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Estimation of optimum tilt angle for solar panels, with the help of the incoming radiation (Case Study of Isfahan Province, Iran)

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Abstract
Iran is a sunny country and In terms of amount of energy is one of the best countries. Electricity from Photovoltaic (PV) is by nature a fluctuating energy source due to the movement of the sun and varying cloud coverage causing variable availability throughout the day and seasons. The aim of this study is to provide a model for the initial assessment of the use of solar panels in Isfahan province and to estimate the optimal tilt angles for panels and we used data from NASA's Atmospheric Sciences Research Center of the amount of solar radiation that received from the surface of the panels in last 22 and whit regression and obtain a coefficients, test of the validity of errors was investigated. This study appropriately evaluates the radiation estimation models (linear model) whit SPSS software for initial assessment. Also some other models whit linear model was compared and the best one was introduced. According to the correlation coefficient for all angles except angles of 0, 45, 50 and 55, model was appropriate. As a result, summer is much warmer than winter, and the polar regions are dramatically colder than the tropics and the use of panels in cold seasons with the angle of 45 to 60 degree and in warm seasons whit the angle of less than 45 degree, especially less than 20 degrees to the horizon, will bring the highest payoff.

Keywords: solar panels; optimal slope; Photovoltaic; Iran

1. Introduction

In Iran, more than 95 percent of energy are provided from fossil energy oil and gas (Khosravi 2013) [8]. Types of energies consumed in the residential and commercial sectors in Iran include: crude oil and oil productions, natural gas, coal, combustible renewable resources and electricity; the consumption rate of each computed to be 8.39, 46.13, 0.01, 1.31 and 8.58, respectively (Nazari*et al*. 2015) [14]. Even though there are cheap renewable energy sources like wind and solar energy. Iran is also a sunny country and In terms of amount of energy is one of the best countries (Fraisse*et al*. 2009) [5]. Increase of the use of fuel and gas causes atmospheric problems like air pollution and greenhouse effects (Mostafaeipour and Abarghooei 2008) [13]. It seems that the use of renewable energies like solar energy instead of other fuels and gas may alleviate consequences of these problems (Kazemi J 2011) [7]. Such as world's growing population and limited energy resources, costly and environmental pollution, caused by the consumption of these fuels that has prompted scientists to look for low-cost and clean renewable resources such as renewable energies (M.J 2010) [10]. Renewable energy is often viewed as a good option because it is widely available and environmentally friendly (Fazelpour, Soltani, and Rosen 2014) [4] (Gunerhan and Hepbasli 2007) [6], increasingly becoming popular all over the world (M.A 2015) [9], and may be captured almost anywhere on the planet and converted directly into electric power through photovoltaic (PV) panels (Meral and Dinçer 2011) [12]. In some residential buildings, installation of nonconventional energy utilization devices such as solar thermal collector or photovoltaic panels (Santos and Rüther 2012) [19] (Takuma *et al*. 2006) [22], also one of the most important factors that contribute to achieving sustainable development is the requirement for a supply of energy resources that is both efficient and fully sustainable (Dincerb 1999) [3]. The amount of solar radiation that panels receives, depends on its position relative to the equator and Tilt angle with the ground (Skeiker 2009) [21]. Another factor in effective is the amount of radiation received per unit area that measured by experts and with special devices in different months of the year (Shariah, Al-Akhras, and Al-Omari 2002) [20]. The utilization of solar energy depends highlyon the technology's performance, economics, efficiency, reliability and durability (ROSEN MARC A. * 2011) [17]. Previous studies, such as KadirBakirci (Bakirci 2012) [2], assessed general models for the optimum tilt angle of solar panels and optimization of tilt angles was performed using solar radiation data measured for eight big provinces in warm and cold seasons in Turkey. Also Gunerhan and Hepbasli (Gunerhan and Hepbasli 2007) [6], calculated the optimum tilt angles by searching for the values for which the total radiation on the collector surface is at a maximum for a particular day or a specific period. Mehleri*et al* (Mehleri*et al*. 2010) [11], carried out a study on the determination of the optimum tilt angle and orientation for solar photovoltaic arrays in order to maximize the incident of solar irradiance exposed on the array, for a specific period of time. Research works have been conducted to develop mathematical relations to assess the received solar radiation on sloped surfaces, in which the models of KhaiMun Ng *et al* (Ng *et al*. 2014) [15], KlemenZaksek*et al* (Zakšek, Podobnikar, and Oštir 2005) [24]

This research was done to primary and easy evaluation of optimum tilt angle for solar panels in Isfahan province. The prime objectives of this study include (i) estimation of optimal slope for solar panels by linear regression model using solar radiation (ii) comparing the linear regression model with other models [16].

