rank correlation tests. Factors were considered to affect COVID-19 if significant differences were observed in both statistical tests.

Spearman's rank correlation coefficient is the nonparametric version of the Pearson product-moment and is used to examine the strength of the association between two variables (monotonic relationship). The formula for the Spearman rank correlation test is as follows (e.g., [23]):

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

where ρ is the Spearman rank correlation coefficient; d_i is the difference between the ranks of corresponding values xi and yi; and n is the number of x and y pairs.

The Kendall rank correlation, another non-parametric test, is used to assess statistical associations based on the ranks of the data and can be estimated as follows:

$$\tau = \frac{n_c - n_d}{\frac{1}{2} n\left(n - 1\right)} \tag{2}$$

where τ is the Kendall rank correlation coefficient while n_c and n_d represent the number of concordant and discordant pairs, respectively. Here, n represents the number of pairs.

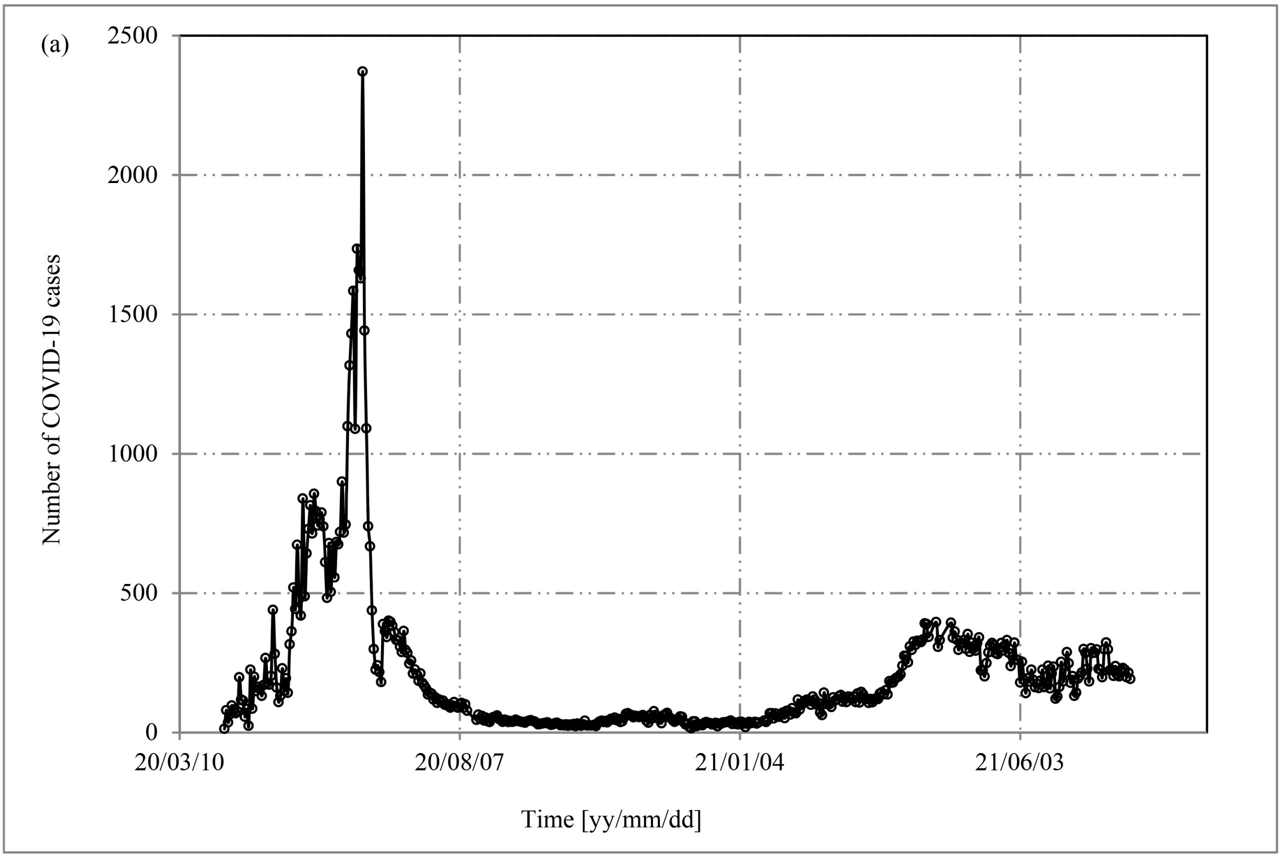
3. Results

3.1. General Trends

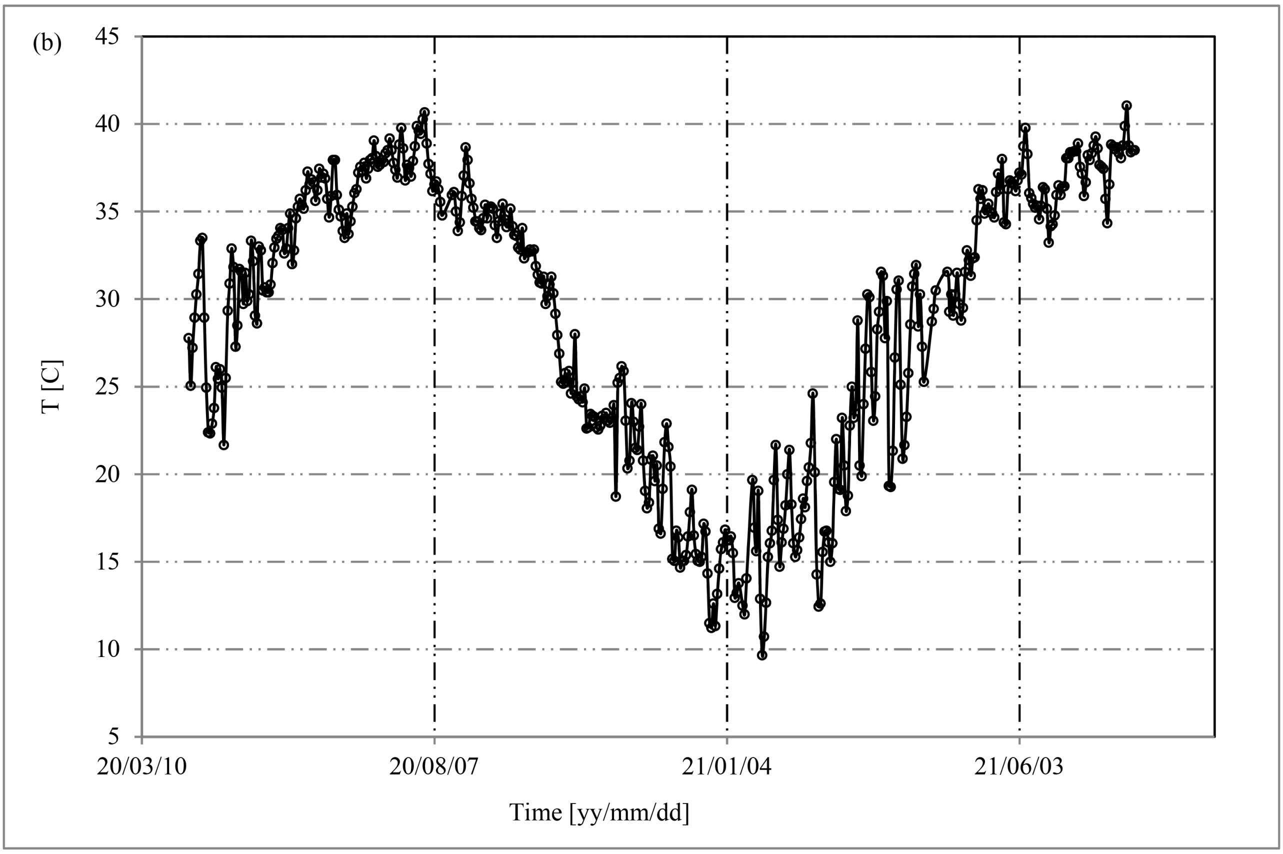
