Modeling Solar Energy Potential in Turkey by using GWR

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Abstract

Small portion of the incoming solar energy into the world is sufficient to meet human needs. Renewable energy sources such as solar energy are very important to protect atmosphere.

Geographic variables are measured at certain points, and prediction map for the entire area is been obtained by some spatial interpolation methods. Prediction map can be obtained from observed data and also by using secondary variables which have spatial relationship with the measured values (Bostan et al, 2007).

Geographically Weighted Regression(GWR) methods were applied in the modeling of radiation. GWR is the multi-faceted approach to the analysis of spatial data. GWR opens a window through the data set to calculate local r^2 (Laffan, 1999).

In the modeling of spatial interpolation of radiation data, latitude, relative humidity and cloudiness were used as secondary variable. Best results were obtained with the cloudiness and relative humidity parameters. Simple linear models generally are been solved by ordinary least square method.

GWR model results were compared by the lowest RMSE and higher r^2 values obtained in the model. According to model result, southern parts of Izmir-Igdir line, have over 1500 KWh/m²/Year radiation potential and is considered as optimum area for the photovoltaic installation.

Keywords: *GWR, Co-kriging, Modeling, Radiation, Photovoltaic*

1. Introduction

Due to the geographical location, Turkey is lucky country compared to the others in terms of solar energy potential. According to sunshine duration and radiation data measured by TSMS from 1971 to 2000, Turkey's annual mean total sunshine hours are 2573 (daily mean is 7 h) and mean total radiation is 1474 KWh/m²-year (daily 4 KWh/m²). Monthly and regional solar energy potential of Turkey has been given at Table 1.

Photovoltaic (PV), is a method of obtaining electricity from the sun through silicon crystals.
Crystalline solar cell layer in the bottom portion covered with one of P-type material (e.g. Aluminum, Gallium, Indium) to create green spaces. N-type top layer, covered with chemicals such as arsenic, phosphorus or antimony which create traveler electrons. The light falling on the electrons stimulate them through the lower layers (P region). In the solar cell, these electrons makes short-circuit in the ways drawn that separates two layers and circuit again through drawn road towards the entire N region and thereby generate electricity. With today's technology, depending on the used material on PV, approximately 15% of the total potential of the sun can be converted into electrical energy. Depending on the PV type and area, the amount of energy can be produced in Turkey shown at below Chart 1.

Table 1. Monthly and regional solar energy potential of Turkey (TSMS)

REGION	TOTAL SOLAR ENERGY (KWh/m²-year)	SUNSHINE HOUR (hour/year)
Southeastern Anatolia	1648	2845
Mediterranean	1548	2737
Aegean	1528	2615
East Anatolia	1523	2519
Inland Anatolia	1481	2563
Marmara	1329	2250
Black Sea	1305	1929

Chart 1. The amount of energy can be produced in Turkey depending on the PV type and area (KWh/Year)

