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ESTIMATION OF SOLAR RADIATION FROM ANGSTROMS COEFFICIENTS BY USING GEOGRAPHICAL AND METEOROLOGICAL DATA IN BISHKEK, KYRGYZSTAN

İnci TÜRK TOĞRUL
Afyon Kocatepe University, Engineering Faculty, Chemical Engineering Department,
03200 Afyon Karahisar; e-mail: itogrul@aku.edu.tr

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Abstract: In this study, the usability of clear sky radiation and Angstrom coefficients depend on geographical and meteorological parameters for predicting monthly mean global solar radiation in Bishkek, Kyrgyzstan were investigated. A multiple linear regression was applied to explain the relationship among Angstrom coefficients and geographical and meteorological data sets which were monthly mean clear sky or extraterrestrial radiation, the ratio of sunshine hours to day length, ambient and soil temperatures, relative humidity, sine of declination angle. Variables in these equations were used to estimate the global solar radiation. Values calculated from models were compared with the meteorological values.
Keywords: Clear sky radiation, solar energy estimation, Angstrom coefficient, multiple linear regression, t statistic

BİŞKEK, KIRGIZİSTAN'DA COĞRAFİK VE METEOROLOJİK VERİYİ KULLANARAK ANGSTROM KATSAYILARINDAN GÜNEŞ IŞIMASININ HESAPLANMASI

Özet: Bu çalışmada, Bişkek, Kırgızistan'da coğrafik ve meteorolojik parametrelere bağlı olarak Angstrom katsayısı ve açık gökyüzü ışımasının kullanılabilirliği araştırıldı. Aylık ortalama açık gökyüzü ışıması veya atmosfer dışı ışıma, güneşlenme süresinin gün uzunluğuna oranı, çevre ve toprak sıcaklıkları, bağıl nem, deklinasyon açısı gibi meteorolojik parametreler ve Angstrom katsayıları arasındaki ilişkiyi açıklamak için çok yönlü lineer regresyon uygulandı. Daha sonra bu eşitliklerdeki değişkenler toplam güneş ışımasını hesaplamada kullanıldı. Modellerden hesaplanan değerler meteorolojik değerlerle mukayese edildi.
Anahtar Kelimeler: Açık gökyüzü ışıması, güneş ışımasının hesaplanması, Angstrom katsayısı, çok yönlü lineer regresyon, t- istatistik

INTRODUCTION

Energy and fresh water are two major commodities furnishing the fundamentals of every human activity for reasonable and good life quality. These two resources are intricately related to each other. In fact, during the early civilizations, water power has been employed as the major energy sources. Solar energy is the most ancient source, and root material for almost all fossil and renewable types. Special devices have been used for benefiting from the solar energy since immemorial and such applications actually date back to before Christ. Energy is a continuous steering power for the social and technological prospective developments. Energy sources are vital and essential ingredients for all human transactions and without them human activities of all kinds will not be progressive at all. On one hand, the energy sources are limited and on the other, the population growth at present average rate 2% inserts extra pressure on additional energy demands. Solar energy is an almost inexhaustible source for future generations. Recent progress in solar and possible future research trends is presented by Şen (2004, 2007).

In many applications of solar energy, the most important parameters that are often needed are the average global solar irradiation and its components. Unfortunately, the measurements of this parameter are done only at a few places. For this reason there have been attempts at estimating them from theoretical models. This correlations estimate the amounts of monthly average solar radiation from more readily available meteorological parameters such as the sunshine duration, extraterrestrial radiation.

Several empirical models have been developed to calculate global solar radiation using various parameters. Angstrom (1924) developed the earliest model used for estimating global radiation, in which the sunshine duration data and clear sky radiation ($\overline{H_c}$) data were used.

$$\frac{\overline{H}}{\overline{H_c}} = a' + b' \frac{\overline{n}}{\overline{N}} \quad (1)$$

Because there may be problems in calculating clear sky radiation accurately, by replacing clear sky radiation with extraterrestrial radiation ($\overline{H_o}$), this model was modified to a more convenient form by Prescott in 1940 (Prescott, 1940).

$$\frac{\overline{H}}{\overline{H_o}} = a + b \frac{\overline{n}}{\overline{N}} \quad (2)$$

Many researchers have used this model to develop empirical correlations (Togrul , 1999; Togrul et.al.,2000; Akinoğlu and Ecevit, 1990; Moriarty,1991; Gopinathan, 1992; Şahin and Şen, 1998; Paulescu et.al. 2006; Muneer and Younes, 2006; Menges et.al. 2006; Skeiker , 2006; Rietweld , 1978; Benson et.al. 1984; Jin et.al. 2005). Some researchers have found that the regression coefficients in the model are site dependent and have suggested regression coefficients in term of some geographical factors, such as latitude, elevations etc. (Paulescu et.al. 2006; Muneer and Younes, 2006; Menges et.al. 2006; Skeiker, 2006; Rietweld, 1978; Benson et.al. 1984; Jin et.al. 2005). In addition, other empirical models have been developed to calculate solar radiation not only using sunshine duration, extraterrestrial radiation and geographical parameters but also using some other parameters such as, relative humidity, ambient temperature, soil temperature, number of rainy days, precipitation, cloudiness and evaporation (Yorukoglu and Celik, 2006; El-Metwally, 2005 ; Elagib and Mansell, 2000; Abdul-Aziz et.al. 1993; Chow et.al. 2006; Rehman and Halawani, 1997; Aksakal and Rehman, 1999; Lin and Gao, 1999; Togrul and Onat, 1999). However, it can be seen from the study of that these models show no more accuracy than that based only on sunshine duration and inconvenient to use (Ertekin and Yaldiz , 2000).

