ORIGINAL ARTICLE

Prediction of Solar Ultraviolet Radiations Using Random Matrix Theory

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Abstract

Purpose: The correlation of different samples can be described by analytical models such as random matrix theory. In this study, we tried to describe the correlation of different types of ultraviolet values in different months, weeks, and hours to get a significant relationship of special times, which one needs to get enough intensity of the sun or avoid getting sunburn.

Materials and Methods: To this aim, we focused on the hourly and daily mean amounts of ultraviolet A, B, and C intensities of solar radiation in Tabriz urban area were measured during a full year of 2017-2018. We used such ultraviolet values which are measured at the same hour of the day to satisfy the same symmetry criteria which are necessary in random matrix theory. These data are unfolded and classified in different sequences to analyze in the nearest neighbor spacing distribution framework via the maximum likelihood estimation technique.

Results: Strong correlation is yielded for daily values of UVA in comparison with the other types of ultraviolet radiations. Also, we considered the dependence of correlation degrees of these three types of ultraviolet to average temperature and humidity at different months.

Conclusion: The results propose more correlation of UVA indices in August while such correlation of UVC radiations are yielded in December.

Keywords: Random Matrix Theory; Modeling; Environmental Radiation; Ultra Violet.

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1. Introduction

Random matrix theory (RMT) is a research topic of modern mathematics, in which different data can be used in its statistics, including mathematical analysis and probabilities, mathematics, and theoretical physics [1, 2]. This formalism has many applications such as in financial mathematics, number theory, and more in statistics, theoretical physics, biology, and engineering [3-5]. The recent application of RMT is used to characterize the states of brain cognition. These results demonstrated that RMT can effectively apply to capture the intrinsic changes in the brain functional network and is not only a context to predict the universal behavior of different systems such as the brain functional network. The primary purpose of RMT is to help understand the various features of samples with inputs that are randomly drawn from different probability distributions, commonly referred to as random matrix sets [6].

Ultraviolet Radiation (UVR) is a section of the electromagnetic spectrum, which has a wavelength bigger than 100 nm and smaller than 400 nm and it is actually hazardous for health and photochemistry because of energetic photons in this range. The UVR is classified into three parts namely UVA (400-315 nm), UVB (315-280 nm), and UVC (280-100 nm) [7]. Very little UVC reaches Earth's surface due to absorption by the atmosphere. The UVC spectrum, specifically the range of 250–270 nm, is powerfully absorbed by the nucleic acids of a microorganism and damages DNA. The UVB part causes various biological damages such as skin disease, sunburn, and eye diseases. On the other hand, it is also necessary for the synthesis of vitamin D that occurs in mammalian skin [8]. The monitoring of ultraviolet radiation amount and accurate awareness of the accessibility of the solar resource can be beneficial for community health officials to plan the prevention of skin diseases, reduce vitamin D deficiency, and personal radiation protection [9-11]. Because Iran is sufficiently exposed to sunlight, cutaneous synthesis of vitamin D is possible in most months [12]. However, Marzban *et al* revealed the incidence of vitamin D deficiency among the Iranian population with a big sample size [13]. It was revealed that both men and women in all major cities such as residents of Tabriz suffer from vitamin D deficiency [14]. The highly damaging ability of UVR has made the World Health Organization (WHO) recommend its continuous evaluation. Also, studies have shown that almost 90% of the body's need for vitamin D is produced through the absorption of solar UVR in the skin [15]. A correlation between UV values is yielded; one can organize a program for different times of days, weeks, and months to absorb enough sunlight. Such correlation can be predicted via different statistics of RMT.

In the present study, we tried to consider possible correlations of different types of UV indexes. To this aim, the daily and hourly amounts of solar UV (A, B, and C) intensity in Tabriz urban area were investigated during a full year of 2017-2018. Sequences were prepared with measured UV values and analyzed within the framework of the Nearest Neighbor Spacing Distribution (NNSD) and the Maximum Likelihood Estimation (MLE) technique.

