ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

Hatice Başak YILDIRIM

INTRODUCING NOVEL MODELS TO ESTIMATE GLOBAL SOLAR RADIATION BASED ON METEOROLOGICAL PARAMETERS IN EASTERN MEDITERRANEAN REGION

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Doctor of Philosophy by the board of jury on 05/12/2016.

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ABSTRACT

PhD THESIS

INTRODUCING NOVEL MODELS TO ESTIMATE GLOBAL SOLAR RADIATION BASED ON METEOROLOGICAL PARAMETERS IN EASTERN MEDITERRANEAN REGION

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Sunshine duration, relative humidity, precipitation and air temperature are measured in most of the meteorological stations in all over the world. However global solar radiation measurements are very rare and some of the data are missing at some time periods for unknown reasons. Therefore, global solar radiation models are required to estimate global solar radiation with high accuracy. In this study, 4 monthly mean daily global solar radiation models and 18 daily global solar radiation models are presented to model global solar radiation based on meteorological parameters in Eastern Mediterranean Region. Different meteorological parameters are used separately and combined together to determine most accurate model. Parametric models and artificial neural networks model are evaluated and the results are compared with each other. In this thesis, two new models are presented and compared with other models available in the literature. Meteorological parameters used to develop models are provided by Turkish State Meteorological Services.

Key Words: Global Solar Radiation, Parametric Models, Angström-Prescott Method, Artificial Neural Network, Eastern Mediterranean Region.

ÖZ

DOKTORA TEZİ

METEOROLOJİK VERİLER KULLANILARAK DOĞU AKDENİZ BÖLGESİ'NDE GÜNEŞ IŞINIMI TAHMİN MODELLERİNİN OLUŞTURULMASI

Hatice Başak YILDIRIM

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Güneşlenme süresi, nisbi nem, yağışlılık ve hava sıcaklığı gibi meteorolojik parametreler bütün dünyadaki meteoroloji istasyonlarında sıklıkla ölçülürken, küresel güneş ışınımı ölçümü nadirdir ve ölçümlerde belirli peryotlarda veri kayıplarına rastlanmaktadır. Bu nedenle, küresel güneş ışınımı miktarını tahmin edebilmek için küresel güneş ışınımı modellerine ihtiyaç duyulmaktadır. Bu çalışmada Doğu Akdeniz Bölgesinde küresel güneş ışınımını farklı meteorolojik parametrelere bağlı olarak modelleyebilmek için 4 adet aylık ortalama günlük ve 18 adet günlük küresel güneş ışınım modeli sunulmuştur. Farklı meteorolojik parametreler ayrı ayrı ele alınarak ve bir araya getirilerek en doğru model oluşturulmaya çalışılmıştır. Parametrik modeler ve yapay sinir ağları modelleri geliştirilerek, karşılaştırmaları yapılmıştır. Bu çalışmada iki adet yeni model geliştirilerek, bu modeler literatürde sunulan modellerle karşılaştırılmıştır. Meteorolojik parametreler Devlet Meteoroloji Enstitüsü tarafından sağlanmıştır.

Anahtar Kelimeler: Küresel Güneş Işınımı, Parametrik Modeler, Angström-Prescott Metodu, Yapay Sinir Ağları, Doğu Akdeniz Bölgesi.

GENİŞLETİLMİŞ ÖZET

Günümüzde enerji kullanımı ülkeler için gelişmişlik düzeyini gösteren en önemli parametrelerden biridir. Bununla beraber en çok kullanılan enerji kaynağı olan fosil yakıtların sınırlı ömrü ve fosil yakıtların kullanımı ile atmosfere yayılan sera gazlarının iklim değişikliğine neden olması kullanıcıları alternatif enerji kaynaklarına yöneltmiştir. Güneş enerjisi, fosil yakıtların yerini alabilecek ve sera gazı emisyonlarını azaltacak bir potansiyele sahip olduğu için önemli bir role sahiptir. Güneş enerjili sistemlerin tasarımında mühendislik, mimarlık ve ziraat alanlarında çalışanlar için küresel güneş ışınımı bilgisine ihtiyaç bulunmaktadır.

Güneş ışınımı atmosfer dışına gelen güneş ışınımı ve yeryüzüne ulaşan güneş ışınımı olarak iki ana başlıkta incelenir. Atmosfer dışına ulaşan güneş ışınımı dünya ile güneşin birbirine göre pozisyonuna ya da bir başka değişle yılın gününe göre ve dünya üzerinde bulunulan yere yani o yerin enlemine göre değişir. Atmosfer dışına ulaşan güneş ışınımı literatürde çok yakın bir doğrulukla hesaplanmaktadır. Yeryüzüne ulaşan güneş ışınımı ise küresel güneş ışınımı olarak isimlendirilmektedir ve güneş ışınlarının havadaki toz ve nem parçacıkları tarafından soğurulması ve yansıtılması nedeniyle meteorolojik olaylara göre değişmektedir.

Güneşlenme süresi, bağıl nem, yağış ve hava sıcaklığı tüm dünyadaki meteorolojik istasyonların çoğunda ölçülür ancak küresel güneş ışınımı ölçümleri çok nadirdir ve verilerde eksikliklere rastlanmaktadır. Güneş ışınımı ölçümleri aktinograf ve piranometre gibi cihazlarla yapılmaktadır. Güneş ışınımı ülkemizde diğer meteorolojik parametreler gibi T.C. Orman ve Su İşleri Bakanlığı Meteoroloji Genel Müdürlüğü tarafından ve birkaç üniversitede araştırma amaçlı olarak yapılmaktadır. Ülkemizde toplamda 1158 ölçüm merkezinden 115'inde güneş ışınım ölçümü yapılmaktadır. Özellikle dağlık ve kırsal alanlarda güneş ışınımı ölçümü yapılmamış meteoroloji istasyonları bulunabilmektedir.

Bunun yanı sıra ölçüm yapılan istasyonlarda dahi teknik nedenlerden ötürü kısa ve uzun vadeli eksikliklere rastlanmaktadır. Bu cihazların maliyetli olması, bakım ve kalibrasyon ihtiyaçları ve konusunda uzman kişilerce kullanılması gerektiği için güneş ışınımı ölçümü yaygın olarak yapılamamaktadır. Güneş ışınımı tahmini ile ilgili ülkemizde de yapılan birçok çalışma literatüre girmiştir. Buna rağmen hem parametre optimizasyonu konusunda hem de veri sıklığına göre tahmin aralığı konusunda yeterince çalışma bulunduğu söylenemez.

Bu noktada küresel güneş ışınımının tahmini önemli bir rol oynamaktadır. Güneş ışınımı miktarının belirlenmesi için literatürde farklı modeller geliştirilmiştir. Bunun yanı sıra güneş ışınımı tahmini, tahminin yapıldığı bölgenin coğrafi ve atmosferik parametrelerine göre değişiklik göstermektedir. Özellikle Doğu Akdeniz Bölgesi (Adana, Mersin, Kahramanmaraş, Hatay ve Osmaniye illeri) için güneşlenme süresi, nem ve sıcaklık parametreleriyle deterministtik metotlar kullanılarak modelleme çalışması mevcut olmamakta, güneş ışınımıyla tahmin çalışması da deterministtik olarak sadece aylık ortalama günlük tahmin çalışması olarak literatürde yer almaktadır. Dolayısıyla araştırmanın konusu olan çalışma alanı için cevaplanması gereken birçok soru mevcuttur.

Angström, güneş ışınımını güneşlenme süresine bağlı olarak hesaplamak için bir model geliştirmiştir. Prescott, Angström modelinde açık gökyüzü süresince elde edilen güneş ışınımı bilgisini atmosfer dışına gelen güneş ışınımı bilgisi ile değiştirerek modeli modifiye etmiştir. Angström-Prescott metodunda güneş ışınımı ile güneşlenme süresi arasında doğrusal bir regresyon ilişkisi kurulmaktadır. Angström-Prescott metodu olarak bilinen bu model literatürde güneş ışınımı miktarını belirlemek için yaygın olarak kullanılmaktadır. Bunun yanı sıra literatürde Angström-Prescott metoduna dayanan bazı farklı yaklaşımlar da bulunmaktadır. Bu yaklaşımlar içerisinde en yaygın olarak kullanılanlar güneş ışınımı ile güneşlenme süresi arasında karesel ve kübik regresyon ilişkisi kurulan yaklaşımlardır.

Bu çalışmada Doğu Akdeniz Bölgesi'nde bulunan dört büyük şehirdeki (Adana, Mersin, Antakya ve Kahramanmaraş) meteoroloji istasyonları için güneş ışınımı ve güneşlenme süresi verileri kullanılarak küresel güneş ışınımı doğrusal, karesel ve kübik regresyon modelleri ile modellenmiştir. Bu veriler Devlet Meteoroloji İşleri Genel Müdürlüğü tarafından sağlanmıştır. Modeller her bir şehir için ayrı ayrı belirlenmesinin yanı sıra bütün bölge için genel modeller de oluşturulmuştur. Modeller geliştirilirken R istatistiksel hesaplama programı kullanılmıştır.

Aylık ortalama günlük güneş ışınımını modellemek için doğrusal, karesel ve kübik modellerin katsayıları belirlenmiştir. Model hata hesaplamaları ve istatistiksel testleri, R^2 (Belirlilik katsayısı), MAE (Ortalama Mutlak Hata), RMSE (Ortalama Karesel Hata Kökleri) ve MBE (Ortalama Sistem Hatası) formülleri kullanılarak yapılmıştır. İstatistiksel test sonuçlarına ve hata hesaplamalarına göre göre, Doğu Akdeniz Bölgesinde güneş ışınımının güneşlenme süresi ile modellenmesinde en iyi sonuçlar Angström-Prescott metodunun kübik modeli ile elde edilmiştir. Angström-Prescott modeline dayalı kübik regresyon modeli için MBE 0.090, MAE 3.60, RMSE 4.703 ve R^2 0.541'dir.

Bununla birlikte, literatürde küresel güneş ışınımı tahmini için farklı yaklaşımlar da mevcuttur. Yapay Sinir Ağları metodu güneş ışınımı modellemesinde en yaygın olarak kullanılan ve yüksek doğruluk edilen modellerin en önemlilerindendir. Bu tezde Doğu Akdeniz Bölgesinde aylık ortalama günlük küresel güneş ışınımını modellemek için yapay sinir ağı modellerinin performansları araştırılarak en uygun giriş parametreleri, aktivasyon fonksiyonu ve saklı katman sayıları belirlenmiştir. Belirlenen bu değerler ile yapay sinir ağı modeli hedef değer olan küresel güneş ışınımının ölçülmüş değerine yüksek doğrulukla yaklaşmaktadır. Geliştirilen yapay sinir ağı modelinin eğitimi ve test edilmesi için Adana, Mersin, Antakya ve Kahramanmaraş meteoroloji istasyonlarından alınan 11 yıllık meteorolojik veriler kullanılmıştır bu veriler

içerisinde güneş ışınımı ölçümleri aktinograf cihazı ile yapılmaktadır. Bunun yanı sıra parametrik modeller için 4 yıllık piranometre verisi seti kullanılmıştır.

Literatürde sıkça kullanılan yılın ayı, yükseklik, boylam, enlem, aylık ortalama sıcaklık ve aylık ortalama güneşlenme süresi olan giriş parametrelerinin çeşitli kombinasyonları kullanılarak Levenberg-Marquardt ve Scaled Conjugate Gradient algoritmalarıyla yapay sinir ağı modelleri denenmiş, en doğru sonucu veren yapay sinir ağı modeli için, giriş parametreleri, algoritma ve gizli katmandaki nöron sayıları belirlenmiştir. Geliştirilen yapay sinir ağı modelinin sonuçları, uygulanabilirliği ve üstünlüğünü göstermek için model hataları hesaplanmış, istatistiksel testler yapılmış ve model geleneksel regresyon modelleriyle karşılaştırılmıştır. Geliştirilen yapay sinir ağı modeli ile elde edilen en yüksek MAE değeri 0.502, en düşük MAE değeri 0.450'dir. RMSE değeri 0.504 ile 1.573 arasında değişmektedir. MBE değeri (-0.454) ile 0.249 arasında değişmektedir. R^2 değeri ise 0.983 ve 0.998 arasında değişmektedir. Test sonuçları, aylık ortalama günlük küresel güneş ışınımının modellenmesi için yapay sinir ağı modelini kullanmanın, ölçüm cihazlarının mevcut olmadığı birçok yer için uygulanabilir bir seçim olduğunu ortaya koymaktadır.

Bu çalışma, çeşitli günlük küresel güneş ışınım modellerinin ayrıntılı bir tarifi ve analizini sunmaktadır. Ayrıca, yine aylık ortalama günlük küresel güneş ışınımı modelindeki gibi günlük küresel güneş ışınım modelinde de optimize edilmiş bir yapay sinir ağı modeli giriş parametreleri, algoritması ve gizli katmandaki nöron sayıları ile belirlenmiştir. Bunun yanı sıra günlük küresel güneş ışınımı modellenmesi için Angström-Prescott metoduna dayanan modeller sunulmuştur. Günlük güneş ışınımının modellenmesinde de aylık ortalama günlük güneş ışınımı tahmininde olduğu gibi en iyi sonuçlar Angström-Prescott metodu temelli kübik regresyon modeli ile elde edilmiştir. Bu modelin tüm çalışma bölgesinde hesaplanan hata sonuçları MAE için 1.923, MBE için 0.368, RMSE için 2.778 ve R^2 için 0.850'dir. Günlük yapay sinir ağı modeli hata hesapları sonuçları ise, MAE için 0.997, RMSE için 1.487, MBE için (0.429) ve R^2 için 0.961'dir.

Görüldüğü gibi aylık ortalama güneş ışınımı modellerinde olduğu gibi günlük güneş ışınımı modellerinde de yapay sinir ağı modelleri daha iyi sonuçlar vermektedir.

Doğu Akdeniz Bölgesinde mevcut olan birçok meteoroloji istasyonunda güneş ışınımı ile birlikte güneşlenme süresi ölçümünün de yapılmadığı tespit edilmiştir. Bunun yanı sıra sıcaklık ve nem ölçümlerinin neredeyse tüm istasyonlarda yapıldığı gözlemlenmiştir. Sıcaklık parametresinin yaygın olarak ölçülmesi güneş ışınımının sıcaklıkla modellenmesini ölçülmüş güneş ışınımı değerleri bulunmayan yerler için önemli bir alternatif haline getirmektedir. Sıcaklık temelli bu modellerde maksimum sıcaklık değeri ve minimum sıcaklık değeri arasındaki farkın güneş ışınım bilgisiyle ilişkili olduğu varsayılır.