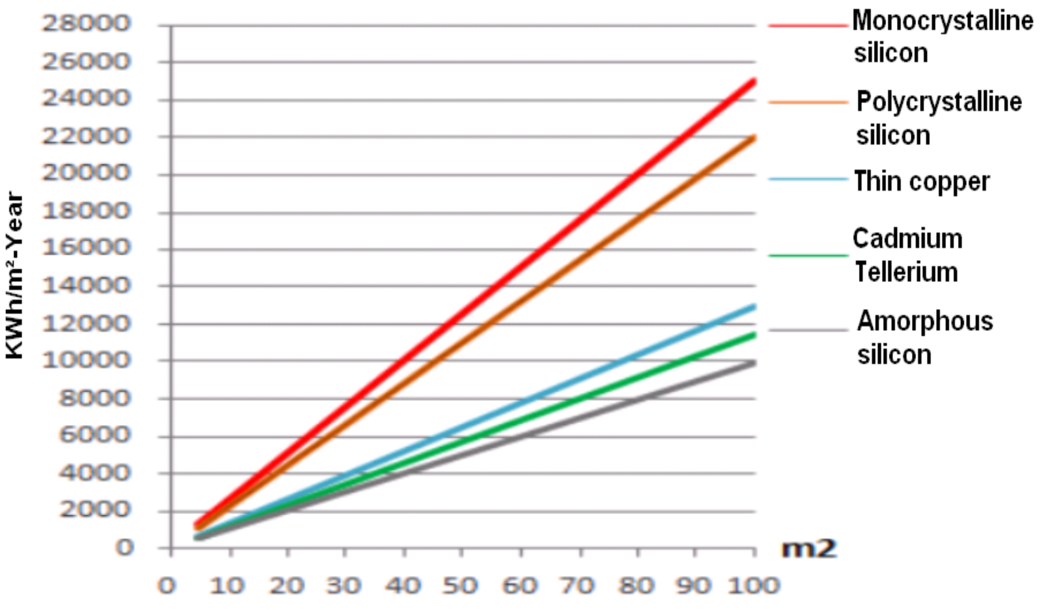


Table 2. Sunshine hour and radiation data of the cities

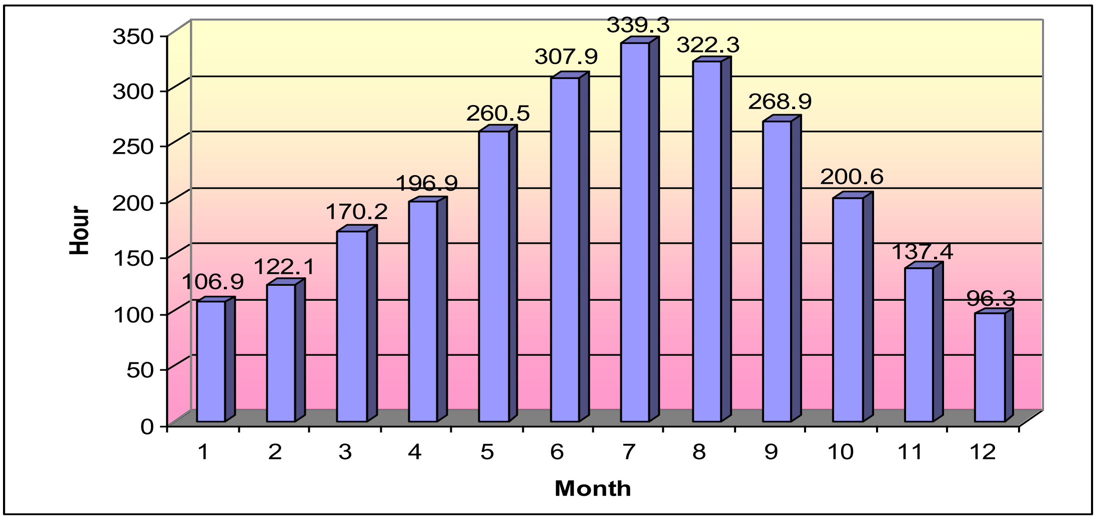
STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	KWh/m²-year observed	KWh/m²-day observed	KWh/m²-year Model	PV Equivalent	City area (km²)	Sunshine hour (h/day)	Sunshine hour (h/year)
ADANA	62	75	113	134	167	172	181	164	130	102	68	54	1421	3.9	1525	228.8	14256	7.4	2704
ADIYAMAN	54	68	104	126	156	167	168	152	124	92	62	47	1320	3.6	1681	252.2	7572	8.1	2950
AFYON	63	82	130	153	183	199	209	192	154	107	69	53	1594	4.4	1456	218.4	14532	6.7	2461
AGRI	58	74	115	127	161	178	183	167	136	93	58	43	1392	3.8	1383	207.4	11315	6.3	2306
AKSARAY	67	84	124	141	174	186	194	179	146	106	74	59	1534	4.2	1557	233.5	8051	7.5	2728
AMASYA	47	66	109	136	170	184	192	174	134	89	52	38	1393	3.8	1469	220.3	5731	5.6	2059
ANKARA	50	67	108	128	164	178	189	172	137	96	58	41	1389	3.8	1440	216.1	25615	6.9	2506
ANTAKYA	49	66	105	132	163	178	182	164	130	95	60	45	1369	3.8	1510	226.5	5678	7.4	2689
ANTALYA	75	91	138	160	197	208	215	196	163	123	82	66	1715	4.7	1562	234.2	20599	8.4	3054
Ardahan	56	75	114	133	164	179	184	166	132	94	60	47	1404	3.8	1405	210.8	5495	5.9	2136
ARTVIN	50	69	114	138	168	177	169	156	126	89	55	42	1352	3.7	1310	196.5	7493	4.9	1789
AYDIN	63	76	119	145	183	197	204	187	151	110	71	57	1562	4.3	1610	241.5	7922	7.6	2768
BALIKESIR	41	53	86	113	145	162	167	152	120	80	48	34	1202	3.3	1383	207.4	14442	6.9	2528
BARTIN	42	59	93	121	158	172	182	162	121	82	49	36	1277	3.5	1200	180.0	1960	5.6	2041
Batman	67	86	128	148	182	199	206	187	152	110	72	56	1593	4.4	1600	240.0	4671	7.5	2744
Bayburt	57	75	113	132	165	180	184	166	132	94	60	46	1404	3.8	1410	211.5	4043	6.0	2205
BILECIK	54	67	106	129	166	180	186	169	136	91	58	45	1384	3.8	1370	205.5	4181	6.4	2318
BINGOL	61	83	122	144	184	210	218	196	150	99	59	47	1574	4.3	1571	235.7	8402	6.5	2360
BITLIS	62	83	126	138	165	196	199	181	150	104	60	49	1512	4.1	1559	233.9	8413	6.4	2324
Bolu	48	64	103	125	157	171	179	161	125	85	53	40	1311	3.6	1318	197.7	10716	5.4	1983
BURDUR	71	89	130	156	193	213	221	197	160	121	85	56	1691	4.6	1567	235.0	7238	7.4	2695
BURSA	48	58	90	114	146	160	166	149	119	81	52	41	1225	3.4	1418	212.8	11087	6.3	2296
CANAKKALE	51	67	108	141	173	186	193	174	136	95	58	45	1427	3.9	1329	199.3	9887	7.3	2649
CANKIRI	51	71	118	135	169	184	195	176	142	101	61	42	1445	4.0	1397	209.5	8411	6.1	2227
CORUM	55	75	117	137	168	183	193	177	140	96	60	44	1444	4.0	1394	209.1	12833	6.1	2230
DENIZLI	51	65	100	124	153	171	174	154	123	87	56	44	1300	3.6	1566	234.9	11716	7.5	2722
DIYARBAKIR	63	82	126	148	193	211	216	194	156	115	72	54	1629	4.5	1620	243.1	15162	7.8	2859
DUZCE	39	54	85	111	143	157	162	148	115	75	46	34	1169	3.2	1247	187.0	2593	5.1	1868
EDIRNE	34	47	76	103	130	139	143	131	99	66	39	29	1037	2.8	1363	204.5	6241	6.2	2248
ELAZIG	53	72	112	136	171	194	199	179	143	101	62	44	1467	4.0	1602	240.3	9181	7.3	2677
ERZINCAN	58	76	114	130	158	174	182	163	131	94	60	49	1389	3.8	1463	219.4	11974	6.5	2376
ERZURUM	70	91	132	138	162	181	193	174	142	103	68	56	1511	4.1	1455	218.3	24741	6.7	2439
ESKISEHIR	50	66	101	121	153	166	178	160	130	89	59	39	1311	3.6	1396	209.3	13904	6.7	2439
GAZIANTEP	58	72	111	136	172	190	196	177	142	104	68	51	1478	4.0	1628	244.2	7194	7.3	2658
GIRESUN	42	55	81	96	130	146	125	109	74	70	43	32	1003	2.7	1187	178.0	7151	3.7	1351
GUMUSHANE	50	88	134	149	180	198	211	192	148	101	54	39	1543	4.2	1420	213.0	6125	5.9	2144
HAKKARI	76	95	135	147	175	191	198	181	147	110	74	67	1596	4.4	1657	248.5	7729	7.9	2877
IGDIR	52	71	110	126	153	167	169	154	123	90	58	44	1318	3.6	1525	228.7	3584	6.3	2315
ISPARTA	59	73	107	123	149	161	168	154	126	94	64	50	1328	3.6	1535	230.3	8733	7.5	2741
