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Modeling Environmental UV and Gamma Radiations for Health Protection

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Abstract

Background: Recently, increasing exposure to radiations such as ultraviolet (UV) and gamma has led to growing incidence of different types of cancer and damage to aquatic and terrestrial ecosystems. Studies have shown that natural features such as latitude, elevation, weathering, local pollution, cloudy cover and earth surface play a remarkable role in distribution of UV and gamma radiations. In this regard, modeling and predicting UV and gamma rays distribution in each region is necessary.
Objectives: The purpose of this study was modeling environmental UV and gamma radiations in Gonabad city, Iran.
Methods: In this cross-sectional study, for modeling environmental UV and gamma radiations, several stations in Gonabad city were selected. Distance between two stations was 5 km, and a total of 1800 samples were collected from the considered region. UV and gamma radiations were detected by radiometer and survey-meter, respectively. In the end, data were modeled by Kriging model in GIS 10.3 and MATLAB software programs and their relationships were analyzed by performing *t*-test and ANOVA in SPSS version 16.
Results: The predicted values for UV and gamma ranged from 0.03 to 1.829 Wm^{-2} and from 0.08 to 0.42 mSv, respectively. The highest UV and gamma doses were observed in the southwest region of Gonabad city. Minimum mean square error (MMSE) in GIS model related to UV and gamma were 0.24 and 0.02, respectively. Based on MATLAB, distribution of UV and gamma radiations showed high and low scattering, respectively, versus elevation and latitude. The most permanent weather condition for the measured UV and gamma radiations was sunny condition. Weather conditions had a significant ($P < 0.001$) and insignificant relationship ($P > 0.001$) with UV and gamma radiations, respectively.
Conclusions: Integration of Kriging and MATLAB models led to obtaining more valuable estimates and maps about distribution of UV and gamma radiations from solar and terrestrial resources and weather conditions in a large region. These models showed that the population residing in mountainous areas received higher doses of UV and gamma radiations.

Keywords: Environmental Radiations, Modeling, Elevation, Latitude, Weather Condition, Gonabad, Iran

1. Background

Due to concerns about public health and environmental protection, it is suggested to measure ultraviolet (UV) and gamma radiations. The most common sources of UV and gamma radiations are natural resources (1, 2). UV radiation related to human exposure ranges between 290 and 400 nm, which has both positive and adverse health effects. Low doses of UV are sufficient to enable calcium and phosphorous metabolic regulation. Due to insufficient UV absorption by human body, approximately 50% of the world's population suffer from vitamin D3 deficiency. This deficiency has been associated with increased rates of osteoporosis, cardiovascular diseases and cancers (3, 4). Excessive UV exposure can induce erythema (sunburn) and melanogenesis (suntan), and in the long run, it can lead to premature skin aging, cataract and cancer (5).

Elevation, latitude, zenith angle of the sun, cloud cover, ozone thickness, air pollution and surface reflectance (albedo) also influence UV irradiation substantially. Some of these factors are interrelated, making the assessment of their individual effects difficult. The impact of latitude has been evidenced in epidemiological studies around the world, indicating a negative association between latitude of residence and incidence of melanoma or mortality. Outdoor activities in mountainous areas entail, for workers and receptionists alike, a particularly increased risk of overexposure to UV radiation (5).

Moreover, UV and gamma radiations are emitted from radioisotopes existing in the earth. All the building materials made from rocks and soils contain natural radionuclides of uranium (^{238}U), and thorium (^{232}TH) series and the radioactive isotope of potassium (^{40}K) (6-8). These radionuclides release gamma radiation. Globally, the average natural radiation dose received by humans is almost 2.4 millisievert (mSv) per year. This is four times the worldwide average for artificial radioactive exposure (0.6 mSv per year). However, due to greater access to medical imaging in the US and Japan, the average dose of artificial exposure is greater than natural exposure in these countries. Natural background radiation in different regions is varied, for example the average radiation in the UK and Finland is 2 mSv and 7 mSv per year, respectively (9). The International Atomic Energy Agency states: "exposure to radiation from natural sources is an inescapable feature of everyday life in both working and public environments. This exposure is in most cases of little or no concern to the society, but in certain situations the introduction of health protection measures needs to be considered, for example when working with uranium and thorium ores and other naturally occurring radioactive materials (NORM). These situations have become the focus of greater attention by the agency in recent years".

