A simplified method for infrared and ultraviolet solar radiation analysis in Riyadh, Saudi Arabia

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ABSTRACT

The present work describes a simplified method for field data which include total, direct, infrared (IR) and ultraviolet (UV) solar radiation in Riyadh for the period from 1982 to 1992. Four dimensionless parameters namely A_d, A_t, B_d *and* B_t *are considered to study the daily, monthly and yearly variations. Two normalized parameters for UV and IR are also introduced. The observed variations in UV and IR together with their implicit and normalized parameters enable us to a better understanding of some environmental effects in the region such as UV/IR scattering, UV/IR reflection, clouds, ozone, and temperature.*

KEYWORDS: Ultraviolet, infrared, solar radiation measurement, environmental effects, Riyadh, Saudi Arabia

INTRODUCTION

The importance of infrared (IR) and ultraviolet (UV) solar radiation is becoming a vital subject in recent years, it is recognized that field measurements for solar radiation are needed in several research areas such as renewable energy (solar-thermal and photovoltaics), environmental and biological studies. The solar radiation traversed the earth's atmosphere is in the form of electromagnetic waves that include cosmic rays, gamma rays, x-rays, ultraviolet rays, visible light, infrared rays and radio waves. Atmospheric conditions make the solar radiation to be 9% ultraviolet, 45% visible and 46% near infrared. Considerable works in the visible-light bands had been published; and a lot of studies had been published for ultraviolet, but less for infrared radiation, (Giese, 1976, WHO, 1977). The importance of infrared and ultraviolet of the electromagnetic spectrum urged to record and analyze to find its effects on climate, environment, pollution, communication, industrial materials, human health and other biological systems, (Merrigan, 1980, McMaster, 1980, Al-Ayed and Elani, 1998). The solar radiation that reaches the earth's surface is given by Lambert-Beer-Bourgeur extinction law:

$$I(\lambda) = I_o \ e^{-m\,\delta(\lambda)} \qquad (1)$$

Where I_0 and I are the spectral solar irradiances outside the atmosphere and at the earth's surface respectively, m is the relative air mass, and is the total optical thickness or depth (including all relevant atmospheric constituents). Thus, it is possible to deduce the ozone column, water vapor content, nitrogen oxide amount, atmospheric turbidity, solar ultraviolet, infrared spectrum, and aerosol optical depth at any specific location.

The ultraviolet solar radiation (UV) covers wavelengths ranging from about 100 nm to nearly 400 nm. The UV is partially absorbed in the stratosphere. The ozone shield, an important constituent of the stratosphere that results from the photochemical reactions of O with UV radiation, converts the high-energy UV radiation into thermal energy, which raises the

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ultraviolet A (UV-A), the ultraviolet B (UV-B) and the ultraviolet C (UV-C). The last one, being highly destructive to life (biological) it is absorbed by ozone and only a little or none reaches the surface of the earth. The UV-B or the so-called active UV radiation is important because of its long-term damaging effects on materials and biological systems, (Katsmbas et al 1991). More than 40% of UV is available at the ground level in the direct - beam of solar radiation and 60% of UV is, thus, available within the diffuse radiation, (Klein and Goldber, 1978). On the other hand, it is well known that the clear day's ozone measurements are used to predict the UV-radiation received at the earth's surface (Koller, 1965). It was also shown by (Varotsos et al., 1998) and on the basis of satellite sensor data that the active UV radiation increases by 35% during 1986 -1992 periods, while the total ozone amount decreases by nearly 10% during the same period at Dundee in Scotland. Furthermore the ratio of UV increase to ozone concentration decrease was at maximum in July, showing that a small percentage decrease in total ozone column during summer leads to a large percentage increase in the UV radiation reaching the ground. Moreover UV data is constantly monitored for environmental and biological purposes. For instance, the interpretation of the on-line UV information is currently very useful technique to determine the variation of accumulated UV-dose with solar time (i.e. the unit of UV-dose is MED, Minimal Erythemal Dose), Solar light Co. (2000), Morys and Berger (1993).