ISTANBUL	41	56	95	129	166	180	184	161	127	83	50	36	1306	3.6	1303	195.5	5170	5.9	2163
IZMIR	64	79	123	151	186	203	207	186	154	111	71	55	1589	4.4	1562	234.3	11811	7.9	2893
KAHRAMANMARAS	60	78	124	153	193	214	224	199	161	112	69	51	1638	4.5	1628	244.2	14213	7.2	2619
Karabük	48	64	101	123	156	170	179	160	124	83	52	39	1299	3.6	1307	196.1	2864	5.9	2170
KARAMAN	72	91	140	169	199	216	223	202	168	119	79	61	1739	4.8	1554	233.1	8816	8.0	2926
KARS	68	85	129	134	155	170	182	166	134	97	64	57	1441	3.9	1414	212.1	9594	6.4	2324
KASTAMONU	43	60	95	110	136	150	157	142	110	75	46	33	1157	3.2	1342	201.3	13473	5.8	2129
KAYSERI	58	76	113	132	163	179	196	178	142	99	64	50	1451	4.0	1491	223.7	17116	6.8	2464
KILIS	70	89	136	167	200	219	221	198	164	125	82	60	1731	4.7	1651	247.7	1239	7.8	2838
KIRIKKALE	53	73	116	136	170	185	200	182	144	99	58	41	1458	4.0	1433	215.0	4589	6.9	2509
KIRSEHIR	60	79	121	140	172	183	193	175	141	104	69	53	1490	4.1	1449	217.3	6434	7.2	2619
Kirklareli	47	63	100	125	157	172	179	160	125	84	52	40	1304	3.6	1302	195.3	6056	6.9	2531
KOCAELI	39	50	82	106	137	152	155	136	108	70	45	33	1113	3.1	1280	192.0	3635	5.4	1971
KONYA	62	81	123	144	174	188	197	179	145	107	71	54	1524	4.2	1554	233.1	40824	7.2	2637
KUTAHYA	53	72	117	145	175	191	202	184	143	92	58	43	1474	4.0	1418	212.7	12119	5.7	2071
MALATYA	55	73	113	140	175	199	209	190	151	106	64	45	1519	4.2	1617	242.5	12235	7.6	2768
Manisa	64	79	121	146	178	192	198	180	146	106	69	54	1533	4.2	1530	229.5	13120	6.9	2534
Mardin	68	87	130	149	183	201	208	189	154	111	73	57	1610	4.4	1612	241.8	9097	8.1	2972
MERSIN	76	94	143	167	198	209	212	195	163	125	82	66	1729	4.7	1512	226.8	15737	7.5	2750
MUGLA	60	73	111	134	164	177	181	165	135	101	66	51	1419	3.9	1566	234.8	12716	7.4	2713
MUS	61	80	119	139	172	191	199	183	153	107	64	44	1511	4.1	1463	219.4	8023	7.3	2671
Nevsehir	62	79	120	142	174	190	197	179	144	104	68	52	1511	4.1	1509	226.4	5438	7.1	2601
NIGDE	87	107	157	181	214	233	248	225	185	135	90	73	1935	5.3	1550	232.5	7318	7.6	2759
ORDU	44	60	93	118	149	166	157	141	111	77	52	37	1206	3.3	1209	181.3	5894	4.4	1621
Osmaniye	64	82	123	145	178	193	200	181	147	107	70	54	1544	4.2	1545	231.8	3189	7.2	2643
RIZE	41	54	85	106	125	133	112	102	87	65	44	34	988	2.7	1183	177.5	3792	4.1	1481
SAKARYA	46	61	96	124	160	179	185	166	129	84	51	39	1320	3.6	1269	190.3	4895	5.2	1904
SAMSUN	46	58	90	114	147	167	171	150	112	78	50	39	1222	3.3	1222	183.3	9474	5.0	1834
SANLIURFA	57	74	116	142	179	197	200	181	146	109	70	52	1522	4.2	1721	258.1	23321	8.1	2941
SIIRT	65	85	124	151	185	205	205	187	153	112	73	58	1602	4.4	1667	250.1	5465	7.7	2795
SINOP	39	56	93	117	150	166	173	151	113	77	45	33	1214	3.3	1262	189.3	5858	5.5	1992
SIVAS	47	61	93	107	138	154	167	152	120	84	51	36	1210	3.3	1474	221.2	28129	6.7	2449
Sirnak	67	86	128	148	181	198	205	186	151	109	72	56	1587	4.3	1590	238.5	7296	7.3	2650
TEKİRDAG	45	60	94	127	161	174	182	158	125	82	49	37	1296	3.5	1307	196.1	6345	5.8	2099
TOKAT	55	74	115	136	170	185	183	175	143	98	61	46	1442	4.0	1389	208.3	9912	5.9	2166
TRABZON	44	58	89	109	134	146	132	118	97	73	48	38	1087	3.0	1250	187.5	4495	4.3	1554
TUNCELI	66	85	122	145	188	212	220	199	160	111	69	51	1629	4.5	1556	233.4	7406	7.3	2671
USAK	55	65	101	117	152	164	168	161	129	93	60	49	1313	3.6	1513	227.0	5174	7.6	2756
VAN	82	102	142	163	197	215	218	201	163	120	82	69	1755	4.8	1593	239.0	20927	7.9	2899
YALOVA	41	58	96	132	173	188	191	170	130	84	46	34	1343	3.7	1297	194.5	403	5.6	2041
YOZGAT	58	76	115	132	161	175	193	172	132	95	60	45	1416	3.9	1453	217.9	14083	6.7	2458
ZONGULDAK	40	57	93	127	165	183	192	171	133	85	48	35	1329	3.6	1365	204.7	3470	5.8	2108