Literatürde mevcut olan küresel güneş ışınımını güneşlenme süresinden ziyade farklı parametrelerle modellemeyi öneren çalışmalar üzerine bir araştırma yapılarak, günlük küresel güneş ışınımını sıcaklık, nem ve yağışlılık gibi parametrelere bağlı olarak modelleyen çalışmalar belirlenmiştir. Bu sınıflandırmanın ışığında metotlar belirlenmiş, güneş ışıması tahmini için yaygın olarak kullanılan ve doğruya en yakın sonucu veren sıcaklık ve nem parametrelerinin bağımsız değişken olarak kullanıldığı modeller belirlenmiştir. Sıcaklık temelli modeller atmosferik geçirgenliği hesaplayabilmek için maksimum ve minimum sıcaklık değerlerinden faydalanılarak oluşturulur. Bu modeller maksimum sıcaklığın düşük geçirgenlik ile azalacağını, minimum sıcaklığın ise bulut emisyonu nedeniyle artacağını varsayar. Açık gökyüzü koşullarında maksimum sıcaklık artarken minimum sıcaklık da yüksek geçirgenlik nedeniyle azalacaktır. Dolayısıyla maksimum sıcaklık ile minimum sıcaklık arasındaki fark havanın bulanıklık göstergesi olacaktır. Bununla birlikte bulutlulukla maksimum sıcaklık azalırken minimum sıcaklık artacaktır. Bu nedenle günlük olarak önerilen modeller daha yüksek doğruluk ve düşük hata vermektedir. Bu çalışmalar içerisinde en sık kullanılan ve referans alanlar, Bristow-Campbell, Hargraves-Samani, Hunt, Meza-Varas, Abraha –Savage, Annandale et al., Antonanzas et al.,

Mahmood-Hubard, Donatelli Campbell, Weiss et al, , Goodin et al. ve Swartman-Ogunlade modelleridir. Literatürde mevcut olan ve günlük küresel güneş ışınımı tahmininde kullanılan bu oniki model Doğu Akdeniz Bölgesi için kalibre edilerek en uygun katsayılar belirlenmiştir. Bu modeller hata hesaplama yöntemleri ve istatistiksel test sonuçlarına göre değerlendirilmiş ve birbirleri ile karşılaştırılmıştır.

Bristow-Campbell modeli kalibre edilmiş parametreleri ile birlikte sıcaklık farkı ile günlük güneş ışınımını modelleyen en uygun model olarak belirlenmiştir. Bu model güneşlenme süresi ölçümlerinin yapılmadığı, sadece sıcaklık ölçümlerinin yapıldığı istasyonlar için önerilmiştir. Tüm bölge için oluşturulan Bristow-Campbell modeli için MAE değeri 2.033, MBE değeri 0.308, RMSE değeri 2.651 ve R^2 değeri 0.856'dır.

Bu çalışmada Doğu Akdeniz Bölgesinde güneş ışınımı tahmini için değişkenleri belirlenen tüm parametrik modeller içerisinde Swartman-Ogunlade modeli ile alınan sonuçların yapay sinir ağı modeli ile elde edilen sonuçlara en yakın sonuçlar olduğu gözlemlenmiştir. Buradan hareketle Swartman-Ogunlade modeli geliştirilerek literatürde bulunmayan iki adet güneş ışınım modeli oluşturulmuştur. Her iki modelde de küresel güneş ışınımı güneşlenme süresi ve nem parametrelerine bağlı olarak modellenmiştir. Modeller için hata hesapları ve istatistiksel testler yapılmıştır. Elde edilen sonuçlara göre her iki modelin de literatürdeki mevcut parametrik modellerden daha iyi sonuç verdiği gözlenmiştir. Ayrıca, bu modeller ile elde edilen sonuçlar hedef değer olarak belirlenen yapay sinir ağı modeli ile elde edilen sonuçlara çok yaklaşmış, yer yer daha iyi sonuçlar vermiştir. Modeller içerisinde daha basit yapısından ötürü Sunulan Model 1 önerilmiştir. Sunulan Model 1 ile elde edilen sonuçlar MAE değeri 0.958 ile 1.924, MBE değeri 0.203 ile 0.477, RMSE değeri 1.248 ile 2.569 ve R^2 değeri ise 0.874 ile 0.964 arasında değişmektedir. Bu sonuçlara dayanarak Sunulan Model 1, Doğu Akdeniz Bölgesinde günlük küresel güneş ışınımının modellenmesi için uygundur. Ayrıca farklı bölgelerin veri setleri için denenmesi ve geleneksel modellerle ve yapay sinir ağları modelleri ile karşılaştırılması önerilir.

This thesis is dedicated to

Efla Nil Yıldırım…

It is my sincere hope that she is as proud of her mother as her mother is of her.

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LIST OF SYMBOLS

°	:	Degree
ω_s	:	Hour angle
ΔT	:	Temperature difference
∑	:	Sum
°C	:	Centigrade degree
Cal	:	Calorie
D	:	Day of the year
E	:	East
exp	:	Exponential function
h	:	Altitude
H	:	Global solar radiation
H_0	:	Extraterrestrial radiation
H_c	:	Calculated global solar radiation
H_m	:	Measured global solar radiation
I_{sc}	:	Solar constant
J	:	Joule
log	:	Logarithm
LM	:	Levenberg-Marquard
M	:	Logical variable of rainfall
m^2	:	Meter square
MAE	:	Mean absolute error
MBE	:	Mean bias error
N	:	North
P	:	Air presure
P_0	:	Atmospheric presure at sea level
P_s	:	Atmospheric presure at site
R^2	:	Coefficient of determination

RH	:	Relative humidity
RMSE	:	Root mean squared error
S	:	Sunshine duration
S_0	:	Maximum possible sunshine duration
SCG	:	Scaled conjugate gradient
T	:	Air temperature
T_m	:	Daily mean temperature
T_{max}	:	Daily maximum temperature
T_{min}	:	Daily minimum temperature
W	:	Watt
Z	:	Elevation
π	:	The ratio of a circle's circumference to its diameter
δ	:	Declination angle
φ	:	Latitude

1. INTRODUCTION

1.1. General Information

The rapid depletion of the energy resources, increasing energy demand and ecological degeneration need an urgent solution in this age in which the consumption of energy shows inter-regional differences in terms of development. Solar energy as the most important energy resource of world that creates physical formation of earth and atmosphere becomes a trend solution. Solar radiation which arrives to earth surface every year is approximately 160 times greater than all known fossil fuel reserves discovered up until now (Ayana, 2011). Solar energy is the main, biggest and most important energy resource and the other energy resources are the form of solar energy. Solar energy is clean, free and endless energy resource that will exist till the end of the world. Solar energy is being used for years for many type of applications such as photovoltaic applications in which the solar energy is directly transformed to electrical energy. Large scale photovoltaic plants and concentrated solar power plants are going to be used much widely with developing technological novelty and incitement laws of states. Solar radiation data directly affects the efficiency of solar system such as photovoltaic systems therefore solar radiation data is mostly used for design optimization.

Solar energy is comprised of global solar energy existed under the atmosphere and extraterrestrial solar energy existed over the atmosphere (Khatib et al., 2012). Global solar radiation is the total amount of solar energy received by the Earth's surface and the principal energy source for life in our planet. Solar radiation data provides the information on how much energy strikes to the earth. Hence, records of observed solar radiation are required in different fields such as energy planning, climate monitoring and agriculture management. Global solar radiation data in a specific geographical area is significant for correct identification of investment, system design, projection, planning and continuity of the system. However in many areas of the earth's surface especially in agrarian and

mountainous areas, it is not easy to realize a measurement of solar radiation because of the initial costs and technology requirements. Therefore solar radiation modelling techniques are being handled as an important topic. Generally and principally, the best source of solar radiation data comes from on-ground measurements with high quality and correctly maintained pyranometers. Solar energy maps which show the global solar radiation potential of the country can be useful to locate the most suitable locations to install solar systems and reduce the costs of feasibility studies for such projects Chelbi et al., 2015). However, it is not always possible to obtain global solar radiation data in such a way, due to cost and operation maintenance requirements, as well as the need of having installed the pyranometers with sufficient time in advance in order to have a record. For these reasons, solar energy planners seek other approaches to obtain long-term accurate solar radiation records. Therefore solar energy prediction methods are becoming more and more important due to the increasing need for the design, performance evaluation and improvement of the solar energy application. Among these methods, parametric models and artificial neural network models have been widely used in literature due to their simplicity. These parametric techniques model the atmospheric transmittance using other commonly measured meteorological variables that are related to solar radiation (Urraca et al., 2015). Once trained in a location with a pyranometer, solar radiation can be estimated in stations without pyranometers with the only need of the other input variables, the calculation of the extraterrestrial irradiation and in some cases the calculation of maximum possible sunshine duration (Wong and Chow, 2001).

There are many prediction techniques existed in the world for solar radiation by some meteorological parameters such as geographical parameters (latitude, longitude, altitude] and meteorological parameters (ambient temperature, cloudiness, humidity, atmospherics pressure and sunshine duration). Artificial Neural Networks (ANN) are other widely used models to estimate global solar radiation in the literature that uses meteorological parameters as inputs. ANNs are

used for wide range of applications such as pattern classification, clustering, prediction, recognition, function approximation and optimization (Hasni et al., 2012). The aim of developing ANN model to estimate global solar radiation is to determine the optimal general model with indicated most relevant input parameters, most proper neuron numbers in hidden layer and transfer function to estimate the global solar radiation with high accuracy where the solar radiation measurement devices are not available.

ANN models are other alternative for modelling global solar radiation with satisfactory accuracy.

1.2. Objective and Organization of the Thesis

The subject of the thesis is "Introducing novel models for estimating global solar radiation in Eastern Mediterranean Region (EMR) based on Angström-Prescott and ANN methods by using meteorological data". Global solar radiation will be modelled for Eastern Mediterranean Region which covers Adana, Mersin, Kahramanmaraş, Osmaniye and Antakya. Meteorological parameters are going to be used in different combinations to get most desirable estimation by linear, nonlinear and ANN modelling techniques. The results will be tested by statistical test and error calculations such as mean bias error (MBE), mean absolute error (MAE), root mean squared error (RMSE) and coefficient of determination. Most accurate model will be proposed for the region and it is going to be useful for students, meteorologist, researchers and investors. It is aimed to model global solar radiation with less than 5% error and use this model to have a database where there is no global solar radiation measurement or it is not proper.

The objectives of this thesis are as follows:

- To summarize the global solar radiation estimation techniques, problems and solutions.

- To develop a model for the estimation of monthly mean daily global solar radiation from sunshine duration in Eastern Mediterranean Region based on Angström-Prescott method.
- To develop a model for the estimation of daily global solar radiation from sunshine duration in Eastern Mediterranean Region based on Angström-Prescott method.
- To develop a model for the estimation of daily global solar radiation from air temperature, relative humidity, precipitation etc. in Eastern Mediterranean Region.
- To develop a model for the estimation of monthly mean daily global solar radiation from meteorological parameters in Eastern Mediterranean Region with ANN.
- To develop a model for the estimation of daily global solar radiation from meteorological parameters in Eastern Mediterranean Region with ANN.
- To compare global solar radiation data with CMSAF (The Satellite Application Facility on Climate Monitoring) satellite based model database.
- To evaluate the performance of the models by statistical test results.
- To describe more functional model for the estimation of global solar radiation in Eastern Mediterranean Region.

After the introduction section that general information about the topic and organization, subject, object and contribution of this thesis are introduced, the structure of this thesis is as follows:

Chapter 2: global solar radiation importance, components and definitions, Earth's geometry which is directly effects the global solar radiation amount over a year and measurements device of solar radiation components are presented.

Chapter 3: Global solar radiation modelling techniques are classified after literature review. Most widely used models are determined with their advantages and disadvantages.

Chapter 4: The climate of the study area, the situation of meteorological stations where the data is collected and the data period and types are explained. The structure and mathematical explanation of the models which are calibrated in this thesis are presented. On the other hand, the formula of statistical tests and error calculation methods which exhibits the accuracy rating of the models are given.

Chapter 5: The global solar radiation modelling algorithms are given. The basic function of these models are presented.

Chapter 6: The coefficients of monthly mean daily and daily parametric models which are based on different meteorological parameters are given. The features of chosen most efficient ANN model is given. CMSAF Satellite derived database is presented. The results of statistical test R^2 and other error calculation methods are introduces to compare models among themselves.

Chapter 7: the summary of research findings, contributions of the thesis, concluding remarks and author's recommendations are explained.

Finally, all the references used in the thesis, autobiography of the author and sections of the Appendix are presented. Thesis flowchart is given below;

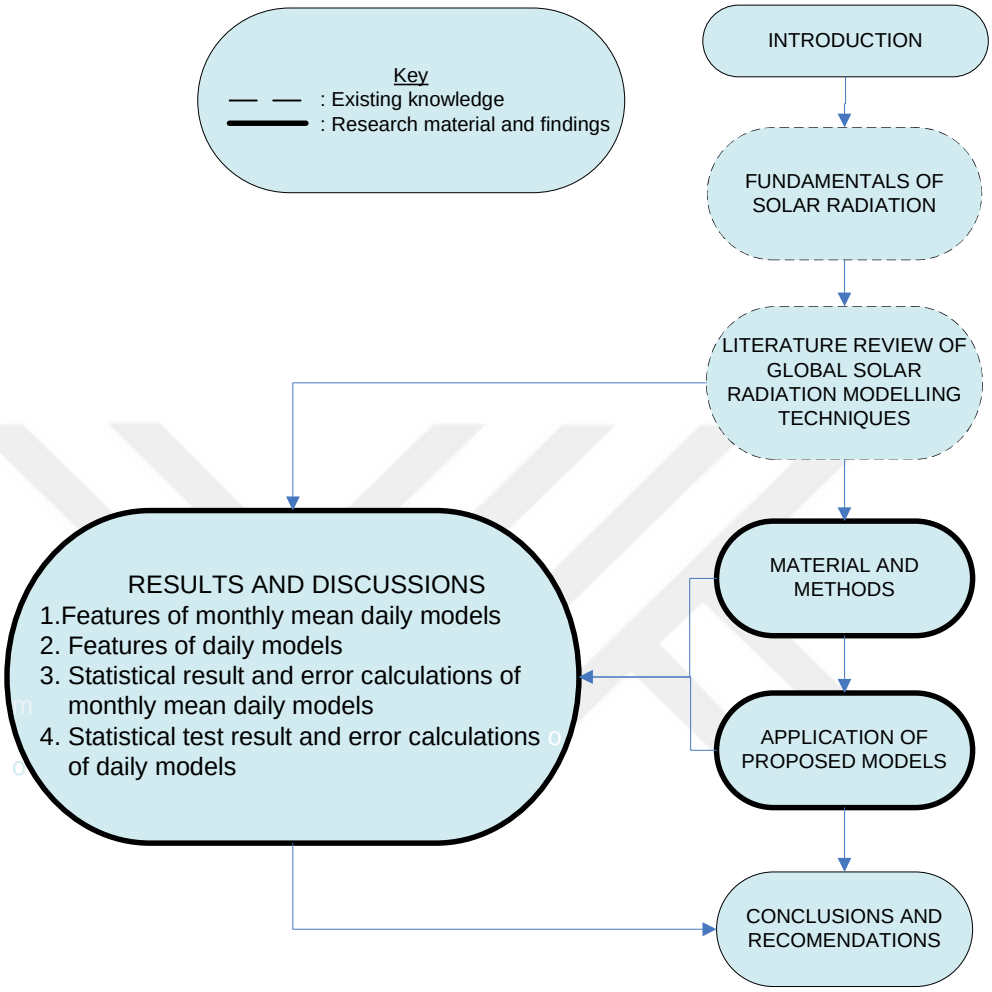


Figure 1.1. Flowchart of thesis

1.3. Contribution of the Thesis

The contributions of this thesis to the existing literature can be summarized as follows:

- A detailed description and analysis of various global solar radiation modelling methods are introduced in this thesis. Main and recent research

studies on the estimation of monthly mean global solar radiation are summarized by reviewing more than 100 papers and books.