Infrared radiation (IR) has many practical and scientific applications, including physico therapy, medical diagnosis, thermovision technique, vibrational spectroscopy, and sensors and detecting devices, temperature control, meteorology and military instrumentation. Temperature and IR simulation are also studied for vehicles (hot bodies) in order to establish the 3-D transient IR radiation model, (Xuan et al., 1998). As an example, the analysis given by Udo and Aro (1999) for IR radiation in Horin-Nigeria shows that it was almost uniform throughout the year with the exception of the relatively small values in the winter; they also showed that the seasonal variations of IR radiation illustrate that IR levels are relatively low in the dry season months especially in December and January, and therefore, seem to indicate the dryness of the atmosphere during this period, and thus IR data could also be used as an index of the moisture content of the atmosphere. A Japanese research group at the Osaka Life Science Electronics Institute shows that the low temperature infrared radiation (i.e. middle IR wavelengths 3000-5000 nm) should always be investigated in the tropical forests, (Minato et al., 1998). The remote sensing is also recommended for new satellite tasks in order to improve the accuracy of the IR data measurement, (Boyd et al., 1999).

A descriptive study for UV and IR variations presented in this work together with the fractional fluctuations of UV and IR in Riyadh area is based on almost ten years recorded data covering the period from 1982 to 1992 To understand the environmental effects such as UV/IR scattering, UV/IR reflection, clouds, ozone, and temperature, four dimensionless parameters and two normalized parameters will be defined implicitly to include the fractional values of UV and IR levels based on direct - beam and total - global solar radiation.

MEASUREMENTS AND THE METHOD OF ANALYSIS

Measurements of several meteorological parameters were carried out at the Solar Village (Latitude 24^{o} 34'N, longitude 46^{o} 43'E and altitude 620 m) which is 40 km northwest of Riyadh city the capital of Saudi Arabia. This site is a research station under the supervision of Energy Research Institute at King Abdulaziz City for Science and Technology (KACST). The recorded data were monitored continuously for nearly ten years. These data include the total - global irradiance (300 – 2800 nm) which was measured with Eppley precision spectral pyranometer, the direct - beam normal irradiance (400 – 1100 nm) was measured using

Eppley normal incidence pyrheliometer, the ultraviolet rays (290 – 390 nm) was measured with Eppley total UV radiometer, the infrared irradiance ($4x10^3$ – $50x10^3$ nm) was also monitored with the Eppley precision infrared radiometer. The wind speed, wind direction, ambient temperature and relative humidity were also stored using Climatronics assembly, and the sunshine hours were measured with Campbell-Stock spherical glass. All solar (total-global), UV and IR measuring instruments were interfaced with a typical data acquisition system (DAS) which was programmed to record the average maximum and minimum output signals from each instrument or device every 10 minutes, and then a computer program is used to store readings in (Wm^{-2}) between sunrise and sunset; hourly, daily and monthly. Most of the recorded data were tabulated, analyzed and plotted except the missing or sudden errors in the data due to equipment/sensors, rain and some other electrical faults. Equipment calibration and data check-up procedure was also considered throughout the experimental work. It is estimated, however, that the accuracy of the recorded data using the field's equipment and the calibration procedure lies within %. Recent measurements are also initiated based on new equipments to improve the accuracy of the recorded data, and to verify the present analysis. The new equipment (digital and analogue) includes a number of UV sensors obtained from the UVP British Company, (UVP, 2003). Due to the nature of data and its variations, it was decided to make a simple analytical method; that involves the determination of four dimensionless analytical parameters A, A, B and B_t which are defined as follows:

$$A_d = \frac{I_{UV}}{I_d} , \quad A_t = \frac{I_{UV}}{I_t} \qquad (2, a)$$

$$B_d = \frac{I_{IR}}{I_d} , \quad B_t = \frac{I_{IR}}{I_t} \qquad (2, b)$$

Where I_d is the direct - beam radiation, I_{UV} is the ultraviolet radiation, I_{IR} is the infrared radiation, and I_t is the total - global radiation. Thus, A_d and A_t will give the fractional UV levels based on direct - beam and total - global radiation respectively, whereas, B_d and B_t parameters include the fractional IR levels under direct - beam and total - global radiation throughout the day, the month and the year. Two normalized parameters A_n and B_n are also included here as follows:

$$A_n = \frac{(UV)}{(UV)_{max}} \qquad (3, a)$$

where $(UV)_{max}$, $(IR)_{max}$ are the highest values of UV and IR respectively in a certain day or month or year.

