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Araştırma Makalesi / Research Article

Estimation of Cloudiness Data Based on Multiple Linear Regression Model

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Abstract

This study estimates cloudiness data using meteorological parameters which include climatic variables and air quality index. Daily average observed values of all meteorological parameters used in this study were transformed to monthly mean data for 1990-2015 period. The monthly mean values of cloudiness were estimated by using the other climatic elements and the value air quality index at urban area in Kayseri. Multiple Linear Regression model was built to determine the mathematical relationships for predicting cloudiness. It has been shown that meteorological parameters affect cloudiness the most in May and October, and the least in September and January. Additionally, according to the estimated models, air quality index value has effect on cloudiness data on January, July, October and November as statistically significant.

Keywords: Cloudiness, Climatic Variables, Air Quality Index Value, Multiple Linear Regression Model.

Bulutluluk Verisinin Çoklu Doğrusal Regresyon Modeli Kullanılarak Tahmin Edilmesi

Öz

Bu çalışma, iklim verileri ve hava kalite indisi gibi meteorolojik değişkenler kullanılarak bulutla kaplılık verisini tahmin etmektedir. Bu çalışmada kullanılan tüm meteorolojik parametrelerin günlük ortalama gözlem değerleri 1990-2015 dönemi için aylık ortalama verilere dönüştürülmüştür. Aylık ortalama bulutluluk değerleri, Kayseri'de kentsel alanda diğer iklim unsurları ve değer hava kalitesi indeksi kullanılarak tahmin edilmiştir. Bulutluluğu tahmin etmek için matematiksel ilişkileri belirlemek için Çoklu Doğrusal Regresyon modeli oluşturulmuştur. Meteorolojik parametrelerin bulutluluğu en fazla Mayıs ve Ekim aylarında, en az ise Eylül ve Ocak aylarında etkilediği gösterilmiştir. Ayrıca tahmin edilen modellere göre hava kalitesi indeks değeri Ocak, Temmuz, Ekim ve Kasım aylarındaki bulutluluk verileri üzerinde istatistiksel olarak anlamlı etkiye sahiptir.

Anahtar Kelimeler: Bulutluluk, İklimsel Değişkenler, Hava Kalitesi İndis Değeri, Çoklu Doğrusal Regresyon Modeli.

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1. Introduction

Climate is an important factor for our planet in many ways. The information on meteorological parameters has a crucial significance in defining the characteristics of climatic variables. Clouds play an important role in climate system via affecting the atmosphere. They are related to climate feedback and radiation balance of Earth. Clouds reflect the incoming solar radiation and cause the cooling of planet. Besides, clouds absorb the heat that surface emits and then radiate it to the space and cause the warming of the Earth. Furthermore, clouds form the precipitation as water supply for the Earth's surface. According to some studies about air pollution meteorology, it has been shown that air pollutants were related to climatic variables (Zateroglu, 2021a,b,c,d, 2022). Zateroglu (2021a) shown that sunshine duration was associated with particulate matter and sulphur dioxide. Cuhadaroglu and Demirci (1997) studied the effect of some meteorological factors on air pollution for Trabzon province located in the region Black Sea. Dominick et al., (2012) examined the meteorological factors on air pollutants in Malaysia.

Air pollutants, i.e. aerosols, have an increment effect on the absorption and scattering of incoming solar radiation. Also, they serve as cloud condensation nuclei and influence characteristics of clouds (Liepert, 1997, Liou et al., 1990; Twomey 1974, Twomey et al., 1977). Furthermore, cloud condensation nuclei may enhance cloud concentration, and in turn, cloud albedo and may decrease the dimension of droplets of clouds. Mateos et al., (2013) investigated about the radiative effects of aerosols and clouds for long-term records.

Clouds are observed via two methods i.e. ground-based observation and satellite-based observation. Those have been utilized in many areas for many applications such as cloud distribution and effects on climate (Changnon, 1981; Kaiser 1998, 2000). Cloud amount is related to sunshine duration according to some studies (Essa and Etman, 2004; Elnesr and El-Sabban, 1964; Badescu et al., 2016; Hoyt, 1977; Zateroglu 2021, 2022). Cloudiness and climatic variables have interactions in atmospheric environment. Clouds have relationships with atmospheric dynamics, precipitation and energy balance of earth (Norris and Slingo, 2009). Webster (1969) examined the relationship between the sunshine duration and total cloud amount. Matuszko (2012) evaluated the influence of cloudiness on sunshine duration. Weber (1994) studied on the relationships between cloudiness, sunshine and temperature range, for the seasonal variation. For Egypt, Robaa (2008) investigated the sunshine duration with the effect of cloudiness data. Otherwise, Neske (2014) analyzed the relations between cloudiness and sunshine duration data in Hamburg. Furthermore, different cloud types have different effects on climate. Liou et al. (1990), have constructed a two dimensional model to investigate the disturbance of high cloud cover on temperature areas.

