Research Article

UV Index for Public Health Awareness Based on OMI/NASA Satellite Data at King Abdulaziz University, Saudi Arabia

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Exposure to ultraviolet radiation (UV) is essential for good health and formation of vitamin D while overexposure poses a risk to public health. Therefore, it is important to provide information to the public about the level of solar UV radiation. The ultraviolet index (UVI) is used to help avoid the negative effects of ultraviolet (UV) radiation on humans and to optimize individual exposure. There is limited ground measurement of solar UV radiation, but satellite Ozone Monitoring Instrument (OMIs) satellite products with a spatial resolution of $1° \times 1°$ can be used to create UV index climatology at local noon time. In this study, we utilize OMI satellite products collected over the campus of King Abdulaziz University (KAU) (21.5° North and 39.1° East), Jeddah, Saudi Arabia, to estimate changes in exposure to UV over a period of 15 years (2004-2020). The results indicate a significantly increasing trend in UV index over this period. Between 2004 and 2020, daily "extreme" UV (UVI > 11, as defined by the World Health Organization (WHO)) occurred on 46.60% of days. The frequency of low UVI (UVI < 2) was only about 0.06%. These results imply dangerous exposure levels to solar UV radiation on the KAU campus and call for safety measures to increase awareness and decrease direct exposure; for example, by implementing the United States Environmental Protection Agency (EPA) general guidelines.

1. Introduction

Most people love the sun and spend significant amounts of time outdoors, often in clothing that exposes their skin to direct ultraviolet (UV) radiation (UVR). Medical research has shown that some exposure to sunlight can be beneficial; for example, increasing the production of vitamin D [1–3]. However, overexposure to UVR can contribute to serious health problems, ranging from sunburn (erythema) and skin damage to skin cancer [4–8]. The effects of sunburn worsen with cumulative exposure, and a higher number of incidents of severe sunburn, especially during childhood, increase the risk of developing skin cancer [9–11]. UVR exposure also places eyes at risk of photokeratitis, photo conjunctivitis, and cataracts [12–17].

1.1. Skin Cancers. Skin cancers present the greatest risk to fair skinned people because they have less protective melanin than people with darker skin [18]. Keratinocyte carcinomas, basal cell carcinoma, and squamous cell carcinoma are the

most common [19]. The third type of skin cancer, melanoma, is less common than the other skin cancers, but it accounts for most skin cancer deaths [4, 20, 21]: 95% of such deaths worldwide [22]. It is concerning that, in fair skinned populations, the incidence of melanoma is rising more quickly than it is for most other types of cancer [23]. The number of cases is expected to continue to rise [24], due in part to increased recreational and intentional UVR exposure, particularly in younger individuals [25]. The trends in the incidence of keratinocyte cancers are difficult to establish because of unreliable data [26] .

1.2. Ocular Disease. Solar UVR causes various ocular diseases including eyelid malignancies and cortical cataracts [13]. UVR is linked to cataract induction [27], which is the most common cause of blindness globally [28, 29]. Cortical cataracts are more prevalent at lower geographical latitudes where UVR is abundant [30]. Studies have shown that even a single exposure of the cornea to UV light can lead to detectable changes [31]. While there are different risk factors associated with cataracts, sunlight is estimated to be the cause of 10–20% of cataracts [32, 33]. While there is increased awareness of the link between exposure to direct sun and skin cancer, fewer people are aware that the risks extend beyond skin cancer [34].

In response to increased awareness of the risks associated with exposure to direct UVR, the UV index (UVI) was developed by the World Health Organization (WHO) in collaboration with the United Nations Environment Programme (UNEP), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the World Meteorological Organization (WMO), and the German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS). The higher the UVI, the greater the risk of skin or eye damage, and the less time it takes for damage to occur.

The UVI is important in raising public awareness of the risks involved in high exposure to UVR and in alerting people to the need for protective measures. Encouraging people to reduce exposure can limit the harmful effects and related healthcare costs. The equation to derive the UVI is as follows [35–37]:

$$UV \ Index = 40 \int E(\lambda) \, S_{er}(\lambda) \, d\lambda, \qquad (1)$$

where λ is the wavelength in nm, $E(\lambda)$ is the irradiance in W/m^2, and $S_{er}(\lambda)$ is the erythemal weighting function, which is defined as

$$S_{er}(\lambda) = 1.0 \ for \ 250 < \lambda \le 298,$$

$$nm S_{er}(\lambda) = 10^{0.094(298-\lambda)} for \ 298,$$

$$< \lambda \le 328 \ nm S_{er}(\lambda) = 10^{0.015(139-\lambda)} for \ 328 > \lambda \le 400 \ nm,$$

$$S_{er}(\lambda) = 0.0 \ for \ \lambda > 400 nm.$$

$$(2)$$

The UVI is derived from the erythemal irradiance, integrating UV irradiance at ground level with weighting deter-

mined by the Commission International de l' Eclairage (CIE). The CIE weighting function is based on the susceptibility of the Caucasian skin to sunburn [38, 39].