- New models with calibrated coefficients based on Angstrom-Prescott method for the estimation of monthly mean daily global solar radiation and daily global solar radiation are presented. Regression models are estimated for each station separately and for whole study area generally by curve estimation techniques with R programming. The monthly mean daily linear, quadratic and cubic models for estimating monthly average daily global solar radiation are validated.
- A new model based on ANN method for the estimation of monthly mean daily global solar radiation and daily global solar radiation is presented and the performance of these models are investigated.
- 12 different models which are based on other meteorological parameters such as mean temperature, maximum temperature, minimum temperature, relative humidity, elevation and precipitation are presented for each station separately and for whole study area. The coefficients of these models are determined for the most accurate estimation of global solar radiation in Eastern Mediterranean Region.
- Two new parametric models based on sunshine duration and relative humidity are presented for each station separately and for whole study area. The models proposed improve the estimation of global solar radiation with around 1MJ/m^2day mean error.
- The CMSAF satellite based model database is procured and comparison between CMSAF model and measured data is presented. Errors between CMSAF model and measured data is calculated.
- The comparison between measured data and developed models are introduced with error calculations and statistical test R^2.

- It is determined that the proposed models which significantly approximates to measurements from pyranometers can be useful for the modelling global solar radiation in Eastern Mediterranean Region.

2. FUNDAMENTALS OF SOLAR RADIATION

2.1. The Importance and Definitions

The rapid depletion of the energy resources, increasing energy demand and ecological degeneration need an urgent solution in this age which energy usage is the most important input parameter for economic growth and social development of the countries. There are two main type of energy resources; renewable and non-renewable energy resources. Fossil fuels as non-renewable energy resources are still major primary energy resource even though their environmental disadvantages and limited lifetime. According to the studies about their lifetime, there is 50-55 years left for oil reserves, 80-100 years left for natural gas and around 250 years left for coal reserves (Önal and Doğan., 2010). Large scale oil companies realized that oil would be not efficient in the future and they started to invest in solar research after the oil crisis in 1970's. From 1970 solar systems get ahead in respect to technologic progress and cost. It has been accepted that solar energy is one of the eco-friendly energy resources. There are several ways of capturing and using the sun's energy, including photovoltaic cells, active solar energy and passive solar energy systems. Passive solar energy usually means energy efficient architectural design by using or blocking sunlight. Basic principles of passive solar energy usage is using sun in the winter, avoiding it in the summer and large glazing which can be insulated at night in cold climates and blocking sunlight and providing ventilation in hot climates. Solar pumps and flat plate or concentrating solar collectors can be investigating as active solar energy (Reyes and Rosen, 2007). On the other hand, photovoltaics also known as solar cells are another solar systems which can directly transform the solar energy to the electricity. PV cells are made of special materials called semiconductors and when a photon (a light particle) hits the panel, it has enough energy to knock an electron loose, allowing it to flow freely. The panel then has several electrical fields to force the electrons to move in a certain direction, creating a current which can be used to do work (Reyes and Rosen,

2007). Accurate design and construction of all these kinds of solar energy systems needs proper knowledge of global solar radiation falling on the surface of the earth.

2.2. Extraterrestrial Solar Radiation

Solar Energy originates with the thermonuclear fusion reactions occurring in the sun and represents the entire electromagnetic radiation (visible light, infrared, ultraviolet, x-rays, and radio waves). This radiant energy from the sun has powered life on Earth for many millions of years (Ahrens, 2012).

The radiation from the Sun travels in space as electromagnetic wave. Above the Earth's atmosphere, sunlight carries 1367 watts of power per square meter. This is known as solar constant. Solar constant is defined as the amount of solar radiation received outside the Earth's atmosphere on a unit area perpendicular to the rays of the sun, at the mean distance of the Earth from the Sun. Earth receives 1.8×10^{17} W of incoming solar radiation continuously at top of its atmosphere (Ahrens, 2012). But only half of it reaches the Earths' surface. Factors like absorption, scattering and reflection of light during its passage through the atmosphere are responsible for reduction of the amount of solar radiation available on the Earth's surface (Pidwirny, 2016).

The solar radiation at the entrance into the Earths' atmosphere is known as extraterrestrial radiation. The intensity of extraterrestrial solar radiation changes because of the change in distance between Earth and Sun. The value of this radiation during the course of a year changes in the range from 1307 (W/m^2) to 1393 (W/m^2) (Radosavljević and Đorđević, 2001). The change of extraterrestrial solar radiation is shown in Figure 2.1.

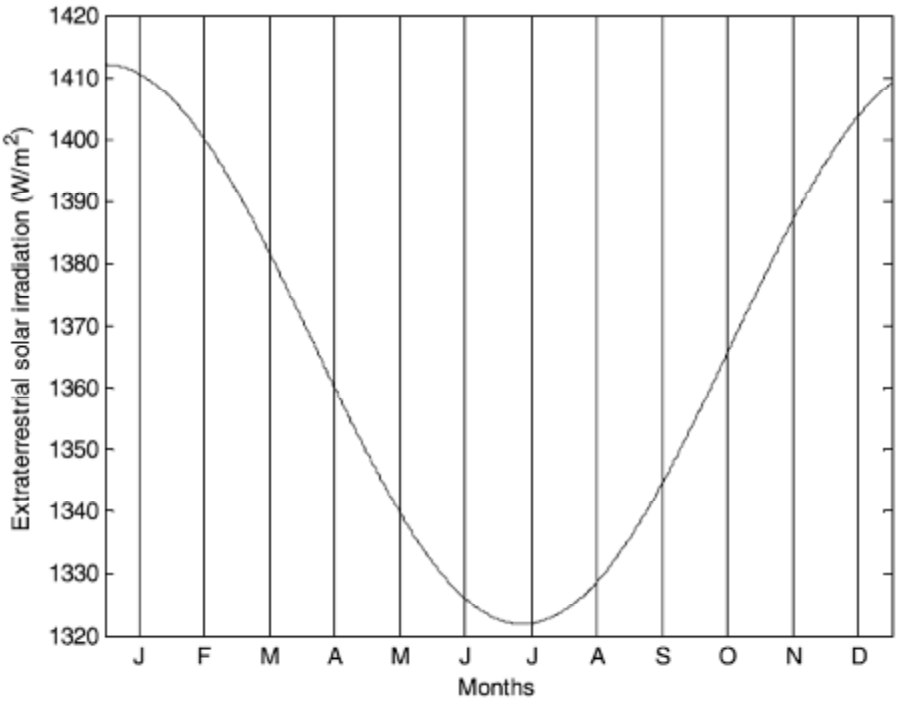


Figure 2.1. Monthly variation of extraterrestrial solar radiation (W/m^2)

To sum up; extraterrestrial solar energy is the energy it is the maximum possible energy obtainable from the Sun at the edge of the Earth's atmosphere for any given day of the year and it can be calculated by the following equation (Duffie and Beckman, 2013) ;

$$H_0 = \frac{24}{\pi} I_{sc}(1 + 0.033cos\frac{360D}{365}) \times (cos\varphi cos\delta sin\omega_s + \frac{2\pi\omega_s}{360} sin\varphi sin\delta)$$

where I_{sc} is the solar constant, φ is the latitude of the site, δ is the solar declination angle, ω_s is the mean sunrise hour angle for the given month and D is the number of days of the year starting from first of January.

2.3. Earth's Geometry

2.3.1. Solar Constant

The average value of irradiance per year is called as the solar constant. The solar constant actually varies by +/- 3% because of the Earth's slightly elliptical orbit around the Sun. The sun-earth distance is smaller when the Earth is at perihelion (first week in January) and larger when the Earth is at aphelion (first week in July) (Duffie and Beckman, 2013).

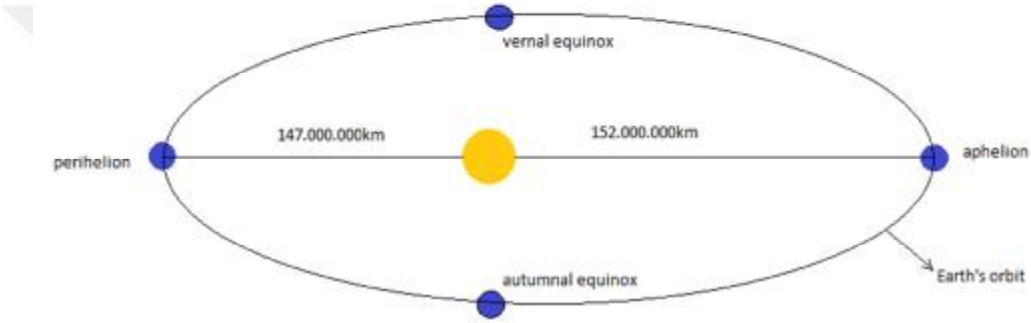


Figure 2.2. The ellipticity of Earth's orbit around the sun

The radiation intensity on the surface of the sun is approximately 6.33 × 107 W/m^2. Since radiation spreads out as the distance squared, by the time it travels to the earth (1.496 × 1011 m or 1 AU is the average Earth-Sun distance) (Harris, 1985), the radiant energy falling on 1 m^2 of surface area is reduced to 1367 W/m^2 as depicted in Figure 2.3.

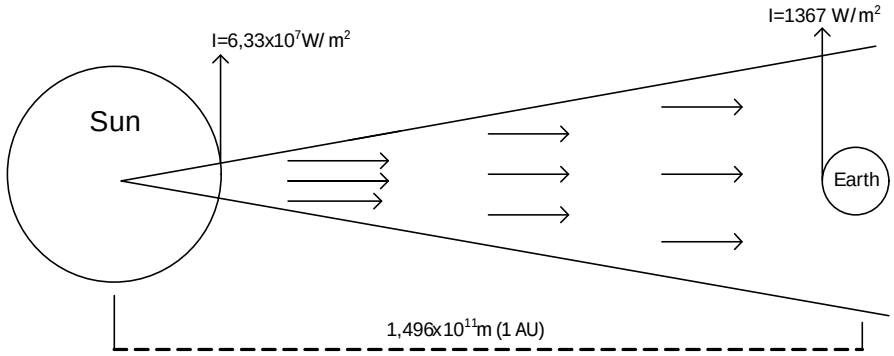


Figure 2.3. The divergence of energy from the sun to the earth

2.3.2. Solar Declination Angle

The solar declination angle is the angle between the vector of incoming solar rays and the vector normal to the Equator. It arises because the axis of the Earth is Tilted 23.5 Degrees.

The solar declination angle varies seasonally and explains the seasons and it is zero during the Spring and Autumn Equinox. The solar declination angle is +23.5 degrees during the Summer Solstice and it is – 23.5 degrees during the Winter Solstice (Radosavljević and Đorđević, 2001). The change in declination angle is given in Figure 2.4.

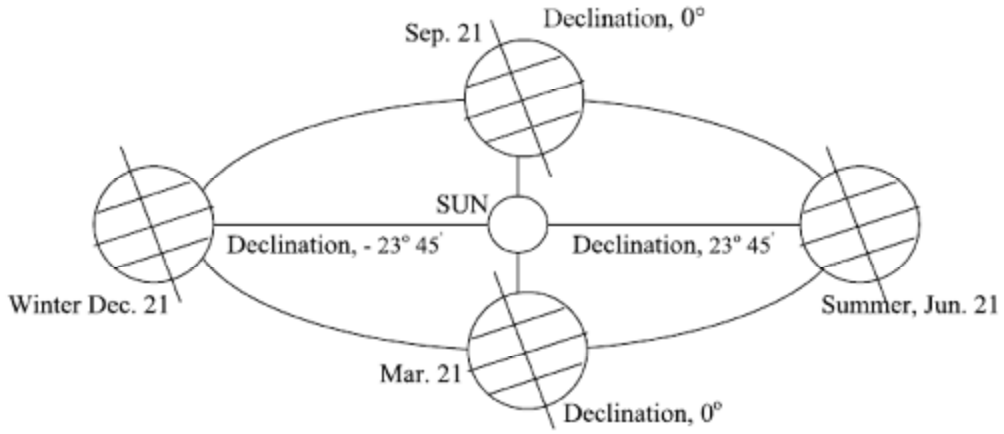


Figure 2.4. Declination angle over a year

The calculation of solar declination angle is given below;

$$\boldsymbol{\delta} = 23.45sin\left(\frac{360(D + 284)}{365}\right)$$

2.3.3. Hour Angle

The hour angle is the angular displacement of the sun east or west of the local meridian due to the rotation of the Earth. It is denoted by (w). The hour angle changes 15° per hour. The hour angle in noon is zero so it is negative in mornings and positive in afternoon. The hour angle is depends on apparent solar time (Radosavljević and Đorđević, 2001) (Sproul, 2002)

$$\omega_s = cos^{-1}[-\tan(\delta)\tan(\varphi)]$$

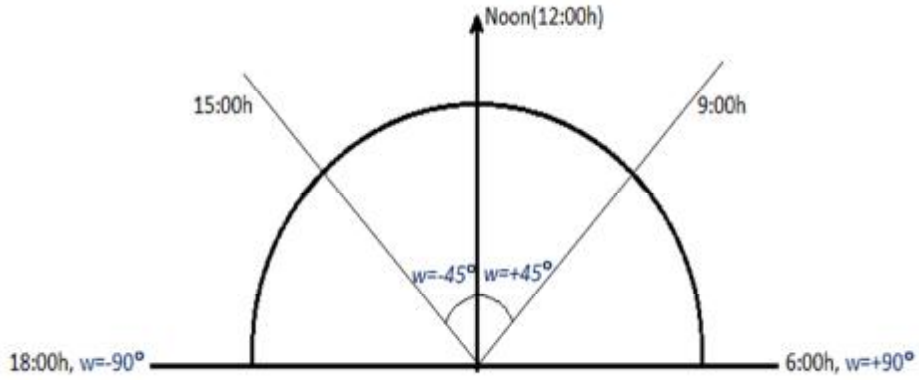


Figure. 2.5. The changes of hour angle during a day

2.4. Global Solar Radiation

Global solar radiation (GSR) is the total amount of solar energy received by the Earth's surface and the sum of direct solar radiation, diffuse solar radiation, and ground-reflected radiation; however, because ground reflected radiation is usually insignificant compared to direct and diffuse, for all practical purposes global radiation is said to be the sum of direct and diffuse radiation only:

GSR = Direct Solar Radiation + Diffuse Solar Radiation

The percentage of global solar radiation components is shown in Figure 2.6.