In this study, it is aimed to examine the variation of cloudiness data related to air quality index value and climatic variables by employing the Kayseri meteorological station data.

2. Materials and Methods

Regression analysis was performed to analyze dataset. This technique is used in modeling the relationships between two or more variables as mathematical structure. The aim is to predict the parameters in established model by using a dependent variable (Y) and one or more independent variables (X) and then, to estimate the value of dependent variable for measured values of independent variables. That is, to determine the relationship structure between the dependent and independent variables. The regression method is called multiple linear regression method when the independent variables are two or higher . For k-independent variables such as X_1, X_2, X_3,…., X_k, affecting the dependent variable, Y, the multiple regression model is formed as shown in Equation (1),

$$Y_i = b_0 + \sum_{j=1}^{k} b_j X_{ij} + \varepsilon_i \quad , \quad i = 1,2,\dots,n \tag{1}$$

In Equation (1), b_0 and b_j (where j=1,2, …….,k) are the estimated regression coefficients, Y is observed valueof dependent variable, Xs are the independent variables and Ɛ is error term. The purpose of the model prediction is to estimate the regression coefficients that make smaller the error term. The regression coefficients are predicted via least squares method (Montgomery et al., 2001).

At the end of the analysis, it is crucial if the significance value that is estimated in the models is smaller than the critical value (0.05). This feature indicates the statistically meaningful of the estimated models. Additionally, some statistical evaluation criteria such as Correlation Coeffient (R), Determination Cofficient (R^2) and Standard Error of Estimation (SEE) were used to interpret the success of the estimated model. The value of Correlation Coeffient, R, varies between -1 and +1. Its formula is shown in Equation (2). Determination coefficient, R^2, is the square of the value R. SEE expresses a size that indicates difference between observed and estimated values. An R-value close to absolute 1 and SEE value in low degree indicate that the model is successful.

$$R = \frac{\sum_{i=1}^{n}\left(\hat{Y}_i - \bar{\hat{Y}}_i\right)(Y_i - \bar{Y}_i)}{\sqrt{\left[\sum_{i=1}^{n}\left(\hat{Y}_i - \bar{\hat{Y}}_i\right)^2\right]\left[\sum_{i=1}^{n}(Y_i - \bar{Y}_i)^2\right]}} \tag{2}$$

$$SEE = \sqrt{\frac{\sum\left(Y_i - \hat{Y}_i\right)^2}{n-2}} \tag{3}$$

In these equations, n is the number of observations, Y_i is the observed value and, $\widehat{Y_i}$ is the estimated value, $\overline{Y_i}$ and $\overline{\widehat{Y_i}}$ is the average of the observed and estimated values respectively.

The dataset utilized in present study were provided from ground based meteorological station and air pollutants monitoring station located in Kayseri. Before employing the regression methods, Daily air quality index values were computed by the formula proposed by United States Environmental Protection Agency (USEPA) utilizing the air pollutants concentrations (Table 1). For any air pollutant, an index value is calculated by using the Equation (4).

$$I_p = \left[\frac{(I_{Hi} - I_{Lo})}{(BP_{Hi} - BP_{Lo})}\right](C_p - BP_{Lo}) + I_{Lo} \quad (4)$$

In Equation (4), I_p denotes the index value for pollutant p; C_p is the concentration value of the pollutant p; BP_{Hi}, is the breakpoint that is equal to or bigger than C_p ; BP_{Lo} is the breakpoint that is equal to or smaller than C_p ; I_{Hi} is the index value defining to BP_{Hi} and I_{Lo} is the index value defining to BP_{Lo}. Hence, the daily AQI value was defined as the highest value among computed index values by using Equation (5).

$$AQI = Max(I_1, I_2, ..., I_p), \quad p = 1, 2, ..., 5 \quad (5)$$

Table 1. United States Environmental Protection Agency breakpoints of air pollutants for the air quality index (AQI) (EPA, 1999)

Breakpoints							AQI	Category
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour[1]	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	CO (ppm)	SO_2 (ppm)	NO_2 (µg/m^3)		
0.000-0.064	-	0-54	0.0-15.4	0.0-4.4	0.000-0.034	([2])	0-50	Good
0.065-0.084	-	55-154	15.5-40.4	4.5-9.4	0.035-0.144	([2])	51-100	Moderate
0.085-0.104	0.125-0.164	155-254	40.5-65.4	9.5-12.4	0.145-0.224	([2])	101-150	Unhealty for sensitive groups
0.105-0.124	0.165-0.204	255-354	65.5-150.4	12.5-15.4	0.225-0.304	([2])	151-200	Unhealty
0.125-0.374	0.205-0.404	355-424	150.5-250.4	15.5-30.4	0.305-0.604	0.65-1.24	201-300	Very unhealty
([3])	0.405-0.504	425-504	250.5-350.4	30.5-40.4	0.605-0.804	1.25-1.64	301-400	Hazardous
([3])	0.505-0.604	505-604	350.5-500.4	40.5-50.4	0.805-1.004	1.65-2.04	401-500	Hazardous