2. Materials and Methods

2.1. Ultraviolet Radiation Measurements

Appropriate sensors were used to measure UVA, UVB, UVC, and visible light radiation values, and a hand-held UV-IR lux meter was used to evaluate these radiations. We used the UV-IR- lux meter (Lux-UV-IR meter 666 230, LEYBOLD, Hürth, Germany) for measuring solar UVA, UVB, UVC, and visible light intensity. The calibration was performed by the manufacturer with a sun-like spectrum and the irradiance is evaluated according to the response curves. Tabriz University of Medical Sciences campus was chosen as the measurement station. There was no building at a distance of more than 70 m. Measurements were taken in outdoors and under sunlight, and to avoid the disruption of reflected UVR, the sensors were positioned in a horizontal position at one meter above the ground. Experiments were done daily at a one-hour interval from July 2017 to July 2018. The data were taken three days a week continuously and in varying weather conditions. For each hour, the data were recorded five times in order to diminish the probable error in the measurement [16]. Various analyses are applied to the environmental data; however, the investigation on ultraviolet radiations and their correlations is done for the first time in this study.

2.2. Statistical Analyses by RMT

RMT and its changed statistics are applied to associate the statistical properties of energy spectra and quantum chaos. Due to various limitations of RMT, NNSD is used to describe the statistical situation. Consequently, a combination of different level schemes must happen. Also, to get a sequence of unit mean level spacing, the sequences must be unfolding, which in this study, followed the unfolding procedure given in Refs. [17-20]. Assume we have a sequence of UV values $E_1 \leq E_2 \leq \ldots \leq E$. The integrated (or cumulative) level density is defined as follows (Equation 1):

$$N(E) = \sum_{i=1}^{n} \Theta(E - E_i) \tag{1}$$

Where $\Theta(E)$ is the Heaviside step function. The function $N(E)$ is decomposed into a smooth average part and a fluctuation part (Equation 2):

$$N(E) = N_{av}(E) + N_{fluct}(E) \tag{2}$$

The fluctuation part is used to compare different systems that may have different average behavior. Consequently, in practice, one carries out the unfolding process to get rid of the average smooth part. Technically speaking, one performs a mapping from the old variables$E_i$to the new variable ε_i with $\varepsilon_i = N(E_i)$. In other words, the integrated level density is a straight line in the new variables. The mean spacing is a constant, scaled to unity. The unfolding procedure is by no means unique as it depends on the way the decomposition Equation 2 is achieved.

The $N_{av}(E_i)$ is fixed by taking a smooth polynomial function of degree 6 to fit the staircase function $N(E)$. We obtain finally, the unfolded spectrum with the mapping (Equation 3):

$$\{\varepsilon_i\} = N(E_i) \tag{3}$$

The nearest neighbor level spacing is defined as $s_i = (\varepsilon_{i+1}) - (\varepsilon_i)$. The distribution $P(s)$ will be in such a way that it is the probability $s_i$to lie within the infinitesimal interval $[s, s + ds]$. For systems with time-reversal symmetry which spectral spacing follows Gaussian Orthogonal Ensemble (GOE) statistics, the NNS probability distribution function is estimated by Wigner distribution (Equation 4):

$$P(s) = \frac{1}{2}\pi s e^{-\frac{\pi s^2}{4}} \tag{4}$$

which have been applied to show the chaotic properties of considered spectra. However, the fluctuation properties of non-chaotic systems, i.e., regular systems, follow the Poisson distribution (Equation 5):

$$P(s) = e^{-s} \tag{5}$$

Literature review [21-23] exhibited that the NNS distributions are placed between Poisson and chaotic (GOE) limits. The Abul-Magd distribution is one of the widespread distributions in which it is assumed that the energy level spectrum is a product of the superposition of independent subspectra. This distribution is based on the Rosenzweig and Porter random matrix model [24]. It has a very complicated form, the straightforward form of this distribution suggested by Abul-Magd *et al.* as (Equation 6):

$$P(s,q) = [1 - q + q(0.7 + 0.3q)\frac{\pi s}{2}] \times exp(-(1 - q)s - q(0.7 + 0.3q)\frac{\pi s^2}{4}) \tag{6}$$