2. Materials and methods

2.1. Study area

Isfahan province is one of the 34 provinces of Iran located in the central part of Iran and about 10% of Iranian deserts are placed in this province. Isfahan province with an area of 107,027 km2 is located between 3043/N and 3427/N and also between 4936/E and 5531/E. City of Isfahan is the center of the province situated at 3237/N and 5140/E and its elevation is 1550.4 m above sea level. Weather condition in Isfahan is totally mild and dry and amount of rainfall and snowfall is low. Due to placement in sunny region of Iran, Isfahan city enjoy great solar energy source throughout the year. (Sabzpooshani and Mohammadi 2014) [18]

Fig 1: Location of study (Isfahan, Iran)

2.2. Research Method

Based on the information of Atmospheric Sciences Research Center of NASA [1], average solar energy, in different months was received (atmospheric). Then by the software Microsoft Visual Studio Ultimate 2013 (Version 12.0.30723.00) and using the C ++ programming language To Estimates the incoming solar radiation was performed and data entered to SPSS (version 19.0.0.329) software.

2.3. Calculate the amount of incoming radiation

To calculate the amount of receiving energy per unit area of the panel that the n-th day of January and latitude φ angle β with the horizon and is located to the south is estimated from the following equation (W 1992):

$$\overline{H}_0 = \frac{24\times3600G_{SC}}{\pi}\times\left(1+\ .033\cos\left(\frac{360\times n}{365}\right)\right)\times\left[\cos\varphi.\cos\delta.\sin\omega_s+\frac{\pi\omega_s}{180}\sin\varphi.\sin\delta\right] \quad (1)$$

In the above equation $\overline{H}_0$ is intensity of solar radiation outside the atmosphere and $\bar{H}$ is the daily average radiation in per month. G_{SC} is a solar constant and amount of that is intended equal to 1367 watts per square meter. φ is latitude and β is the angle to the horizontal panel. Also δ is a solar angle relative to the equator in degrees and equal to $-23.45\leq\delta\leq23.45$ whose number can be obtained from Cooper Approximately equation (P 1969). ω_S is also the angle of the sun at sunrise and sunset, and the value of that can be calculated from equation (3).

$$\delta = 23.45\sin\left(360\times\frac{284+n}{365}\right) \quad (2)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\,.\tan\delta) \quad (3)$$

Proportion Of radiation energy received by a horizontal plane in the desired time period to amount radiation energy received on the same horizontal plane at the same time and out of the atmosphere is called air filter coefficient at a point with certain latitude. The brightness coefficient equation for each month is defined as following equation:

$$K_t = \frac{\bar{H}}{\bar{H}_0} \tag{4}$$

In the next step, according to the calculated number, ratio of scattered radiation intensity to total radiation intensify, must be taken into account by the following equation:

$$\frac{\bar{H}_d}{\bar{H}} = \begin{cases} 1.39 - 3.560k_t + 4.18{k_t}^2 - 2.1{k_t}^3 \\ 1.311 - 3.022k_t + 3.427{k_t}^2 - 1.821{k_t}^3 \end{cases} \tag{5}$$

Sometimes it happens after sunrise, radiation does not reach to the surface of the panels, so it is necessary that amount of $\omega_s{}'$ that is calculated by the following equation:

$$\omega_s{}' = min\begin{pmatrix} \cos^{-1}(-\tan\varphi.\tan\delta) \\ \cos^{-1}(-\tan(\varphi-\beta).\tan\delta) \end{pmatrix} \tag{6}$$

After determining the above amount, ratio of directly radiation on the slope above the horizontal plane is calculated by the following equation:

$$R_b = \frac{\cos(\varphi-\beta).\cos\delta.\sin\omega_s{}' + \frac{\pi}{180}\omega_s{}'.\sin(\varphi-\beta).\sin\delta}{\cos\varphi.\cos\delta.\sin\omega_s + \frac{\pi}{180}\omega_s.\sin\varphi.\sin\delta} \tag{7}$$

Then, to estimate the scattered radiation and reflection, in addition to direct radiation to the surface of the panel, we need to calculate the ratio of total radiation of the slope to the horizon from the following formula:

$$R = \left(1 - \frac{\bar{H}_d}{\bar{H}}\right)R_b + \frac{\bar{H}_d}{\bar{H}}\left(\frac{1+\cos\beta}{2}\right) + \rho\left(\frac{1-\cos\beta}{2}\right) \tag{8}$$

Finally the intensity of radiation on the slope is accessible according to the following equation:

$$\bar{H}_t = R \times \bar{H} \tag{9}$$

3. Data analysis

3.1. Estimating total solar radiation for different slope

In table 1, amounts of received radiation that calculated for different angles is visible. This table provides a better comparison of amounts of the incoming radiation.