So far, several studies have been conducted on UV and gamma radiations in Iran and other countries. For example, Fattahi Asl et al. (10) and Hokmabadi et al. (11) measured the amount of UV radiation in Ahvaz and Bojnurd cities, respectively. Based on their results, the highest UV was detected in near-noon hours and summer season in Ahvaz and Bojnurd (with maximum and minimum 12 and 2 Wm^{-2}), respectively. In 2008 in New Zealand, it has been cleared that radiation exposure in those working in outdoor environments was 32 wm^{-2} that was higher than the standard threshold (10 Wm^{-2}) (12). Regarding gamma radiation, study of Samadi et al. in Hamadan, Iran, showed that the mean of gamma radiation from natural background in indoor and outdoor places was 0.83 mSv that was higher than its threshold level (0.5 mSv) (13).

In Iran, information related to environmental UV and gamma radiations is very limited. Although there are some useful local studies on UV and gamma radiations, there is a lack of a generalist model over a relatively large area to predict UV and gamma radiation distribution. To solve this problem, integration of GIS and MATLAB models is used (14).

Kriging model in GIS is used to interpolate the probability surfaces that will have the best fitness with a scattered set of UV and gamma radiations and weather condition in a two dimensional space (15). GIS application aims at establishing a database of environmental UV and gamma radiations for reference purposes. This database is necessary for researchers, decision-makers, and the community as a whole, to preserve and sustain a healthy environment for future generations. Also, MATLAB is used in a variety of areas, including signal and image processing, control system design, earth and life sciences, finance and economics, and instrumentation. Because the data is stored in matrices of multiple dimensions, quick data access in 2D, 3D and 4D is also possible (5).

2. Objectives

For critical management of positive and negative effects of environmental UV and gamma radiations on human health and real mapping of them over a large area, it was necessary to model the environmental UV and gamma radiations by GIS and MATLAB models in Gonabad city.

3. Methods

Gonabad is a city located in south of Khorasan Razavi province at latitudes 34° 3' - 34° 54' N, and longitudes 46° 57' - 59° 27' E and has an area of approximately 9584 km^2 (Figure 1). This city is home to approximately 74,000 residents (16).

Samples were collected from different locations. The distance between stations or sampling locations was 5000 m. Totally, the number of these samples was 1800. In this study, the effects of natural geographical features (i.e., latitude and elevation) and climate change (sunny with code 1 - 2, cloudy and semi-cloudy with code 2 - 3) on UV and gamma radiations were measured. Radiometer Hagner and survey-meter model 110 were used for UV and gamma radiations, respectively. Survey meter sensitivity was 0.05 to 100 mSv/h.

In this study, Kriging model in GIS 10.3 was used to interpolate the values. The interpolation of an unknown value $Z(x_0)$ at point x_0 is seen as a linear combination of the nearby measurements $Z(x_i)$ (2):

where λ_i is the weight of linear combination depending on the distance and the degree of variability expressed by the variogram model. Ordinary Kriging represents the best linear unbiased estimator (BLUE) as it ensures a zero mean for the estimation error and it minimizes the estimation variance (2). The coordinates of each sampling location was converted to degree decimal form. The World

Figure 1. Geological location of Gonabad city in Iran and Khorasan Razavi province

Geodetic System of 1984 was used for definition of the coordinate system. In the end, UV and gamma radiation distributions and their relationship with weather conditions were modeled by GIS and MATLAB software programs, and their relationship was analyzed by performing *t*-test and ANOVA in SPSS, version 20.