Information is provided in terms of the UVI scale, which was adopted in 1994 [35] and revised in 2002 to improve its usefulness in raising public awareness [37]. In 2009, the International Agency for Research on Cancer (IARC) stated that UVR is carcinogenic to humans [40, 41]. The WHO promotes messages alerting the public to recommended prevention measures (such as the use of hats or sunscreen) for different UVI values [26].

Most commonly, the UVI is derived from modeling UV irradiance, while taking into account key atmospheric metrics (aerosol optical properties, cloud cover, and ozone levels). Predictive UVI models vary in complexity and accuracy, but all require good information on actual atmospheric parameters, which is often difficult to obtain [42–44] .

Heckman reviewed 20 years of research into awareness of the UVI and its impact and found that awareness varies from country to country, with low levels of comprehension and use of the UVI as a means of informing safe behaviors [45]. It is evident that more research is needed to determine best practices in increasing public awareness of the potential of the UVI to aid effective skin protection [46, 47] and improve public health.

It is especially important to protect the most vulnerable population groups, given that more than 90% of nonmelanoma skin cancers affect skin types I and II [48, 49]; the key messages associated with the UVI need to be focused on people who are at higher risk of sunburn [47, 50]. Children are especially sensitive to UVR and need special protection. Further, even though the occurrence of skin cancer is lower in dark skinned people, they are still susceptible to damage to the eyes and immune system [5, 7, 51, 52]. Messaging at the national and local levels is needed to focus on the needs of vulnerable subgroups of the population. Differences in climate and culture and perceptions of risks also need to be considered [37]. The United States Environmental Protection Agency (EPA) has devised guidelines for using the UVI [53].

In this study, all sky conditions, UV index, climatology over the campus of King Abdulaziz University (KAU), Jeddah, Saudi Arabia, (21.5° North and 39.1° East) based on OMI satellite data with high spatial resolution accuracy of 1° lat. × 1° Lon., and since there are only limited ground measurements, for the period from October 2004 to December 2020, was studied. In the last 15 years, the daily UVI studded to raise awareness among university students and staff of the UVI and its potential value. A description of the methods used is followed by the results and discussion and conclusions.

2. Methods

2.1. Questionnaire on the Awareness of the Effects of UVR. Established in 1967, King Abdulaziz University Campus (KAU) occupies an area of 2,224 acres (9 km^2) in Jeddah, Saudi Arabia, (between 21°29′N and 21°30′N latitude and 39°14′E and 39°16′E longitude). KAU's vision, mission, and goals include protecting the health of students and staff.

TABLE 1: Analyses of the percentage of correct answers to the five statements in KAU during the study.

| Statement	Agreement	Disagreement	Percent of correct responses
Fire burns are more dangerous than sunburn	228	314	42.07
Sunscreen only needs to be applied at resorts in summer	352	190	64.94
Damage from exposure to direct sun can occur on a day with moderate temperatures	327	215	60.33
You cannot get sunstroke on a cloudy day	142	400	26.20
Walking in the shade reduces damage from the sun rays	66	476	12.18
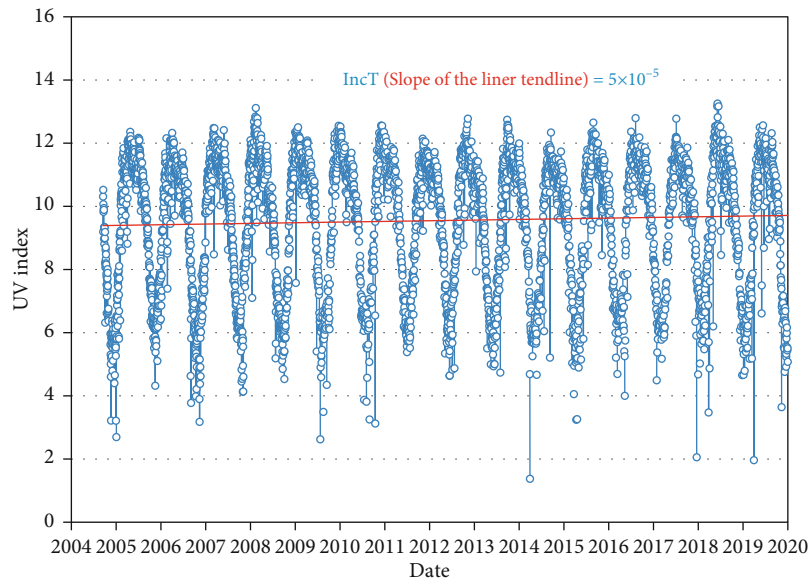
FIGURE 1: Time series variations in daily UVI at noon time on the campus of KAU during the study period.