Table 1: The average solar energy incident in the Isfahan province in different months ($\frac{MJ}{M^2}$)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lat 32.64												
Lon 51.66												
22-year Average	3.25	4.38	5.09	5.98	6.85	7.50	7.07	6.74	5.98	4.67	3.50	2.99

The Amount of received radiation during the above steps on the surface of the panel for all possible angles of tilt is obtained. These amounts are shown in Table 2 for different angles.

Table 2: The monthly amount of received radiation for different panels tilt for Isfahan province. ($\frac{MJ}{M^2}$)

Ang	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Cold months	Warm months
0	11.70	15.77	18.32	21.53	24.66	27	25.45	24.26	21.53	16.80	12.6	10.76	85.95	144.43
5	12.90	16.99	19.06	21.86	24.62	26.75	25.30	24.47	22.24	17.87	13. 81	11.96	92.59	145.24
10	14.02	18.10	19.70	22.06	24.46	26.37	25.04	24.54	22.81	18.84	14.94	13.10	98.7	145.28
15	15.07	19.11	20.22	22.15	24.18	25.87	24.65	24.49	23.26	19.69	15.98	14.15	104.22	144.6
20	16.01	20.00	20.63	22.12	23.79	25.26	24.15	24.30	23.57	20.43	16.93	15.13	109.13	143.19
25	16.87	20.77	20.92	21.97	23.27	24.52	23.53	23.98	23.73	21.04	17.77	16.00	113.37	141
30	17.62	21.41	21.09	21.70	23.64	23.67	22.80	23.53	23.76	21.53	18.49	16.77	116.91	139.1
35	18.25	21.92	21.13	21.31	21.90	22.71	21.97	22.96	23.65	21.88	19.10	17.45	119.73	134.5

40	18.77	22.28	21.06	20.81	21.05	21.65	21.03	22.27	23.40	22.10	19.59	18.00	121.8	130.21
45	19.16	22.51	20.85	20.20	20.11	20.50	19.99	21.46	23.00	22.18	19.95	18.44	123.09	125.26
50	19.44	22.59	20.53	19.48	19.09	19.27	18.88	20.54	22.48	22.13	20.19	18.77	123.65	119.74
55	19.59	22.53	20.10	18.67	17.96	17.96	17.69	19.52	21.82	21.93	20.30	18.97	123.42	113.62
60	19.6	22.33	19.53	17.75	16.78	16.60	16.44	18.40	21.04	21.60	20.27	19.04	122.37	107.01
65	19.51	21.98	18.86	16.76	15.53	15.19	15.14	17.20	20.14	21.14	20.12	19.00	120.61	99.96
70	19.28	21.50	18.09	15.68	14.24	13.76	13.80	15.93	19.13	20.56	19.83	18.83	118.09	92.54
75	18.92	20.88	17.21	14.54	12.92	12.31	12.44	14.60	18.00	19.84	19.42	18.53	114.8	84.81
80	18.45	20.14	16.25	13.34	11.57	10.88	11.08	13.22	16.79	19.00	18.89	18.12	110.85	76.88
85	17.85	19.27	15.19	12.09	10.24	9.50	9.74	11.81	15.49	18.06	18.23	17.59	106.19	68.87
90	17.15	18.28	14.06	10.81	8.94	8.21	8.47	10.39	14.11	17.01	17.46	16.94	100.9	60.93

3.2. Model estimation

Relationships and the effects of phenomena on other phenomena are considered. For this reason, one of the issues examined in these studies, is the amount of relationships and effects of the phenomena and determines the correlation and performance of a phenomenon from other phenomenon that has a significant effect on it.