In this study, the first aim was to determine monthly variation and to estimate clear sky radiation in Bishkek, Kyrgyzstan. The second aim was to find some statistical relations among the Angstrom coefficients and astronomical and/or meteorological parameters, i.e., monthly mean extraterrestrial radiation or monthly mean clear sky radiation, fraction of sunshine duration, monthly mean declination angle, mean ambient temperature ($\overline{T_a}$), mean soil temperature ($\overline{T_s}$), relative humidity (% RH). After the determination of variables, the final aim was to investigate whether these variables could be in estimation of global solar radiation in Bishkek, Kyrgyzstan by using various statistical comparison methods such as MBE, RMSE and t-statistic.

ESTIMATION METHODS

To estimate the global solar radiation $\overline{H}$, data consisting of monthly mean temperature, relative humidity, soil temperature, ambient temperature and sunshine duration were taken from the State Meteorology Office of Bishkek, Kyrgyzstan between 2003 and 2005. The geographical location of Bishkek and the apparatus of measurements were shown in Table 1. Monthly mean daily extraterrestrial radiation H_o, daylength N, and declination angle, for using the average day of the month, were calculated from Eqs. (1)-(3), respectively (Duffie and Beckman, 1991). The clear sky radiation was determined by using methodology related in section Estimation of clear sky radiation.

$$H_o = \frac{24x3600xG_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n'}{365}\right)x \left(\cos\phi\cos\delta\sin\omega_{ss} + \frac{\pi\omega_{ss}}{180}\sin\phi\sin\delta\right) \quad (3)$$

$$N = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) = \frac{2}{15}\omega_{ss} \quad (4)$$

$$\delta = 23.45\sin\left(360\frac{284+n'}{365}\right) \quad (5)$$

Table 1. The of geographical properties of Bishkek and apparatus of measurements

Location: Bishkek, Kyrgyzstan	**Altitude**	**760 m**
	Latitude	**42°51'**
	Longitude	**74°32'**

Measurement	Apparatus
Solar Energy	Pryranometer of Yanisherskiy
Sunshine hours	Universal Heliograph , UH-1 model
Soil temperature	Urgent numerical thermometer TM-3
Ambient Temperature	Dry and wet bulb thermometer TM-4
Relative Humidity	Meteorological hair hygrometer

In this work, we developed equations to estimate the monthly mean global solar radiation $\overline{H}$ by applying multiple linear regression to various parameters, such as $\overline{H_o}$, $\overline{H_c}$, $\overline{n}/\overline{N}$, sin δ , $\overline{T_a}$, $\overline{T_s}$, % RH. The values of $\overline{H}$ were estimated by using these equations.

In linear regression, starting with one parameter, the equation took the form:

$$y = a + bx \quad (6)$$

where a and b are regression coefficient and x is the correlated parameter.

As the number of parameters is increased, the correlation becomes a multiple linear regression taking the following form:

$$y = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5 + gx_6 + hx_7 + \imath x_8 + kx_9 \quad (7)$$

Multiple linear regression analyses were done by using the Statistica routine.

Estimation of clear sky radiation

Hottel (1976) has presented a method for estimating the beam radiation transmitted through clear atmospheres which takes into account zenith angle and latitude for a standard atmosphere and four climate types. The atmosphere transmittance for beam radiation τ_b is given in the form (Duffie and Beckman, 1991):

$$\tau_b = a_o + a_1 \exp(-k / \cos\theta_z) \quad (8)$$

The constant a_o, a_1 and k for the standard atmosphere with 23 km visibility are found from a_o^*, a_1^* and k^*, which are given for altitudes less than 2.5 km by

$$a_o^* = 0.4237 - 0.00821(6 - A)^2 \quad (9a)$$

$$a_1^* = 0.5055 + 0.00595(6.5 - A)^2 \quad (9b)$$

$$k^* = 0.2711 + 0.01858(2.5 - A)^2 \quad (9c)$$

where A is the altitude of the observer in kilometers.

Correction factors are applied to a_o^*, a_1^* and k^* to allow for changes in climate types.

The correction factors $r_o = a_o / a_o^*$, $r_1 = a_1 / a_1^*$, and $r_k = k / k^*$ are given in Table 2. Thus, the transmittance of this standard atmosphere for beam radiation can be determined for any zenith angle and any altitude up to 2.5 km. The clear sky beam normal radiation (G_{cnb}, Wm^{-2}) is then

$$G_{cnb} = G_{on}\tau_b \quad (10)$$

where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the n'th day of the year and given in following form (Wm^{-2}):

$$G_{on} = 1367\left(1 + 0.033\cos\frac{360n'}{365}\right) \quad (11)$$

The clear sky horizontal 'beam' radiation is

$$G_{cb} = G_{on}\tau_b \cos\theta_z \quad (12)$$

Table 2. Correction Factors for climate types (Duffie and Beckman, 1991)

Climate type	r_o	r_1	r_k
Tropical	0.95	0.98	1.02
Mid latitude summer	0.97	0.99	1.02
Subarctic summer	0.99	0.99	1.01
Mid latitude winter	1.03	1.01	1.00

It is also necessary to estimate the clear sky diffuse radiation on a horizontal surface to get the total radiation Liu and Jordan (1960) developed in an empirical relationship between the transmission coefficients for beam and diffuse radiation for clear days:

$$\tau_d = 0.271 - 0.294\tau_b \quad (13)$$

where τ_d is the ratio of diffuse radiation to the extraterrestrial (beam) radiation on the horizontal plane. (Duffie and Beckman, 1991)

The clear sky diffuse radiation G_{cd} (Wm^{-2})

$$G_{cd} = G_{on}\tau_d \cos\theta_z \quad (14)$$

For periods of an hour, the clear sky horizontal beam radiation and clear sky diffuse radiation is

$$I_{cb} = I_{on}\tau_b \cos\theta_z \quad (15)$$

$$I_{cd} = I_{on}\tau_d \cos\theta_z \quad (16)$$

I_{cb} and I_{cd} can be calculated for each hour of the day, based on the midpoints of the hours, to obtain a standard clear's day radiation. The day's total radiation H_c is the sum of I_{cb} and I_{cd} for all hours.