4. Results

4.1. Distribution of UV and Gamma Radiations in Gonabad City

Figures 2 and 3 show the average UV and gamma doses predicted based on the Kriging model in Gonabad city. The predicted values for UV and gamma ranged from 0.03 to 1.829 Wm^{-2} and from 0.08 to 0.42 mSv, respectively. The highest UV and gamma doses were observed in the southwest region of Gonabad city. Minimum mean square errors (MMSEs) related to UV and gamma were 0.24 and 0.02, respectively.

4.2. Distribution of UV and Gamma Doses vs. Latitude and Elevation

Based on the obtained results, it was clear that UV scattering points were within the range of 0 - 1 Wm^2 (Figure 4A). Therefore, change of latitude was effective in UV radiation. However, regarding gamma dose, almost overall points with dose < 0.2 mSv had a suitable uniformity with lower scattering than UV (Figure 4B), which explains why latitude does not affect gamma radiation ($P > 0.001$).

Figures 5A and 5B show the plot of UV and gamma radiation doses versus elevation. Gamma distribution versus elevation had a lower scattering than UV distribution.

4.3. The Effect of Weather Condition on UV and Gamma Radiations

Study of weather conditions revealed that sunny weather condition (1 - 2 code) had the highest distribution in Gonabad area (Figure 6). ANOVA test reflected a significant relationship between UV radiation dose and sunny weather ($P < 0.001$), while weather conditions did not affect gamma radiation dose ($P > 0.001$).

5. Discussion

Integration GIS and MATLAB models was a suitable tool for showing distribution of UV, gamma, and weather conditions in Gonabad city. MMSEs for UV and gamma were equal to 0.24 and 0.02, respectively, showing the values were moderately scattered. GIS is used as an interpolation technique to map the corresponding environmental UV and gamma radiations; this integration model gives readers a comprehensive insight into UV and gamma radiation distribution over a large region (15).

Based on the results of Kriging model, range of predicted UV and gamma radiations was 0.252 - 1.826 Wm^2 and 0.08 - 0.165 mSv, respectively. Unlike 2D distribution (Figures 4 and 5) of MATLAB, the Kriging model showed 3D distribution of UV and gamma vs. altitude and elevation simultaneously on the real map of Gonabad city. Irregular distribution of UV versus latitude and elevation is due to the presence of Siyah Kuh mountain located in the southwest of Gonabad. Topography is a major factor determining the amount of solar energy incidence at a location on the earth's surface. Variability in elevation, slope, slope orientation, and shadowing can create strong local gradients in solar radiation that directly and indirectly affect solar radiations (17-19). It seems that topography and rocks composition of Siyah Kuh play an important role in the amount of UV and gamma radiations, respectively. "Higher gamma radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. There are exceptions however, as some shales and phosphate rocks have relatively high content of radionuclides. Granites are the most abundant plutonic rocks of mountain belts and