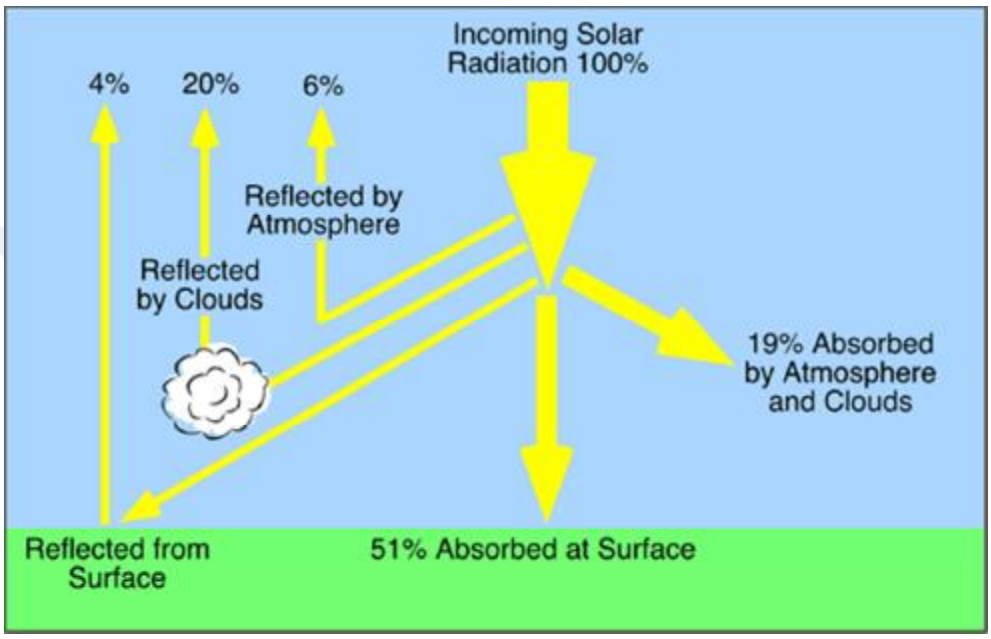


Figure 2.6. The percentage of global solar radiation components. (Pidwirny, 2006)

2.4.1. Direct Solar Radiation

Solar radiation amount that reaches the atmosphere is considered as parallel rays that comes from the sun in a straight line. However, the form and amount of solar radiation not as same as extraterrestrial radiation which is the amount of solar radiation that reaches the upper side of atmosphere. The straight line and amount of solar radiation change because of scattering, diffusion and absorption when it reaches the earth's surface by passing through the atmosphere. The reason of this effect of atmosphere is caused by gasses, water vapour, particles and clouds. Even so, some of the solar radiation keeps this straight line while it is travelling through the atmosphere (Harris, 1985).

Direct solar radiation is the amount of solar radiation which travels in a straight line from Sun to Earth's surface. Direct solar radiation value in a clear sky day is measured by authorities and companies such as meteorological stations and entrepreneurs. The amount of direct solar radiation is the solar radiation which reaches the any place on the Earth directly from the Sun without any disturbances. In other words, direct solar radiation is the amount of solar radiation that is not effected by dust, gas, water vapour and cloud or any other material over Earth's surface.

Sunlight reaching the Earth's surface unmodified by any of the above atmospheric processes is termed direct solar radiation (Pidwirny, 2016). On a cloudless day, direct solar radiation represents about 80 or 90 percent of the total amount of solar energy reaching the surface of the Earth. Local blockage of the direct component of solar irradiance produces shadows. On a cloudy or foggy day when Sun is not apparent the direct component of solar irradiance is essentially zero and there are no shadows. The direct component of solar irradiance is of the greatest interest to designers of high-temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses, whereas the diffuse component cannot (Harris, 1985). The term "sunshine" implies not the diffuse but the direct solar radiation (Şen, 2008) Direct shortwave radiation is the most important component of global radiation because it contributes the most to the energy balance and also the other components depend on it, either directly or indirectly (Şen, 2008).

2.4.2. Diffuse Solar Radiation

The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere (Pidwirny, 2016). The presence of the atmosphere the climate character of the regions effects the solar radiation that reaches the earth's surface. The diffuse radiation occurs by the effect of reflection, absorption (filtering), refraction, and scattering (Şen, 2008). The solar radiation

amount that enters the atmosphere is partially scattered and partially absorbed. Scattering reduces the amount of incoming solar radiation. Diffuse radiation is the solar radiation that is scattered because of atmospheric presence (Şen, 2008). Some of these scattered radiation goes back to the space and some of them reach the Earth's surface.

Diffuse radiation occurs when small particles and gas molecules diffuse part of the incoming solar radiation in random directions without any alteration in the wavelength of the electromagnetic energy (Pidwirny, 2016). On the other hand, portion of solar radiation is absorbed by these gas molecules, particles as well. The absorption of solar radiation by substances in the Earth's atmosphere results in temperatures that get no higher than 1800° Celsius. According to Wien's Law, bodies with temperatures at this level or lower would emit their radiation in the longwave band. Further, this emission of radiation is in all directions so a sizable proportion of this energy is lost to space (Pidwirny, 2016).

Diffuse radiation is first intercepted by the constituents of the air such as water vapour, CO_2, dust, aerosols, clouds, etc., and then released as scattered radiation in many directions. This is the main reason why diffuse radiation scattering in all directions and being close to the Earths' surface as a source does not give rise to sharp shadows. When the solar radiation in the form of an electromagnetic wave hits a particle, a part of the incident energy is scattered in all directions and it is called diffuse radiation (Şen, 2008).

2.5. Measurements of Solar Radiation Components

Routine measurement of diffuse solar energy from sky and the global (total) radiation incident on a horizontal surface is usually undertaken by an agency such as the national meteorological office (Pidwirny, 2016). Global solar radiation is measured with pyranometers, which are radiometers designed for measuring the total radiation on a plane surface (Paulescu et al., 2013). A pyranometer is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a

sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view 180^o (Tiwari and Dubey, 2009).

Direct solar radiation is measured by means of pyrheliometers, the receiving surfaces of which are arranged to be normal to the solar direction. By means of apertures, only the radiation from the sun and a narrow annulus of sky is measured, the latter radiation component is sometimes referred to as circumsolar radiation or aureole radiation (WMO, 2010). Pyrheliometer must be assembled to automatic two-axis sun tracker to make measurements of direct solar radiation (Tiwari and Dubey, 2009).

A pyranometer can also be used to measure diffuse solar radiation by blocking direct solar radiation with a shading disk that mounted on a solar tracker to block direct component of global solar radiation whole day. On the other hand, a shadow ring is also useful to block direct solar radiation reaching the sensor continuously (Paulescu et al., 2013). The needed measurement devices with their auxiliary equipment to measure global solar radiation and its components is shown in Table 2.1.

Table 2.1. Measurement Devices of terrestrial solar radiation components

Parameter	Measurement Device	Auxiliary Equipment
Direct Solar Radiation	Pyrheliometer	Sun Tracker
Diffuse Solar Radiation	Shaded Pyranometer	Shading disk or ring with sun tracker
Global Solar Radiation	Pyranometer	—

2.6. Summary

The amount of extraterrestrial solar radiation changes because of the change in distance between Earth and Sun. Extraterrestrial solar radiation is a function of latitude, day of the year, declination angle and hour angle while declination angle is a function of day of the year starting from first of January and hour angle is a function of declination angle and latitude of side. Therefore, if there is information about the latitude of the side, extraterrestrial solar radiation which is above the atmosphere can be calculated with a mathematical equation. However, global solar radiation which is under the atmosphere cannot be calculated. This is because of meteorological events happen in the atmosphere.

The amount of global solar radiation is affected by meteorological events such as cloudiness, precipitation, humidity and air temperature. By the way, amount of global solar radiation is needed for design and operation of solar systems. Principally the best source of global solar radiation data is observed by measurement. There are high quality devices to measure global solar radiation data that reaches the Earth's surface. Pyranometers are commonly used and cutting edge technology devices to measure global solar radiation. Furthermore the components of global solar radiation are also measured with specialized devices or auxiliary equipment. It is possible to measure direct solar radiation with pyrheliometers and diffuse solar radiation with auxiliary equipment added pyranometers.

A comphrehensive literature review on methods used before for modelling global solar radiation is presented in next chapter.

3. LITERATURE REVIEW OF GLOBAL SOLAR RADIATION MODELLING TECHNIQUES

3.1. Linear-Nonlinear Models

Many types of linear and nonlinear models and methods have been presented to estimate global solar radiation based on meteorological parameters such as sunshine duration, air temperature, maximum air temperature, minimum air temperature, precipitation and relative humidity. The linear models utilize simple linear function while the nonlinear models utilize polynomial function of the second, third or fourth degree (Khatib et al., 2012). One of the widely used models are Angström-Prescott based linear and nonlinear regression models which estimates global solar radiation based on sunshine duration(Angström, 1924) (Mousavi et al., 2015). Angström first suggested the idea of calculating the global solar radiation that uses the sunshine duration and clear sky radiation data as model parameters. Prescott modified this model by replacing clear sky radiation with extraterrestrial radiation (Prescott, 1940). Since then, this model has been used by many researchers to develop empirical correlations between global solar radiation which reaches the Earths' surface and sunshine duration. Global solar radiation is dependent variable and sunshine duration is independent variable in this model. The most important advantage of Angström method is the estimation of global solar radiation by just single measured parameter which is the sunshine duration (Prescott, 1940).

Angström model is used by many researchers directly or modified by them (Li et al., 2010), (Poudyal et al., 2012), (Hassanal et al., 2016), (Adaramola et al., 2012), (Suehrcke et al., 2013), (Rahimi et al., 2012). Angström offered monthly-average daily-global solar radiation first time (Angström, 1924) and used sunshine duration data and global solar radiation data in a cloudless sky while Prescott used extraterrestrial radiation instead of global solar radiation data (Prescott, 1940).

Angström model can be used for both linear and nonlinear functions of solar radiation calculation.

Sunshine duration is extensively measured in many meteorological stations for long period. Therefore, there have been many investigations to represent a relationship and to develop an equation between global solar radiation and sunshine duration. Most of the sunshine based these equations built to estimate global solar radiation are of the Angström-type equation (Bakirci, 2000). A global study has been made on the global solar radiation models available including the study carried out on estimation of the monthly average daily global solar radiation on horizontal surface (Bakirci, 2000).

Among several empirical models which have been used to calculate global solar radiation, the most commonly used parameter is sunshine hours (Zhao et al., 2013). Other widely used parameters are air temperature, precipitation, relative humidity and cloudiness (Besharat et al., 2013). Empirical models which have been used to calculate global solar radiation are usually based on some factors as shown in Table 3.1;

Table 3.1. Classification of parameters used to calculate global solar radiation

Classification	Parameters
Astronomical factors	Solar constant, earth-sun distance, solar declination and hour angle
Geographical factors	Latitude, longitude and elevation of the site
Geometrical factors	Azimuth angle of the surface, tilt angle of the surface, sun elevation angle, sun azimuth angle
Physical factors	Scattering of air molecules, water vapour content, scattering of dust and other atmospheric constituents such as O_2, N_2, CO_2, O, etc.
Meteorological factors	Extraterrestrial solar radiation, sunshine duration, temperature, precipitation, relative humidity, effects of cloudiness, soil temperature, evaporation, reflection of the environs, etc.

Many types of models and techniques have been presented to estimate solar radiation in the literature that are Angström-Prescott based linear and nonlinear regression model. In some study, it has been found that regression coefficients in the model are site dependent and regression coefficients have been suggested depends on geographical parameters such as latitude, altitude etc. (Gopinathan, 1988), (Kılıç and Öztürk, 1984), (Glower and McGulloch, 1958), (Gopinathan, 1988 b), (Bennet 1965), (Raja, 1994), (Elagib and Mansel, 2000), (Gana et al., 2014) [9-16]. On the other hand, in some other studies different parameters have been added to sunshine duration, extraterrestrial solar radiation and geographical parameters to calculate global solar radiation but these models show no more accuracy than which based on just sunshine duration and are inconvenient to use (Jin et al., 2005). It can be easily seen in the literature that sunshine based models have been used more commonly to estimate monthly average daily global radiation on horizontal surface. Also Angström- Prescott model is the widely used sunshine based model in the literature (Poudyal et al., 2012), (Behrang et al., 2011), (Adaramola, 2012), (Suehrcke, 2013), (Almorox and Hontario, 2004), (Ener et al., 2013), (Robaa, 2009), (Ener et al., 2013 b), (Duzen and Aydin, 2012).

According to studies in the literature, it is concluded that side dependent models which are developed by using data of study area is giving better results than general models. Hence, it is accepted that regression coefficients are site dependent and it depends on geographic parameters such as latitude, longitude, altitude (Gopinathan, 1988), (Glower and McGulloch, 1958), (Gopinathan, 1988 b), (Raja, 1994), (Elagib and Mansel, 2000), (Aras et al., 2006). Briefly, Angström-Prescott model is improved by many researchers by using different type of regression functions. First order regression models based on Angström-Prescott method is summarized in the Table 3.2.

Table 3.2. Linear models based on Angström-Prescott method

Reference	Model
(Page, 1961)	$H/H_0 = 0{,}23 + 0{,}48(S/S_0)$
(Louche et al., 1991)	$H/H_0 = 0{,}206 + 0{,}546(S/S_0)$
(Hay, 1979)	$H/H_0 = 0{,}280 + 0{,}493(S/S_0)$
(Rahimi et al., 2012)	$H/H_0 = 0{,}2773 + 0{,}4715(S/S_0)$
(Srivastava and Pandey, 2013)	$H/H_0 = 0{,}138 + 0{,}5564(S/S_0)$
(Gopinathan and Soler, 1992)	$H/H_0 = 0{,}1961 + 0{,}7212(S/S_0)$
(Almorox and Hontario, 2004)	$H/H_0 = 0{,}690 + 0{,}6142(S/S_0)$
(Almorox and Hontario, 2004)	$H/H_0 = 0{,}0271 + 0{,}3096(S/S_0)$
(Aras et al., 2006)	$H/H_0 = 0{,}3078 + 0{,}4166(S/S_0)$
(Ahmed and Ulfat, 2004)	$H/H_0 = 0{,}324 + 0{,}405(S/S_0)$
(Ulgen and Hepbasli, 2002)	$H/H_0 = 0{,}2671 + 0{,}4754(S/S_0)$
(Toğrul and Toğrul, 2002)	$H/H_0 = 0{,}318 + 0{,}449(S/S_0)$
(Said et al., 1998)	$H/H_0 = 0{,}215 + 0{,}527\left(S/S_0\right)$
(Tiris et al., 1996)	$H/H_0 = 0{,}2262 + 0{,}418(S/S_0)$
(Veeranl and Kumar, 1993)	$H/H_0 = 0{,}34 + 0{,}32(S/S_0)$
(Veeranl and Kumar, 1993)	$H/H_0 = 0{,}27 + 0{,}65\left(S/S_0\right)$
(Lewis, 1992)	$H/H_0 = 0{,}14 + 0{,}57(S/S_0)$
(Jain, 1992)	$H/H_0 = 0{,}313 + 0{,}474\left(S/S_0\right)$