Note: Lowercase and blue colors of the solar radiation data are derived from interpolation.

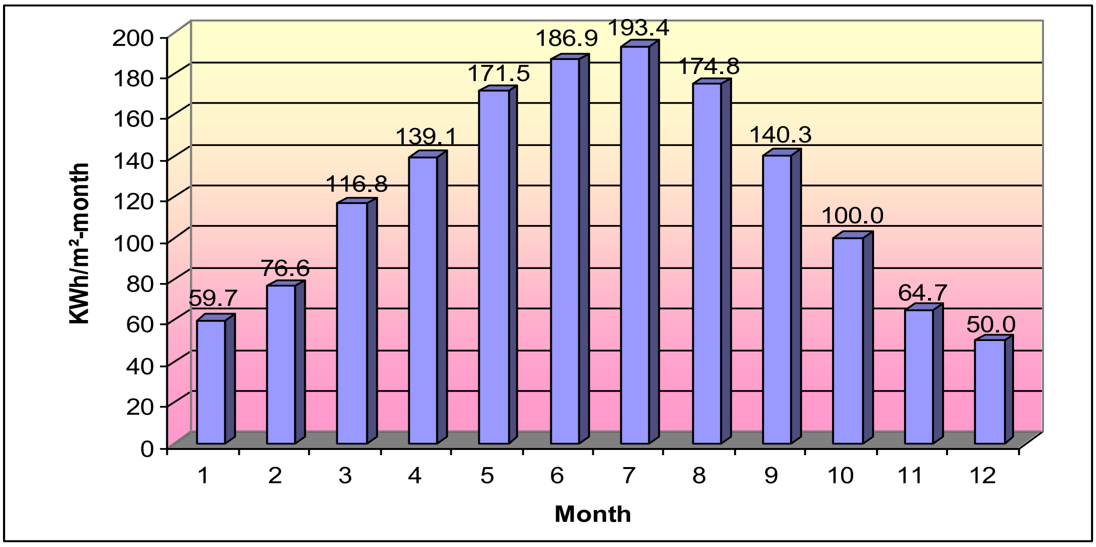
Table 3. Monthly mean sun energy potential in Turkey

MONTHS	Monthly total radiation		Sunshine hour
	Kcal_cm^2_month	kWh/m^2_month	hour/day
JANUARY	5.13	59.7	106.9
FEBRUARY	6.59	76.6	135.2
MARCH	10.04	116.8	170.2
APRIL	11.96	139.1	203.5
MAYIS	14.75	171.5	260.5
JUNE	16.07	186.9	318.1
JULY	16.63	193.4	339.3
AUGUST	15.03	174.8	322.3
SEPTEMBER	12.06	140.3	277.9
OCTOBER	8.60	100.0	200.6
NOVEMBER	5.56	64.7	142.0
DECEMBER	4.30	50.0	96.3
TOTAL	126.7	1473.9	2572.7
MEAN	**347** cal cm^2_day	**4** kWh/m^2_day	**7** hour/day

Graphic 1. Monthly sunshine hour in Turkey



Graphic 2. Monthly radiation in Turkey



2. Material and Method

Data and calculations

In this study 157 weather stations radiation data were used which measured by the Turkish State Meteorological Service in the 1971-2000 climatic periods.