The non-correlated and correlated behaviors are described with $q = 0$ and 1, respectively. In this study, the method of Maximum-Likelihood (ML) is used to extract the best-fit of the Abul-Magd distribution's factor, q. This method makes an estimation which is entirely independent from the binning procedure and describes the real statistical position of each sequence because it is straightly used for the raw data. On the other hand, the least square method which supposes independently, identically, and normally distributed samples, makes a deviation from the chaotic limit. Also, the uncertainty of q values is estimated by the Half-Width at Half Maximum (HWHM) of the likelihood distribution which is made of the multiplication of Equation 3 for each sample of the considered sequence. We developed a program in Matlab software to perform exact statistical analyses. The data which are yielded by the experimental measurement are imported into this program and after unfolding, comparison, and finally the extraction procedure, the q values are reported which are known as the statistical measure for correlated or uncorrelated samples.

Here, we used the UV index reported at a special hour of the day as samples with the same symmetry. Our observations began from 6.30 and finished in 20.30. In this way, 42 samples of UVA, UVB, and UVC are yielded for days. These values are grouped for all 365 days of our observation and then categorized into individual sequences. Then, these sequences are unfolded and investigated by Abul-Magd distribution and the MLE method. Meanwhile, the examination of the short sequences yields an overestimation of the degree of correlation of samples measured by the chaocity parameter of Abul-Magd distribution, i.e. q, we would not focus only on the explicit amounts of these quantities and consider an assessment between the amounts of them in different categories and sequences.

3. Results

In the first part of this study, we classified our measured UV index in different times of day in 14 sequences and analyzed it via the MLE technique. The q values of these sequences are listed in Table 1.

Table 1. The chaocity degrees, q values, of different types of UV index in different hours of day. Each sequence has 365 samples

Time Region	q_{UVA}	q_{UVB}	q_{UVC}
6.30 – 7.30	0.57± 0.07	0.41± 0.09	0.29± 0.03
7.30 – 8.30	0.61± 0.05	0.43± 0.14	0.32± 0.07
8.30 – 9.30	0.64± 0.09	0.46± 0.10	0.37± 0.10
9.30 –10.30	0.69± 0.03	0.48± 0.09	0.40± 0.14
10.30–11.30	0.77± 0.08	0.50± 0.06	0.42± 0.12
11.30 –12.30	0.82± 0.11	0.54± 0.09	0.47± 0.11
12.30 –13.30	0.85± 0.14	0.58± 0.03	0.50± 0.12
13.30 –14.30	0.88± 0.10	0.61± 0.14	0.51± 0.03
14.30 –15.30	0.92± 0.12	0.66± 0.17	0.53± 0.09
15.30 –16.30	0.94± 0.09	0.68± 0.08	0.55± 0.11
16.30 –17.30	0.87± 0.11	0.62± 0.14	0.48± 0.07
17.30 –18.30	0.62± 0.04	0.60± 0.10	0.40± 0.10
18.30 –19.30	0.59± 0.07	0.59± 0.09	0.38± 0.08
19.30 –20.30	0.51± 0.08	0.55± 0.14	0.36± 0.05

In the second part of our analyses on UV indices, we grouped all different types of UV indices measured from 6.30 to 20.30 each day for different months. In this way, we got 12 sequences labeled via the name of months and contained 420 samples for different types of UV indices. The results of chaocity degrees of these sequences are listed in Table 2.

Table 2. The chaocity degrees, q values, of different types of UV index in different months

Time Region	q_{UVA}	q_{UVB}	q_{UVC}
January	0.38± 0.11	0.40± 0.12	0.57± 0.03
February	0.42± 0.09	0.45± 0.05	0.58± 0.07
March	0.48± 0.12	0.47± 0.08	0.60± 0.10
April	0.51± 0.06	0.52± 0.11	0.61± 0.14
May	0.52± 0.05	0.63± 0.04	0.72± 0.12
June	0.59± 0.04	0.66± 0.08	0.52± 0.11
July	0.67± 0.11	0.80± 0.11	0.58± 0.12
August	0.81± 0.15	0.88± 0.10	0.60± 0.03
September	0.70± 0.10	0.73± 0.06	0.61± 0.09
October	0.64± 0.09	0.60± 0.06	0.85± 0.11
November	0.61± 0.11	0.72± 0.11	0.81± 0.07
December	0.54± 0.04	0.70± 0.06	0.89± 0.10