THE COMPARISON METHODS

In this study, two statistical tests, mean bias error (MBE) and root mean bias error (RMSE), and t-statistic were used to evaluate the accuracy of the correlations described above.

Mean Bias Error

The mean bias error is defined as

$$MBE = \frac{1}{n}\sum_{i=1}^{n} d_i \quad (17)$$

where n is the number of data pairs and d_i is the difference ith estimated and ith measured values.

This test provides information on the long-term performance. A low MBE is desired. A positive value gives the average amount of over-estimation in the calculated value and vice-versa. A drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation.

Root Mean Square Error

The root mean square error is defined as

$$RMSE = \left(\frac{1}{n}\sum_{i=1}^{n} d_i^2\right)^{1/2} \quad (18)$$

This test provides information on the short-term performance of the correlations by allowing a term by term comparison of the actual deviation between the calculated value and the measured value the smaller the value, the better the model's performance. However, a few large errors in the sum can produce a significant increase in RMSE.

It is obvious that each test by itself may not be an adequate indicator of a model's performance. It is possible to have a large RMSE value and at the same time a small MBE (a large scatter about the line of perfect estimation). It is also possible to have a relatively small RMSE and a relatively large MBE (consistently small over- or under estimation).

Although these statistical indictors generally provide a reasonable procedure to compare models, they do not objectively indicate whether a model's estimates are statistically significant, i.e., not significantly different from their measured counterparts. In this article, an additional statistical indicator, the t-statistic, was used. The statistical indicator allows models to be compared and at the same time indicate whether or not a model's estimates are statistically significant at a particular confidence level (Stone, 1993). It was seen that the t-statistic used in addition to the RMSE and MBE gave more reliable and explanatory results (Togrul, 1998).

t-statistic

t-statistic is defined as (Walpole and Myers, 1989)

$$t = \left[\frac{(n-1)MBE^2}{RMSE^2 - MBE^2} \right]^{1/2} \qquad (19)$$

The smaller the value of t, the better is the model's performance. To determine whether a model's estimates are statistically significant, one simply has to determine a critical t value obtainable from standard statistical tables, i.e., $t_{\alpha/2}$ at the α level of significance and (n-1) degrees-of-freedom. For the model's estimates to be judged statistically significant at the 1-α confidence level, the calculated t value must be less than the critical t value.

RESULTS AND DISCUSSION

Extraterrestrial radiation on a horizontal surfaces and clear sky radiation in monthly periods were calculated numerical using declination angle, latitude and hour angle at sunset and using methodology section 'estimation methods'.

The changes of the global solar radiation, extraterrestrial radiation and clear sky radiation in monthly periods throughout three year (Fig.1) were investigated. The monthly change of the other meteorological parameters such as, soil and ambient temperature, % relative humidity and sunshine hours were seen Fig. 2.

Daily n/N, H/H_o, and H/H_c ratios were determined by estimated the day length and extraterrestrial radiation and clear sky radiation. Linear regression was made for every months so as to show a relation like y= a+bx between n/N

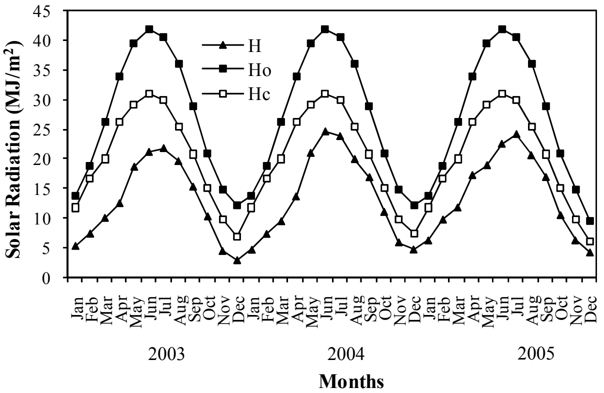

Figure 1. The changes of the global solar radiation, extraterrestrial radiation and clear sky radiation in monthly periods throughout three year

and H/H_o ratios, and between n/N and H/H_c ratios; a - b values and a' - b' values for 36 months and their monthly mean $\overline{n}/\overline{N}$, $\overline{H}/\overline{H_o}$, $\overline{H}/\overline{H_c}$ values determined. This relation between a (and a') , b (and b') and $\overline{n}/\overline{N}$ ratio for extraterrestrial and clear sky radiation were given in Figure 3 and 4, respectively.

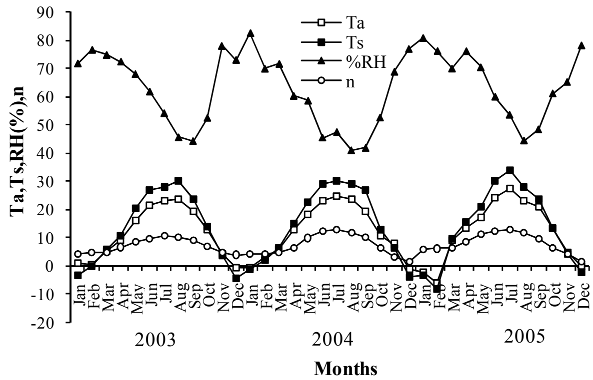

Figure 2. The monthly change of soil and ambient temperature, % relative humidity and sunshine hours.

Then multiple linear regression by using meteorological and geographical parameters were made to investigate the variation of a (and a') and b (and b') vs $\overline{n}/\overline{N}$ for both extraterrestrial radiation and clear sky radiation. In the multiple linear regression analyses, six variables were used in different combinations. Sixty three equations for the each radiation types were obtained. Thus the two equations having the highest determination coefficients for the each variable numbers were selected. The results were given in Table 3.