Unit conversions:

(via www.birimcevir.com)

1Kcal = 1000 cal
PV eşdeğeri = KWh/m2 x 0.15
1TEP = 85.9845 x MW/m²

1KWh/m² = 11.63 x Kcal/cm²
1MW/m² = 1000000 KWh/m²

Geographic variables are measured at certain points, and prediction map for the entire area is been obtained by some spatial interpolation methods. Spatial distribution of geographic data can be obtained only from this data and also prediction map can be obtained by using secondary variables which have spatial relationship with the measured values (Bostan, P.A., et al, 2007). The maps were prepared in Lambert Conformal Conic Projection and ED50 Datum.

Geographically Weighted Regression (GWR) and Co-kriging methods were applied in the modelling of radiation. GWR is the multi-faceted approach to the analysis of spatial data. GWR opens a window through the data set to calculate local r^2 (Laffan, 1999). Co-kriging is an extension of ordinary kriging method which takes into account the spatial cross-validation between two or more data.

In the modelling of spatial interpolation of radiation data, aspect, latitude, relative humidity and cloudiness were used as secondary variable. Best results were obtained with the cloudiness and relative humidity parameters. Simple linear models generally are been solved by ordinary least square method is given below formula:

P= C1+C2+e where;
P= Radiation (KWh/m²)

C1= solar radiation parameters change with the humidity
C2= solar radiation parameters change with the cloud cover
e= error term.

Co-kriging and GWR model results were compared by the lowest RMSE and higher r^2 values obtained in the model. Because of the RMSE is smaller and r2 is grater than the Co-kriging result, GWR tool is been selected for modeling solar energy potential in Turkey. According to model result, southern parts of Izmir-Igdir line, have over 1500 KWh/m²/Year radiation potential and is considered as optimum area for the photovoltaic installation.

17

Secondary variables were used in GWR Model

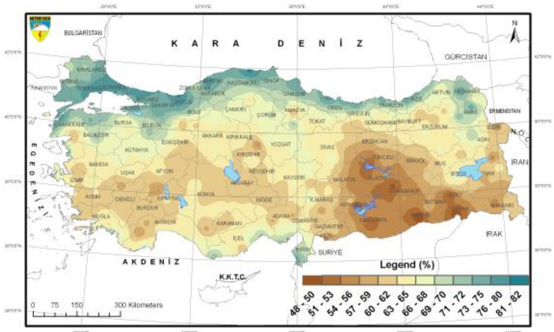


Figure 1. Long term relative humidity

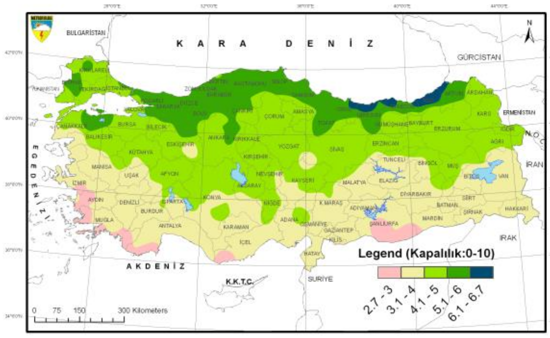


Figure 2. Long term cloudiness

Modeling of the parameters

In the modeling of spatial interpolation of radiation data, aspect, latitude, relative humidity and cloudiness were used as secondary variable. In the co-kriging analysis combination which gives lowest Root Mean Square Error was selected. Maps produced with minimum average error maps are shown in Figure 3 and Figure 4.

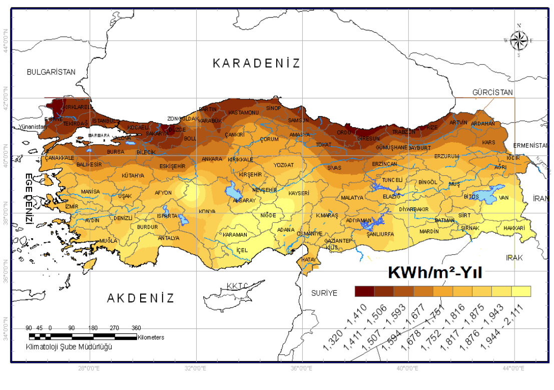


Figure 3. Radiation distribution via Co-kriging

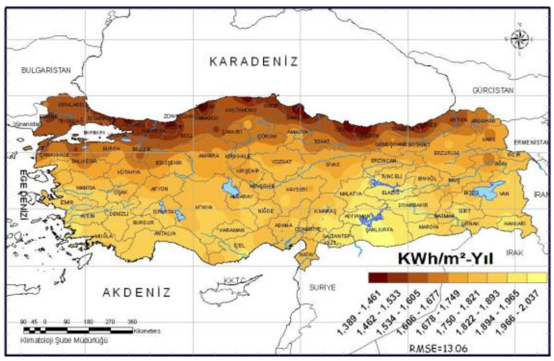


Figure 4. Radiation distribution via GWR

In the modeling of radiation data via co-kriging, best results were obtained with the cloudiness and relative humidity parameters according to the RMSE (RMSE=175.1).