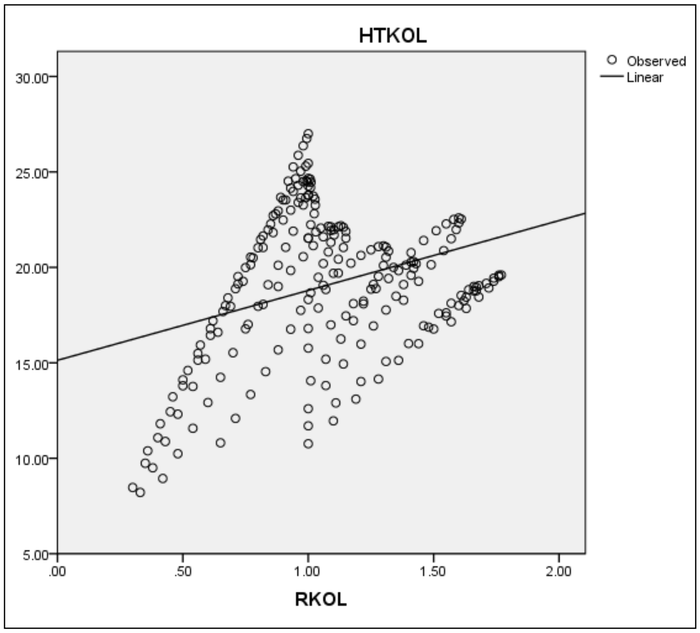

Fig 2: Diagram $\overline{H}_t$ and R relative to each other
(HTKOL= $\overline{H}_t$ $TOTAL$ and RKOL= RTOTAL)

It is clear from Figure 3 that linear relationship between $\overline{H}_t$ and R if an imaginary line drawn on data, not very accurate.

4. Results

4.1. Regression data model

Table 3: Correlation between $\overline{H}_t$ and R

		HTKOL	RKOL
HTKOL	Pearson Correlation	1	.325**
	Sig. (2-tailed)		.000
	N	228	228
RKOL	Pearson Correlation	.325**	1
	Sig. (2-tailed)	.000	
	N	228	228
**.Correlation is significant at the 0.01 level (2-tailed).			

Table 4: Summary Indicators of regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.325[a]	.106	.102	3.70156
a.Predictors: (Constant), RKOL				

Regression equation based on Table of coefficients is equal to:

HT_{Total} = 3.660R +15.133

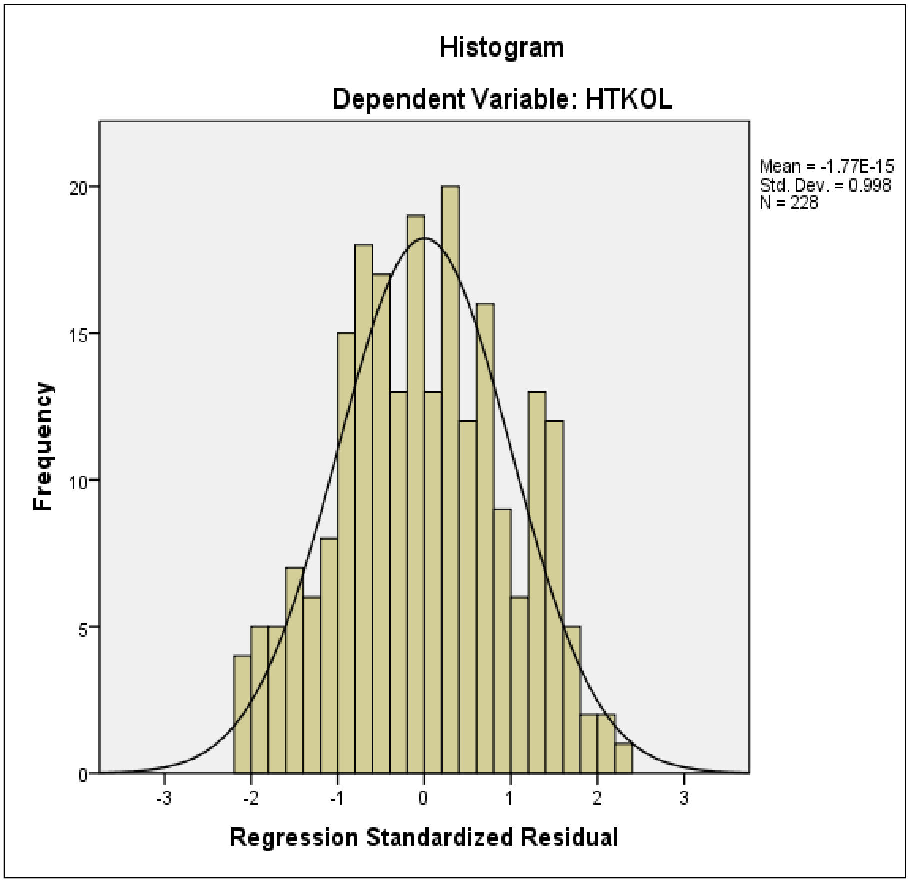

Fig 3: Graph of the normal distribution of residuals

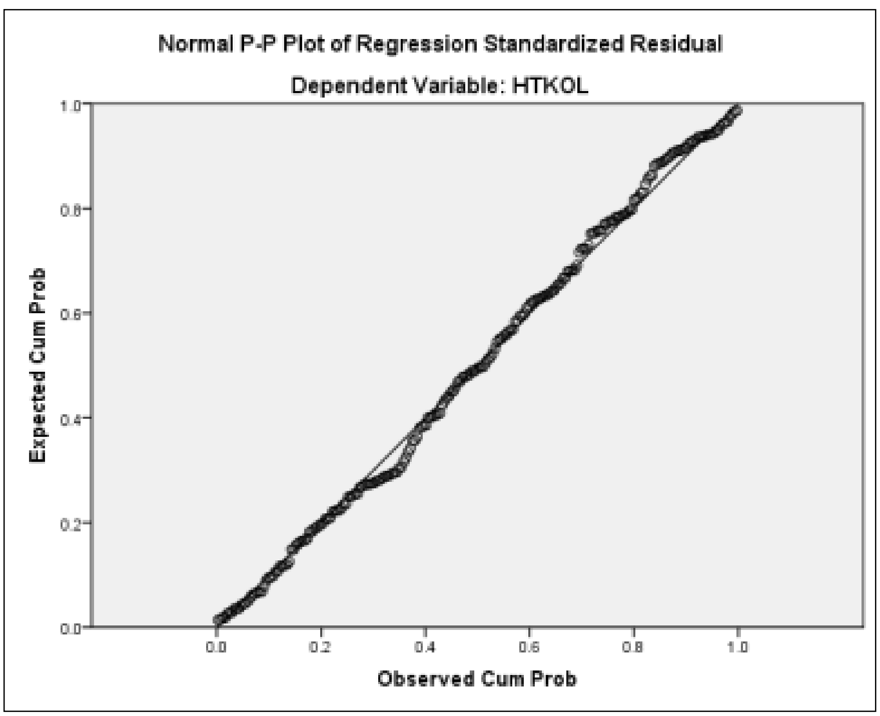

Fig 4: Graph of the regression model residuals

Figure 4 shows the normality of the regression model remains. Because the points on the line. According to Figure 5 that is variance equality, this equality has not been confirmed. So regression based on different angles is more invoked than the general regression of all data.

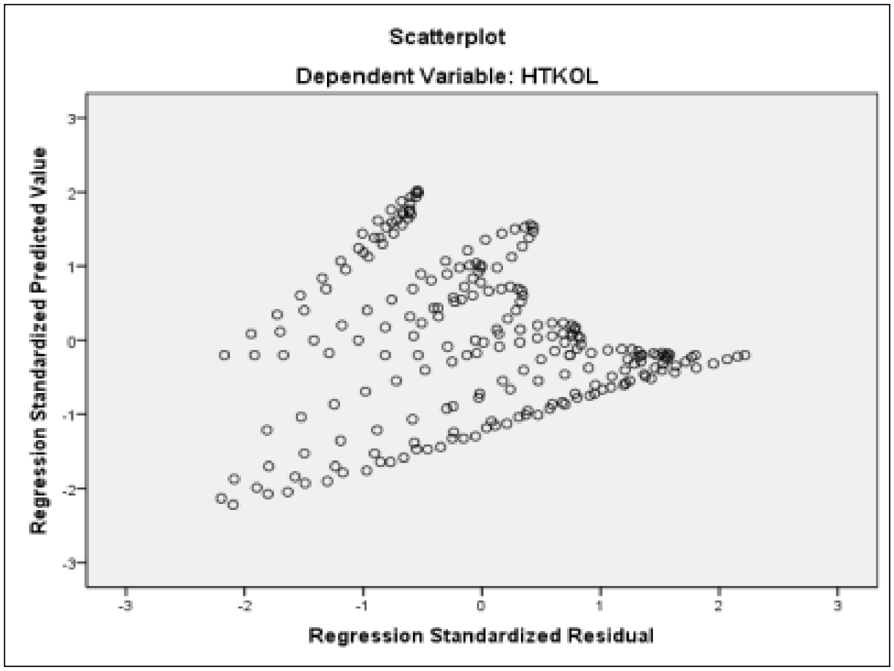

Fig 5: Test the equality of variance

4.2. Regression for each of the angles

At first for each data regression, we sketched the dependent variable and the independent variables to help intuitively understand the relationship between variables below the variable HT (that is assumed as the dependent variable). For zero angle, all numbers related to R is 1, so we can't discuss about of regression.