Since the first confirmed case of COVID-19 in Saudi Arabia on 2 March 2020, a total of 542,000 confirmed cases have been reported as of August 20, 2021. During our study period, from 3 April 2020 to 1 August 2021, a total of 103,729 confirmed that the locally-transmitted COVID-19 cases were identified in Riyadh.

Figure 1 shows the daily mean values of the confirmed COVID-19 cases in Riyadh and the variables considered in this study.

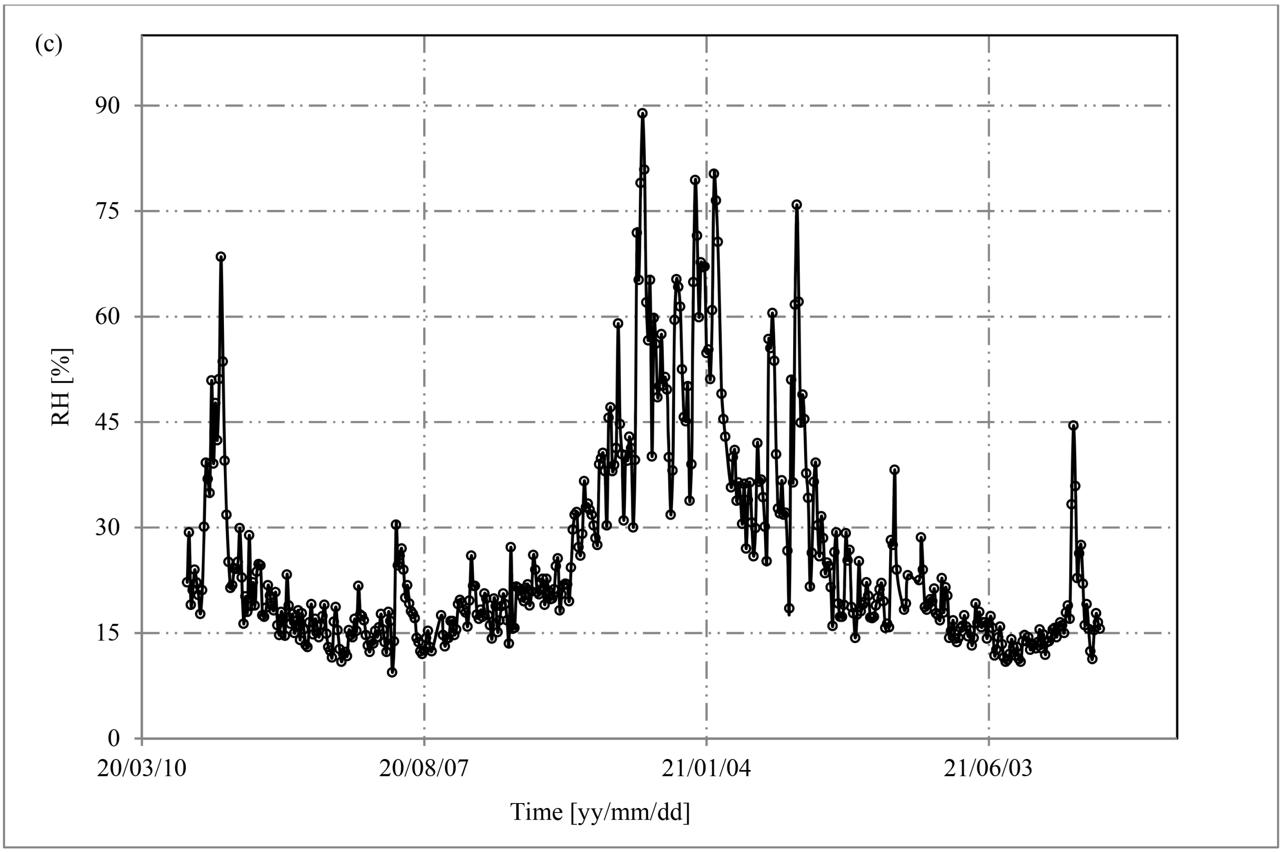
During the study period, the mean number of COVID-19 confirmed cases was 207.54 ± 256.38 with a maximum of 2371 and a minimum of 13. The time series of the reported cases between 3rd April 2020 and 10th August 2020 is characterized by great variations in the number of the reported COVID-19 cases. The number of cases during this period increased rapidly and reached the maximum of 2317 cases on 16th June 2020. The period between 10th August 2020 and 3rd February 2021 features small variations in the number of cases, and the mean number of the reported cases during this period was 42, with a minimum of 14 and a maximum of 78 cases. From 3rd February 2021, the number of the reported