Table 3.2. Continue

(Jain, 1992)	$H/H_0 = 0{,}307 + 0{,}488(S/S_0)$
(Jain, 1992)	$H/H_0 = 0{,}309 + 0{,}599(S/S_0)$
(Raja and Twidell, 1990)	$H/H_0 = 0{,}335 + 0{,}367(S/S_0)$
(Luhanga and Adringa, 1990)	$H/H_0 = 0{,}241 + 0{,}488(S/S_0)$
(Jain and Jain, 1988)	$H/H_0 = 0{,}240 + 0{,}513(S/S_0)$
(Khogali et al., 1983)	$H/H_0 = 0{,}191 + 0{,}571(S/S_0)$
(Newland, 1989)	$H/H_0 = 0{,}18 + 0{,}615(S/S_0)$
(Khogali et al., 1983)	$H/H_0 = 0{,}297 + 0{,}432(S/S_0)$
(Khogali et al., 1983)	$H/H_0 = 0{,}262 + 0{,}454(S/S_0)$
(Alsaad, 1990)	$H/H_0 = 0{,}174 + 0{,}615(S/S_0)$
(Hinrichsen, 1994)	$H/H_0 = 0{,}22 + 0{,}42(S/S_0)$
(Ahmad et al., 1983)	$H/H_0 = 0{,}458 + 0{,}175(S/S_0)$
(Jain, 1986)	$H/H_0 = 0{,}177 + 0{,}692(S/S_0)$
(Bahel et al., 1986)	$H/H_0 = 0{,}175 + 0{,}552(S/S_0)$
(Srivastava et al., 1993)	$H/H_0 = 0{,}2006 + 0{,}5313(S/S_0)$
(Hinrichsen, 1994)	$H/H_0 = 0{,}23 + 0{,}38(S/S_0)$
(Maduekwe and Chendo, 1995)	$H/H_0 = 0{,}36 + 0{,}34(S/S_0)$
(Rehman, 1998)	$H/H_0 = 0{,}3465 + 0{,}352(S/S_0)$

Table 3.2. Continue

(Ahmed and Ulfat, 2004)	$H/H_0 = 0{,}324 + 0{,}405(S/S_0)$
(Jin et al., 2005)	$H/H_0 = 0{,}1332 + 0{,}6471(S/S_0)$
(Katiyar and Pandey, 2010)	$H/H_0 = 0{,}2281 + 0{,}5093(S/S_0)$
(Li et al., 2011)	$H/H_0 = 0{,}2223 + 0{,}6529(S/S_0)$
(Yohanna et al., 2011)	$H/H_0 = 0{,}17 + 0{,}68(S/S_0)$
(Rietveld, 1978)	$H/H_0 = 0{,}10 + 0{,}24(S/S_0)$
(Rietveld, 1978)	$H/H_0 = 0{,}38 + 0{,}08(S/S_0)$
(Iqbal, 1979)	$H/H_0 = 0{,}791 - 0{,}635(S/S_0)$
(Kholagi et al., 1983)	$H/H_0 = 0191 + 0{,}571(S/S_0)$
(Kholagi et al., 1983)	$H/H_0 = 0{,}297 + 0{,}432(S/S_0)$
(Kholagi et al., 1983)	$H/H_0 = 0{,}262 + 0{,}454\left(S/S_0\right)$
(Benson et al., 1984)	$H/H_0 = 0{,}18 + 0{,}60(S/S_0)$
(Benson et al., 1984)	$H/H_0 = 0{,}24 + 0{,}53(S/S_0)$
(Ibrahim, 1985)	$H/H_0 = 0{,}79 - 0{,}59(S/S_0)$
(Gopinathan, 1988 c)	$H/H_0 = 0{,}931 - 0{,}814(S/S_0)$
(Soler, 1990)	$H/H_0 = 0{,}18 + 0{,}66(S/S_0)$
(Soler, 1990)	$H/H_0 = 0{,}20 + 0{,}60(S/S_0)$
(Soler, 1990)	$H/H_0 = 0{,}22 + 0{,}58(S/S_0)$
(Soler, 1990)	$H/H_0 = 0{,}20 + 0{,}62(S/S_0)$

Table 3.2. Continue

(Soler, 1990)	$^{H}/_{H_0} = 0{,}24 + 0{,}52(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}24 + 0{,}53(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}23 + 0{,}53(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}22 + 0{,}55(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}20 + 0{,}59(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}19 + 0{,}60(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}17 + 0{,}66(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}18 + 0{,}65(^{S}/_{S_0})$
(Soler, 1990)	$^{H}/_{H_0} = 0{,}179 + 0{,}099(^{S}/_{S_0})$
(Ulgen and Ozbalta, 2000)	$^{H}/_{H_0} = 0{,}2424 + 0{,}5014(^{S}/_{S_0})$
(Chegaar and Chibani, 2001)	$^{H}/_{H_0} = 0{,}309 + 0{,}368(^{S}/_{S_0})$
(Chegaar and Chibani, 2001)	$^{H}/_{H_0} = 0{,}367 + 0{,}367(^{S}/_{S_0})$
(Chegaar and Chibani, 2001)	$^{H}/_{H_0} = 0{,}233 + 0{,}591(^{S}/_{S_0})$
(Akpabio and Etuk 2003)	$^{H}/_{H_0} = 0{,}23 + 0{,}38(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}285 + 0{,}444(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}272 + 0{,}465(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}291 + 0{,}491(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}266 + 0{,}495(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}286 + 0{,}475(^{S}/_{S_0})$

Table 3.2. Continue

(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}311 + 0{,}439(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}329 + 0{,}406(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}313 + 0{,}410(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}271 + 0{,}479(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}259 + 0{,}465(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}279 + 0{,}431(^{S}/_{S_0})$
(Almorox et al., 2005)	$^{H}/_{H_0} = 0{,}282 + 0{,}428(^{S}/_{S_0})$
(Rensheng et al., 2006)	$^{H}/_{H_0} = 0{,}176 + 0{,}563(^{S}/_{S_0})$
(Bakirci, 2007)	$^{H}/_{H_0} = 0{,}6716 + 0{,}0760(^{S}/_{S_0})$
(Bakirci, 2009)	$^{H}/_{H_0} = 0{,}7836 + 0{,}0460(^{S}/_{S_0})$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 0{,}2626 + 0{,}1391(^{S}/_{S_0})$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 0{,}2989 - 0{,}1577(^{S}/_{S_0})$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 0{,}1532 + 0{,}0283(^{S}/_{S_0})$
(Jiang, 2009)	$^{H}/_{H_0} = 0{,}2420 - 0{,}0650(^{S}/_{S_0})$
(Ulgen and Hepbasli, 2009)	$^{H}/_{H_0} = 0{,}1677 + 0{,}0926(^{S}/_{S_0})$
(El-Sebaii et al., 2010)	$^{H}/_{H_0} = 3{,}542 - 3{,}664(^{S}/_{S_0})$
(Mubiru and Banda, 2007)	$^{H}/_{H_0} = 0{,}257 - 0{,}070(^{S}/_{S_0})$

In order to improve the models to estimate global solar radiation with better accuracy there are several second order polynomial function developed in the literature. These models which are summarized in Table 3.3 are also based on the relation between sunshine duration and global solar radiation.

Table 3.3. Second order regression models based on Angström-Prescott method

Reference	Model
(Singh et al., 1996)	$H/H_0 = 0{,}719 + 1{,}0673(S/S_0) + 1{,}1448(S/S_0)^2$
(Toğrul and Onat, 2000)	$H/H_0 = 0{,}215 + 0{,}624(S/S_0) + 0{,}220(S/S_0)^2$
(Toğrul et al., 2000)	$H/H_0 = 0{,}2816 + 0{,}3713(S/S_0) + 0{,}0174(S/S_0)^2$
(Toğrul et al., 2000)	$H/H_0 = 0{,}2646 + 0{,}2445(S/S_0) + 0{,}982(S/S_0)^2$
(Ahmed and Ulfat, 2004)	$H/H_0 = 0{,}348 + 0{,}320(S/S_0) + 0{,}07(S/S_0)^2$
(Rietveld, 1978)	$H/H_0 = 0{,}10 + 1{,}02(S/S_0) + 0{,}44(S/S_0)^2$
(Akinoglu and Ecevit, 1990)	$H/H_0 = 0{,}145 + 0{,}845(S/S_0) + 0{,}280(S/S_0)^2$
(Srivastava and Pandey, 2013)	$H/H_0 = 10{,}533 + 27{,}18(S/S_0) + 17{,}222(S/S_0)^2$
(Srivastava and Pandey, 2013)	$H/H_0 = 12{,}098 + 29{,}395(S/S_0) + 18{,}676(S/S_0)^2$
(Srivastava and Pandey, 2013)	$H/H_0 = 0{,}1840 + 0{,}6792(S/S_0) + 0{,}1228(S/S_0)^2$
(Ögelman et al., 1984)	$H/H_0 = 0{,}195 + 0{,}676(S/S_0) + 0{,}142(S/S_0)^2$
(Tarhan and Sari, 2005)	$H/H_0 = 0{,}1874 + 0{,}8592(S/S_0) + 0{,}4764(S/S_0)^2$
(Aras et al., 2006)	$H/H_0 = 0{,}3398 + 0{,}2868(S/S_0) + 0{,}1187(S/S_0)^2$
(Toğrul and Toğrul, 2002)	$H/H_0 = 0{,}1541 + 1{,}1714(S/S_0) + 0{,}705(S/S_0)^2$
(Mecibah et al., 2014)	$H/H_0 = 0{,}571 + 0{,}0103(S/S_0) + 0{,}00005(S/S_0)^2$
(Said et al., 1998)	$H/H_0 = 0{,}1 + 0{,}874(S/S_0) + 0{,}255(S/S_0)^2$

Table 3.3. Continue

(Aksoy, 1997)	$^{H}/_{H_0} = 0{,}148 + 0{,}668(^{S}/_{S_0}) + 0{,}079(^{S}/_{S_0})^2$
(Tasdemiroğlu and Sever, 1991)	$^{H}/_{H_0} = 0{,}255 + 0{,}014(^{S}/_{S_0}) + 0{,}001(^{S}/_{S_0})^2$
(Jin et al., 2005)	$^{H}/_{H_0} = 0{,}1404 + 0{,}6126(^{S}/_{S_0}) + 0{,}0351(^{S}/_{S_0})^2$
(Ibrahim, 1985)	$^{H}/_{H_0} = 0{,}252 + 0{,}0001(^{S}/_{S_0}) + 0{,}083(^{S}/_{S_0})^2$
(Iqbal, 1979)	$^{H}/_{H_0} = 0{,}163 + 0{,}478(^{S}/_{S_0}) + 0{,}655(^{S}/_{S_0})^2$
(Yildiz and Oz, 1994)	$^{H}/_{H_0} = 0{,}2038 + 0{,}9236(^{S}/_{S_0}) + 0{,}3911(^{S}/_{S_0})^2$
(Yildiz and Oz, 1994)	$^{H}/_{H_0} = 0{,}1541 + 1{,}1714(^{S}/_{S_0}) + 0{,}705(^{S}/_{S_0})^2$
(Bakirci, 2008)	$^{H}/_{H_0} = 1{,}0192 + 1{,}0547(^{S}/_{S_0}) + 0{,}9661(^{S}/_{S_0})^2$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 0{,}7434 + 0{,}8203(^{S}/_{S_0}) + 0{,}2454(^{S}/_{S_0})^2$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 1{,}0297 + 2{,}1096(^{S}/_{S_0}) + 1{,}5193(^{S}/_{S_0})^2$
(Barbaro et al., 1981)	$^{H}/_{H_0} = 0{,}8159 + 1{,}3289(^{S}/_{S_0}) + 0{,}8668(^{S}/_{S_0})^2$
(Lewis, 1995)	$^{H}/_{H_0} = 1{,}480 + 2{,}890(^{S}/_{S_0}) + 1{,}970(^{S}/_{S_0})^2$
(Trabea, 1999)	$^{H}/_{H_0} = 0{,}839 + 0{,}537(^{S}/_{S_0}) + 0{,}098(^{S}/_{S_0})^2$
(El-Sebaii and Trabea, 2003)	$^{H}/_{H_0} = 0{,}209 + 2{,}183(^{S}/_{S_0}) + 1{,}785(^{S}/_{S_0})^2$
(Mubiru and Banda, 2007)	$^{H}/_{H_0} = 0{,}352 + 1{,}386(^{S}/_{S_0}) + 2{,}235(^{S}/_{S_0})^2$

The global solar radiation third order regression models based on Angström-Prescott method is shown in the Table 3.4.

Table 3.4. Third order regression model based on Angström-Prescott method

Reference	Model
(Bahel et al., 1987)	$H/H_0 = 0{,}16 + 0{,}87(S/S_0) + 0{,}61\left(S/S_0\right)^2 + 0{,}34(S/S_0)^3$
(Zabara, 1986)	$H/H_0 = 0{,}395 + 1{,}247(S/S_0) + 2{,}680\left(S/S_0\right)^2 + 1{,}674(S/S_0)^3$
(Zabara, 1986)	$H/H_0 = 0{,}395 + 1{,}384(S/S_0) + 3{,}249(S/S_0)^2 + 2{,}055(S/S_0)^3$
(Almorox and Hontario, 2004)	$H/H_0 = 0{,}230 + 0{,}381(S/S_0) + 0{,}4694(S/S_0)^2 + 0{,}366(S/S_0)^3$
(Bakirci, 2000)	$H/H_0 = 0{,}631 + 0{,}725(S/S_0) + 1{,}209\left(S/S_0\right)^2 + 0{,}463(S/S_0)^3$
(Tarhan and Sari, 2005)	$H/H_0 = 0{,}152 + 1{,}133(S/S_0) + 1{,}112\left(S/S_0\right)^2 + 0{,}452(S/S_0)^3$
(Aras et al., 2006)	$H/H_0 = 0{,}483 + 0{,}616(S/S_0) + 1{,}893\left(S/S_0\right)^2 + 1{,}097(S/S_0)^3$
(Ulgen and Hepbasli, 2004)	$H/H_0 = 0{,}285 + 0{,}259(S/S_0) + 0{,}617\left(S/S_0\right)^2 + 0{,}483(S/S_0)^3$
(Toğrul and Toğrul, 2002)	$H/H_0 = 0{,}179 + 0{,}981(S/S_0) + 0{,}296(S/S_0)^2 + 0{,}266(S/S_0)^3$
(Ulgen and Hepbasli, 2002)	$H/H_0 = 0{,}241 + 0{,}3625(S/S_0) + 0{,}459\left(S/S_0\right)^2 + 0{,}370(S/S_0)^3$
(Mecibah et al., 2014)	$H = 0{,}572 + 0{,}009(S/S_0) + 0{,}00028\left(S/S_0\right)^2 + 0{,}00002(S/S_0)^3$
(Ertekin and Yaldiz, 2000)	$H/H_0 = 2{,}427 + 11{,}946(S/S_0) + 16{,}745\left(S/S_0\right)^2 + 7{,}957(S/S_0)^3$
(Lewis, 1992)	$H/H_0 = 0{,}81 + 3{,}34(S/S_0) + 7{,}38(S/S_0)^2 + 4{,}51(S/S_0)^3$
(Samuel, 1991)	$H/H_0 = 0{,}14 + 2{,}52(S/S_0) + 3{,}71(S/S_0)^2 + 2{,}24(S/S_0)^3$
(Jin et al., 2005)	$H/H_0 = 0{,}1275 + 0{,}7251(S/S_0) + 0{,}2299\left(S/S_0\right)^2 + 0{,}1837(S/S_0)^3$
(Soler, 1990)	$H/H_0 = 0{,}164 + 0{,}6829(S/S_0) + 1{,}0727(S/S_0)^2 + 0{,}00094(S/S_0)^3$
(Rensheng et al., 2006)	$H/H_0 = 0{,}15 + 1{,}14(S/S_0) + 1{,}47\left(S/S_0\right)^2 + 0{,}96(S/S_0)^3$

Table 3.4. Continue

(Bakirci, 2007):	$H/H_0 = 0{,}6307 + 0{,}7251(S/S_0) + 1{,}2089(S/S_0)^2 + 0{,}4633(S/S_0)^3$
(Tarhan and Sari, 2005)	$H/H_0 = 0{,}1520 + 1{,}1334(S/S_0) + 1{,}1126(S/S_0)^2 + 0{,}4516(S/S_0)^3$
(Tiris et al., 1996)	$H/H_0 = 0{,}4177 + 0{,}007\left(S/S_0\right) - 1{,}9096\left(S/S_0\right)^2 - 1{,}19(S/S_0)^3$
(Pandey and Katiyar, 2009)	$H/H_0 = 2{,}887 + 17{,}95\left(S/S_0\right) + 29{,}4\left(S/S_0\right)^2 + 14{,}92(S/S_0)^3$
(Pandey and Katiyar, 2009)	$H/H_0 = 3{,}419 + 15{,}03\left(S/S_0\right) + 25{,}18\left(S/S_0\right)^2 + 13{,}86(S/S_0)^3$
(Pandey and Katiyar, 2009)	$H/H_0 = 0{,}8384 + 0{,}2841\left(S/S_0\right) + 0{,}8208\left(S/S_0\right)^2 + 0{,}4315(S/S_0)^3$
(Pandey and Katiyar, 2009)	$H/H_0 = 1{,}033 + 0{,}9107\left(S/S_0\right) + 0{,}1288\left(S/S_0\right)^2 + 0{,}0972(S/S_0)^3$
(Pandey and Katiyar, 2009)	$H/H_0 = 0{,}09781 + 4{,}7630\left(S/S_0\right) + 11{,}32\left(S/S_0\right)^2 + 7{,}1670(S/S_0)^3$
Li et al. (Li et al., 2011)	$H/H_0 = 1{,}4069 + 6{,}3866\left(S/S_0\right) + 18{,}4206\left(S/S_0\right)^2 + 18{,}3755\,(S/S_0)^3$

There are several logarithmic and exponential function of global solar radiation model in the literature. Logarithmic and exponential regression function of Angström-Prescott based models are listed in Table 3.5.