Table 5: The relationship between $\overline{H}_T$ and R for angle 5

		HT5	R5
HT5	Pearson Correlation	1	-.949**
	Sig.(2-tailed)		.000
	N	12	12
R5	Pearson Correlation	-.949**	1
	Sig.(2-tailed)	.000	
	N	12	12
**.Correlation is significant at the 0.01 level (2-tailed).			

Correlation coefficient is equal -0.949 and this number is close to -1 indicates a high correlation between these two variables, also the correlation coefficient is negative that indicating an inverse relationship between two variables $\overline{H}_T$ and R for angle

Table 6: Model Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	15.133	.797		18.989	.000
	RKOL	3.660	.708	.325	5.166	.000
a. Dependent Variable: HTKOL						

Our criterion for accepting the regression model is a table of variance analysis. According to Table 8, a definite relationship can be investigated and amount of sig of the regression is very small, and this means that existence of regression test is approved.

Table7: Average and standard deviation of residuals

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	12.1243	25.6372	19.8192	4.88142	12
Residual	-2.81863	2.61351	.00000	1.61807	12
Std. Predicted Value	-1.576	1.192	.000	1.000	12
Std. Residual	-1.661	1.540	.000	.953	12

Table 8: Regression coefficients of model for angle ° 5

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	262.111	1	262.111	91.012	.000[a]
	Residual	28.800	10	2.880		
	Total	290.911	11			

a. Predictors: (Constant), R5
b. Dependent Variable: HT5

Regression model for angle ° 5 is:

$$HT_5 = -112.607R + 137.118$$

However, we investigate the remains of the model to ensure from accuracy of regression model. The remaining of the model should follow a normal distribution that according to Histogram graph we can see the residuals are based on a normal distribution.