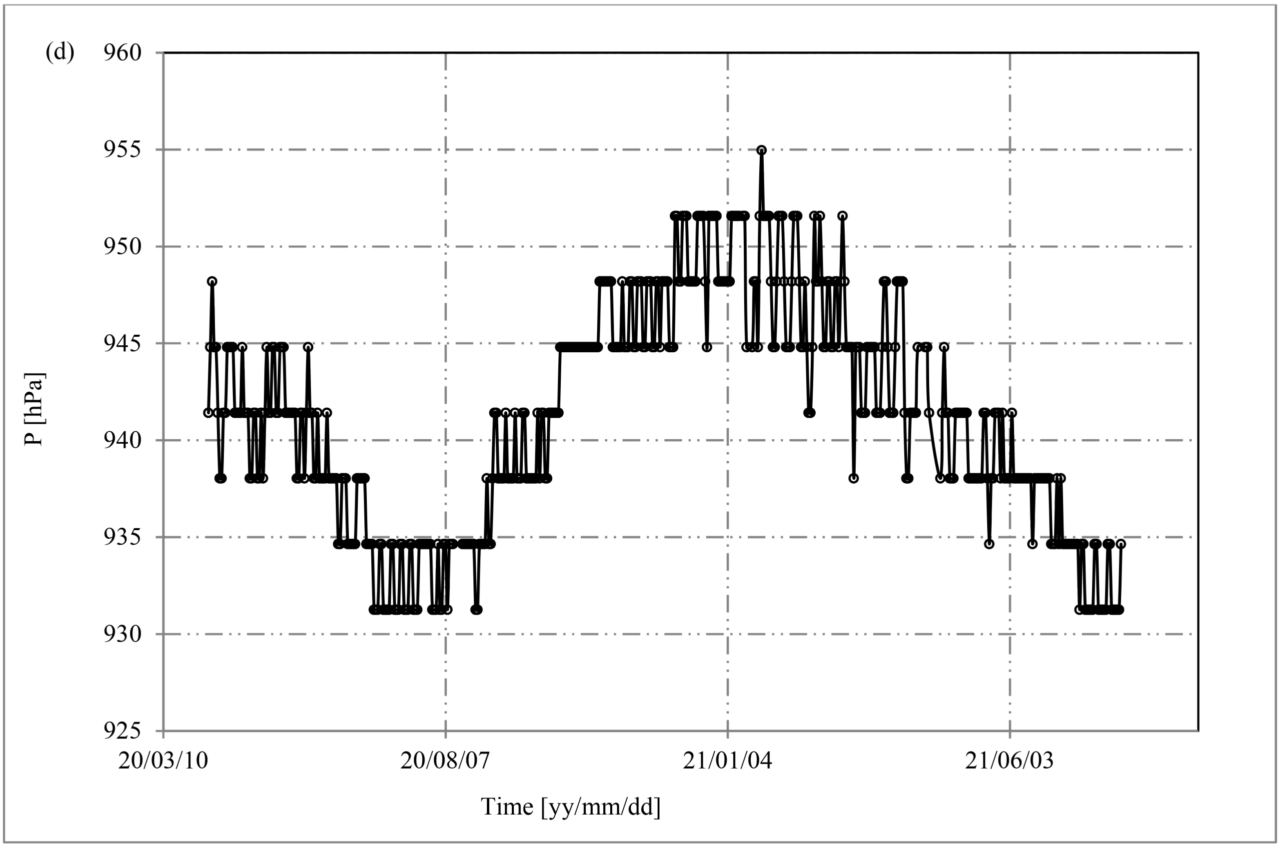


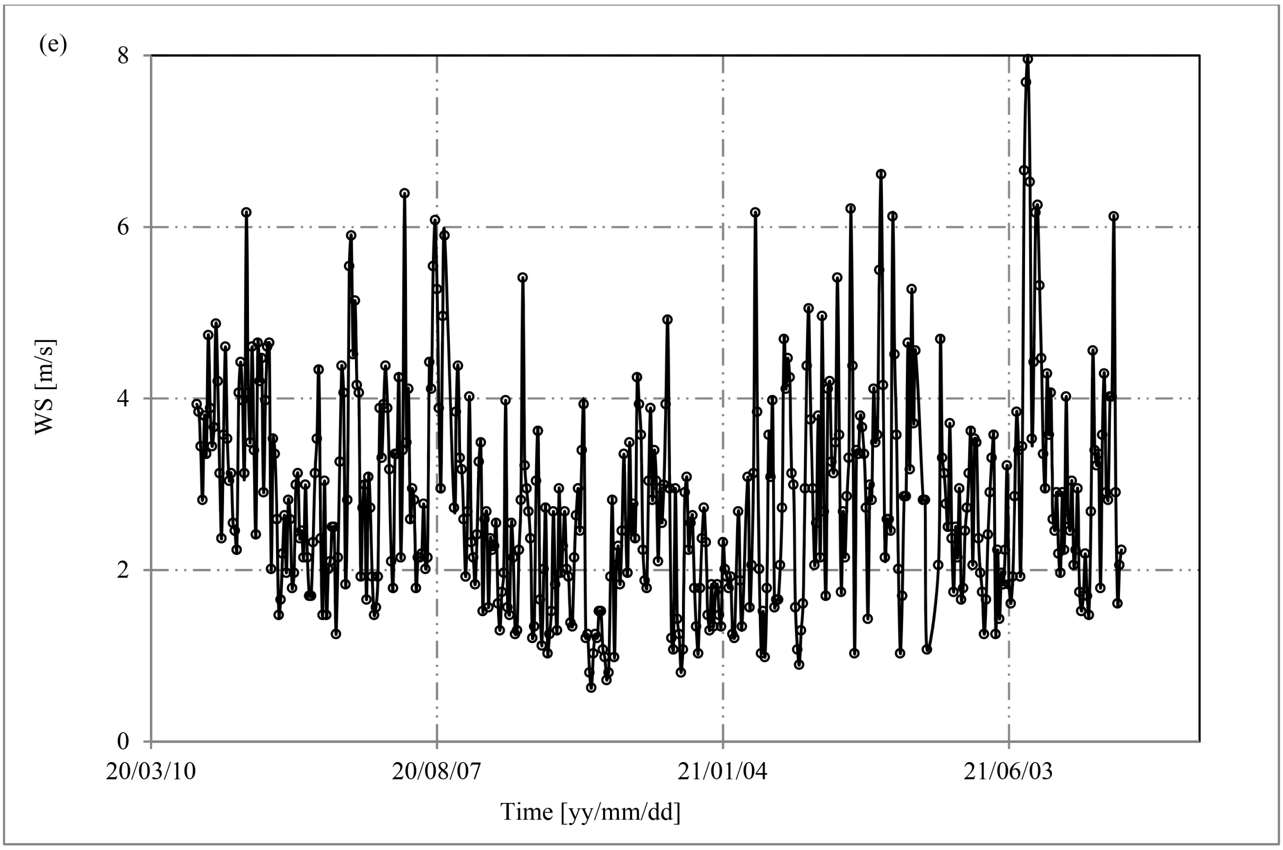
(a)
2500
2000
1500
1000
500
0
Number of COVID-19 cases
20/03/10
20/08/07
21/01/04
21/06/03
Time [yy/mm/dd]