One hundred twenty one equations were obtained by using different combinations of these eleven equations given in Table 3 for the each radiation types. Then the equations having the highest determination coefficients were selected and listed in Table 4 and 5.

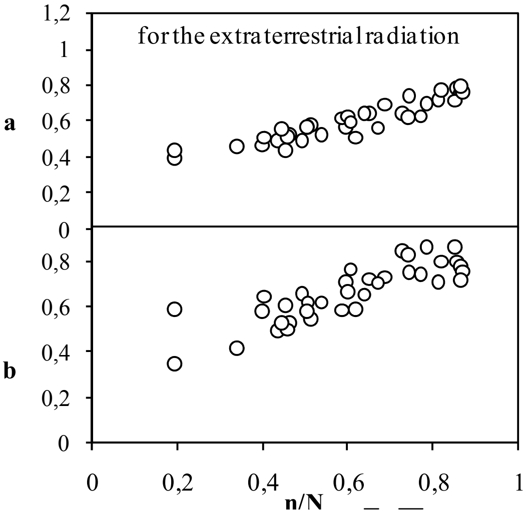

Figure 3. Variation of a and b vs $\overline{n}/\overline{N}$ for extraterrestrial radiation

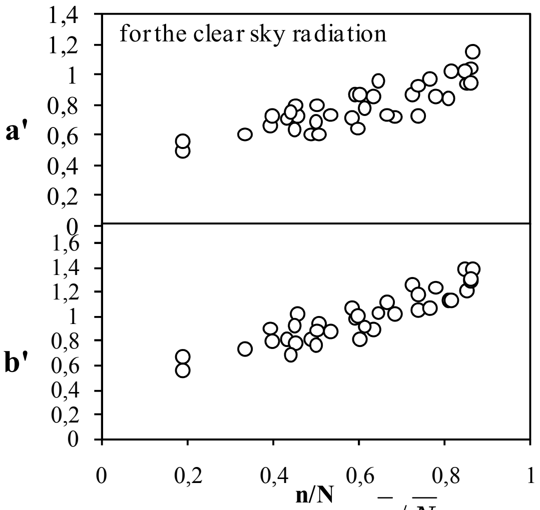

Figure 4. Variation of a' and b' vs $\overline{n}/\overline{N}$ for clear sky radiation

Table 3. The results of multiple linear regression analyses for Angstrom Coefficients

$$\overline{H}/\overline{H_c} = a' + b'.\overline{n}/\overline{N}$$

Variable Number	a' Variables	R^2	b' Variables	R^2
1	II	0,8563	II	0,7134
	V	0,6818	V	0,5828
2	II,IV	0,8646	I,II	0,7257
	II,V	0,8651	II,III	0,7242
3	I,II,III	0,8756	I,II,III	0,7322
	II,III,VI	0,8698	I,II,V	0,7268
4	I,II,III,V	0,8758	I,II,III,IV	0,7365
	I,II,III,VI	0,8797	I,II,III,V	0,7366
5	I,II,III,IV,VI	0,8825	I,II,III,IV,VI	0,7381
	I,II,III,V,VI	0,8827	I,II,III,V,VI	0,7385
6	I,II,III,IV,V,VI	0,8828	I,II,III,IV,V,VI	0,7385

*Variables:I=Hc, II=$\overline{n}/\overline{N}$, III=sin δ, IV=Ta,V=Ts, VI=RH

$$\overline{H}/\overline{H_o} = a + b.\overline{n}/\overline{N}$$

Variable Number	a Variables	R^2	b Variables	R^2
1	II	0,7056	II	0,8216
	V	0,5855	V	0,6232
2	II,IV	0,7208	I,II	0,8251
	II,V	0,7185	II,III	0,8251
3	I,II,V	0,7438	I,II,V	0,8258
	II,III,V	0,7434	II,IV,V	0,8407
4	I,II,V,VI	0,7772	I,II,IV,V	0,8410
	II,III,V,VI	0,7807	II,IV,V,VI	0,8409
5	I,II,III,V,VI	0,7810	I,II,IV,V,VI	0,8410
	II,III,IV,V,VI	0,7812	II,III,IV,V,VI	0,8410
6	I,II,III,IV,V,VI	0,7813	I,II,III,IV,V,VI	0,8410

**Variables: I=Ho, II=$\overline{n}/\overline{N}$, III=sin δ, IV=Ta, V=Ts, VI=RH

Table 4. The results of multiple linear regression analyses for $\overline{H}/\overline{H_o} = a + b.\overline{n}/\overline{N}$ (Variables: I=Ho, II=$\overline{n}/\overline{N}$, III=sin δ, IV=Ta, V=Ts, VI= RH)

Model No	MODELS	R^2
1	H/Ho=(A+B.I+C.II+D.III)+(E+F.I+G.II+H.III+J.V+K.VI).II *A =0.7906 B= -2.81x10^{-8} C = -1.138 D=0.8349 E = - 2.93x10^{-3} F=8.28x10^{8}* *G= -0.4326 H= -2.6862 J= -1.89x10^{-3} K= -1.15x10^{-3}*	0,9696
2	H/Ho=(A+B.I+C.II+D.III)+(E+F.I+G.II+H.III+J.IV+K.V+L.VI).II *A = 0.7903 B= - 2.79x10^{-8} C=-1.0826 D= 0.8359 E= -0.0456 F = 8.19x10^{-8} G= -0.4233* *H= -2.6616 J=5.63x10^{4} K= -2.344x10^{-3} L= -1.143x10^{-3}*	0,9697
3	H/Ho=(A+B.I+C.II+D.III+E.V)+(F+G.I+H.II+J.III+K.V+L.VI).II *A= 0.7091 B= -2.47x10^{-8} C= -0.9985 D = 0.6674 E = 2.6x10^{-3} F= 0.0111 G= 7.37x10^{-8}* *H=-0.2983 J= -2.2857 K= -6.21x10^{-3} L= -1.22x10^{-3}*	0,9701
4	H/Ho =(A+B.I+C.II+D.III+E.V)+(F+G.I+H.II+J.III+K.IV+L.V+M.VI).II *A=0.7092 B= -2.47x10^{-8} C= -1.0984 D=0.6681 E=2.62x10^{-3} F=0.1129 G=7.36x10^{-8}* *H= -0.2968 I= -2.2820H=1.134x10^{-4} K=-6.287x10^{-3} L= -1.22x10^{-3}*	0,9701