Recognizing the significant damage and health risks resulting from exposure to direct solar radiation due to incautious behavior, the university aims to increase awareness of the damaging impact of UVR and address misconceptions. To support this effort, we developed a semistructured questionnaire which was distributed among all university staff and students, spanning all ages and educational groups.

The questionnaire was designed to measure awareness of UVR and its damaging impact and of mitigation measures that could be taken. Participants were asked to express their understanding based on a set of five statements, based on [37]:

(i) Statement 1: fire burns are more dangerous than sunburn

(ii) Statement 2: sunscreen only needs to be applied at resorts in summer

(iii) Statement 3: damage from exposure to direct sun can occur on a day with moderate temperatures

(iv) Statement 4: you cannot get sunstroke on a cloudy day

(v) Statement 5: walking in the shade reduces damage from the sun rays

TABLE 2: Number and ratio of UVI in KAU during the study.

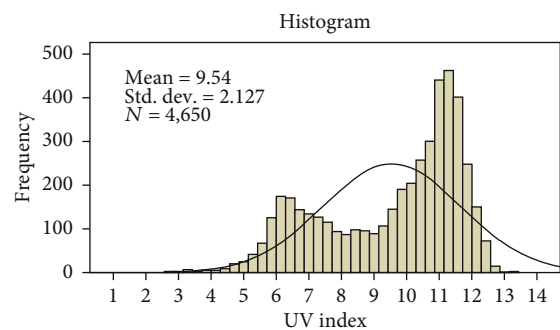| UVI category	UVI value	N	%	%
Low	1,2	3	0.06	
Moderate	3,4,5	127	2.73	23.53
High	6,7	964	20.73	
Very high	8,9,10	1389	29.87	29.87
Extreme	11^+	2167	46.60	46.60
Total		4650		100

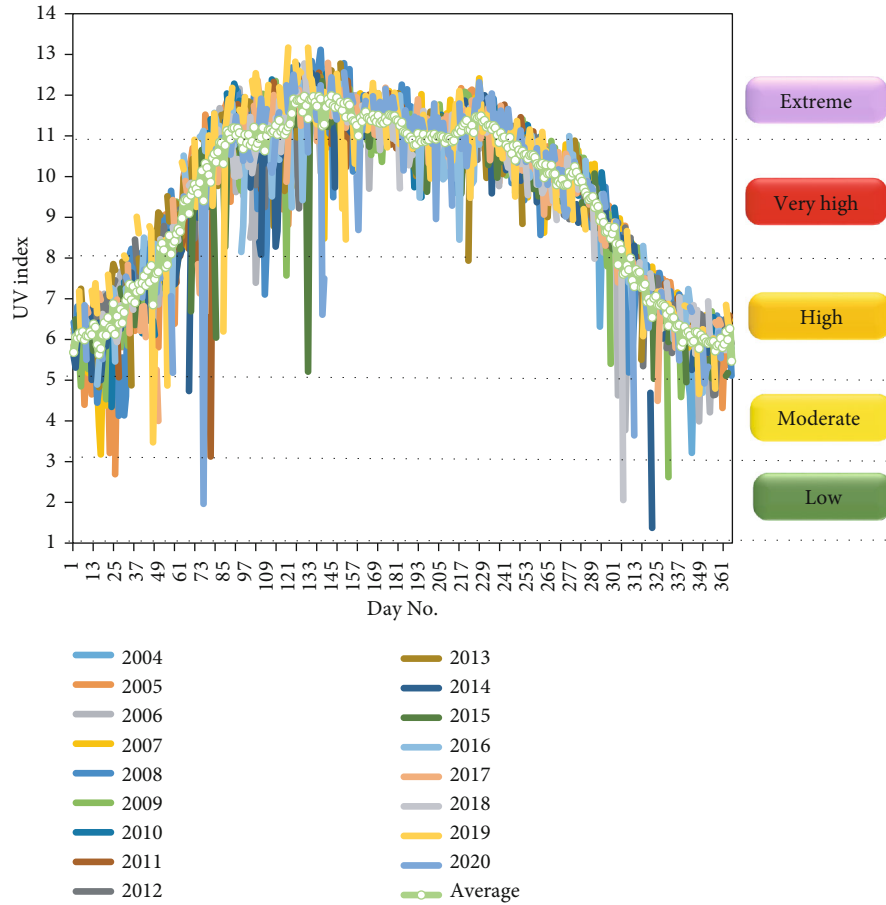FIGURE 2: Histogram with normal distribution of daily UVI on the campus of KAU during the study period.