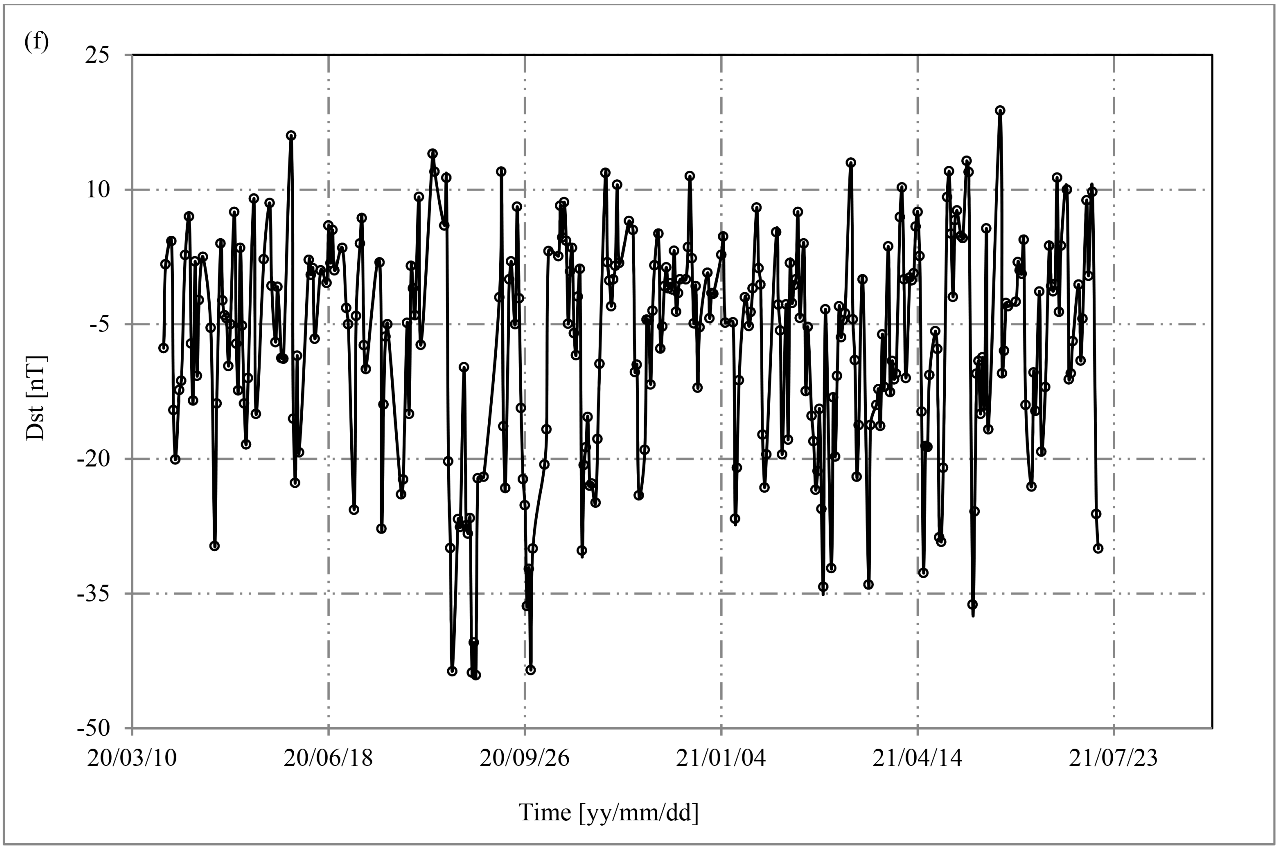


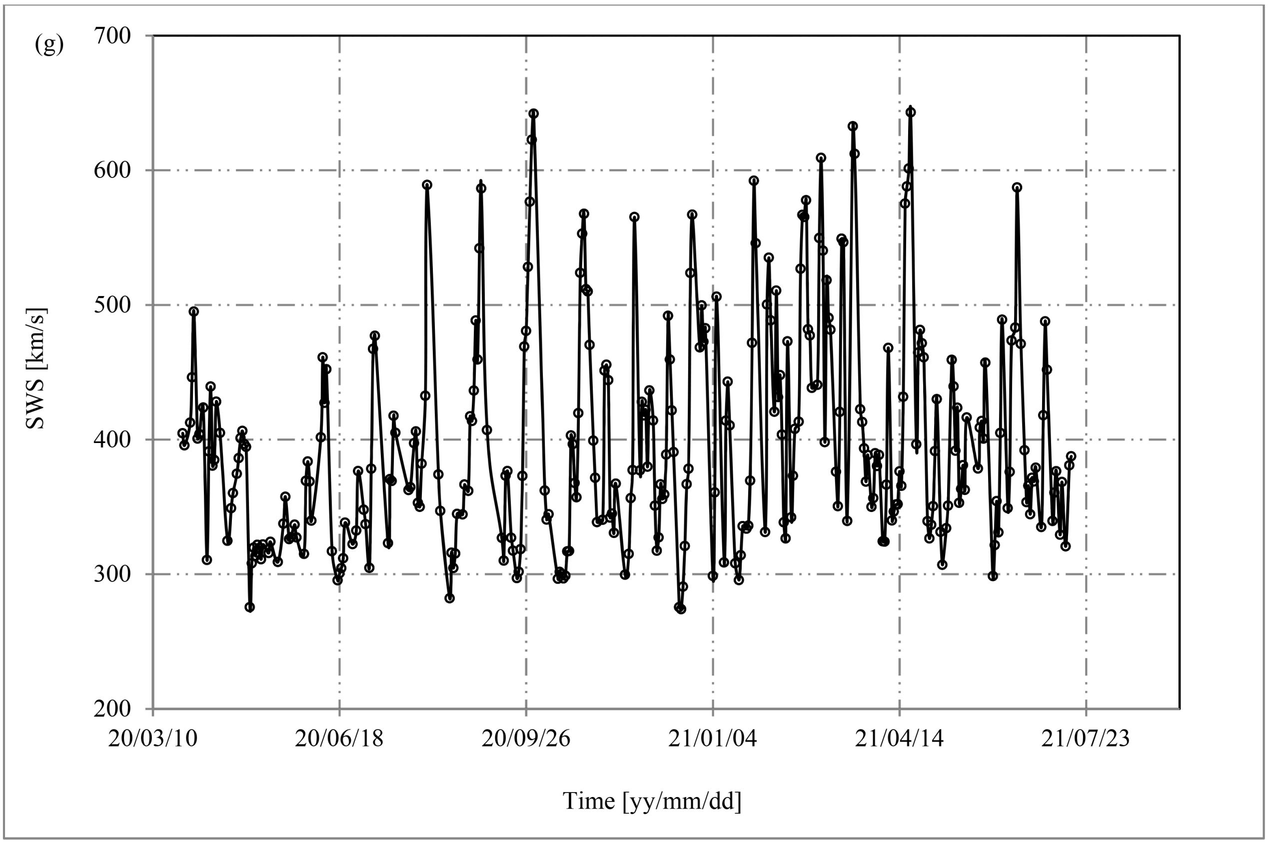
(b)
45
40
35
30
25
20
15
10
5
T [C]
20/03/10
20/08/07
21/01/04
21/06/03
Time [yy/mm/dd]