In the modeling of radiation data via GWR, best results were obtained with the cloudiness and relative humidity parameters according to the RMSE and r^2 values (RMSE=162, r^2=0.435).

Co-kriging and GWR model results were compared, the lowest RMSE and highest r^2 values were obtained with GWR in the modeling radiation data. For this reason modeling of radiation data continued with the GWR method.

Black sea Region (0.49) and lower in the Hatay, Adana and Mersin (0.36). In the other parts local r^2 values have been found in between these two values.

3. Results

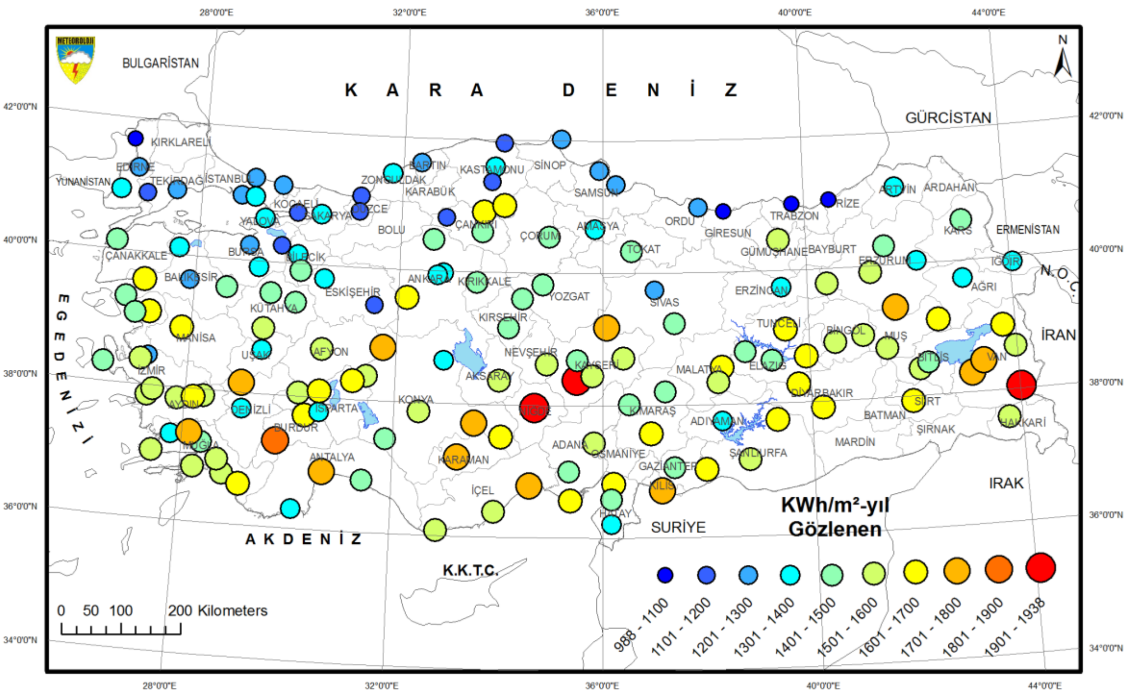


Figure 5. Long term observed annual total radiation

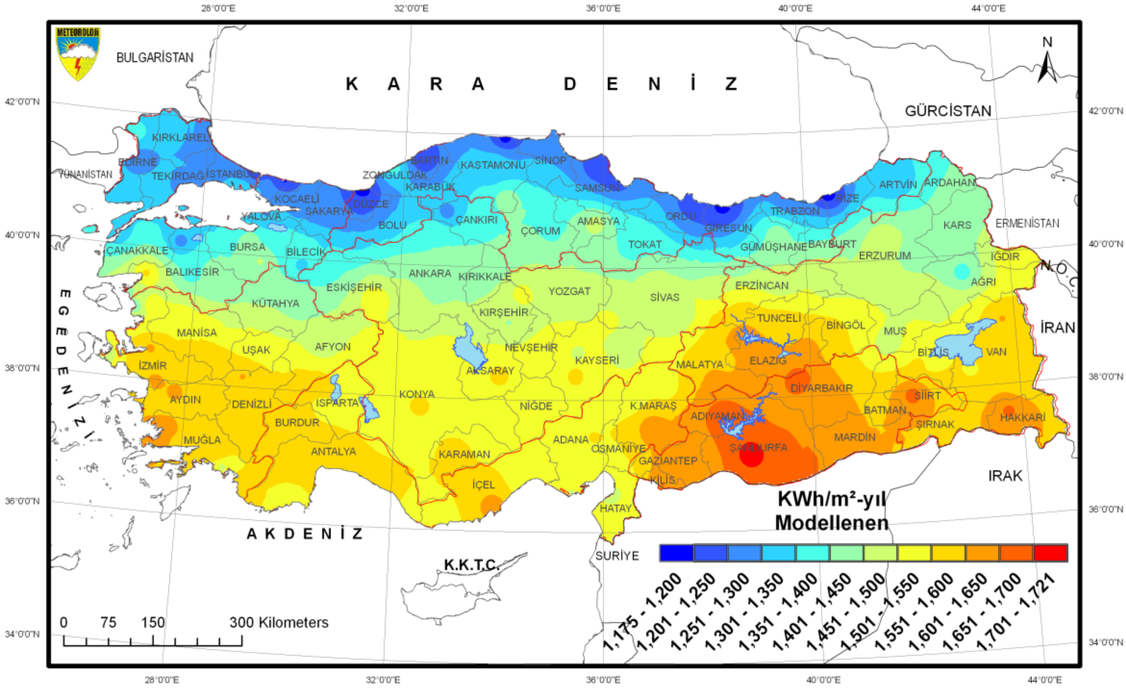


Figure 6. Long term modeled annual total radiation

4. Conclusion and discussion

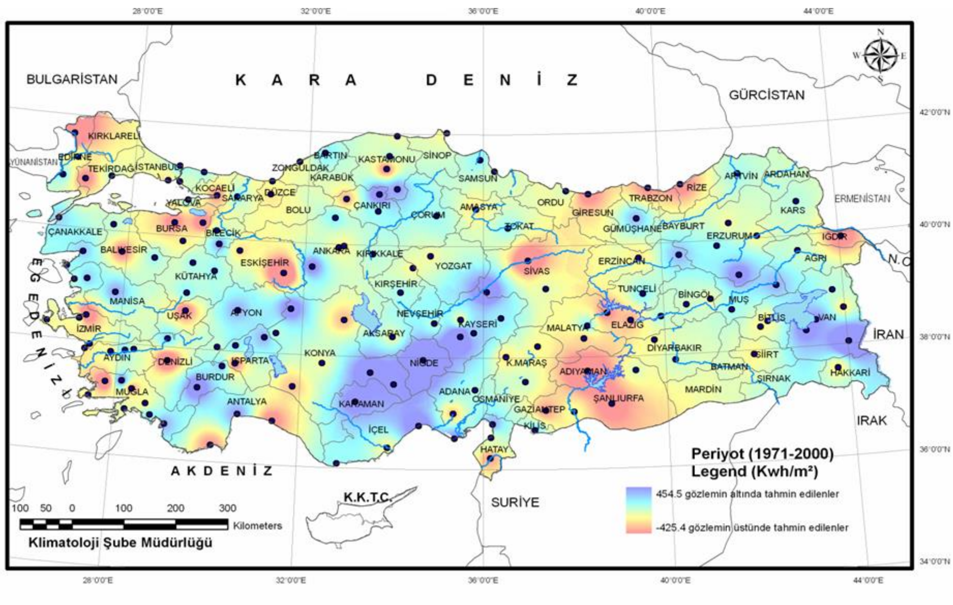