FIGURE 3: Daily average variation in UVI at KAS during the study period.

2.2. Ozone Monitoring Instruments. We also used data collected by the Ozone Monitoring Instrument (OMI) on board the EOS Aura rocket (launched in 2004) [54]. OMIs are derived from NASA's Total Ozone Mapping Spectrometer (TOMS) and the European Space Agency's Global Ozone Monitoring Experiment (GOME). An OMI can provide many more measures than TOMS and better ground resolution than GOME (13 km × 25 km for OMI vs. 40 km × 320 km for GOME) [55]. For more information about OMI instruments and products, refer to Data User's Guide [56].

The Giovanni product by GES DISC is a web application with a simple, intuitive way of visualizing and analyzing earth science remote sensing data, especially from satellites. Giovanni includes data on atmospheric chemistry and temperatures and rainfall. Giovanni is available at [57] and also includes output from models for atmospheric, land surface, and oceanographic parameters.

3. Results and Discussion

3.1. Data Analysis. First, we analyzed the percentage of correct answers to the five statements. Table 1 shows the distribution of the agreement and disagreement with these statements.

The results show that the majority of participants (61.5%) answered at least one of the statements incorrectly compared to 38.5% who answered all statements correctly. The majority of participants who answered all the questions correctly were females who were 35 or older (26.5%). On the other hand, among males, the age group that showed the largest proportion of correct answers was age 30 and younger (11.8%).

When asked if they followed the weather forecast, 46.5% of all participants said they were interested only in knowing the forecast daily temperature, while 22.4% said they did not follow the weather forecast. On the other hand, 31.1% expressed an interest in knowing both the forecast temperature and the UVI. Furthermore, 10.2% of the participants said that they were unaware of the existence of the UVI. However, 60.8% of the participants expressed an interest in learning more about the index; 29% were already aware of the index and followed it.

When asked about protection measures, 22% of participants stated that they did not take any steps to protect themselves from UVR; although, the majority of participants (78%) stated that they did adopt measures, including the use of sunglasses and sunblock with a head cover (24.5%); 11.4% stated that they only used a head cover, 22.4% only used sunglasses, and 19.6% used both. Also, 72.7% of the participants did not have a mobile application or any other means of obtaining the UVI, while 20.8% expressed an interest in knowing about the index and its application, and 89.8%
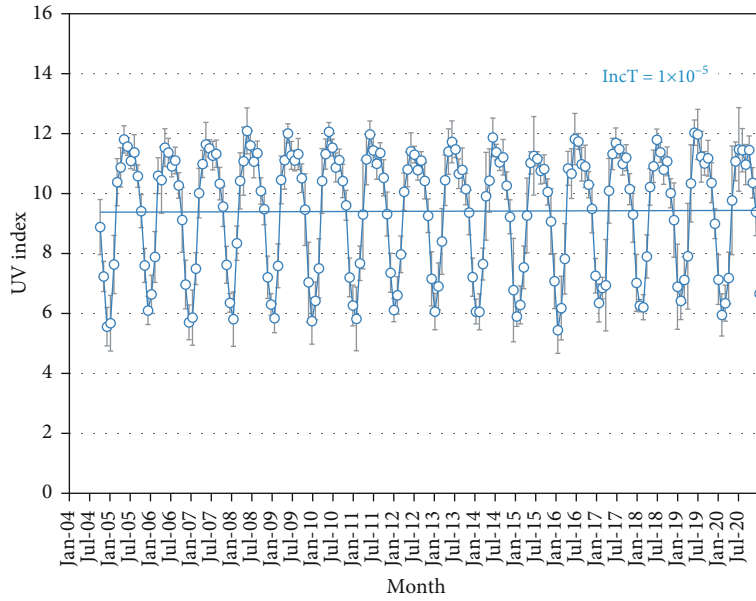
FIGURE 4: Time series variations in the monthly UVI (with standard deviation error bars) on the campus of KAU during the study period.
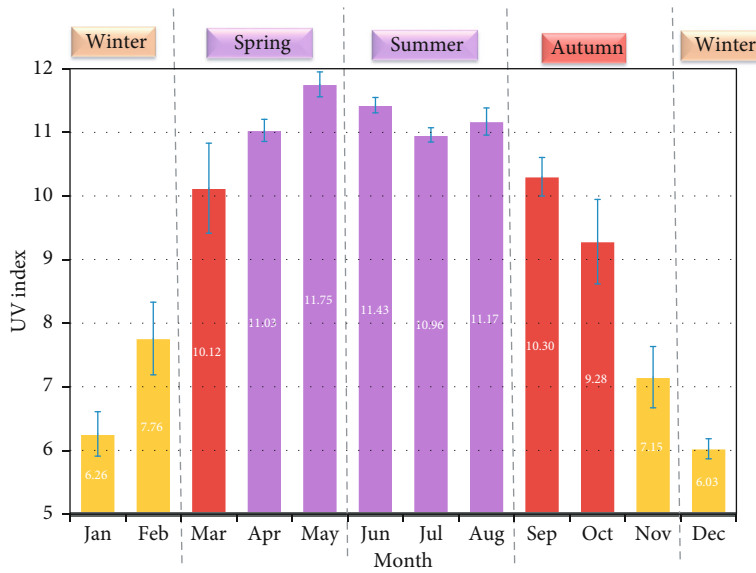