To investigate the reason for such behavior, we considered the variation of q values, the chaocity measure, versus average temperature and humidity for these 12 months. We submitted the temperature and humidity of the zone, the measurements of which are done together with UV indices and then, with an average on these values, the average amount of these quantities are yielded. The results are presented in Figures 1a, 1b, and 1c for UVA, UVB, and UVC, respectively.

On the other hand, we considered similar variation versus average humidity for q values of different types of UV radiations in 12 months. The results are shown in Figures 2*a*, 2b, and 2c for UVA, UVB, and UVC, respectively.

In the last part of this paper, we collected all the measured values of different types of UV radiation in days and months of four seasons. These sequences are unfolded and analyzed similarly to the previous parts. The results are listed in Table 3.

Table 3. The chaocity degrees, q values, of different types of UV index in different months

Time Region	q_{UVA}	q_{UVB}	q_{UVC}
Spring	0.61± 0.10	0.55± 0.09	0.44± 0.05
Summer	0.73± 0.05	0.70± 0.10	0.48± 0.06
Autumn	0.54± 0.06	0.52± 0.04	0.32± 0.04
Winter	0.40± 0.03	0.41± 0.06	0.25± 0.12

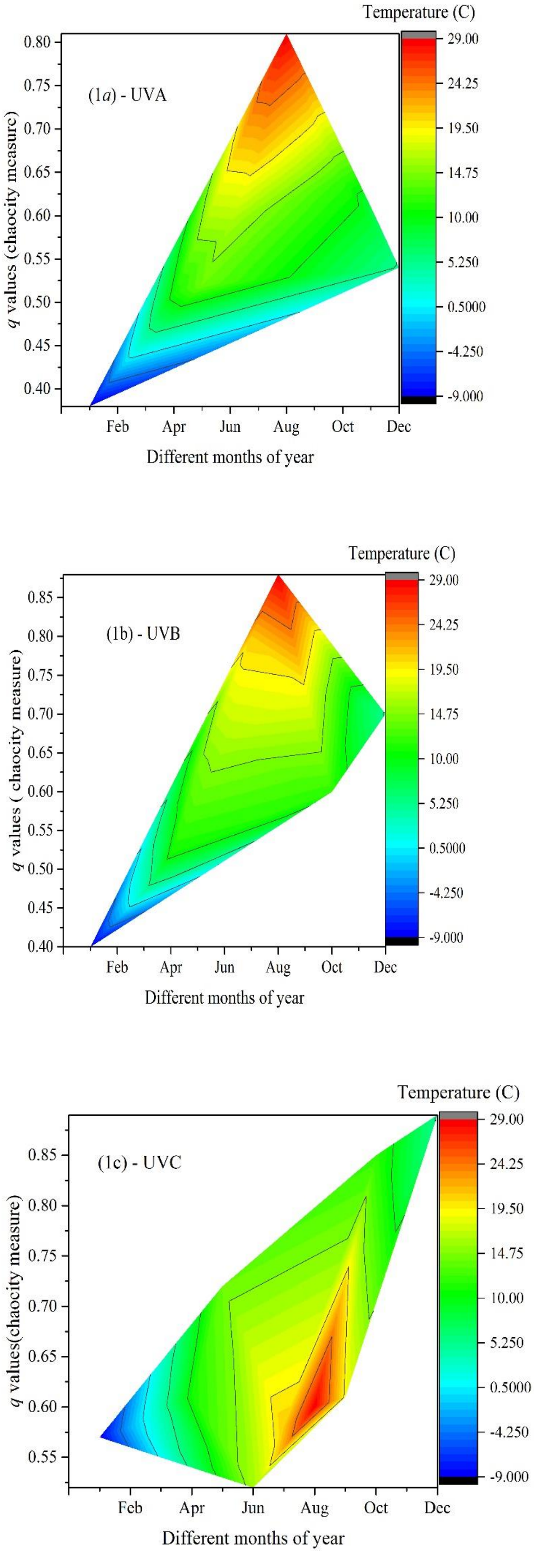

Figure 1. Variations of the q values versus average temperature in different months, a) UVA, b) UVB and c) UVC