RESULTS AND DISCUSSION:

The ultraviolet (UV) levels: A_d and A_t variations

The recorded data were initially plotted for both daily and monthly variations. It is noted that the daily variation of the UV-level is always very changeable, whereas the average monthly variation indicates smoother curves. The average UV levels varied from 15 to 35 W/m^2 in most years, and its variation behavior is very similar to the total solar radiation. Typical daily and monthly readings for UV, direct - beam and global solar radiation are listed in Table 1, 2, 3 and 4 respectively. Due to data fluctuation, it was decided to generate analytical graphs in order to see the behavior of the two dimensionless parameters A_d and A_t for both daily and monthly variations. It is found that A_t is more stable than A_d as shown in Fig. 1. These variations are differing hourly depend on the sun's position in the sky. Solar geometry including azimuth and sun elevation angles has a major effect on climate and seasonal changes as reported recently by Elani (2006). Such changes are existed from day to day, month to month, and thus from year to year. Fig. 1 shows also the presence of one peak A_d while A_t is at minimum. This could be explained from the fact that various atmospheric factors will affect strongly the direct – beam irradiance, and thus reducing A_t values accordingly.

Table 1. Daily variation of total, direct and UV solar radiation in Jan 1986, Riyadh, Saudi Arabia

Day	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	823	454	13
2	780	33	13
3	841	514	14
4	836	673	14
5	780	743	12
6	783	767	13
10	761	517	13
12	828	420	14
15	852	589	15
16	1025	658	17
18	910	462	15
21	929	635	16
22	859	752	15
24	694	372	10
29	816	695	14
30	416	30	8
31	810	197	15

Table 2. Average monthly variation of total, direct and UV solar radiation in the year 1985, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	UV (Wm^{-2}) I_{UV}
1	960	615	37
2	966	665	37
3	1026	649	39
4	976	596	34
5	1015	469	37
6	1002	589	37
7	998	632	36
8	970	614	35
9	959	636	34
10	926	742	32
11	824	676	26
12	736	724	24

Table 3. Average monthly variation of total, direct and UV solar radiation in the year 1987, Riyadh, Saudi Arabia

Month	**Total (Wm^{-2})** I_t	**Direct (Wm^{-2})** I_d	**UV (Wm^{-2})** I_{UV}
1	743	789	28
2	813	795	23
3	923	681	24
4	938	788	26
5	915	689	25
6	875	739	26
7	987	732	38
8	1002	771	38
9	958	783	28
10	835	836	24
11	762	753	20
12	682	734	16

Table 4. Average monthly variation of total, direct and UV solar radiation in the year 1989, Riyadh, Saudi Arabia

Month	**Total (Wm^{-2})** I_t	**Direct (Wm^{-2})** I_d	**UV (Wm^{-2})** I_{UV}
1	1100	923	18
2	1120	927	22
3	1131	892	23
4	1120	899	42
5	1110	870	30
6	875	896	29
7	866	778	28
8	898	813	27
9	937	721	25
10	924	766	20
11	1028	849	16
12	1051	793	17

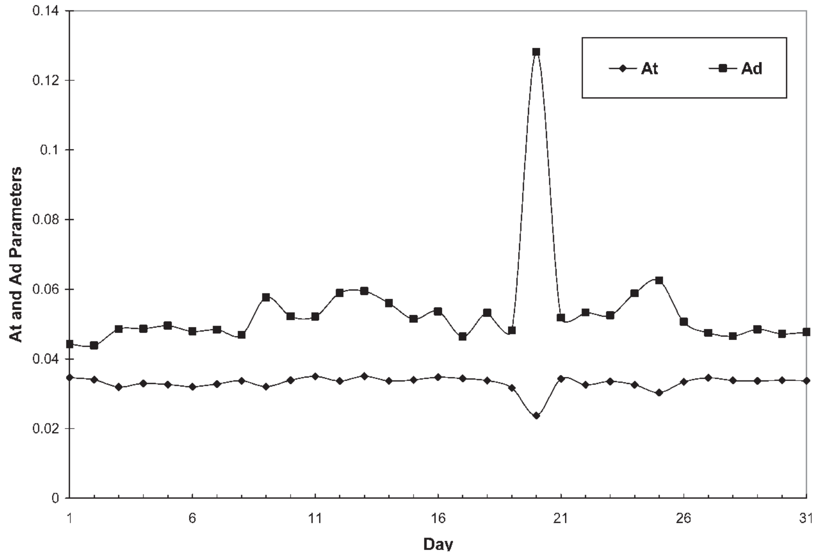

Figure 1. The daily variation of At and Ad parameters. Aug. 83.