FIGURE 5: Monthly mean UVI on the campus of KAU during the study period.

wished that the UVI was advertised in public places to raise awareness.

3.2. Time-Series Variation in the UVI. Analysis of the daily variation in the UVI at midday (local time) over the KAU campus suggests a slightly increasing trend (IncT) over time (indicated by IncT of 0.5×10^{-4} UVI) (Figure 1) [58]. Variation in the UVI shows a clear annual waveform. Starting in the winter months (i.e., January), UVI increases until it reaches its maximum in the summer (i.e., June) and decreases again to a minimum in the fall (i.e., November).

The highest UVI values were recorded on May 2, 2019, (13.25), and the lowest value was recorded on November 18, 2014 (1.38). According to the categories of UVI (Table 2), 46.60% of the days (4,650) had an "Extreme" UVI, 29.87% of the days had a "Very High" UVI, and 23.53% of the days had a "Low", "Moderate," or "High" UVI. Given the EPA guidelines in Table [53], extra care is needed outdoors for much of the year.

Figure 2 provides a histogram with normal distribution and shows that the average value was 9.54 ± 2.127. Figure 3 shows the daily average variation in the UVI in KAU during

TABLE 3: Analysis of the mean monthly UVI during the study period at KAU.

		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
N		31	29	31	30	31	30	31	31	30	31	30	31
Mean		6.26	7.76	10.12	11.03	11.75	11.43	10.96	11.17	10.30	9.28	7.15	6.03
Std. error of mean		.0627	.1060	.1270	.0318	.0352	.0222	.0202	.0386	.0552	.1191	.0879	.0284
Median		6.177[a]	7.660[a]	9.960[a]	11.03[a]	11.81[a]	11.43[a]	10.95[a]	11.21[a]	10.30[a]	9.41[a]	7.11[a]	6.05[a]
Mode		6.04[b]	6.85[b]	9.56[b]	11.01	11.83	11.40[b]	10.95	11.27[b]	10.41	9.03[b]	6.82[b]	5.83[b]
Std. deviation		.3493	.5707	.7073	.1742	.1961	.1218	.1123	.2147	.3025	.6633	.4812	.1581
Variance		.122	.326	.500	.030	.038	.015	.013	.046	.092	.440	.232	.025
Skewness		.529	.311	-.153	.049	-1.033	.869	1.026	-.515	-.231	-.458	.243	.106
Std. error of skewness		.421	.434	.421	.427	.421	.427	.421	.421	.427	.421	.427	.421
Kurtosis		.147	-.956	-.834	-.989	.531	3.566	1.138	-.434	-1.190	-.548	-.876	-.808
Std. error of kurtosis		.821	.845	.821	.833	.821	.833	.821	.821	.833	.821	.833	.821
Range		1.44	2.01	2.60	.61	.81	.65	.48	.81	.99	2.65	1.91	.57
Minimum		5.63	6.85	8.62	10.72	11.25	11.18	10.78	10.72	9.79	7.66	6.26	5.76
Maximum		7.07	8.86	11.22	11.33	12.06	11.83	11.26	11.53	10.78	10.31	8.17	6.33
Sum		194.1	225.1	313.9	330.9	364.4	342.9	339.8	346.1	309.0	287.8	214.6	186.9
	25	6.065	7.350	9.570	10.89	11.70	11.39	10.90	11.02	10.08	8.715	6.800	5.913
Percentiles	50	6.177	7.660	9.960	11.02	11.81	11.43	10.95	11.21	10.30	9.410	7.110	6.047
	75	6.431	8.272	10.75	11.18	11.88	11.48	10.98	11.30	10.55	9.883	7.603	6.142