Table 3.5.Logarithmic and exponential regression function of Angström-Prescott based models

Reference	Model
(Toğrul and Toğrul, 2002)	$H/H_0 = 0{,}2022 ln\left(S/S_0\right) + 0{,}0698$
(Toğrul and Onat, 2000)	$H/H_0 = -0{,}344 l\left(S/S_0\right) + 0{,}1982 + (-0{,}020 ln\left(S/S_0\right) 0{,}4562)(S/S_0)$
(Newland, 1989).	$H/H_0 = 0{,}34 + 0{,}40\left(S/S_0\right) + 0{,}17 log\left(S/S_0\right)$
(Ampratwum and Dorvlo, 1999)	$H/H_0 = 0{,}6376 + 0{,}2490 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}194 - 0{,}020 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}182 + 0{,}010 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}164 + 0{,}200 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}214 + 0{,}218 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}178 + 0{,}061 log\left(S/S_0\right)$
(Boukelia et al., 2014)	$H/H_0 = 0{,}106 - 0{,}280 log\left(S/S_0\right)$
(Almorox and Hontario, 2004)	$H/H_0 = -0{,}0271 - 0{,}3096 exp\left(S/S_0\right)$
(Pandey and Katiyar, 2009)	$H/H_0 = 0{,}09891\left(S/S_0\right)^{-0{,}4014} - 0{,}7839$

In order to improve the accuracy of the models some other meteorological parameters are added to Angström-Prescott model in the literature. Angström-Prescott models with added parameters such as altitude and latitude are summarized in the Table 3.6.

Table 3.6. Angström-Prescott models with added parameters

Reference	Model
(Gopinathan, 1988 d)	$H/H_0 = 0{,}265 + 0{,}07h + 0{,}061log\left(S/S_0\right)$
(Gopinathan, 1988 d)	$H/H_0 = 0{,}401 + 0{,}07 + 0{,}108h + 0{,}0325\left(S/S_0\right)$
(Glover and McCulloch, 1983)	$H/H_0 = 0{,}29cos\emptyset + 0{,}52\left(S/S_0\right)$
(Raja and Twidell, 1990)	$H/H_0 = 0{,}388cos\emptyset + 0{,}367\left(S/S_0\right)$
(Raja and Twidell, 1990)	$H/H_0 = 0{,}388cos\emptyset + 0{,}407\left(S/S_0\right)$
(Glover and McCulloch, 1983)	$H/H_0 = 0{,}3702 + \left[0{,}00506\left(S/S_0\right) - 0{,}00313\right]\emptyset + 0{,}32029\left(S/S_0\right)$
(Ulgen and Hepbasli, 2002)	$H/H_0 = 0{,}3092cos\emptyset + 0{,}4931\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 0{,}0855 + 0{,}002\emptyset + 0{,}03h + 0{,}5654\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 2{,}1186 - 2{,}0014cos\emptyset + 0{,}0304h + 0{,}5622\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 0{,}1094 + 0{,}0014\emptyset + 0{,}0212h + 80{,}5176 + 0{,}0012\emptyset + 0{,}015h)\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 0{,}1094 + 0{,}0014\emptyset + 0{,}0212h + 80{,}5176 + 0{,}0012\emptyset + 0{,}015h)\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 1{,}879 - 1{,}7516cos\emptyset + 0{,}0205h + (1{,}0819 - 0{,}5409\cos\emptyset\, 8 + 0{,}0169h)\left(S/S_0\right)$
(Jin et al., 2005)	$H/H_0 = 0{,}0218 + 0{,}0033\emptyset + 0{,}0443h + (0{,}9979 - 0{,}0092\emptyset - 0{,}0852h)\left(S/S_0\right)$+(-0,5579+0,012∅+0,1005h) +$(12{,}7247 - 13{,}0994cos\emptyset + 0{,}1h)\left(S/S_0\right)^2$
(Rensheng et al., 2006)	$H/H_0 = 4{,}251 - 4{,}1878cos\emptyset + 0{,}0437h + (-10{,}5774 + 11{,}4512cos\emptyset - 0{,}0832h)\left(S/S_0\right) + (12{,}7247 - 13{,}0994cos\emptyset + 0{,}1h)\left(S/S_0\right)^2$

Sunshine duration data is not measured in all of the stations. Therefore developing models which estimates global solar radiation with some alternative meteorological parameters is needed. Temperature-based models for estimating global solar radiation utilize the fact that thermal amplitude directly affects atmospheric transmissivity. In order to model global solar radiation with temperature there are several methods proposed in the literature. Air temperature measurement is commonly available in almost all meteorological stations. Therefore there are several models in the literature which build a relation between global solar radiation and difference in maximum and minimum temperature. The global solar radiation models which uses the difference in maximum and minimum temperature are presented in Table 3.7. Some authors presented different models for each station or for each months. Therefore there are more than one model in some of the studies.

Table 3.7 Temperature based global solar radiation models

Reference	Model
(Hargreaves and Samani, 1982)	$\frac{H}{H_0} = 0{,}17(T_{max} - T_{\min})^{0{,}5}$
(Hargreaves and Samani, 1982)	$\frac{H}{H_0} = 0{,}16(T_{max} - T_{\min})^{0{,}5}$
(Hargreaves and Samani, 1982)	$\frac{H}{H_0} = 0{,}19(T_{max} - T_{\min})^{0{,}5}$
(Bayat and Mirlatifi, 2009)	$\frac{H}{H_0} = 0{,}16(T_{max} - T_{\min})^{0{,}5}$
(Bristow and Campbell, 2009)	$\frac{H}{H_0} = 0{,}7[1 - \exp(-0{,}01\Delta T^{2{,}4})]$
(Bristow and Campbell, 2009)	$\frac{H}{H_0} = 0{,}7[1 - \exp(-0{,}004\Delta T^{2{,}4})]$

Table 3.7. Continue

(Allen, 1997)	$\frac{H}{H_0} = [0{,}17\left(\frac{P_s}{P_0}\right)]^{0,5}(T_{max} - T_{\min})^{0,5}$
(Allen, 1997)	$\frac{H}{H_0} = [0{,}20\left(\frac{P_s}{P_0}\right)]^{0,5}(T_{max} - T_{\min})^{0,5}$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}650[1 - \exp(-0{,}004\left(\frac{\Delta T^{2,55}}{H_0}\right))$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}750[1 - \exp(-0{,}121\left(\frac{\Delta T^{1,67}}{H_0}\right))$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}680[1 - \exp(-0{,}013\left(\frac{\Delta T^{2,02}}{H_0}\right))$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}780[1 - \exp(-5{,}43\left(\frac{\Delta T^{2,51,24}}{H_0}\right))$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}720[1 - \exp(-3{,}14\left(\frac{\Delta T^{0,92}}{H_0}\right))$
(Goodin et al., 1999)	$\frac{H}{H_0} = 0{,}750[1 - \exp(-2{,}61\left(\frac{\Delta T^{0,76}}{H_0}\right))$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.01354\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.01619\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.01944\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00203\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.002\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00677\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00347\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00589\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.01144\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00202\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00152\Delta T^2)]$

Table 3.7. Continue

(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00555\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00159\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00242\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00154\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00150\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00290\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00493\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00463\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00348\Delta T^2)]$
(Meza and Varas, 2000)	$\frac{H}{H_0} = 0.75[1 - \exp(-0.00389\Delta T^2)]$
(Chen et al., 2004)	$\frac{H}{H_0} = 0{,}19(T_{max} - T_{min})^{0.5} - 0{,}13$
(Chen et al., 2004)	$\frac{H}{H_0} = 0{,}64[1 - \exp(0{,}045\Delta T^{1{,}7})]$
(Chen et al., 2004)	$\frac{H}{H_0} = [0{,}15\left(\frac{P_s}{P_0}\right)]^{0{,}5}(T_{max} - T_{\min})^{0{,}5}$
(Chen et al., 2004)	$\frac{H}{H_0} = 0{,}28ln(T_{max} - T_{min})^{0.5} - 0{,}15$
(Chen et al., 2004)	$\frac{H}{H_0} = 0{,}04ln(T_{max} - T_{min}) - 0{,}48\left(S/S_0\right)^{0{,}83} + 0{,}11$

Due to the lack of meteorological variables data which are commonly used as predictor in the literature solar radiation cannot be modelled effectively there. Therefore, many researchers came up with alternative models that model global solar radiation with some other meteorological parameters such as relative humidity and rainfall. In the following table global solar radiation models based on other meteorological parameters are presented.

Table 3.8. Global solar radiation models based on other meteorological parameters

Author	Model
(Swartman and Ogunlade, 1967)	$H = 464 + 265S - 248RH$
(Swartman and Ogunlade, 1967)	$H = 490S^{0,357}\ R^{-0,262}$
(Gariepy, 1980)	$H/H_0 = [0,3791 - 0,0041T - 0,0176P] + [0,4810 - 0,0043T - 0,0907P](S/S_0)$
(El-Metwally, 2005)	$H/H_0 = 0,219 + 0,526\left(S/S_0\right) + 0,004w$
(Lewis, 1983)	$\frac{H}{H_0} = 53,676 - 23,99\left(\frac{S}{S_0}\right) - 26,680RH$
(Lewis, 1983)	$\log H = a + b(log\ RH)$
(Maghrabi, 2009)	$H/H_0 = -0,107 + 0,70\left(S/S_0\right) - 0,0025T + 0,004RH$
(Abdalla, 1994)	$H/H_0 = a + b\left(S/S_0\right) + cT + dRH$
(Ododo et al., 1995)	$\frac{H}{H_0} = a\left(S/S_0\right)^b\ {T_{max}}^c RH^d$
(Supit and Van Kappel, 1998)	$H = H_0\left[0,061\sqrt{T_{max} - T_{min}} + 0,477\sqrt{1 - \frac{C}{8}}\right] - 0,557$
(Trabea and Shaltout, 2000)	$H/H_0 = -0,139 + 0,229\left(S/S_0\right) + 0,009T_{max} + 0,004V + 0,002RH + 0,002PS$
(El-Metwally, 2004)	$H = aH_0 + bT_{max} + cT_{min} + d$
(Chen et al., 2004)	$H/H_0 = aln(T_{max} - T_{min}) + b\left(S/S_0\right)^c + d$
(El-Sebaii et al., 2009)	$H/H_0 = -1,92 + 2,60\left(S/S_0\right) + 0,006T$
(El-Sebaii et al., 2009)	$H/H_0 = -1,62 + 2,24\left(S/S_0\right) + 0,332RH$
(El-Sebaii et al., 2009)	$H/H_0 = 0,139 - 0,003T + 0,896RH$
(El-Sebaii et al., 2009)	$H/H_0 = 2,214 + 0,035(T_{max} - T_{min}) - 0,028C$
(El-Sebaii et al., 2009)	$H/H_0 = -2,76 + 3,72\left(S/S_0\right) + 0,001C$
(El-Sebaii et al., 2009)	$H/H_0 = -0,08 + 0,21(T_{max} - T_{min})^{0,5} - 0,012C$

3.2. Artificial Neural Network Models

According to Mihalakakou et al. (2000) and Tymvios et al. (2005), the most popular estimation models are analytic, stochastic, empirical and ANNs models (Mubiru and Banda, 2008). ANN provides a computationally efficient way of determining an empirical, possibly nonlinear relationship between a number of inputs and one or more outputs (Benghanem et al., 2009). ANNs, which are increasingly receiving attention in solving complex practical problems, are known as universal function approximators. They are capable of approximating any continuous non-linear functions to arbitrary accuracy (Kémajou et al., 2012). Neural networks are used to estimate global solar radiation by many researchers as a function of climatic variables. Ali Rahimikhoob (Rahimikhoob, 2010) used measured temperature data as an input to examine the potential of global solar radiation and compared the model with Hargreaves and Samani equation (Hasni et al., 2010). Sozen at al. (Sözen et al., 2004) used latitude, longitude, altitude, month, mean sunshine duration and mean temperature as an input layer of the network whereas solar radiation as the output layer to estimate the solar potential in Turkey. They used the scaled conjugate gradient (SCG), Pola–Ribiere conjugate gradient (PCG) and Levenberg–Marquardt (LM) learning algorithms and a logistic sigmoid transfer function in the network. A. Fadare (Fadare, 2009) used meteorological and geographical data (latitude, longitude, altitude, month, mean sunshine duration, mean temperature and relative humidity) as input layer of network while the solar radiation intensity was used as the output of the network. A. Fadare (Fadare, 2009) applied the standard multi-layered, feed forward, back-propagation neural networks. Benghanem at al. (Benghanem et al., 2009) used different combinations of inputs (air temperature, relative humidity and sunshine duration) to develop six ANN models and. Hamdy K. Elminir et al. (Elminir et al., 2007) adopted the Levenberg optimization function to predict insolation data in different spectral bands for Helwan monitoring station.