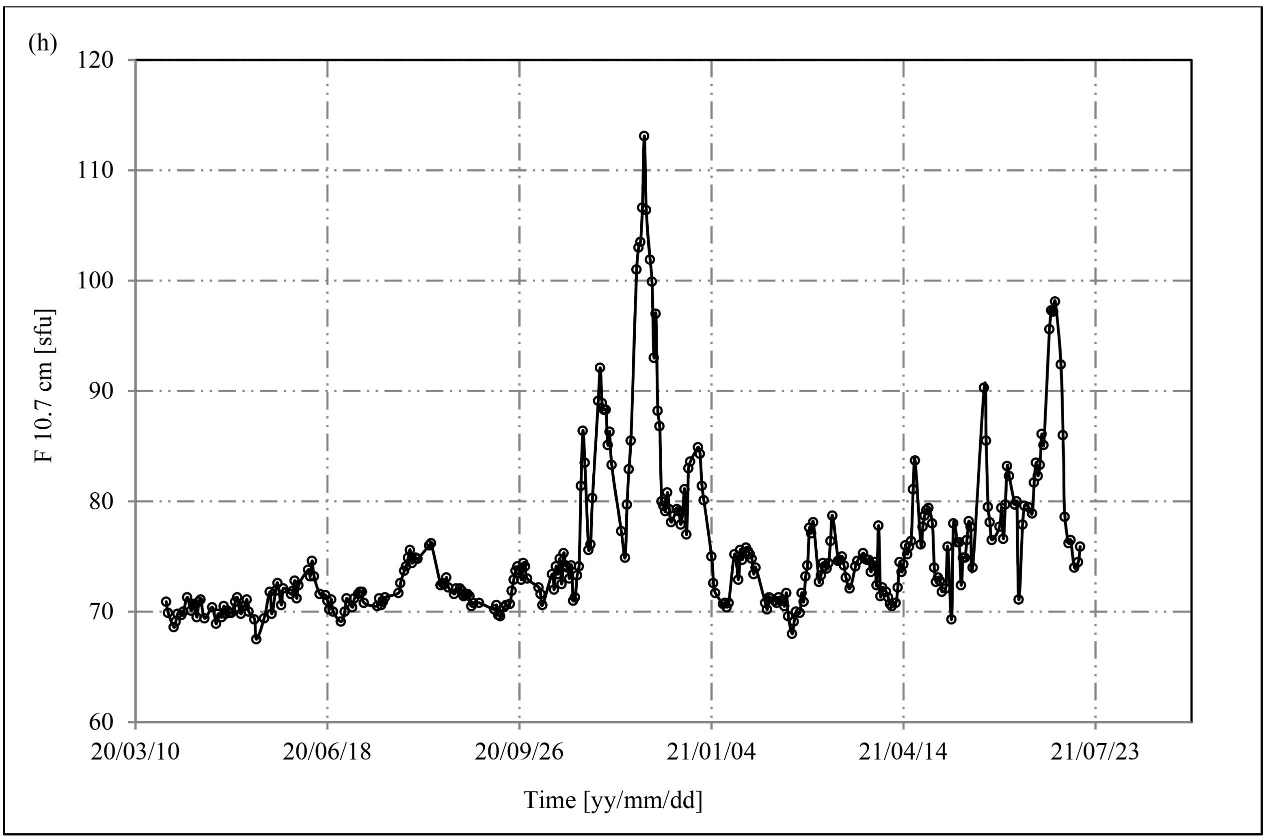

(c)
90
75
60
45
30
15
0
RH [%]
20/03/10
20/08/07
21/01/04
21/06/03
Time [yy/mm/dd]

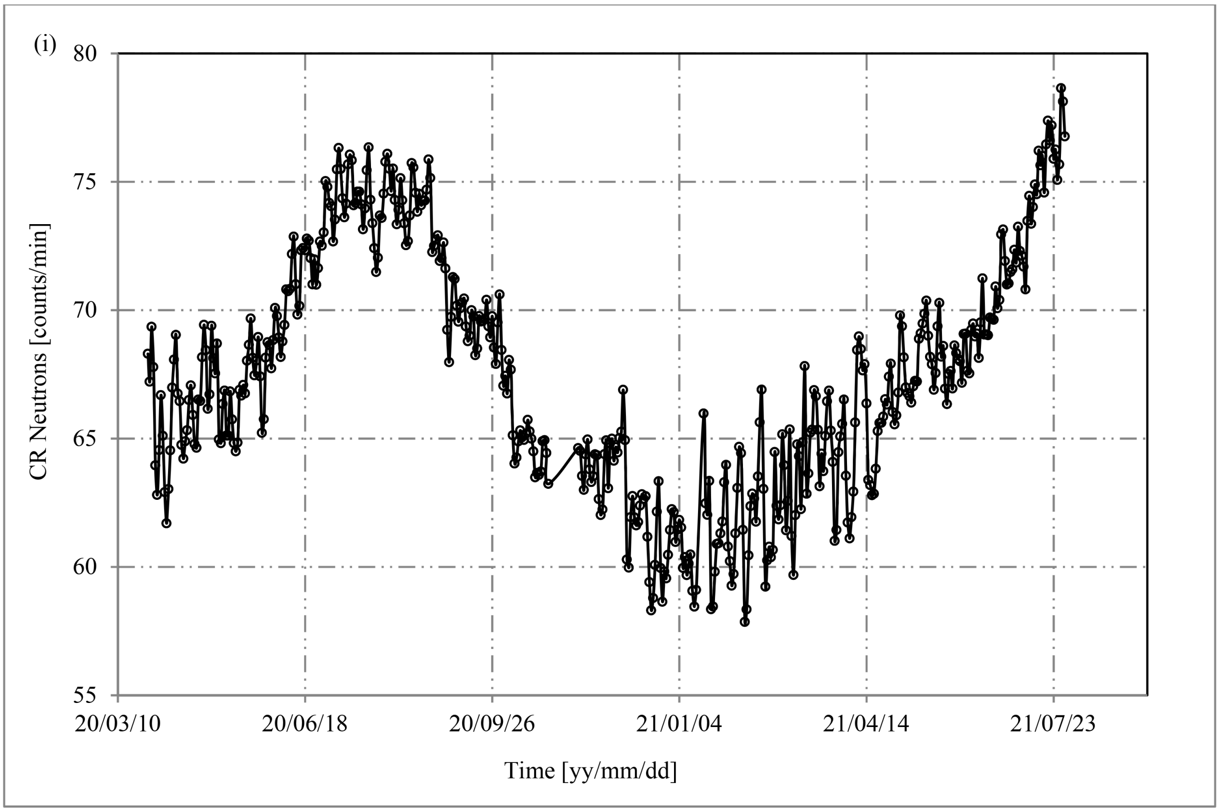

(d)
960
955
950
945
940
935
930
925
P [hPa]
20/03/10
20/08/07
21/01/04
21/06/03
Time [yy/mm/dd]


(e)
8
6
4
2
0
WS [m/s]
20/03/10
20/08/07
21/01/04
21/06/03
Time [yy/mm/dd]


(f)
25
10
-5
-20
-35
-50
Dst [nT]
20/03/10
20/06/18
20/09/26
21/01/04
21/04/14
21/07/23
Time [yy/mm/dd]