[a]Calculated from grouped data. [b]Multiple modes exist. The smallest value is shown.
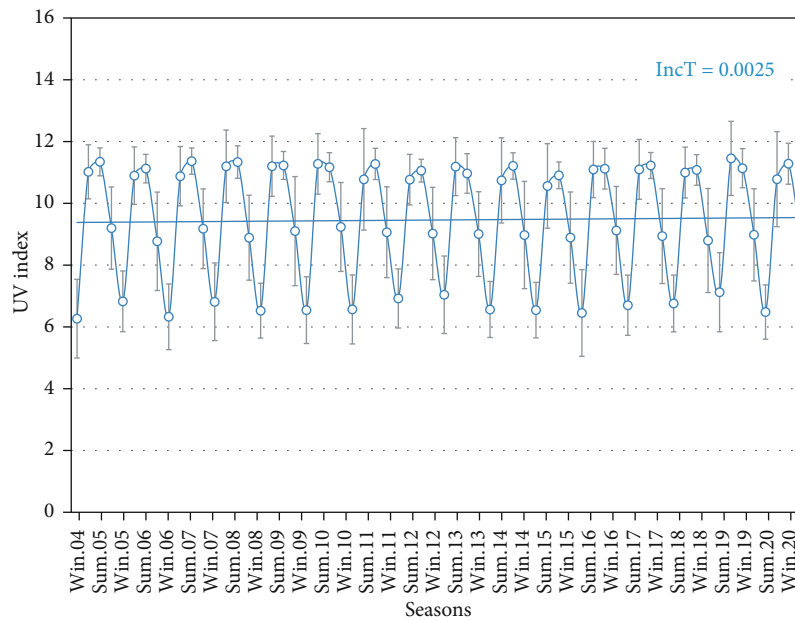

FIGURE 6: Time series variations in the seasonal UVI (with standard deviation error bars) on the campus of KAU during the study period.

the period studied. UVI typically has high values during spring and summer and low values during winter.

3.3. Monthly Variation in the UVI. Examination of the monthly variation in the UVI suggests a moderately increasing trend over time (indicated by IncT of 0.1×10^{-4} UVI) (Figure 4). Figure 5 presents the monthly mean UVI on the campus of KAU during the study period, and Table 3 shows an analysis of the mean monthly UVI during the study period. Several points emerge as follows:
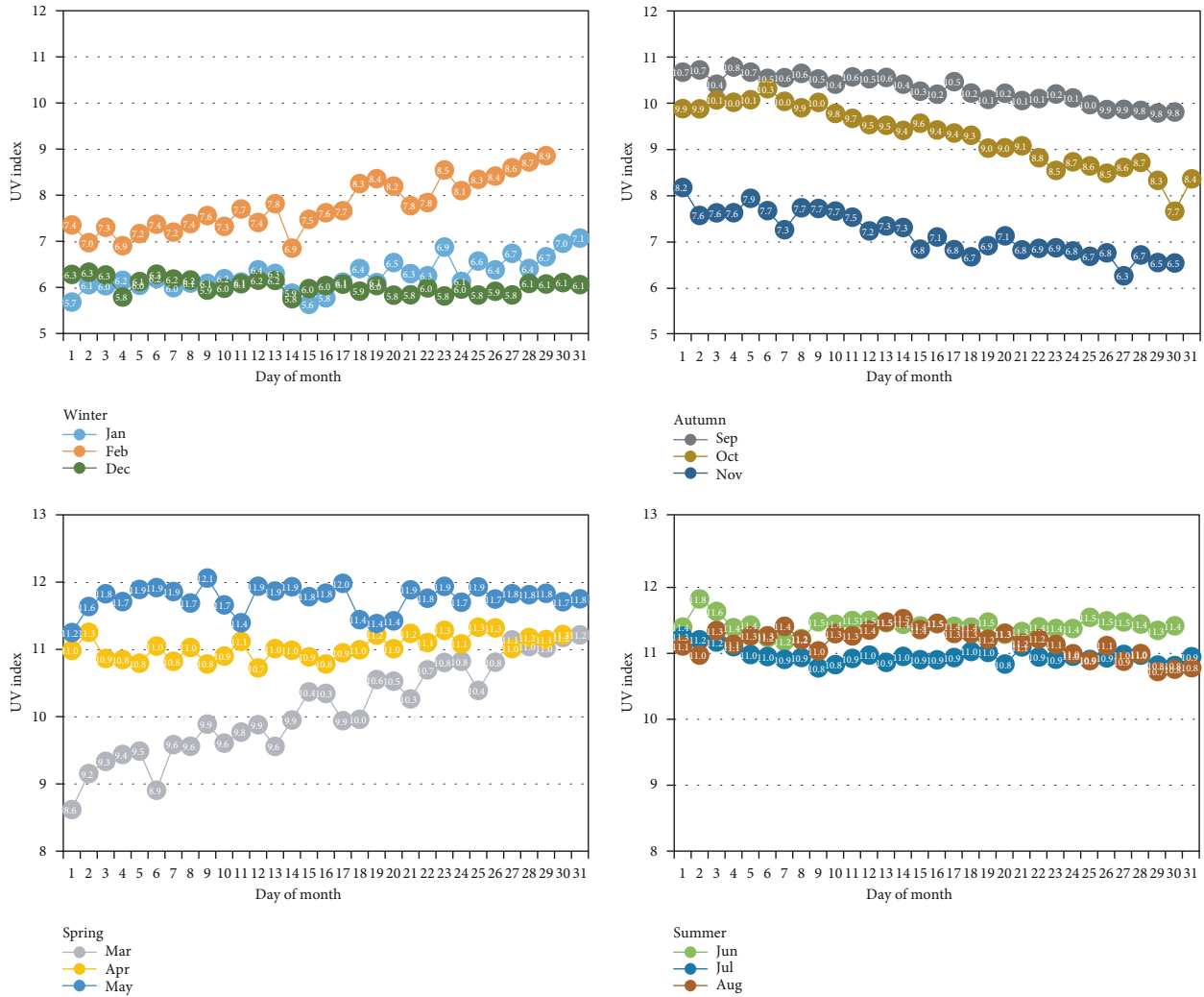
FIGURE 7: Seasonal variations in the UVI on the campus of KAU during the study period.