5	H/Ho =(A+B.I+C.II+D.III+E.VI)+(F+G.I+H.II+J.III+K.V+L.VI).II *A= 0.8164 B= -2.79x10^{-8} C= -1.0911 D=0.8301 E= -3.53x10^{-4}F= -0.0836 G=8.17x10^{-8}* *H= -0.4066 J= -2.6529 K= -1.944x10^{-3} L= -6.438x10^{-4}*	0,9697
6	H/Ho =(A+B.I+C.II+D.III+E.IV+F.VI)+(G+H.I+J.II+K.III+L.V+M.VI).II *A=0.8077 B= -2.77x10^{-8} C= -1.1193 D= 0.8241 E= 1.458x10^{-4} F= -2.88x10^{-4}* *G= -0.0367 H=8.12x10^{-8} J= -0.4018 K=-2.6312 L=-2.13x10^{-3}M= -7.349x10^{-4}*	0,9697
7	H/Ho =(A+B.I+C.II+D.III+E.IV+F.VI)+(G+H.I+J.II+K.III+L.IV+M.V+N.VI).II *A=0.8146 B= - 2.782x10^{-8} C= -1.1219 D=0.8317 E= -1.43x10^{-5} F =-3.255x10^{-4} G = -0.0436* *H =8.134x10^{8} J= -0.4038 K= -2.6429 L= 3.488x10^{-4} M = -2.2x10^{-3} N = -6.78x10^{-4}*	0,9697
8	H/Ho=(A+B.I+C.II+D.III+E.V+F.VI)+(G+H.I+J.II+K.III+L.V+M.VI).II *A=0.6210 B=-2.40x10^{-8} C= -0.9666 D=0.6219 E=3.516x10^{-3} F=8.25x10^{-4} G=0.1102* *H=7.31x10^{-8} J=-0.3134 K=-2.2277 L= -7.55x10^{-3} M= -2.43x10^{-3}*	0,9702
9	H/Ho=(A+B.I+C.II+D.III+E.V+F.VI)+(G+H.I+J.II+K.III+L.V).II *A=0.7892 B= -2.52x10^{-8} C= -1.095 D=0.7109 E=1.75x10^{-3} F= -7.488x10^{-4} G=-0.0188* *H=7.397x10^{-8} J= -0.2783 K= -2.3380 L= -4.722x10^{-3}*	0,9699
10	H/Ho=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.III+M.V).II *A=0.7935 B= -2.57x10^{-8} C=-1.1251 D=0.6876 E=-2.18x10^{-3} F=3.72x10^{-3} G= -8.13x10^{-4}* *H= -0.0676 J=7.87x10^{-8} K= -0.3181 L= -2.4503 M= -5.11x10^{-3}*	0,9702
11	H/Ho=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.III+M.V+N.VI).II *A=0.6549 B=-2.462x10^{-8} C=-1.0269 D=0.6204 E=-1.66x10^{-3} F=4.687x10^{-3} G=4.89x10^{-4}* *H=0.0642 J=7.681x10^{-8}K= -0.3372 L= -2.333 M= -7.33x10^{-3} N= -1.987x10^{-3}*	0,9704
12	H/Ho=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.III+M.IV+N.V+O.VI).II *A=0.7862 B= -2.54x10^{-8} C= -1.1458 D=0.6079 E= -0.0297 F=0.0265 G= -3.813x10^{-4}* *H= -0.07924 J=7.95x10^{-8} K= -0.2839 L= -2.3898 M= 0.0427 N= -0.0404 O= -9.112x10^{-4}*	0,9739

Table 5. The results of multiple linear regression analyses for $\overline{H}/\overline{H_c} = a' + b'.\overline{n}/\overline{N}$ (Variables: I=Hc, II=$\overline{n}/\overline{N}$, III=sin δ, IV=Ta, V=Ts, VI= RH)