(g)
SWS [km/s]
700
600
500
400
300
200
20/03/10
20/06/18
20/09/26
21/01/04
21/04/14
21/07/23
Time [yy/mm/dd]


(h)
F 10.7 cm [sfu]
120
110
100
90
80
70
60
20/03/10
20/06/18
20/09/26
21/01/04
21/04/14
21/07/23
Time [yy/mm/dd]



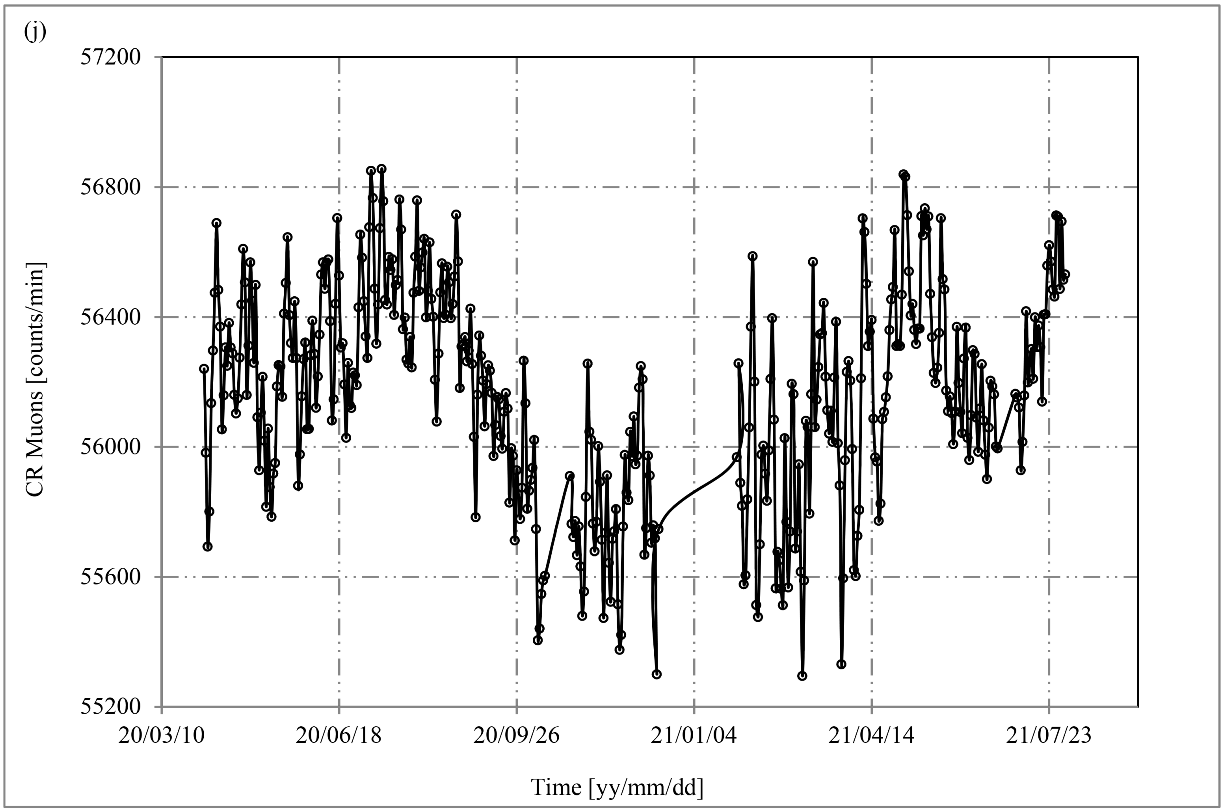


Figure 1. The time series of the daily values of (a) the number of cases of COVID-19; (b) air temperature(T); (c) relative humidity (RH); (d) atmospheric pressure (P); (e) wind speed (WS); (f) Dst index; (g) solar wind speed (SWS); (h) radio flux at F10.7 cm (F10.7); (i) cosmic rays neutrons; and (j) cosmic rays muons; in Riyadh during the study period.

cases increased slightly until 18th March 2021, from which point on the number of cases increased dramatically to reach a maximum of about 400 cases on 14th April 2021. For the next two months, the number of cases decreased slightly to reach a mean of about 220 cases and remained around this number for the rest of the period.

The air temperature and CR muons and neutrons follow a cyclic pattern with their maximum in the summer and minimum in the winter. It is obvious that the cyclic variations of the CR neutron are more evident than those of the CR muons due to the complicated atmospheric influences on the latter than the former (e.g., [27]). Relative humidity and atmospheric pressure, on the other hand, showed the opposite. The radio flux at 10.7 cm (F10.7 cm), Dst index, wind speed, and solar wind speed time series did not show any specific pattern of variations during the considered period.

The considered meteorological variables cover wide ranges of their values experienced in Riyadh during the study period. For instance, the air temperature ranges between 42 and 10 C, RH was between 9% and 89%, and air pressure was between 955 and 931 hPa.

The CR neutrons ranged between 79 and 58 (mean 67) and the CR muons had a mean value of 56,167 with range from 56,856 and 55,295. The solar wind speed, Dst index, and F10.7 presented mean values of 400 km/s, −7 nT, and 76 sfu, respectively.

3.2. Non-Parametric Tests between Meteorological Variables and COVID-19 Cases

Table 1 summarizes the results of the Kendall and Spearman correlation tests on the association of daily COVID-19 cases and the weather parameters in Riyadh from 3 April 2020 to 1 August 2021.

The non-parametric analyses showed with 99% confidence interval that the mean values of the air temperatures and wind speed have positive correlations with the number of the COVID-19 cases, whereas the relative humidity and the atmospheric pressure were significantly anti-correlated with the number of COVID-19 cases. However, the strengths of the correlation were different from one variable to another.