(1) The monthly average values of the UVI are characterized by relatively high values in the spring and summer months (March to August) compared with the corresponding values in the winter and fall months (September to February)

(2) The maximum average value of the UVI recorded was 11.75 ± 0.196 in May, and the minimum value was recorded in December, 6.02 ± 0.158

(3) The standard deviation of the monthly average values is high March (± 0.7), October (± 0.7), February (± 0.6), and November (± 0.5) compared to the summer months; this can be attributed to climatological and synoptical conditions during the spring and winter months

3.4. Seasonally Variation of UV Index. Analysis of seasonal variations in the UVI suggests a moderately increasing trend over time (IncT $= 25 \times 10^{-4}$) (Figure 6). As illustrated in Figure 7, seasonal UVI trends in Winter (Dec.-Jan.-Feb.), Spring (Mar.-Apr.-May), Summer (Jun.-Jul.-Agu.), and

Autumn (Sep.-Oct.-Nov), the UVI generally decreases in the winter (December and January) and increases in February. In the spring, which is characterized by weather fluctuations (i.e., rainfall and temperature) [59–61], there is a notable difference between the three months of March, April, and May, with May showing the highest values. In the summer, climatic conditions are more stable, and the UVI is almost constant for the whole season. In the fall, September has the highest UVI, as weather fluctuations begin, with further fluctuations in October and November, as can be seen clearly in standard deviation.