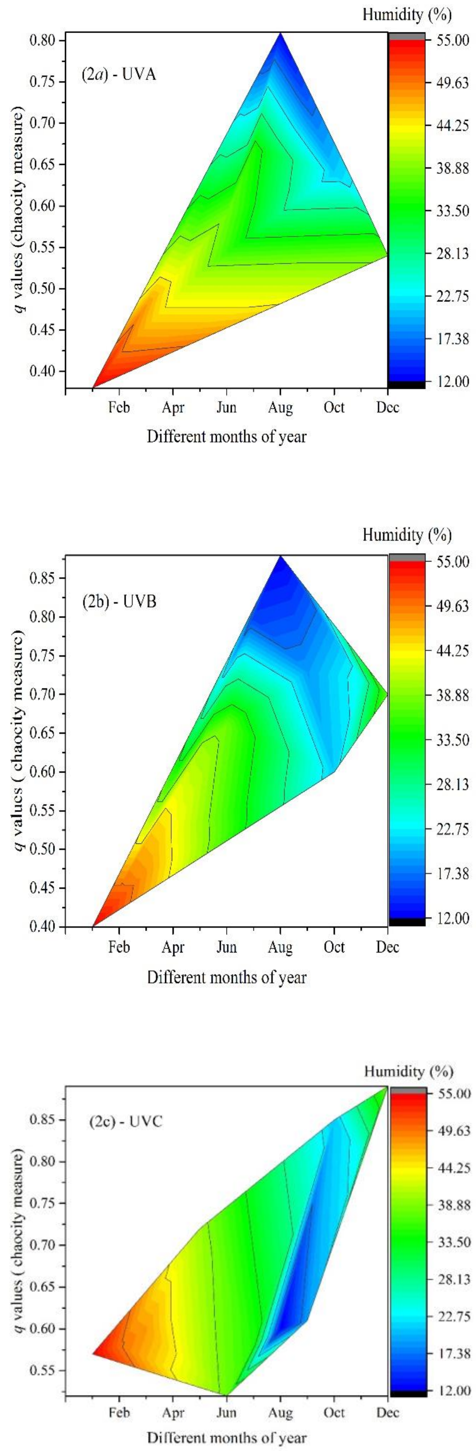

Figure 2. Variations of the q values versus average humidity in different months, a) UVA, b) UVB and c) UVC

4. Discussion

Solar UVR is associated with several meteorological variables and seasonal variations. So, the daily and monthly average of solar irradiance in each location, such as Tabriz, can be recognized as the function of geographic location, season, time of day, humidity and dust, wind speed, participation, atmospheric pressure, and duration of the sun's radiation. Here, we examined the possible correlation between various types of UV radiations using available hourly and daily radiometric data from a whole year study for the first time.