The parameter A_d can also peaks more than one time in a complete month where A_t is nearly constant. The normalized A_n values are given with a typical example in Fig. 2. This graph shows a better presentation of UV data for weather measurements and research work purpose.

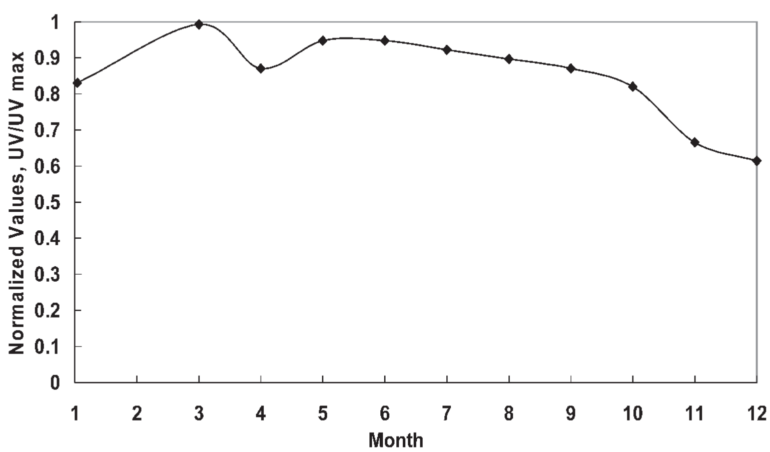

Figure 2. The monthly variation of normalized values UV/UVmax, year 92.

The infrared (IR) levels: B_d and B_t variations

A similar trend is also resulted for daily and monthly IR radiation as illustrated in Tables 5 and 6 respectively. Fig. 3 shows the daily variations of B_d and B_t in Feb. 83. The two parameters are behaving similarly throughout the whole month except that parameter B_d is showing a strong peak at day number 15 and two peaks at day numbers 6 and 26 respectively. Similarly, the variation of daily-normalized values of B_n is given in Fig. 4.

Table 5. Daily variation of total, direct and IR solar radiation in Dec 1990, Riyadh, Saudi Arabia

Day	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	IR (Wm^{-2}) I_{IR}
1	875	941	536
2	867	947	542
3	877	952	555
4	831	930	544
5	742	927	557
9	897	1024	534
10	805	996	549
14	762	996	552
15	803	981	547
19	754	969	555
20	707	944	549
22	694	947	552
26	752	959	547
27	784	960	555
30	726	951	560
31	720	950	540

Table 6. Average monthly variation of total, direct and IR solar radiation in the year 1991, Riyadh, Saudi Arabia

Month	Total (Wm^{-2}) I_t	Direct (Wm^{-2}) I_d	IR (Wm^{-2}) I_{IR}
1	650	923	310
2	665	1026	310
3	649	976	364
4	596	1015	407
5	469	1002	390
6	589	996	328
7	632	970	441
8	614	959	443
9	636	926	443
10	742	624	419
11	676	736	202
12	724	740	306