Ahmet Koca et al. (Koca et al., 2011) implemented an ANN model in MATLAB by using tangent sigmoid and linear activation functions in the hidden layer while the input variables are latitude, longitude, altitude, month of the year and mean cloudiness and the output variable is the solar radiation. M.A Behrang et al. (Behrang et al., 2010) applied multi-layer perceptron and radial basis function neural networks to estimate global solar radiation by different combinations of input variables such as; day of the year, daily mean air temperature, relative humidity, sunshine hours, wind speed, evaporation, while the output variable is global solar radiation.

Agbo et.al applied two methods that are regression analyses and ANN. Agbo et.al used average temperature and relative humidity as input variables and concluded that ANN model gives the best accuracy (Agbo et al., 2012). Ozgoren et.al developed an ANN model based on multi-nonlinear regression (MNLR) method for estimating the monthly mean daily sum global solar radiation at any place of Turkey. Rehman and Mohandes implemented ANN models for the estimation of global solar radiation. Three combinations of data sets are used and results show that using the relative humidity along with daily mean temperature outperforms the other cases (Rehman and Mohandes, 2008).

Mubiri and Banda developed a prediction model using ANN, which could be used to estimate monthly average daily global solar and input parameters was sunshine duration, maximum temperature, cloud cover and location parameters: latitude, longitude, altitude. The results showed good agreement between the estimated and measured values of global solar irradiation (Mubiru and Banda, 2008). Sfetsos and Coonick introduced ANN and adaptive neuro-fuzzy inference systems. The paper investigated the use of additional meteorological variables, such as temperature, pressure, wind speed and wind direction time series, as potential inputs to the forecasting (Sfetsos and Coonick, 2000).

Notton et.al used ANN for estimation of 10 minute global solar radiation. Minute data of horizontal global irradiance; normal beam irradiance, inclined

global irradiance (measured), horizontal extraterrestrial irradiance, solar declination and zenith angles were input parameters (Notton et al., 2013). Qin et al. presented an ANN based algorithm to estimate monthly mean daily global solar radiation. Input parameters are difference between daytime and night time land surface temperature, mean land surface temperature, precipitation, enhanced vegetation index, number of days, ratio of the local air pressure and the one at sea level (Qin et al., 2011).

Amrouche et al. developed a new ANN based model to forecast the global horizontal solar irradiation at the surface and meteorological forecasts are used as inputs to overcome the lack of measured database (Amrouche and Le Pivert, 2014) . Atsu et al. demonstrated the use of neural network methods in modelling solar radiation. Estimation of solar radiation was implemented by using month of the year, latitude, longitude, altitude, sunshine ratio as input parameters. (Atsu et al., 2002). Input variables and output variable of ANN models to predict global solar radiation are illustrated in Table 3.9.

Table 3.9. Input variables used in ANN to predict solar radiation

Model	Input variable(s)	Output variable
(Rahimikhoob, 2010)	Temperature data (T_{max} and T_{min}) and the extraterrestrial radiation	Daily global solar radiation
(Sözen et al., 2004)	Latitude, longitude, altitude, month, mean sunshine duration and mean temperature	Solar potential in Turkey
(Fadare, 2009)	Latitude, longitude, altitude, month, mean sunshine duration, mean temperature and relative humidity	Solar radiation intensity
(Benghanem et al., 2009)	Air temperature, relative humidity, sunshine duration and day of the year	Daily global solar radiation

Table 3.9. Continue

(Elminir et al., 2007)	Temperature, relative humidity, wind speed and wind direction	Insolation data in different spectral bands
(Koca et al., 2011)	Latitude, longitude, altitude, month of the year and mean cloudiness	Solar radiation
(Behrang et al., 2010)	Day of the year, daily mean air temperature, relative humidity, sunshine hours, wind speed and evaporation	Global solar radiation
(Agbo et al., 2012)	Average temperature and relative humidity	Global solar radiation on horizontal surface
(Özgören et al., 2012)	The global solar radiation and other meteorological parameters, like long-wave atmospheric emission, air temperature, relative humidity and atmospheric pressure.	Monthly mean daily sum global solar radiation
(Rehman and Mohandes, 2008)	Day of the year, relative humidity and daily mean temperature	Global solar radiation
(Notton et al., 2013)	Minute data of horizontal global irradiance; normal beam irradiance, inclined global irradiance (measured), horizontal extraterrestrial irradiance, solar declination and zenith angles	10 min solar global irradiation
(Sfetsos and Coonick, 2000)	Temperature, pressure, wind speed and wind direction,	Hourly solar radiation

Table 3.9. Continue

(Mubiru and Banda, 2008)	Sunshine duration, maximum air temperature, cloud cover and location parameters: latitude, longitude, altitude	Average daily global solar irradiation
(Qin et al., 2011)	Difference between daytime and night time land surface temperature, mean land surface temperature, precipitation, enhanced vegetation index, number of days, ratio of the local air pressure and the one at sea level	Monthly mean daily global solar radiation
(Amrouche and Le Pivert, 2014)	Meteorological forecasts	The global horizontal solar irradiation at the surface
(Atsu et al., 2002)	Month of the year, latitude, longitude, altitude and sunshine ratio	Solar radiation

3.3. Summary

The needs of accurate global solar radiation data and the high price of measurement equipments put forward the importance of modelling global solar radiation with high accuracy. Other meteorological parameters such as sunshine duration, air temperature, relative humidity, precipitation, maximum air temperature and minimum air temperature are measured in almost all meteorological stations while global solar radiation measurement is very rare. Many linear, nonlinear or ANN models developed in the literature to make global solar radiation information accessible. It can be concluded from the literature review that there are two main method for modelling global solar radiation. One of them is parametric models which includes linear and nonlinear models and other

one is ANNs. There are some other machine learning techniques such as particle swarm optimization, support vector machine and fuzzy logic, existed in the literature. However, these techniques are not the topic of this thesis.

The comprehensive review on global solar radiation modelling techniques reveals that there is no study for modelling global solar radiation in Eastern Mediterranean Region.

The literature review of global solar radiation modelling will help the researchers to validate different kind of models to find possible model depends on the measured meteorological parameters they have.

In the next chapter, the methods of validated models in Eastern Mediterranean Region, the climate of study area and used data for modelling global solar radiation is explained.

4. MATERIAL AND METHODS

4.1. Material

Due to its geographical position Turkey receives huge amount of solar energy potential. According to GEPA (The Atlas of Solar Energy Potential) atlas which is provided by Directorate General of Renewable Energy, Turkey's total annual sunshine duration is 2.640 hours (daily total sunshine duration is 7,2) and total annual global solar radiation 1.311 kWh/m².year (daily total global solar radiation is 3,6 kWh/m²) (http://www.enerji.gov.tr/tr-TR/Sayfalar/Gunes).

It can be easily seen from the map of Directorate General of Renewable Energy which is shown in Figure 4.1 that according to the distribution of global solar radiation generally Turkey and especially Eastern Mediterranean Region has a great potential of solar energy. It is important to activate this potential and getting economic benefits from producing domestic energy from its own renewable energy resources for Turkey as a developing country.

In Turkey, electricity generation and solar thermal use of solar energy is getting more and more common. Especially in Mediterranean Region of Turkey hot water is being obtained by solar energy for many years. Installed capacity of photovoltaic solar electric system reached 660 MW in the country (October 2016). Beside this, it is calculated that the country's' installed total solar collector area is 18.640.000 m² in 2012. Total annual solar collector production is 1.164.000 m², vacuum tube collect tor production is calculated as 57.600 m². Half of the planar solar collector and whole vacuum tube collector production is used in the country (http://www.enerji.gov.tr/tr-TR/Sayfalar/Gunes).



Figure 4.1. Turkey's solar energy potential map (www.eie.gov.tr, 2016)

Tablo.4.1 Turkey's monthly mean solar energy potential (www.eie.gov.tr, 2016)

Months	Monthly mean total solar energy		Sunshine duration
	(MJ/m^2-month)	(KWh/m^2-month)	(Hour/Month)
January	186.010	51.75	103.0
February	227.392	63.27	115.0
March	347.358	96.65	165,0
April	439.318	122.23	197.0
May	553.014	153.86	273.0
June	606.518	168.75	325.0
July	630.344	175.38	365.0
August	569.316	158.40	343.0
September	443.080	123.28	280.0
October	323.114	89.90	214.0
November	218.614	60.82	157.0
December	168.454	46.87	103.0
Total	4712.532	1311	2640
Avarage	12.8744 MJ/m^2 day	3.6 kWh/m^2-day	7.2 hour/day

Turkey is divided into seven regions, each has its own different topography and climatic characteristics. Total solar energy and sunshine duration in respect to regions is given in Table 4.2. It can be seen from the table that Mediterranean Region as one of the 7 regions of Turkey is getting highest solar energy after Southeast Anatolian Region of Turkey.

Tablo 4.2. Turkey's total annual regional distribution of solar energy potential (http://www.eie.gov.tr , 2016)

Region	Total Solar Energy (kWh/m^2-year)	Sunshine Duration (Hour/year)
Southeastern Anatolia	1460	2993
Mediterranean	1390	2956
Eastern Anatolia	1365	2664
The Central Anatolia	1314	2628
Aegean	1304	2738
Marmara	1168	2409
Black Sea	1120	1971

4.1.1. Climate of Study Area

Turkey’s geographical position is advantageous to receive solar energy. The mean temperature of the country is usually below 5°C in winter, the rate of evaporation is low and the most of the country receives precipitation during this season. High temperature and high level of the evaporation causes water deficit in summer and rainfall is not enough to cover it. The country has seven different regions called as Mediterranean Region, Black Sea Region, Aegean Region, Region of Marmara, Central Anatolia Region, Eastern Anatolia Region and Southeast Anatolia Region. Each region of the country has different topography hence different climates (http://www.eie.gov.tr/eie-web/english/solar/solarTurkey_e.html)

(http://www.mgm.gov.tr/FILES/iklim/turkiye_iklimi.pdf). The Mediterranean Region is one of these main regions. Eastern Mediterranean Region (EMR) is the east side of the Mediterranean Region and under the Mediterranean climate. Eastern Mediterranean Region contains five city centres namely Adana, Mersin, Antakya, Osmaniye and Kahramanmaraş. The geographic information of these cities are given in Table 4.3 (http://www.mgm.gov.tr). The Mediterranean coasts have cool, rainy winters and hot, moderately dry summers. The meteorological characteristics of 3 city in Eastern Mediterranean Region centres which have the stations that global solar radiation measurements is being made by pyronemeters are given in Table 4.4.a,b, and c (http://www.mgm.gov.tr). According to these tables, solar energy should be paid attention in this region.

Table 4.3. The geographical coordinates of the stations. (ww.mgm.gov.tr, 2016)

Coordinates	Stations		
	Adana	Kahramanmaraş, Göksun	Mersin, Tarsus
Latitude	37° 0' N	38° 1' N	36° 54' N
Longitude	35° 20' E	36° 29' E	34° 58' E
Elevation(m)	27	1344	12

Average meteorological values observed from the city of the stations of the study area from 1950 to 2014 is given in Table 4.4.a, 4.4.b, and 4.4.c.

Table 4.4.a. Average meteorological values of Adana

Adana	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature (°C)	9.6	10.5	13.5	17.5	21.7	25.6	28.1	28.4	25.9	21.3	15.4	11.2
Average maximum temperature (°C)	15.0	16.2	19.5	23.8	28.2	31.7	33.8	34.6	33.1	29.0	22.4	16.8
Average minimum temperature (°C)	5.5	6.1	8.5	12.2	15.9	20.0	23.2	23.5	20.3	15.9	10.7	7.1
Average sunshine hours (hour)	4.4	5.2	6.0	7.1	9.1	10.4	10.5	10.3	9.0	7.2	5.6	4.3
Average rainy day	10.4	10.3	9.9	9.1	6.7	3.0	0.9	0.7	2.6	5.5	7.2	10.5
Average total monthly rainfall(kg/m^2)	109.9	84.2	66.8	55.2	47.3	20.0	7.1	5.2	15.8	40.7	73.7	128.7

Table 4.4.b. Average meteorological values of Mersin

Mersin	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature (°C)	10.1	10.9	13.6	17.5	21.3	25.2	27.9	28.3	25.6	21.1	15.7	11.7
Average maximum temperature (°C)	14.7	15.5	18.2	21.6	24.8	28.1	30.7	31.5	30.0	26.7	21.4	16.5
Average minimum temperature (°C)	6.3	6.8	9.2	13.0	16.8	20.8	23.9	24.2	20.9	16.3	11.4	7.8
Average sunshine hours (hour)	4.6	5.4	6.5	7.3	8.5	10.1	10.1	10.0	9.2	7.5	5.5	4.5
Average rainy day	10.1	9.2	7.6	6.8	5.2	2.2	0.9	0.8	1.7	5.0	6.8	10.2
Average total monthly rainfall(kg/m^2)	112.9	78.7	56.4	35.2	23.6	8.9	7.6	4.7	8.5	38.3	78.6	135.7

Table 4.4.c. Average meteorological values of Kahramanmaraş

Kahraman maras	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature (°C)	4.9	6.4	10.7	15.4	20.3	25.2	28.3	28.4	25.1	19.0	11.8	6.7
Average maximum temperature (°C)	9.2	10.9	15.8	21.1	26.7	31.9	35.5	35.9	32.3	25.9	17.5	11.0
Average minimum temperature (°C)	1.3	2.2	5.7	9.8	14.0	18.8	22.0	22.1	18.3	12.8	6.9	3.0
Average sunshine hours (hour)	3.2	4.1	5.3	6.4	8.3	10.2	10.5	10.1	9.0	6.5	4.3	3.2
Average rainy day	11.9	11.6	11.7	10.9	7.9	2.4	0.5	0.4	2.0	6.3	8.4	11.6
Average total monthly rainfall(kg/m^2)	124.8	109.9	93.9	73.5	38.9	7.2	1.2	0.8	8.5	44.7	81.1	125.5

4.1.2. Meteorological Stations

The meteorological stations of Adana, Mersin, Antakya and Osmaniye is visited to check the quality of measurement devices and data collected from that devices. These visits are organized by permission and given appointment of meteorological stations to determine the status and problems of measurement stations. According to these visits, it is noted that the most detailed and comprehensive measurements is being done in Regional Office of Meteorology in Adana. Air temperature, humidity, precipitation, water vapour and soil temperature parameters are being measured in whole stations. Beside this, sunshine duration and global solar radiation are being measured in only Adana station. However, global solar radiation is measured until 2007 by actinography device in Adana, Mersin and Antakya stations. After 2007, global solar radiation measurement is stopped by general directorate of institution to install automatic measurement stations. Automatic station is installed in Adana station since 2008 and global solar radiation measurement with pyronometers is started at the same time. Global solar radiation is never measured in Osmaniye meteorological station. However it is informed by General Directorate of Meteorology that global solar radiation is being measured in Tarsus Meteorological Station and Göksun Meteorological stations since 2011. Tarsus is one of the district of Mersin and Göksun is one of the district of Kahramanmaraş. Therefore, the meteorological data of Adana, Tarsus and Göksun is used to develop global solar radiation model in this thesis.

4.1.3. Meteorological Data Collection

General Directorate of Meteorology which is in Ankara is the one institute that collects the meteorological data from all over the country. The measurements of meteorological parameters by this time is in their database. It is mandatory to obtain data from the General Directorate of Meteorology neither from the stations nor regional offices. Therefore, the necessary official calls between university and meteorological stations is made and it is assured that the data is used in scientific

researches than the meteorological data is collected free of charge after for a while. The list of the data which is provided by meteorological stations is given in Table 4.5.