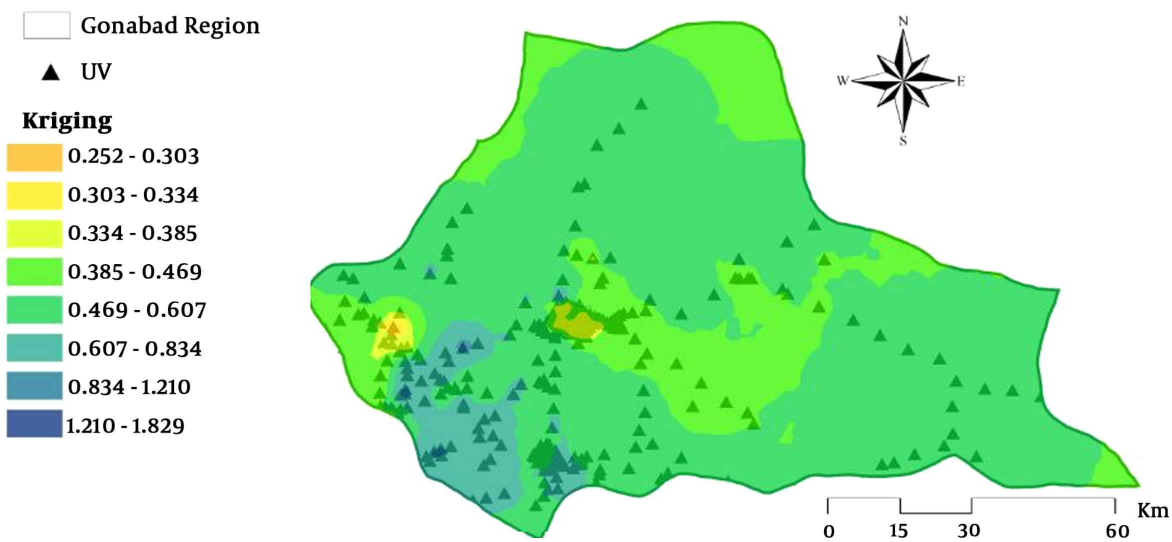

Figure 2. UV dose distribution (Wm^{-2}) in Gonabad city based on Kriging model

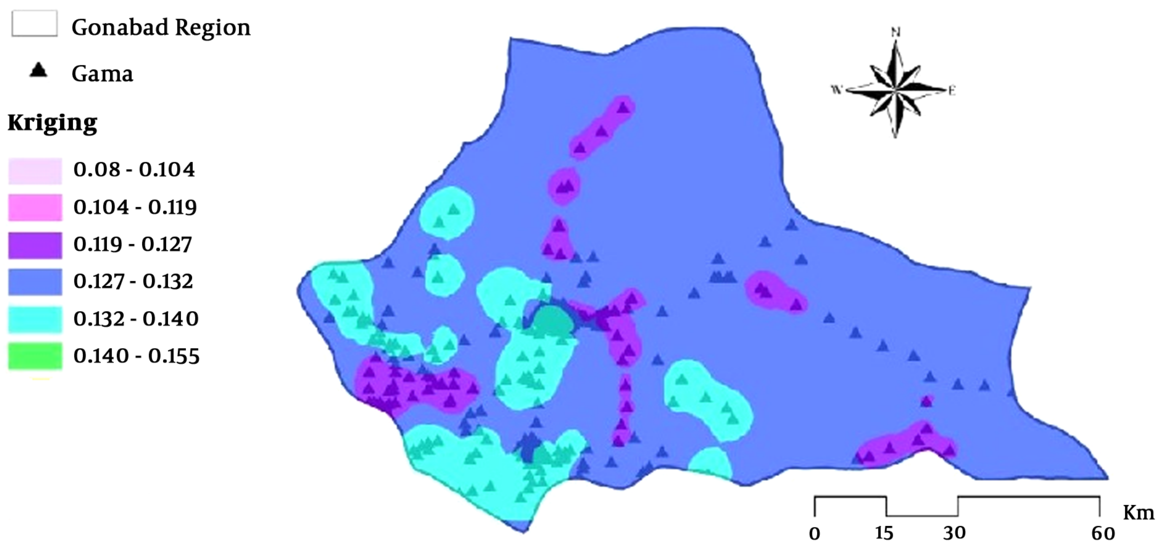

Figure 3. Gamma dose distribution (Wm^{-2}) in Gonabad city based on Kriging model

continental shield areas. Typical granites are chemically composed of 75% silica, 12% aluminum, less than 5% potassium oxide, less than 5% soda, as well as lime, iron, magnesia, and titanium in smaller quantities"(20).