[1] Generally AQI is reported by using 8-hour ozone values. Anyway, for some areas, AQI is evaluated using both 1- and 8-h ozone (O_3) levels and reported as the maximum of each.
[2] NO_2 has no short-term National Ambient Air Quality Standards (NAAQS) and can generate AQI if it is >200.
[3] For higher AQI values (301-400 and 401-500), 1-h O_3 concentrations are used instead of 8-h O_3 concentrations.

3. Findings and Discussion

3.1. Statistical values of meteorological parameters

Table 2 shows the descriptive statistics for meteorological parameters such as cloudiness (TCC), relative humidity (RHM), wind speed (WINS), precipitation (PREC), air pressure (PRES), minimum air temperature (MINT), maximum air temperature (MAXT) and air quality index (AQI). Those were determined for annual and seasonal i.e. winter months (December, January, February coded as DJF), spring months (March, April, May coded as MAM), summer months (June, July, August coded as JJA), autumn months (September, October, November coded as SON). Minimum, Maximum, Mean and Standard Deviation values were listed according to related period for each parameter. In Table 1, the mean values were defined for parameters such as TCC changed seasonal from 2.0681 (JJA) to 5.61 (DJF), RHM 50.4605 (JJA) to 73.6829 (DJF), WINS 1.4314 (SON) to 2.0276 (MAM), PREC 20.0819 to 52.9657, PRES 890.1333 (JJA) to 893.5867 (SON), MINT -14.7662 (DJF) to 7.4919 (JJA), MAXT 13.4833 (DJF) to 35.4924 (JJA), AQI 37.356 (JJA) to 93.8062 (DJF).

Table 2. Descriptive statistics for meteorological parameters

Parameter	Statistics	ANNUAL	DJF	MAM	JJA	SON
TCC	Minimum	3,4	4,07	4,17	1,4	2,73
	Maximum	4,47	6,63	6,03	3,27	4,03
	Mean	4,0005	5,61	4,8986	2,0681	3,4257
	Std. Deviation	0,3354	0,76901	0,54944	0,54793	0,41077
RHM	Minimum	56,54	65,8	51,9	44,93	54,73
	Maximum	67,81	79,97	68,67	62,47	66,63
	Mean	61,839	73,6829	61,7614	50,4605	61,4481
	Std. Deviation	2,81947	3,46777	4,18111	4,44842	3,36277
WINS	Minimum	1,44	1,07	1,67	1,43	1,2
	Maximum	1,91	1,87	2,67	2,17	1,87
	Mean	1,6638	1,519	2,0276	1,6738	1,4314
	Std. Deviation	0,1476	0,20861	0,23755	0,20578	0,16153
PREC	Minimum	21,49	12,13	21,97	0,47	7,47
	Maximum	47,8	59,1	76,43	45,75	53,35
	Mean	34,4162	36,2819	52,9657	20,0819	27,09
	Std. Deviation	6,82668	11,23343	15,70843	12,09553	11,33242
PRES	Minimum	890,63	888,3	888,63	888,93	892,03
	Maximum	893,01	895,33	892,63	891,53	895
	Mean	891,589	892,3062	890,3267	890,1333	893,5867
	Std. Deviation	0,6355	1,77219	0,84486	0,77689	0,68692
MINT	Minimum	-6,47	-19,7	-7,03	5,9	-5,57
	Maximum	-0,38	-10	0,03	10,83	1,17
	Mean	-3,2276	-14,7662	-3,2571	7,4919	-2,3752
	Std. Deviation	1,34417	2,89461	1,81654	1,26104	1,83245
MAXT	Minimum	22,79	6,37	23,87	32,5	24,27
	Maximum	27,51	19,03	29,47	37,33	29,13
	Mean	25,4948	13,4833	25,7581	35,4924	27,239

	Std. Deviation	0,92235	2,79732	1,45213	1,22031	1,26268
AQI	Minimum	48,86	53,99	30,74	20,38	39,74
	Maximum	77,62	120,28	67,61	74,1	102,38
	Mean	62,0633	93,8062	47,2395	37,356	67,6938
	Std. Deviation	9,01045	18,76332	10,20803	12,05633	15,50122

Statistical expressions were performed with statistical anlysis with SPSS. Significance (Sig.) value for models were obtained from ANOVA table. Those were shown the statistically significance of the estimated models in which lower than 5% significance level.