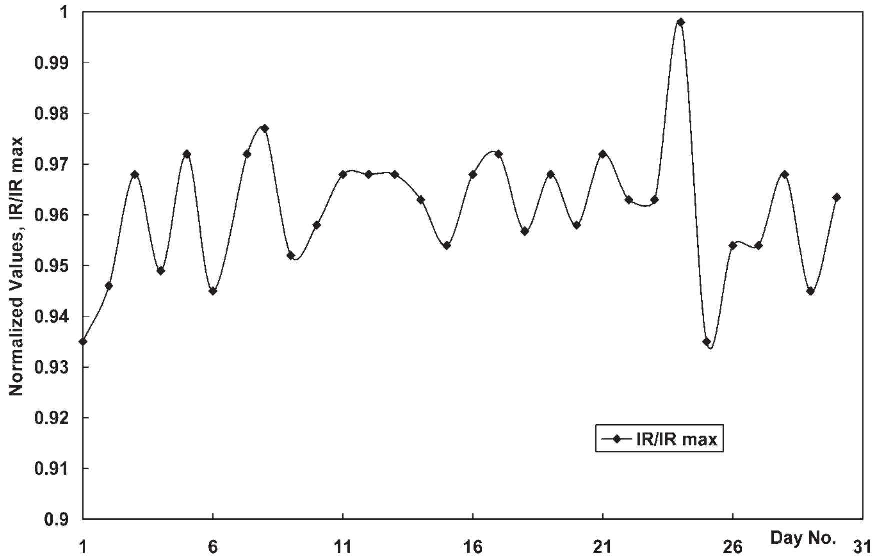

Figure 3. The daily variation of normalized values of IR/IRmax, June 1990.

The results reported here could be explained from the fact that the infrared radiation near the earth's surface is available at a higher level more than the ultraviolet radiation. Solar radiation and other heat sources on ground such as cars, buildings and roads seem to contribute considerably in the infrared radiation levels in Riyadh region. The environment and pollution are also other important factors affecting the infrared levels. Therefore, multiple peaks mean that the accumulated environmental effects could affect the distribution of infrared radiation in Riyadh. Thus B_d, B_t curves give a direct indication on the amount of daily IR levels and its distribution during the month of the year.

AVERAGE YEARLY VARIATIONS FOR THE ANALYTICAL DIMENSIONLESS AND NORMALIZED PARAMETERS

As mentioned earlier, the average daily values for both A_d and A_t lie between 0.035 to 0.06. Similarly, the average daily, monthly and annual values of B_d and B_t are at higher levels (0.35 to 0.65). It is also clear that the parameters A_t and A_d are fairly stable with $A_t < A_d$ in all studied years between 1982 – 1992. Their average values are 0.05 and 0.09 for A_t and A_d respectively. Furthermore, B_d values are always higher than B_t from 1982 to 1992. Thus, the highest parameter among others is B_d, which represents the fraction of infrared radiation. The yearly variation for these analytical parameters is summarized in Fig. 5. These curves may change from area to area and from one country to another, and are fully dependent on environmental and industrial activities such as air pollution, aerosol loading, and aerosol optical properties, (Sadler, 1992), (Mujahid, 1994, Alnaser, 1997, and Robaa, 2004). Moreover, it is important that these parameters become very sensitive when a sudden decrease in solar radiation accompanied with increased atmospheric effects. Thus, these parameters are believed to be simple indicators, which can be suitable for various solar radiation research studies.