Findings of Warnery et al. in France confirmed our results (2). They found the highest gamma radiation (from 120 to 230 nSv/h) in granitic or metamorphic areas, but the lowest values (from 28 to 50 nSv/h) were detected in Bassin Parisien, in northern France on the Mediterranean coast. Previous studies were performed to analyze European maps of terrestrial gamma dose rate based on routine monitoring data. For France, 168 stations were used for outdoor measurement. According to these results, the range of gamma dose in Europe was between 0 and 180 nSv/h (2, 21). Based on a study entitled "terrestrial gamma radiation dose study to determine the baseline for environmental radiological health practices in Melaka state, Malaysia" performed by GIS mapping, the values of terrestrial gamma

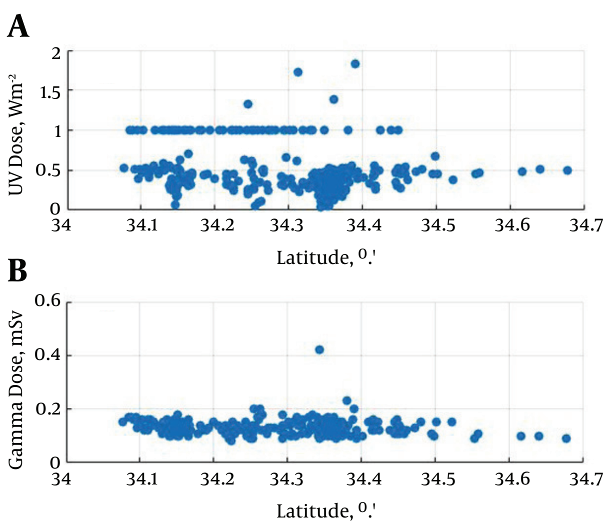

Figure 4. Distribution of UV (A) and gamma (B) doses vs. latitude

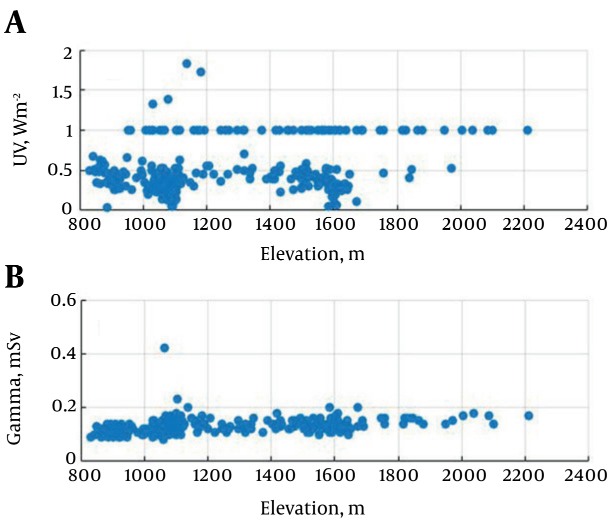

Figure 5. Distribution UV (A) and gamma (B) doses vs. elevation

radiation dose had a significant relationship with different soil types and different underlying geological characteristics. The values ranged from 54 ± 5 to 378 ± 38 nGy.h^{-1}. The highest gamma radiation was measured over soil types of granitic origin and in areas with underlying geological characteristics of an acid intrusive (undifferentiated) type. The lower values were obtained in the central area of the state where the lithology was dominated by sedimentary rocks (22).

However, study of gamma in Ramsar city, Iran, showed that the gamma radiation dose received by people from natural resources was 260 mSv.y^{-1} and this mount was 20 times higher than its allowable standard considered for workers (23). Similar results were obtained by Abbaspour et al. at western part of Mazandaran province, these researchers approved that the annual effective gamma dose was 750 μSv. In this region, the average soil radionuclide concentration was higher than the global range. Annual effective dose of gamma and its excess lifetime risks of cancer were higher than the global average (10). Due to difference in the amount of radionuclides activity, gamma dose varied even among the neighboring regions (10). Gholami et al. in Lurestan and Samadi et al. in Hamadan indicated that gamma doses in these regions of Iran were higher than the standard limit (13, 24).