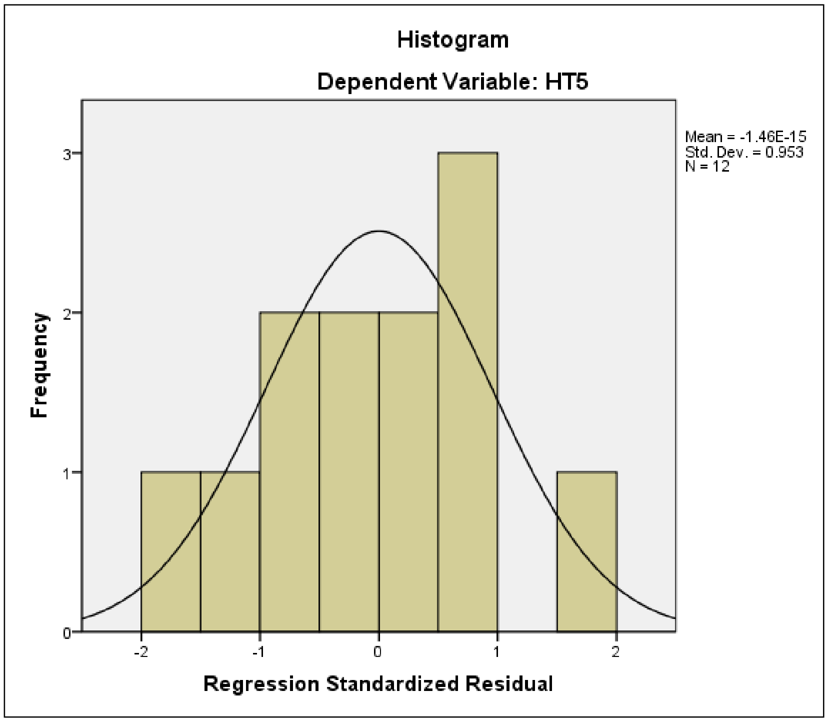

Fig 7: Residuals of the normal distribution diagram

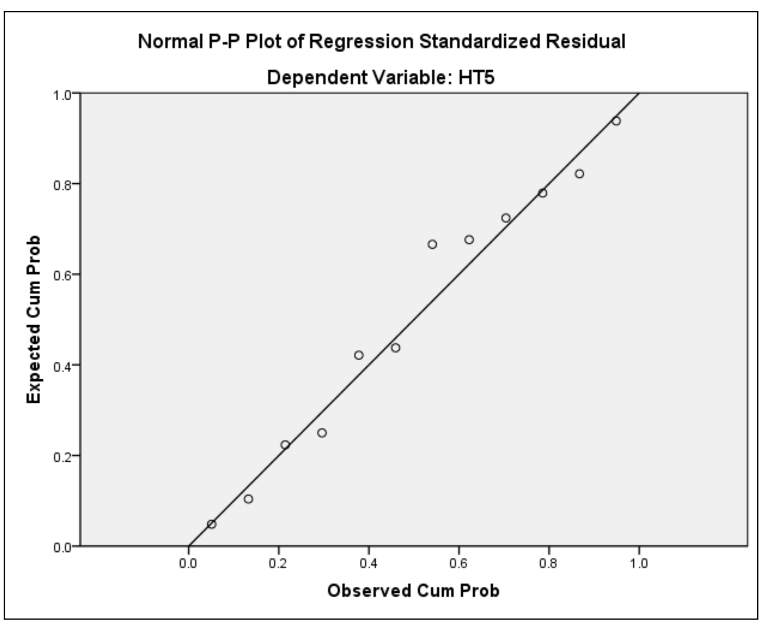

Fig 8: Distribution of measured data to estimate

In Figure 8, we can see that points are almost on the line and this is another proof of the normality of residuals. Finally, check the stable of variance was investigated.

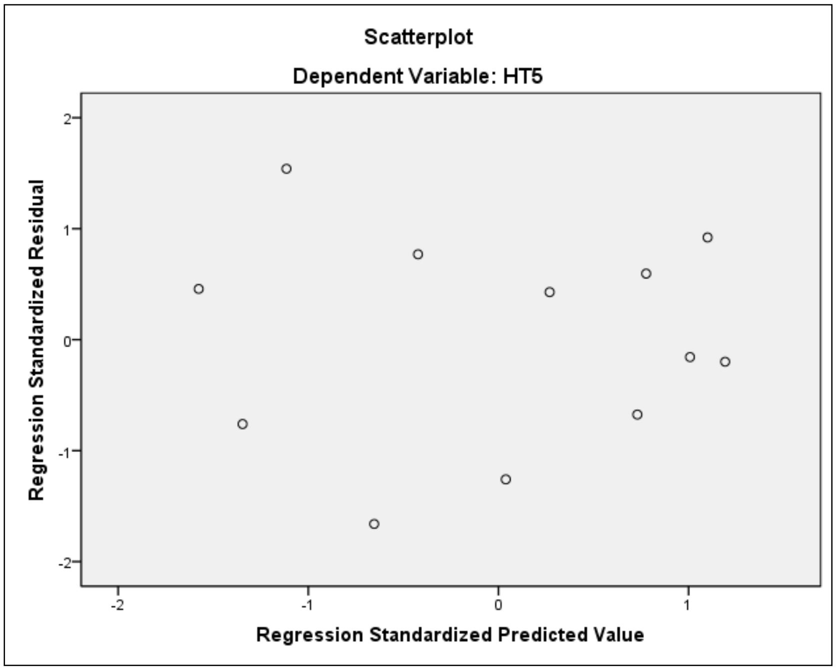

Fig 9: Testing the equality of variances

According to Figure 9 a trend of increase or decrease, can't be seen and we expect the points distribute around a zero horizontal imaginary line to stable or in other words, equal error variance is approved, but in Figure 9 with some discounts can be accept these item.

The above process for all angles, have been conducted and the results can be seen below.

HT_{10} = -49.949R + 74.181
HT_{15}= -29.134R + 53.116
HT_{20} = -18.774R + 42.363
HT_{25} = -12.463R + 35.625
HT_{30} = -8.676R + 31.480
HT_{35} = -5.323R + 27.445
HT_{40} = -3.009R + 24.537
HT_{55} = 1.631R + 17.906
HT_{60} = 2.708R + 16.120
HT_{65} = 3.680R + 14.443
HT_{70} = 4.537R + 12.875
HT_{75} = 5.282R + 11.418
HT_{80} = 5.977R + 10.051
HT_{85} = 6.614R + 8.752
HT_{90} = 7.168R + 7.578

For angles of 0, 45, 50 and 55, regression has not been confirmed.

4.3. Review other models

In Table 9, Configuration details of three models including, Quadratic, cubic and exponential, are visible on whole numbers. The best model is the simplest one that has a sig less than 0.15 and more R square (is better to closer to 1) that third degree model has a maximum R square but, It seems, Quadratic model Compared to others is more appropriate also that is complex compared to linear model, so the linear model is better for forecasting.