3.5. The Box-Whisker Plots for UV Index. Boxplot or box-whisker plots is a method for graphically depicting groups of numerical data through their quartiles. It has also lines extending from the boxes (whiskers) indicating variability outside the upper and lower quartiles The spacings between the different parts of the box indicate the degree of dispersion (spread) and skewness in the data and show outliers. In addition to the points themselves, they allow one to visually estimate the mean value. Seasonal values of UV index at midday
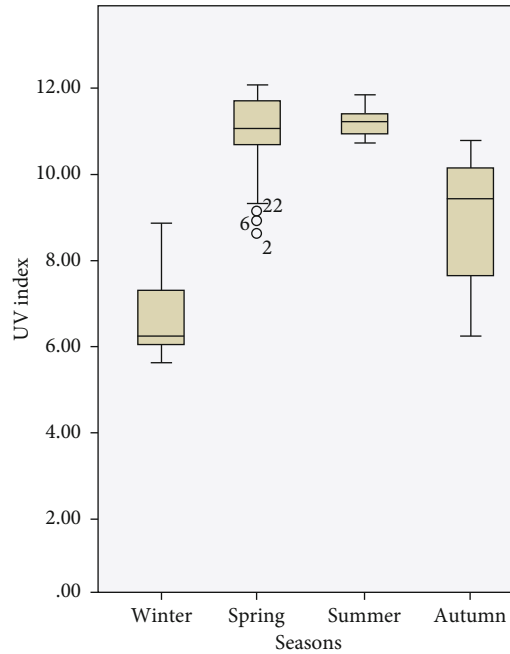
(a)
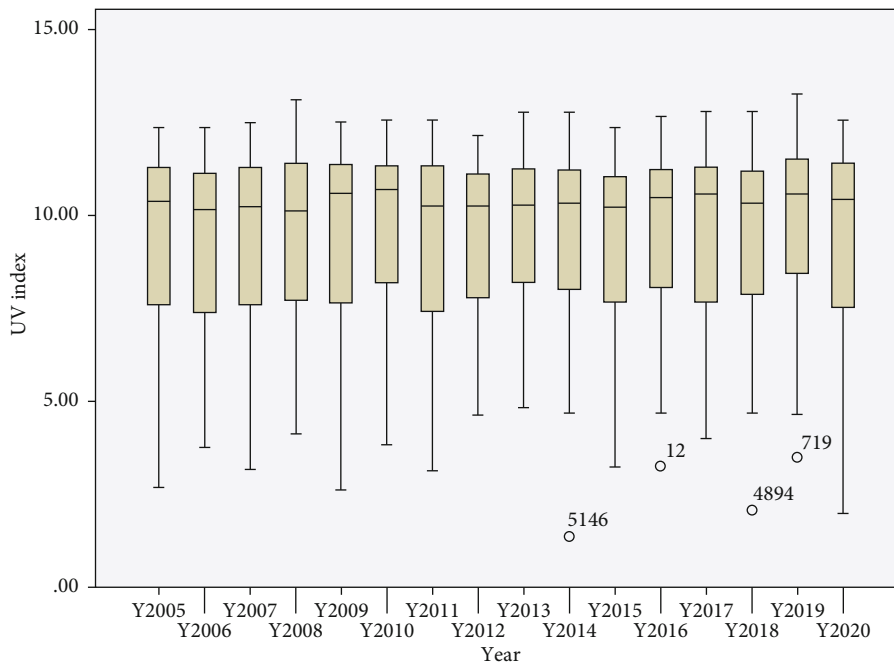
(b)

FIGURE 8: The box-whisker plots for UV index measured by OMI, the 5th and 95th percentiles (whisker), the interquartile range (box), and the mean value (dash in the Box Medill): (a) indicates for each season statistics, and (b) indicates for each year statistics on the campus of KAU during the study period.

(local time) over the KAU campus by box and whiskers diagrams were shown in Figure 8(a). Here, we notice a significant increasing trend from autumn to summer during spring and decreasing again to winter with low degree of dispersion in summer and high degree of dispersion in autumn. In Figure 8(b), it is clear to note that annual boxplot of UV index from year to another was approximately constant, the mean value (UVI $\cong$ 10).

4. Conclusions

OMI (Ozone Monitoring Instruments) satellite products collected over the campus of King Abdulaziz University (KAU), Jeddah, Saudi Arabia, could estimate changes in UV index over a period of 15 years (Oct.2004-Dec. 2020), since there are only limited ground measurements, until now, in order to optimize individual exposure to solar UV radiation, public

health awareness, behavior in outdoor, and planning to sun safety by taken UV index (UVI) into account. UVI values at midday (local time) over the KAU campus suggest a slightly increasing trend (IncT) over time (indicated by an IncT of 0.5×10^{-4} UVI). Variability of the UVI shows an annual waveform. Starting in the winter months, the UVI increases until it reaches its maximum in summer, decreasing again to a minimum in the fall. According to the categories of UVI, 46.60% of the days (4,650) showed "Extreme" UVI while 29.87% showed "Very High" UVI; 23.53% of the days were characterized as "Low", "Moderate," or "High" UVI. From these findings, in the KAU campus, we recommended that

-Future studies should examine the effects of different parameters (such as surface ozone, aerosol, albedo, and cloud) on the UVR reaching the Earth's surface

-The UVI should be reported along with the weather forecast in newspapers, on TV, the radio, and on webpages in affected countries and in different languages

We hope that this study will open the way to greater public awareness in KAU and the Kingdom to encourage safe exposure to the sun by alerting people to the health implications.

Data Availability

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons.

Consent

Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

AA, EE, and SA contributed to the conceptualization. AA, AM, MR, SA, and EE contributed to the methodology. AA, AM, MR, SA, and EE contributed to the formal analysis. AA, AM, MR, SA, and EE contributed to the investigation. AA and A.M. contributed to the resources. AA, AM, MR, SA, and EE contributed to the data curation. AA, EE, and SA performed the writing—original draft preparation. AA, AM, MR, SA, and EE performed the writing—review and editing. AA, AM, MR, SA, and EE performed the visualization. AA contributed to the supervision. AA contributed to the project administration. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

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