Along with the quantity change, latitude and season affect the quality of solar radiation on the earth's surface, especially in the UV region of the spectrum (25). Results of our study confirmed this issue because UV distribution was influenced by sunny condition in Gonabad city ($P < 0.001$). Also, with the measurement of UV radiation in Isfahan, it was found that in 2011 the average yearly UV index was 6 that was lower than Tehran because Tehran's latitude was more than Isfahan (26). In this respect, Hokmabdi et al. showed that UV radiation measured (with the minimum and maximum of 2 and 12 Wm^{-2}, respectively) in Bojnurd city was lower than those in Ahvaz and Isfahan. This finding is due to mountainous weather conditions of Bojnurd compared to warm and dry weather conditions in Ahvaz and Isfahan (11). In general, in Gonabad city the mean daily outdoor doses of UV and gamma radiations were lower than the world average.

5.1. Conclusion

One of the greatest problems in previous studies is the lack of comprehensive data regarding the relationship between geographical conditions and UV and gamma dose distributions in the cited regions. Modeling environmental factors (i.e., latitude, elevation and weather conditions) by GIS is a favorable tool for their simultaneous mapping in the form of regional and general maps. Based on the results of this study, environmental factors had a significant association with UV radiation. It is clear that measurement of UV and gamma radiations will be necessary to determine the baseline for environmental radiological health practices in the considered regions. For this purpose and to obtain insight into the environmental UV and gamma radiations received by the population, further comprehensive studies are recommended.

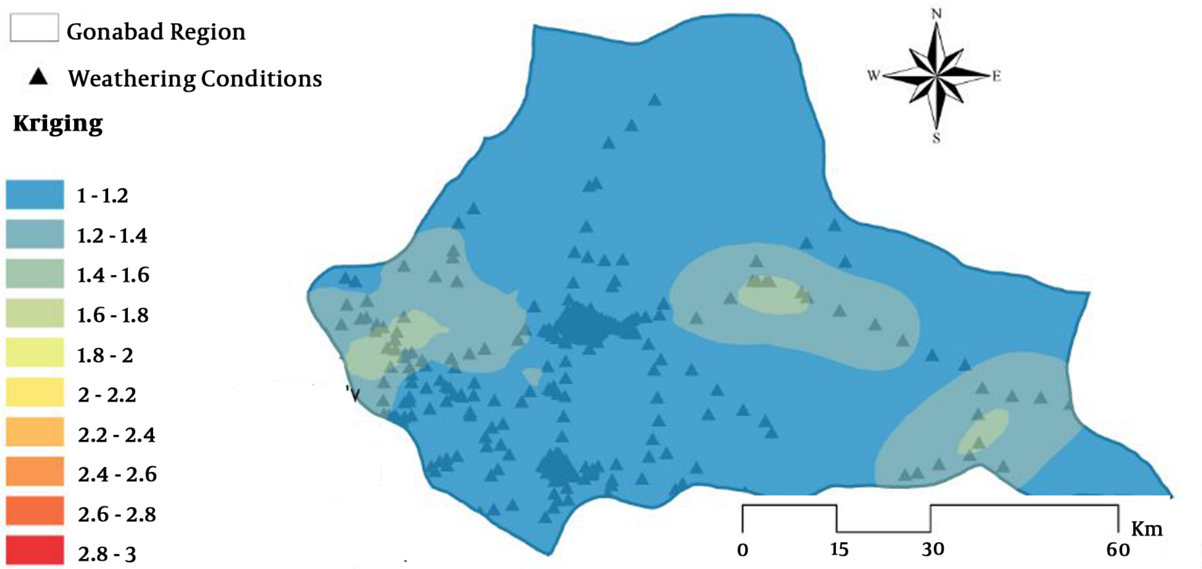

Figure 6. Distribution of weather conditions (1 - 2 sunny, 2 - 3 cloudy and semi-cloudy) in Gonabad city

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Footnotes

Authors' Contribution: In this article Afsane Chavoshani is coauthor and writer of article, other authors are advisors, Assistants and revisers in this article.

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