Figure 7. Residual maps between GWR model output and observed radiation

According to the residual map of modeling radiation data with the GWR method; Nigde, Karaman, Van, Afyon and Burdur have been under estimated while

Kırklareli, Tekirdağ, Balıkesir, Bursa, Kocaeli, Izmir, Aydin, Denizli, Eskisehir, Kastamonu, Sivas, Giresun, Trabzon , Rize, Elazığ, Adıyaman, Şanlıurfa, Gaziantep, and Igdir have been over estimated values were obtained. In the other places, model results are close to the observed value.

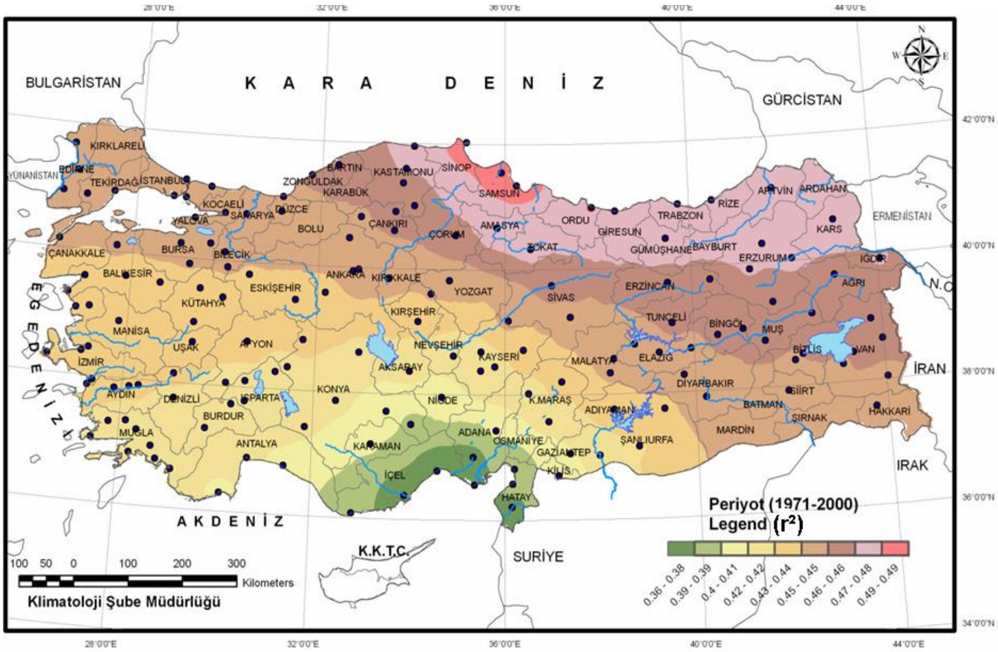


Figure 7. Local r^2 values between GWR model output and observed radiation

According to the Local r^2 map of modeling radiation data with the GWR method; local r^2 values between GWR model output and observed radiation are higher in the Eastern