Table 9: Model Summary and Parameter Estimates

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Quadratic	.367	65.180	2	225	.000	.697	33.545	-13.871	
Cubic	.446	60.075	3	224	.000	-17.795	99.002	-82.324	21.738
Exponential	.149	39.645	1	226	.000	14.115	.257		

Quadratic model:

$$HT_{kol} = 0.697 + 33.545\ R_{kol} - 13.871 R_{kol}^2$$

Cubic model:

$$HT_{kol} = -17.795 + 99.002\ R_{kol} - 82.324 R_{kol}^2 + 21.738 R_{kol}^3$$

Exponential model:

$$HT_{kol} = 14.115 * e^{0.257\ R_{kol}}$$

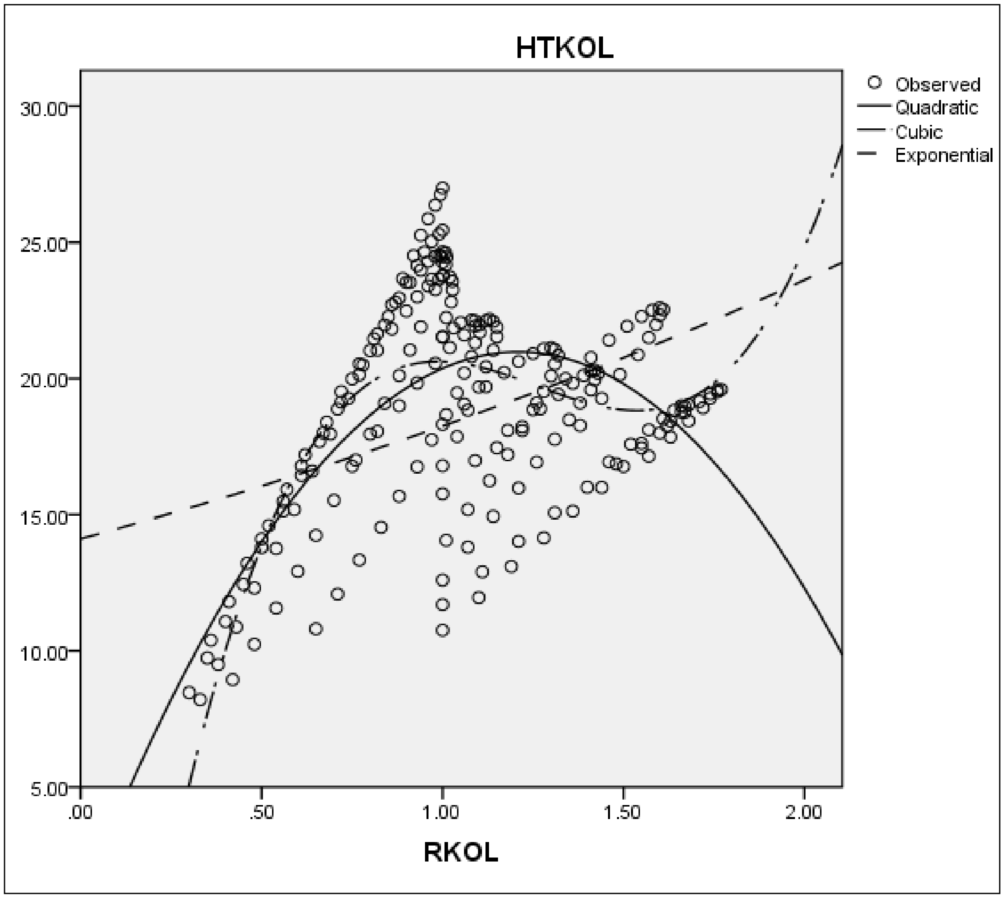

Fig 10: Graph of Quadratic, cubic and Exponential Models

5. Conclusion

If we want to compare the relationship between the data regardless of different angles, we confront with a correlation coefficient of 0.325. Although the diagram of the data in Figure 3 does not shows a linear relationship, but regression with the sig 0.15 and normalization of remaining of models is approved. But test of variance equality that is clear in Figure 6 has not been confirmed while for an appropriate model, we need confirmation of all the default tests. Due to the mentioned reasons, the regressions based on different angle, is more invoked than the general regression of the data. Regression of the various angles showed a high correlation coefficient for angles of less than 45, and all models are approval but for angles of 0, 45, 50 and 55, was not obtained suitable regression equation and for angles greater than 55 also model was approved, but the correlation coefficient was less than the angles smaller than 45. Another important point is that before angle of 50, HT and R numbers have an inversely relation to each other and from angle of 50 onwards, they have a direct relation to each other. According to normal of data and high correlation coefficient, predictive models are radiation is confirmed and in initial assessments estimated to be appropriate. According to this study, the use of panels in cold seasons, the angles of 45-60 degrees to horizon and in warm seasons, angles of less than 45 degree, specially less than 20 degree to horizon is the most appropriate estimate. Also by comparing the linear model with other models, this result was achieved that linear model is better for forecasting.

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