The results of UV index classification and analysis obtained in Tabriz city at different times of the day showed that (i) the maximum correlations are observed in UVA values in comparison with other types of sunlight radiations, (ii) our results suggest the maximum correlation for all three UV-types in the 15.30-16.30 time region, and (iii) the minimum correlations are for UVC indices and especially before 7:30 and after 18:30 o'clock. Results revealed that the proposed theoretical model predicts hourly and daily values accurately. These results can be practiced to organize a program to get enough sun lights from three types of UV radiations at different hours a day. For example, the correlation of UV index in the 15:30-16:30-time region makes this opportunity for such one to be sure of the absorption of similar radiation on different days. The monitoring of UVR amount on the specific surface of the earth is truly important, especially in identifying the specific time of year with the highest and lowest intensity of UV photons. In addition, this can be used in terms of agricultural and health applications and is economically feasible in terms of solar energy. Also, accurate awareness of the accessibility of solar resource for forecasting the avoidance of skin diseases, and the exclusion of vitamin D deficiency can be beneficial for community health officials. Considering the advantages of modeling over measurement, numerous models have been established, and many studies based on these models have been performed to forecast solar radiation [25]. The most frequently desired solar radiation models are based on classical models such as linear [26] and artificial intelligence models [27]. Khorasanizadeh and Mohammadi conducted a comprehensive study to present the best model for forecasting the monthly average UVR over six main cities of Iran. Using long-term data on UVR and other climatological factors, they conducted 11 models taken to predict the monthly average daily UVR. Their results showed that, like the present study, the duration of sunshine hourly data is the best model [25]. In a similar study, Piri *et al*. recommended the Lunberg-Marquardt theoretical model for modeling solar radiation in southeast Iran compared to other experimental models [28].

These results suggest more correlation of UVA&B indices in August while for UVC, we observed such correlation in May and especially between October and December months. An obvious relation between average temperature and correlation of UVA&B indices are yielded. In August when we reported the highest average temperature, we got the maximum correlation of these two types of UV radiations. Also, for UVC indices, the minimum correlation is suggested in January when the minimum average temperature is reported for it. Gholamnia *et al*. evaluated UVR at the national, provincial, and city levels of Iran during the years 2014 to 2018 based on the Ozone Monitoring Instrument (OMI) dataset. They found that the highest erythemally weighted daily dose occurred in June and the lowest was in December. The solar UVA/UVB ratios at the national level during 2005–2019 were significantly lower in the summer [29]. Several studies have been carried out on the measurement of ground-level solar UVR intensity in many areas of Iran, as well as in the Persian Gulf region and neighboring countries [30]. The minimum and maximum mean values of UVA in Kermanshah city also were in December and August, respectively [31]. The highest amounts of UVR (A&B) were found between 13 and 14 o'clock. They are in agreement with the results of comparable studies in the other reigns of Iran [10, 31-35].

In both UVA and UVB radiations, we observed the maximum correlation for such months which the minimum average humidity is reported for them. On the other hand, for UVC radiation, our results suggest opposite dependence between correlation measure and humidity where in January and February months with the maximum average humidity, the minimum correlation is yielded. From these two analyses, one can conclude a maximum correlation of two UVA&B types of radiation in the high average temperature and the minimum average humidity. Also, the cold weather and high humidity, increase the correlation of UVC- type of radiations. These results together with the reports on the average weather of Tabriz, cold winter and dry summer, are in agreement with our results in the previous section. UVA&B values show a maximum correlation in the summer which is the maximum average temperature and minimum average humidity reported for it. Also, the results of UVC in winter, non-correlated results, may be yielded due to the lack of enough non-zero results in this season. The effect of the day length and the interval of recording of UV indexes is a possible issue in their intensities and therefore, their statistical properties. To investigate this subject and study the statistical correlation, we take into account the total amount of UV radiations for the time period between sunrise and sunset in future studies.

5. Conclusion

Here, the fluctuation properties of different types of ultraviolet radiation were investigated via nearest neighbor spacing statistics of RMT. Using all the measured values between the 6.30-20.30-time region in 2017-2018 year in Tabriz, different sequences are equipped and then, the MLE method is engaged to approximate the chaocity parameter with more accuracy. The difference in the chaocity parameter of each category is statistically significant. The correlation of UVA is more than other types of sum light radiations in the sequences constructed with samples measured at different times of a day. Also, we consider the correlations of different UV types in different months and also their dependence on average temperature and humidity.

Results show a different tendency of these three types of UV radiations versus temperature and humidity while, the most correlation of UVA&B are observed in August but for UVC indices, such correlation is reported in December. The results of these studies are completely depending on our observations in this special zone and one can apply similar considerations in different areas. Such analyses make it possible to predict conceivable radiations in different hours, days, months, and seasons, and therefore, one can plan for the amount of vitamin D absorbed by the human body or the working hours of solar thermal power plants.

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