Model No	MODELS	R^2
13	H/Hc=(A+B.I+C.II+D.V+E.VI)+(F+G.I+H.II+J.IV+K.V+L.VI).II *A=1.9539 B= -2.53x10^{-8} C= -1.3870 D=0.0137 E= -0.0152 F= -0.3789 G=3.14x10^{-8}* *H=0.4897 J= -0.0206 K= -1.45x10^{-4} L=0.0164*	0,8376
14	HHc=(A+B.I+C.II+D.V+E.VI)+(F+G.II+H.III+J.IV+K.V+L.VI).II *A= 2.0631 B= -1.649x10^{-8} C= -0.8171 D= 8.89x10^{-3} E=-0.0175 F= -0.9173* *G= 0.7258 H=0.5244 J= -0.021 K=6.33x10^{-3} L=0.02046*	0,8339
15	H/Hc=(A+B.I+C.II+D.V+E.VI)+(F+G.I+H.II+J.III+K.IV+L.V+M.VI).II *A=1.9524 B= -2.55x10^{-8} C=-1.5204 D=0.0138 E= -0.0152 F=-0.2527 G=3.22x10^{-8}* *H=0.4857 J= -0.0173 K= -0.0206 L=-2.412x10^{-4} M=0.0163*	0,8376
16	H/Hc= (A+B.I+C.II+D.III+E.V+F.VI)+(G+H.I+J.II+K.IV+L.V).II *A=1.3054 B=-3.59x10^{-8} C=-0.6550 D=0.3334 E=0.01848 F= -4.603x10^{-3} G=0.4239* *H=3.42x10^{-8} J=0.1539 K=-0.01411 L=-0.0159*	0,8316
17	H/Hc= (A+B.I+C.II+D.III+E.V+F.VI)+(G+H.II+J.IV+K.V+L.VI).II *A=2.4871 B= -2.52x10^{-8} C=-1.0147 D=0.6095 E=-4.55x10^{-5} F= -0.0195 G=-1.0978* *H=0.7302 J=-0.0206 K=0.017 L=0.0239*	0,8428
18	H/Hc=(A+B.I+C.II+D.III+E.V+F.VI)+(G+H.II+J.III+K.IV+L.V+M.VI).II *A=2.6337 B= -2.64x10^{-8} C=-1.1455 D=0.7854 E=-3.37x10^{-3} F=-0.02054 G=-1.2088* *H=0.7733 J= -0.2344 K=-0.0197 L=0.0227 M=0.0257*	0,8435
19	H/Hc=(A+B.I+C.II+D.III+E.V+F.VI)+(G+H.I+J.II+K.III+L.IV+M.V+N.VI).II *A=3.9454 B= -1.277x10^{-8} C= -3.0023 D=3.6903 E= -0.0135 F= -0.0151* *G= -1.9242 H=2.324x10^{-7} J= -0.7834 K= -6.9495 L= -0.0074 M=0.0361 N=0.0157*	0,9056
20	H/Hc=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.III+M.IV+N.V+O.VI).II *A=3.9552 B= -1.28x10^{-7} C= -3.0030 D= 3.6938 E= -0.0014 F= 0.01252 G= -0.0151* *H= -1.9365 J= 2.326x10^{-7} K= -0.7830 L=-6.9544 M= -0.0054 N=0.0346 O=0.0158*	0,9056
21	H/Hc=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.II+K.III+L.IV+M.V+N.VI).II *A=2.5445 B= -2.562x10^{-8} C= -1.2171 D=0.7761 E=0.0145 F = 0.0143 G= -0.0198*	0,8440

	H= -1.0263 J=0.7552 K= -0.2457 L= -0.0403 M= 0.0382 N= 0.0249	
22	H/Hc= (A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.III+M.V+N.VI).II *A=2.2152 B= -2.93x10^{-8} C= -1.4015 D=0.44808 E=0.01074 F= -2.07x10^{-3} G= -0.0167* *H= -0.3174 J= 1.62x10^{-8} K=0.5214 L=-0.0367 M=0.0206 N=0.0188*	0,9056
23	H/Hc=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.II+K.IV+L.V+M.VI).II *A= 2.3970 B= -2.44x10^{-8} C=-1.1031 D=0.5929 E=0.0136 F=-0.0101* *G=-0.0189 H= -0.8946 J=0.7114 K=-0.0399 L=0.0322 M=0.0230*	0,8433
24	H/Hc=(A+B.I+C.II+D.III+E.IV+F.V+G.VI)+(H+J.I+K.II+L.IV+M.V).II *A=1.2188 B= -3.363x10^{-8} C= -0.6161 D=0.3203 E=0.026 F=- 2.14x10^{-3}* *G= -4.4x10^{-3} H=0.4679 J=3.182x10^{-8} K=0.15846 L= -0.05152 M=0.01380*	0,8334

The values of monthly mean daily global solar radiation intensity estimated using above derived correlations were compared with the corresponding meteorological values. The statistical performance of developed equations was investigated by using MBE, RMSE, t-statistic and R^2. The statistical analyses results and variances of models were seen in Table 6.

Table 6. The results of statistical analyses of the models

Model number	MBE x10^3	RMSE x10^2	t	R^2	Variance x10^3
Extraterrestrial Radiation					**8,542 (for the measures)**
1	1.260	3.485	0.2141	0,9696	8,283
2	1.262	3.492	0.2140	0,9697	8,283
3	1.258	3.448	0.2160	0,9701	8,287
4	1.258	3.449	0.2159	0,9701	8,287
5	1.265	3.489	0.2147	0,9697	8,283
6	1.266	3.490	0.2147	0,9697	8,283
7	1.266	3.493	0.2145	0,9697	8,283
8	***1.245***	***3.423***	***0.2153***	***0,9702***	***8,288***
9	1.275	3.478	0.2170	0,9699	8,285
10	1.253	3.417	0.2171	0,9702	8,287
11	***1.234***	***3.387***	***0.2157***	***0,9704***	***8,289***
12	***1.123***	***3.212***	***0.2070***	***0,9739***	***8,320***
lear Sky Radiation					**13,542 (for the measures)**
13	6.212	7.946	0.4639	0,8376	11,343
14	6.280	7.961	0.4681	0,8339	11,293
15	6.216	7.950	0.4640	0,8376	11,343
16	6.373	8.060	0.4692	0,8316	11,262
17	5.796	7.681	0.4477	0,8428	11,413
18	5.780	7.679	0.4466	0,8435	11,422
19	***3.473***	***6.206***	***0.3316***	***0,9056***	***12,264***
20	***3.474***	***6.203***	***0.3318***	***0,9056***	***12,264***
21	5.753	7.678	0.4445	0,8440	11,430
22	***3.476***	***6.200***	***0.3322***	***0,9056***	***12,264***
23	5.771	7.680	0.4458	0,8433	11,420
24	6.280	8.001	0.4658	0,8334	11,286

Higher t-values than critical t- values show that the equation has no statistical significance. According to Table 6, all equations for extraterrestrial radiation and Eqs.19, 20, 22 for clear sky radiation have statistical significance. The lowest MBE, RMSE and t values were obtained by Eq. (8), Eq.(11)-(12) and by Eq.(19)-(20), Eq.(22), for extraterrestrial radiation and clear sky radiation, respectively.