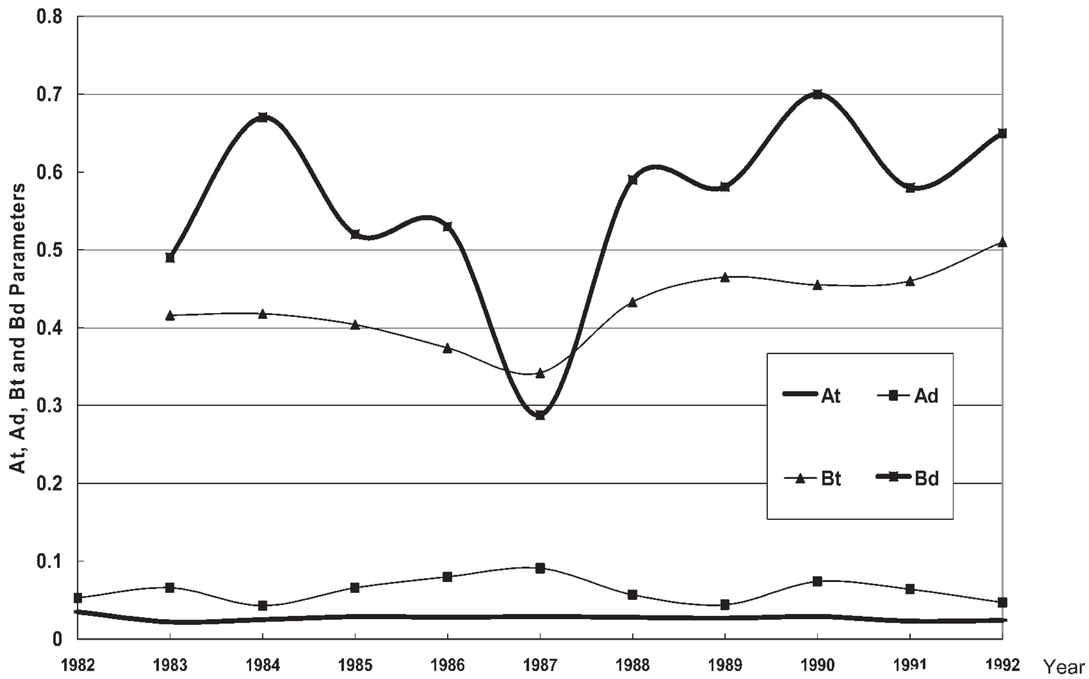

Figure 4. The annual variation in the analytical dimensionless parameters for Riyadh, Saudi Arabia.

ENVIRONMENTAL EFFECTS

It is also suggested to apply the present analysis on other locations in Riyadh, and in particular, in industrial areas, highways, crowded traffic junctions and near electric power stations. Several research projects are already underway to take these considerations into account for measuring both UV and IR radiation simultaneously. Based on earlier works by (Smith, 1996) and (Al-Dhafiri et al., 2000), the present analysis indicates that the UV and IR radiation interact with the atmosphere and the earth's surface through the following considerations:

1. **UV/IR scattering:** the UV radiation is scattered in the atmosphere more than the visible light and this will result in UV effects from both direct solar radiation and a scattered radiation from the sky. Also industrial pollutants or aerosols from natural sources can reduce the amount of UV radiation and increases the IR levels rapidly.
2. **UV/IR reflection:** UV radiation is reflected well by surfaces such as sand. Thus a high level of UV is expected in this environment. Similar trend could be adopted for IR radiation in such dry weather in Riyadh region.
3. **Clouds:** The clouds are usually attenuate UV radiation. It is believed that clouds affect UV levels in wet seasons (eg. Dec. and Jan.) in Riyadh area.
4. **Effect of ozone:** the effect of ozone on the intensity of UV at the earth's surface depends on the sun altitude (solar angle). It is possible to see this effect during the summer and winter seasons.
5. **Temperature effects:** although temperature has no direct effect on UV levels reaching the earth, it does indirectly affect through the over-exposure to UV solar radiation. Whereas IR levels are highly dependent on the surrounding temperature. This is easily realized in certain locations such as highways, crowded junctions

and populated areas, where the higher IR levels are indicating to hot and dry weather throughout the year in Riyadh.

CONCLUSION

A simplified method is presented to include four dimensionless parameters A_t, A_d, B_t and B_d and two normalized parameters A_n, B_n respectively. It was found that the sensitivity of A_d and B_d has larger values than the nearly stable A_t and B_t values due to sudden changes in the direct - beam solar radiation. It is believed that the present simple method could be applied to different locations in the middle - east and other regions. Finally the present work gave a better understanding of UV/IR effects on environment, but more emphasis on weather data and quantitative studies are still required to include the atmospheric or/and climate considerations.

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طريقة تحليلية مبسطة للأشعة تحت الحمراء والأشعة فوق البنفسجية – الشمسية في الرياض، المملكة العربية السعودية

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ملخص

يتناول البحث الحالي طريقة مبسّطة لتحليل البيانـات المسجلة (10 سنوات متتالية) للإشعاع الشمسي بما يحتويه من مكونات كالإشعاع الشمسي الكلي، والإشعاع الشمسي المباشر والأشعة تحت الحمراء IR، والأشعة فوق البنفسجية – الشمسية UV في منطقة الرياض. تتضمن هذه الطريقة استخدام أربعة عوامل كسرية يُرمز لها A_d ، A_t ، B_d ، B_t وذلك بهدف دراسة توزع الإشعاع الشمسي ومكوناته المختلفة من خلال التغيرات اليومية والشهرية والسنوية. كما تم إدخال عاملين آخرين لكل من الأشعة فوق البنفسجية والأشعة تحت الحمراء. لقد ساعدت الطريقة الواردة في هذا البحث على فهمٍ أفضلٍ للتغيرات البيئية في المنطقة المدروسة وخاصة تغيرات الكسور الإشعاعية $\frac{UV}{IR}$ في مجال انتشارها أو انعكاسها وذلك من خلال تأثيرها على توزع الغيوم وطبقة الأوزون ودرجات الحرارة.