- In the modelling of spatial interpolation of radiation data, aspect, latitude, relative humidity and cloudiness were used as secondary variable. Best results were obtained with the cloudiness and relative humidity parameters.

- The lowest RMSE and highest r^2 values have been looked for between GWR model output and observed radiation.

- Co-kriging and GWR model results were compared, the lowest RMSE and highest r^2 values were obtained with GWR in the modeling radiation data. For this reason modeling of radiation data continued with the GWR method.

- Relationship between radiation and latitude and aspect is extremely low (r^2 0.04 and 0.01). It has been found that cloudiness and relative humidity parameters are more effective on interpolation of radiation. Best model combination according to r^2 and RMSE are: Radiation(Relative humidity + Cloudiness).

- According to the residual map of modeling radiation data with the GWR method; Nigde, Karaman, Van, Afyon and Burdur have been under estimated while Kırklareli, Tekirdağ, Balıkesir, Bursa, Kocaeli, Izmir, Aydin, Denizli, Eskisehir, Kastamonu, Sivas, Giresun, Trabzon , Rize, Elazığ, Adıyaman, Şanlıurfa, Gaziantep, and Igdir have been over estimated values were obtained. In the other places, model results are close to the observed value.

- According to the Local r^2 map of modeling radiation data with the GWR method; local r^2 values between GWR model output and observed radiation are higher in the Eastern Black sea Region (0.49) and lower in the Hatay, Adana and Mersin (0.36). In the other parts local r^2 values have been found in between these two values.

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References

[1] Bostan P.A., Akyürek Z., 2007, İkincil Veriler Kullanılarak Türkiye Ortalama Yıllık Yağış Değerlerinin Mekansal Dağılımının Modellenmesi, TMMOB Harita ve Kadastro Mühendisleri Odası, Ulusal Coğrafi Bilgi Sistemleri Kongresi, 30 Ekim –02 Kasım 2007, KTÜ, Trabzon

[2] Brundson, C., Fotheringham, S., Charlton, M., 2000, Geographically Weighted Regression as a Statistical Model.

[3] Brundson, C., McClatchey, J., Unwin, D.J., 2001, Spatial Variations in the Average Rainfall–Altitude Relationship in Great Britain: An Approach Using Geographically Weighted Regression, International Journal of Climatology, volume 21, issue 4, page: 455–466.

[4] Carrera-Hernandez, J.J, Gaskin, S.J., 2007, Spatio temporal analysis of daily precipitation and temperature in the Basin of Mexico, Journal of Hydrology, volume 336, issue 3-4, p: 231-249.

[5] Heuvelink, G.B.M., 2006, Incorporating process knowledge in spatial interpolation of environmental variables, 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, 5-7 July, Lisbon, Portugal.

[6] Lloyd, C.D, 2005, Assessing the Effect of Integrating Elevation Data into the Estimation of Monthly Precipitation in Great Britain, Journal of Hydrology, volume 308, issue 1-4, p: 128–150.

[7] Özmen, A., 2007, Güneş pilleri kullanarak elektrik üretimi, G.Ü. Fen Bilimleri Enstitüsü Yüksek lisans tezi

[8] Propastin, P., Muratova, N., Kappas, M., 2006, Reducing uncertainty in analysis of relationship between vegetation patterns and precipitation, 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, 5-7 July, Lisbon, Portugal.

[9] Simbahan, G.C., Dobermann, A., Goovaerts, P., Ping, J., Haddix, M.L, 2005, Fine-resolution mapping of soil organic carbon based on multivariate secondary data, Geoderma, volume 132, issue 3-4, p: 471-489.

[10] Tappeiner U., Tappeiner G., Aschenwald J., Tasser E., Ostendorf B., 2001, GIS-based modeling of spatial pattern of snow cover duration in an alpine area, Ecological Modeling, volume 138, issue 1-3, p: 265–275.

URL 1, Meteoroloji Ders Kitabı, www.ssd.dhmi.gov.tr/getBinaryFile.aspx?Type=3&dosyaID=48 , 01.11.2016

URL 2, Gamma Design software, Geostatistics for the Environmental Sciences, Cokriging in GS, https://www.gammadesign.com/ , 19.09.2016.

URL 3, Goecomputation 99, Spatially Assessing Model Error Using Geographically Weighted Regression, http://www.geocomputation.org/1999/086/gc_086.htm, 19.09.2016.

URL 4. Enerji birimleri çevirici, http://www.birimcevir.com, 15.07.2016