It has been seen that variance values of selected models are more convenient than that of measurement with testing of variances in meteorological data and models. Thus, it can be represented that variances are almost balanced.

The values of the global solar radiation estimated using these three equations are compared with meteorological values in Fig. 5. As was seen in Fig. 5, estimated values didn't scattered on solid line and gave good results. The models were given in following form.

Model 8: $\overline{H}/\overline{H_o}$ = [0.6210 - 2.40x10^{-8} $\overline{H_o}$ - 0.9666 $\overline{n}/\overline{N}$ + 0.6219 sin δ + 3.516x10^{-3} $\overline{T_s}$ + 8.25x10^{-4} (% RH)]+ [0.1102 + 7.31x10^{-8} $\overline{H_o}$ - 0.3134 $\overline{n}/\overline{N}$ - 2.2277 sin δ - 7.55x10^{-3} $\overline{T_s}$ -2.43x10^{-3} % RH] $\overline{n}/\overline{N}$ (20)

Model 11: $\overline{H}/\overline{H_o}$ = [0.6549 - 2.462x10^{-8} $\overline{H_o}$ - 1.0269 $\overline{n}/\overline{N}$ + 0.6204 sin δ - 1.66x10^{-3} $\overline{T_a}$ + 4.687x10^{-3} $\overline{T_s}$ + 4.89x10^{-4}(% RH)]+ [0.0642 + 7.681x10^{-8} $\overline{H_o}$ - 0.3372 $\overline{n}/\overline{N}$ - 2.333 sin δ - 7.33x10^{-3} $\overline{T_s}$ - 1.987x10^{-3} (% RH)] $\overline{n}/\overline{N}$ (21)

Model 12: $\overline{H}/\overline{H_o}$ = [0.7862 -2.54x10^{-8} $\overline{H_o}$ - 1.1458. $\overline{n}/\overline{N}$ + 0.6079 sin δ - 0.0297 $\overline{T_a}$ + 0.0265 $\overline{T_s}$ - 3.813x10^{-4} (% RH)] + [- 0.07924 + 7.95x10^{-8} $\overline{H_o}$ - 0.2839 $\overline{n}/\overline{N}$ -

$2.3898 \sin \delta + 0.0427\ \overline{T_a} - 0.0404\ \overline{T_s} - 9.112\text{x}10^{-4}\ (\%\ RH)]\ \overline{n}/\overline{N}$ (22)

Model 19: $\overline{H}/\overline{H_c} = [3.9454\ -1.277\text{x}10^{-8}\ \overline{H_c} - 3.0023\ \overline{n}/\overline{N} + 3.6903 \sin \delta\ -0.0135\ \overline{T_s} - 0.0151\ (\%\ RH)] + [-1.9242 + 2.324\text{x}10^{-7}\ \overline{H_c} - 0.7834\ \overline{n}/\overline{N}\ -6.9495 \sin \delta - 0.0074\ \overline{T_a} + 0.0361\ \overline{T_s} + 0.0157\ (\%\ RH)]\ \overline{n}/\overline{N}$ (23)

Model 20: $\overline{H}/\overline{H_c} = [3.9552 - 1.28\text{x}10^{-7}\ \overline{H_c} - 3.0030\ \overline{n}/\overline{N} + 3.6938 \sin \delta\ -0.0014\ \overline{T_a} + 0.01252\ \overline{T_s} - 0.0151\ (\%\ RH)] + [-1.9365 + 2.326\text{x}10^{-7}\ \overline{H_c}\ -0.7830\ \overline{n}/\overline{N} - 6.9544 \sin \delta - 0.0054\ \overline{T_a} + 0.0346\ \overline{T_s} + 0.0158\ (\%\ RH)]\ \overline{n}/\overline{N}$ (24)

Model 22: $\overline{H}/\overline{H_c} = [2.2152 - 2.93\text{x}10^{-8}\ \overline{H_c}\ -1.4015\ \overline{n}/\overline{N} + 0.44808 \sin \delta + 0.01074\ \overline{T_a} - 2.07\text{x}10^{-3}\ \overline{T_s} - 0.0167\ (\%RH)] + [-0.3174 + 1.62\text{x}10^{-8}\ \overline{H_c} + 0.5214\ \overline{n}/\overline{N} - 0.0367 \sin \delta + 0.0206\ \overline{T_s} + 0.0188\ (\%\ RH)]\ \overline{n}/\overline{N}$ (25)

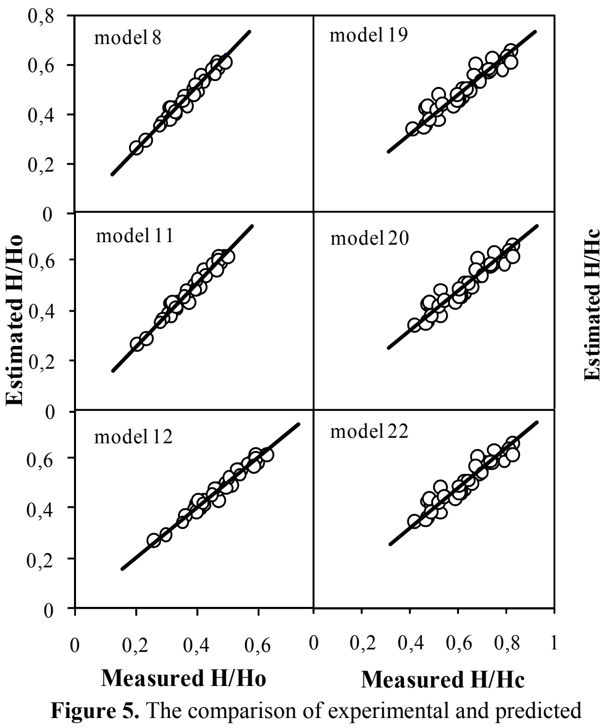

Figure 5. The comparison of experimental and predicted radiation (for extraterrestrial and clear sky radiation

Since these equations gave the highest determination coefficient and relatively small values of the statistical indicators, it was considered as the best equations for estimating the monthly global solar radiation for the Bishkek, Kyrgyzstan. It could be represented that errors of selected models were found as normal distribution (Fig 6).