Table 3. Statistical expressions for monthly periods

Period	Mathematical Expression	Sig	R	R^2	SEE
JAN	149,341+0,126*RHM+1,33*WINS+0,005*AQI-0,174*PRES	0,04	0,684	0,468	0,77213
FEB	146,341+1,303*WINS-0,163*PRES-0,111*MINT	0,004	0,734	0,538	0,70253
MAR	292,614-0,320*PRES-1,012*WINS	0,000	0,769	0,591	0,61843
APR	411,132+0,067*RHM-0,463*PRES+0,085*MAXT	0,000	0,845	0,713	0,47807
MAY	-0,82+0,07*RHM+0,013*PREC+0,129*MINT	0,000	0,92	0,847	0,35772
JUN	-1,91+0,091*RHM	0,001	0,722	0,521	0,69433
JUL	-296,622+0,072*RHM+0,336*PRES-0,151*MAXT+0,050*AQI	0,003	0,882	0,779	0,35267
AUG	1,649+0,126*RHM-3,109*WINS-0,152*MINT	0,003	0,825	0,68	0,40539
SEP	-1,642+0,075*RHM	0,016	0,545	0,297	0,56089
OCT	344,172+0,118*RHM-0,388*PRES-0,019*AQI	0,000	0,951	0,904	0,34588
NOV	282,862+2,051*WINS-0,315*PRES+0,007*AQI	0,005	0,719	0,516	0,79012
DEC	166,919+0,154*RHM+0,016*PREC-0,194*PRES	0,002	0,748	0,56	0,97636

According to Table 3, the signifance values were found as smaller than the critical value (0,05) so the estimated regression coefficients and models were statistically meaningful. The effect of RHUM, PREC and AQI was found generally to increase the TCC whereas PRES, MINS and MAXT to decrease in different months. WINS has an effect on increasing TCC in JAN, FEB, NOV, and decreasing in MAR, and AUG. MAXT has negative effect on TCC for JUL and positive effect on APR. Furthermore, MINT provided an increment on TCC on MAY and decrement on AUG. RHM and PRES were generally occured in the estimated models. AQI has positive effect on TCC in JAN, JUL and NOV but negative effect in OCT. Determination coefficients, R^2, were varied from 0,297 to 0,904. Minimum value as low scale was obtained on SEP whereas maximum as high scale in OCT. The degrees of R have obtained in different values as moderate (0,49 to 0,7) on JAN, SEP, and as high (0,7 to 1) on FEB, MAR, APR, MAY, JUN, JUL, AUG, OCT, NOV and DEC.

Additionally, meteorological dataset were analyzed for annual and seasonal time scales. Regression models were also constructed for each time scale as mentioned and shown in Table 4. The time scales were abbreviated as ANN, DJF, MAM, JJA, SON for Annual, December-January-February, March-April- May, June-July-August, September-October-December respectively.

Table 4. Statistical expressions for annual and seasonal periods

Period	Mathematical Expression	Sign.	R	R2	SEE
ANN	413,951-0,048*RHM-0,464*PRES-0,100*MINS+0,008*AQI	0,000	0,849	0,72	0,19835
DJF	158,121+0,129*RHM+1,641*WINS-0,185*PRES+0,004*AQI	0,016	0,648	0,42	0,65479
MAM	378,006-0,423*PRES+0,056*RHM	0,000	0,782	0,612	0,36091
JJA	410,264-1,410*WINS+0,026*PREC-0,446*PRES-0,279*MAXT+0,010*AQI	0,008	0,785	0,615	0,40576
SON	187,823+0,050*RHM-0,210*PRES	0,042	0,53	0,281	0,36727

In ANN period, TCC was predicted from RHM, PRES, MINS with negative effect and AQI with positive effect of parameters. For winter time scale, RHM, WINS and AQI have contributions in the model as positive directions but PRES as negative. In periods MAM and SON, the prediction models were constructed with RHM (provides increment on TCC) and PRES (causes decrement on TCC). In summer, the increments on parameters WINS, PRES, and MAXT caused a decrease on TCC but PREC and AQI provided the positive effect on increasing TCC. For DJF and SON, correlation coefficient has a moderate value whereas the other periods, high values.

4. Conclusions and Recommendations

This study analyzed long-term climatic variables measured in meteorological station and air quality index values to examine the impact of these parameters on predicting cloudiness in Kayseri. The mathematical models as shown in Table 3 and Table 4 were obtained statistically significant. For different time scales, different linear models were established due to the relations of meteorological parameters. These differences may also be due to the other reasons. Atmospheric environment is a dynamic structure and many interactions may occur. Elements in the atmosphere have an effect on each other.

The results indicated that meteorological parameters affect cloudiness the most in May and October, and the least in September and January. Additionally, according to the estimated models, air quality index value has effect on cloudiness data on January, July, October and November as statistically significant.

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Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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