Table 1. Summary of nonlinear correlation results between COVID-19 and meteorological parameters (3 April 2020 to 1 August 2021; N = 484) in Riyadh.

Test	T	RH	P	WS
Kendall τ	0.331**	−0.324**	−0.323**	0.143**
Sig. (2 tailed)	0.000	0.000	0.000	0.000
Spearman ρ	0.507**	−0.494**	−0.456**	0.219**
Sig. (2 tailed)	0.000	0.000	0.000	0.000

**. Correlation is significant at the 0.01 level (2-tailed).

The Kendall correlation coefficients between the number of COVID-19 cases and air temperature, RH, atmospheric pressure, and wind speed were 0.331, −0.324, −0.323, and 0.143, respectively. On the other hand, the Spearman correlation coefficient between the COVID-19 cases and air temperature was 0.507, between the cases and relative humidity was 0.494, and between the cases and atmospheric pressure was −0.456 and lower value of 0.219 with wind speed.

The obtained results, presented here, are in total agreement with some of the previously established studies and partly or totally contradicted several others conducted at several locations around the world. For instance, our finding of the positive effect of the mean temperature and wind speed and the number of COVID-19 cases was supported by the work of (e.g., [7] [11]). Auler [28] established that the mean temperature and average relative humidity are significant in enhancing the COVID-19 contamination rate in Brazil. Xie and Zhu [29] established that the humidity, wind speed, and temperature are inversely associated with the infection rate of COVID-19.

3.3. Non-Parametric Tests between Cosmic Rays, Cosmo-Geophysical Variables, and COVID-19 Cases

The results of Spearman and Kendall tests between the number of confirmed COVID-19 cases and the considered variables are presented in **Table 2**.

It is clear that all the variables have a significant association to the COVID-19 cases. However, the strength and the type of the association differ from one variable to another. The Dst, SWS and F10.7 are significantly correlated with the COVID-19 cases with a 95% confidence level, whereas the CR neutrons and muons have a significant relationship with the COVID-19 cases with a 99% confidence level. While the solar wind speed and radio flux (F10.7 cm) have negative correlations with the COVID-19 cases, the Dst index and the CR muons and neutrons are positively correlated with the COVID-19 cases. Spearman correlation coefficients were 0.14, −0.084, and −0.095 for Dst, SWS, and F10.7 respectively. For correlations between these variables and COVID-19 cases, the Kendall correlation coefficients were 0.072, −0.063, and −0.61 respectively. On the other hand, Spearman and Kendall tests showed stronger correlation coefficients (0.429 for NM and 0.405 for Muons) than the Kendall correlation coefficients

Table 2. Summary of nonlinear correlation results between COVID-19 cases and meteorological parameters (April 3 2020-July 29 2021; N = 484) in Riyadh.

Test	DST	SWS	F10.7	CR-Neutrons	CR-Muon
Kendall τ	0.072*	−0.063*	−0.061	0.284**	0.273**
Sig. (2 tailed)	0.028	0.046	0.044	0.000	0.000
Spearman ρ	.104*	−0.084	−0.095*	0.429**	0.406**
Sig. (2 tailed)	.031	0.047	0.044	0.000	0.000

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

(0.284 for NM and 0.273 for muons)

While the above findings showed the significant influences of the solar and geophysical variables on the number of the COVID-19 cases, the exact mechanism that explains this relationship is not yet clear.

Several researches conducted in the last 20 years have shown that solar activity and its consequent disturbances may directly or indirectly affect the spread and outbreak of infectious diseases; we expect the same for the current COVID-19 pandemic. These include the potential impact of the solar activity at the maximum or lowest period through its influence on the environmental, atmospheric, and climate variability. These include the changing of the ionization levels in the atmosphere caused by the cosmic rays, which are affected by solar modulations (e.g., [1] [6] [12] [14] [22] [30]).

Moreover, the interactions of the solar wind with the earth's magnetosphere are causing magnetosphere-ionosphere interactions, which may have a pronounced impact on the health and physiological functions due to the subsequent variations on the ultra-low frequency [6] [16] [19] [20] [22] [31] [32] [33]. This ULF is somehow correlated with solar wind speed. The variations of the magnetic fields are negatively correlated with cosmic ray counts, which is consistent with the well-known inverse action of solar and geomagnetic activity and cosmic ray counts on the Earth's surface.

4. Conclusions

In this study, the effect of the meteorological variables, the solar and geophysical factors, and the cosmic rays on the number of the daily COVID-19 cases recorded in Riyadh, Saudi Arabia, for the period 3 March 2020 to 1 August 2021, was investigated using the Spearman and Kendall rank correlation tests. The meteorological factors were air temperature, relative humidity, wind speed, and atmospheric pressure. The solar and geophysical variables were the solar radio flux at 10.7 cm, Dst index, and solar wind speed. The analysis results showed the following conclusions:

1) The considered meteorological variables air temperature, relative humidity, air pressure, and wind speed, which cover all the atmospheric conditions experienced in Riyadh, have a significant impact on the number of COVID-19 cases.

2) Air temperature and wind speed correlated positively with the COVID-19 cases.

3) Relative humidity and air pressure are inversely correlated with the COVID-19 cases.

4) The Dst index is correlated with the COVID-19 cases.

5) Solar wind speed and radio flux at 10.7 cm have negative correlations with the COVID-19 cases.

6) Cosmic ray muons and neutrons are positively correlated with the number of COVID-19 cases.

The present study contributes additional knowledge to the understanding of the effects of meteorological, solar, and geophysical factors on the transmission of COVID-19 and can be useful for national and international organizations in the process of their strategy to combat COVID-19. The results will also help researchers to understand the behavior of the virus against these factors and establish surveillance and early warning systems.

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Conflicts of Interest

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

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