CONCLUSION

The relationship among Angstrom coefficients and meteorological and geographical parameters data, such as Hc or Ho, the ratio of bright sunshine hours to day length, ambient and soil temperatures, relative humidity, sine of declination angle, were investigated by using multiple linear regressions. Sixty three equations were obtained for the each radiation types. Then the equations of best explaining of the relationship were used in the Angstrom-type radiation equations and one hundred models in different combinations were obtained. Twenty four models having the best determination coefficient were compared with measured meteorological values by using statistical tests.

In this study, first of all it was seen that the clear sky radiation can be used to estimate the global solar radiation in Bishkek. Finally, the using of the geographical and meteorological variables commonly has given the good results in estimating global solar radiation in Bishkek, Kyrgyzstan.

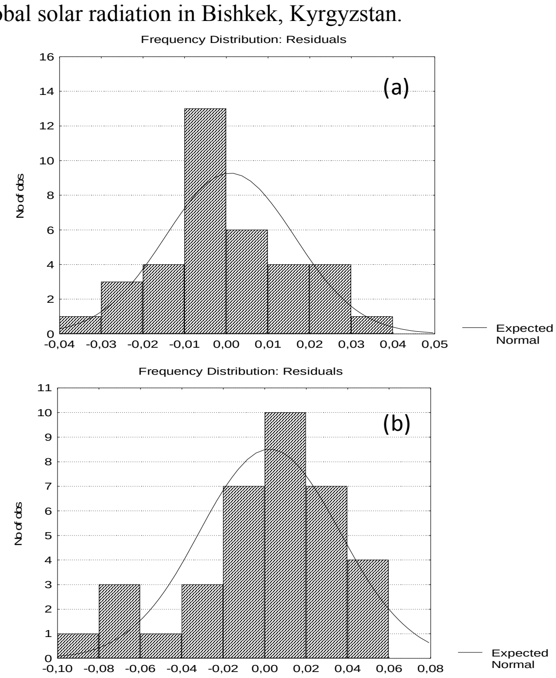

Figure 6. Distribution of errors: (a) for extraterrestrial radiation (eqs.(8,11,12) (b) for clear sky radiation (eqs. (19,20,22)

NOMENCLATURE

$a^{'}, b^{'}, a, b$ Angstrom Coefficients
A-O multiple linear regression coefficients
G_{on} the extraterrestrial radiation, measured on the plane normal to the radiation on the nth date of the year [W/m^2]
G_{cb} the clear sky beam radiation [W/m^2]
G_{cd} the clear sky diffuse radiation [W/m^2]
G_{sc} solar constant [1367 W/m^2]
G_{cnb} clear sky beam normal radiation [W/m^2]
H_o daily extraterrestrial radiation [MJ/m^2]
$\overline{H}$ monthly mean daily global radiation [MJ/m^2]
$\overline{H_c}$ average clear sky radiation for the location and month in question[MJ/m^2]
$\overline{H_o}$ monthly mean daily extraterrestrial radiation[MJ/m^2]
I_c hourly global clear sky radiation[MJ/m^2]
I_{cb} hourly beam clear sky radiation[MJ/m^2]
I_{cd} hourly clear sky diffuse radiation [MJ/m^2]
I_{on} hourly extraterrestrial radiation [MJ/m^2]
$n^{'}$ day of the year
$\overline{n}$ monthly average daily hours of bright sunshine [hour]
$\overline{N}$ monthly average of maximum possible daily hours of bright sunshine (i.e. day length of the average day of the month) [hour]
$\overline{T_a}$ monthly mean ambient temperature, ^{o}C
$\overline{T_s}$ monthly mean soil temperature, ^{o}C
R^2 determination coefficient
RH relative humidity, %

Greek symbols
ω_{ss} the sunset hour angle, the angular displacement of the sun east or west of the local meridian due to rotation of the Earth on its axis at 15^o per hour (morning negative, afternoon positive), in degrees
δ declination angle
ϕ latitude, the angular location north or south of the equator, north positive
θ_z zenith angle, the between the vertical and line to the sun, i.e., the angle of incidence of beam radiation on a horizontal surface
τ_b the atmospheric transmittance for beam radiation
τ_d the ratio of diffuse radiation to the extraterrestrial (beam) radiation on the horizontal plane

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Doç.Dr. İnci TÜRK TOĞRUL, 8.10.1971 tarihinde Malatya'da doğdu. 1992 yılında İnönü Üniv. Müh. Fak. Kimya Müh. lisans programından, 1995 yılında Fırat Üniv. Fen Bilimleri Enstitüsünden Kimya Yüksek Mühendisliği programından, 2001 yılında da aynı üniversitenin doktora programından mezun oldu. 2005 yılında Kimya Müh. anabilim dalında Temel İşlemler ve Termodinamik alanında doçent oldu. 1994-2005 yılları arasında Fırat Üniv. Mühendislik Fakültesi Kimya Mühendisliği bölümünde araştırma görevlisi, Dr., Yardımcı Doçent ve Doçent olarak çalıştı. 2005-2007 yılları arasında Kırgızistan-Türkiye Manas Üniv. Müh. Fak. Gıda Müh. ölümünde bölüm başkanı olarak çalıştı. Halen Afyon Kocatepe Üniversitesi Mühendislik Fakültesinde Kimya ve Gıda Mühendisliğinde öğretim üyesi ve Dekan Yardımcısı olarak görev yapmaktadır.