Tablo 4.5. The list of meteorological parameters for each stations

Daily mean temperature (For last 20 years)
Daily maximum temperature (For last 20 years)
Daily minimum temperature (For last 20 years)
Daily sunshine duration (For last 20 years)
Daily global solar radiation (For last 20 years)
Daily relative humidity (For last 20 years)
Daily precipitation (For last 20 years)
Daily wind speed (For last 20 years)
Daily wind direction (For last 20 years)
Daily water vapour (For last 20 years)

In this thesis, daily global solar radiation on a horizontal surface, number of bright sunshine hours, temperature, maximum temperature, minimum temperature, relative humidity and rainfall data for Göksun, Tarsus and Adana for the period between 2012 and 2015 are used which are most qualified data obtained from Turkish State Meteorological Service. The global solar radiation has been measured with pyranometer in these stations since 2012. The list of stations which global solar radiation is being measured is given in Appendix A. There are more data available for other stations such as Antakya and Mersin which global solar radiation measured by actinography in the study area, however due to the high errors between actinography measurements and pyranometers (Karakoc, 2010) and different time period of measurements these stations are disregarded. Therefore, only the data from Göksun, Tarsus and Adana is used to train and test the parametric models. The mean daily values for each data are then organized as train

dataset and test dataset. The dataset are then divided into two sub-data sets, one of which for 2012, 2013 and 2015 was used for calibrating and developing the models, and another for the year 2014 for evaluating models.

On the other hand, pre-processing is used to remove data based on the limits. Limits for the pre-processing filter which aims the data accuracy and consistency are illustrated in Table 4.6.

Table 4.6. The limits of the filter

Parameter	Maximum limit	Minimum limit
T (Temperature)	40 °C	5°C
T_{max}	45°C	0°C
T_{min}	40°C	-10°C
RH	100%	20%
H/H_0	0.8	0.2

4.2. Methods

4.2.1. Sunshine Based Models

The Angström Prescott model that examines the linear correlations between clearness index (H/H_0) and sunshine duration ratio (S/S_0) is used to model global solar radiation in EMR in this thesis. The equation used in this model is (Angström, 1924) (Prescott, 1940);

$$H/H_0 = a + b(S/S_0) \quad (4.1)$$

where H is the monthly average daily global solar radiation on a horizontal surface, H_0 is the daily extraterrestrial radiation on a horizontal surface, S is the monthly average daily sunshine duration, S_0 is the monthly average maximum possible daily sunshine duration and a and b are Angström coefficients (also called

as regression coefficients). S_0 can be calculated as following equation (Duffie and Beckman, 2013);

$$S_0 = \frac{2}{15}\omega \tag{4.2}$$

where w is the hour angle. The quadratic model which is used to develop another global solar radiation model in this study is proposed by Akinoglu and Ecevit (Akinoglu and Ecevit, 1990). It is also based on Angström-Prescott premises and the related equation is;

$$H/H_0 = a + b(S/S_0) + c(S/S_0)^2 \tag{4.3}$$

The used cubic model is proposed by Bahel et al (Bahel et al., 1987) and the related equation is;

$$H/H_0 = a + b(S/S_0) + c(S/S_0)^2 + d(S/S_0)^3 \tag{4.4}$$

4.2.2. Temperature Based Models

The empirical air-temperature-based solar radiation models used in this study to optimize the coefficients for Eastern Mediterranean Region of Turkey and to develop new models based on air difference between maximum air temperature and minimum air temperature are the Hargraves and Samani model, the Bristow and Campbell model, the Hunt model, the Goodin et al. model, the Meza and Varas model, the Weiss et al. model, the Annandale model, the Mahmood and Hubbard model, Chen et al. model and the Abraha and Savage model, the Donatelli and Campbell model, and the Hargreaves model. These models are developed because daily air-temperature range is being measured most of the weather stations while

there is a lack in sunshine duration measurements, these models can be easily applied for many stations.

In order to model global solar radiation with temperature there are several methods proposed in the literature. Hargraves and Samani developed a global solar radiation model which assumes there is a relation between global solar radiation and maximum and minimum temperature deference**.** (Hargreaves and Samani, 1982).

$$\frac{H}{H_0} = a(T_{max} - T_{\min})^{0,5} \quad (4.5)$$

where H is the daily global solar radiation on a horizontal surface, H_0 is the daily extraterrestrial radiation on a horizontal surface, T_{max} is daily maximum temperature and T_{min} is daily minimum temperature. The calculated coefficient is firstly determined as 0.17 then it is changed as 0.16 for hinterland and 0.19 for littoral zone.

Bristow and Campbell suggested an exponential function relationship between global solar radiation and Daily temperature difference. (Bristow and Campbell, 2009)**.**

$$\frac{H}{H_0} = a[1 - \exp(-b\Delta T^c)] \quad (4.6)$$

where ΔT is the difference between Daily maximum and minimum air temperature, a, b and c are empirical coefficients.

Donatelli and Campbell suggested the following formula for modelling global solar radiation. (Donatelli and Campbell, 1982).

$$\frac{H}{H_0} = a[1 - \exp(-b\frac{\Delta T^c}{T_m}) \quad (4.7)$$

Hunt, has added the coefficient b to Hargraves and Samani model (Hunt et al., 1998).

$$H = a(T_{max} - T_{min})^{0.5} H_0 + b \quad (4.8)$$

Goodin et al. developed a model based on, Bristow and Campbell model and they used extraterrestrial radiation in both sides of the formula (Goodin et al., 1999).

$$\frac{H}{H_0} = a[1 - \exp(-b\left(\frac{\Delta T^c}{H_0}\right)) \quad (4.9)$$

Meza and Varas are calibrated coefficients b and c in Bristow and Campbell model and they got less error with this model (Meza and Varas, 2000)

$$\frac{H}{H_0} = 0.75[1 - \exp(-b\Delta T^{2,4})] \quad (4.10)$$

Weiss et al. simplified Donatelli and Campbell model and determined the coefficient a as 0.75 (Weiss et al., 2001) .

$$\frac{H}{H_0} = 0.75[1 - \exp(-b\frac{\Delta T^2}{H_0})] \quad (4.11)$$

Annandale et al. modified Hargraves and Samani model by multiplying coefficient a with a correction factor. (Annandale et al., 2002) .

$$\frac{H}{H_0} = a(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0,5} \quad (4.12)$$

where Z is the elevation of the site.

Mahmood and Hubbard, modelled global solar radiation with maximum and minimum temperature and added the formulation below to the literature. (Mahmood and Hubbard, 2002) .

$$\frac{H}{H_0} = a(T_{max} - T_{\min})^{0,69} x H_0^{0.91} \quad (4.13)$$

Abraha and Savage modelled solar radiation with temperature difference by determining a and c coefficients of Donatelli and Campbell model (Abraha and Savage, 2008) .

$$\frac{H}{H_0} = 0.75[1 - \exp(-b\frac{\Delta T^2}{T_m}) \quad (4.14)$$

4.2.3. Other Meteorological Parameters Based Models

Due to the lack of measurement results of commonly used predictor in some of the stations in the world, solar radiation cannot be modelled effectively there. Therefore, many researchers came up with alternative models that model global solar radiation with some other parameters such as relative humidity and rainfall. One of the oldest parameter which is used as predictor to model global solar radiation is relative humidity. Relative humidity cause scattering and affects only diffuse solar radiation compenent and without combining it with different parameters such as temperature difference in the models is not validated in this study because of high errors of the models (Lewis, 1983).

Swartman and Ogunlade proposed a model which calculates solar radiation by using the ratio between sunshine duration and maximum sunshine duration and relative humidity (Swartman and Ogunlade, 1967).

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + cRH \quad (4.15)$$

where RH is the relative humidity.

Antonanzas-Torres et al. determined that rainfall is shown to influence the accuracy of model performance and presented a new model to estimate global solar radiation and the new model includes M, M_{i-1}, M_{i+1}, ΔT_{i-1} and ΔT_{i+1} (Urraca et al., 2015).

$$\frac{H}{H_0} = a(1 - \exp(-b(\Delta T)^c(1 + dM_{i-1} + eM + fM_{i+1} + g(\Delta T)_{i+1} + h(\Delta T)_{i-1} + j \quad (4.16)$$

where M is the logical variable of rainfall. Following flowchart explains the process of developing acceptable linear or nonlinear models for the estimation of global solar radiation.

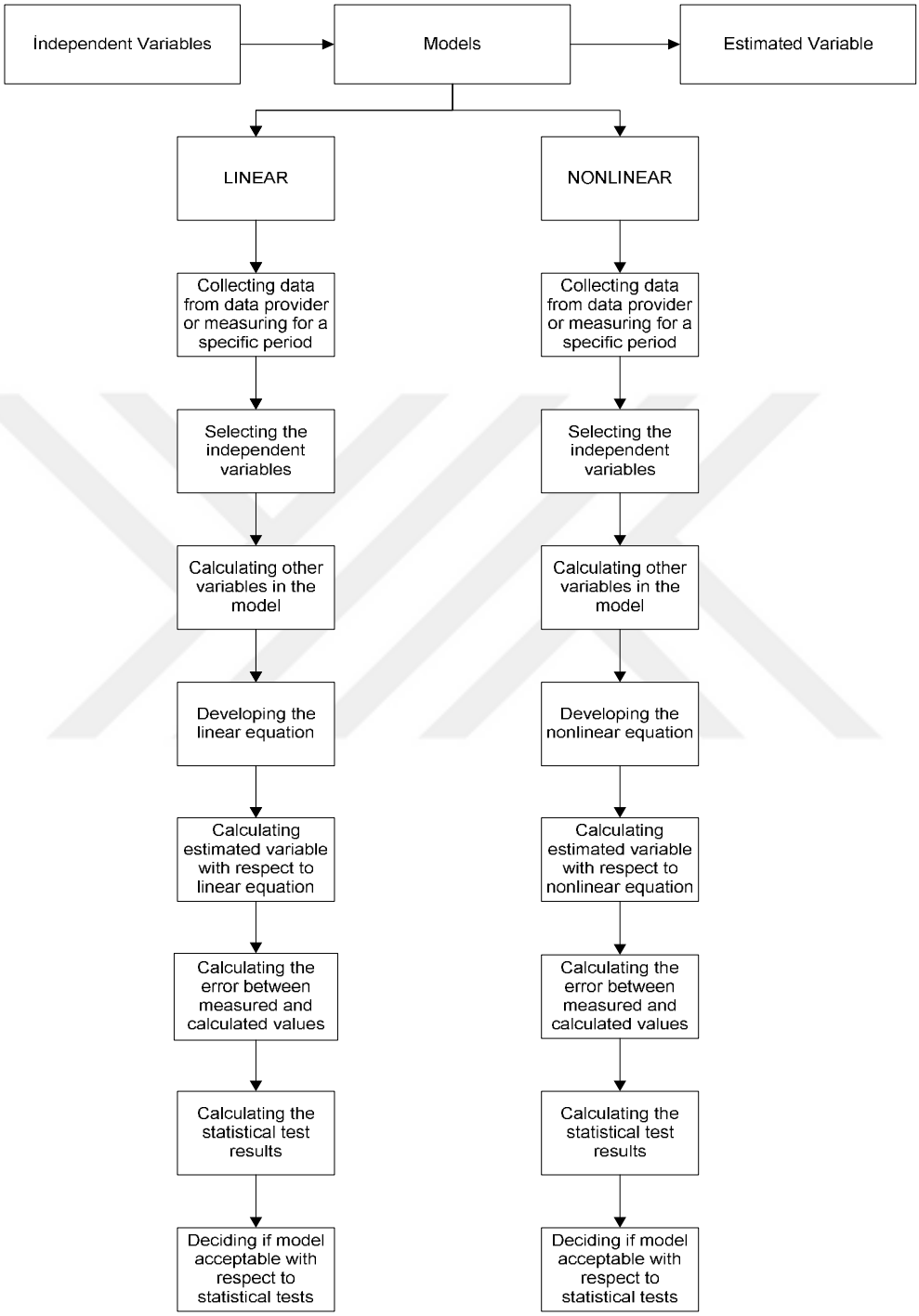


Figure 4.2. Flowcharts of models to estimate global solar radiation

4.2.4. Artificial Neural Network Models

ANN method is used as an application to determine the most proper input parameters for the estimation of global solar radiation in Eastern Mediterranean Region in this thesis. ANNs are other widely used methods to estimate global solar radiation by using measured meteorological parameters. Global solar radiation is being estimated as monthly mean daily, daily or hourly by using ANN models. ANN structure is basically based on human's comprehension of biological nervous system. ANNs are intelligent systems that let complicated problems to be solved such as pattern recognition, identification, classification and other specific issues (Hasni et al., 2012). Understanding of human biological nervous system is the source of inspiration of ANN (Lippmann, 1997). Neurons are the fundamental component of nervous system and receive inputs from other receivers, associate them in a meaningful way, conduct linear or nonlinear operation on the result, and create an output (Kung, 1998). Basically, multiple connected neurons and nodes are the form of ANN models. The neurons have five basic components namely input, weight-bias, threshold, summing junction and output as illustrated in Figure 4.3.

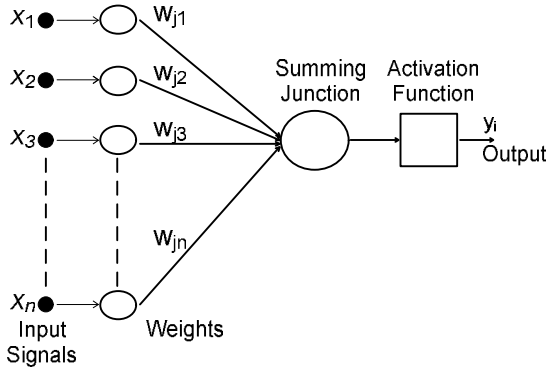


Fig 4.3. Basic structure of an artificial neuron

ANNs have the ability to model linear and non-linear systems without the need to make assumptions. For a basic ANN model, each input "x_k" is multiplied with a weight and transferred to the hidden layer. Each neuron in the hidden layer sums up its input signals after weighting them with the related connections "w_{ji}" from the input layer (Toğrul and Onat, 2000). Then, a bias is applied to this summation for shifting the entire curve. Network with biases represents better relationship in terms of preventing the error threshold from continuously passing through the zero point (Maitha et al., 2011). Consequently, net input "u_k" is calculated by using *n* input nodes as given below;

$$u_k = \sum_{k=1}^{n} w_{jk} x_k - \emptyset_j$$

In order to form the output "y_j", a transfer function is applied to input "u_k", which can be a linear, threshold, sigmoid or gaussian function. Output from the ANN can be mathematically stated as given in the equation below;

$$y_j = f\left(\sum_{k=1}^{n} w_{jk} x_k - \emptyset_j\right)$$

where n is the number of the input signals, w_{jk} is the weight which expresses the strength of the synapse connecting input k to neuron j, and $\emptyset_j$ is the applied bias [152] (Kriesel, 2007).

The learning strategy can be modified by an algorithm thus desired output is produced in the network by given input (Fadare, 2010) (Rojas, 1996). Fundamentally, three simple learning techniques which are unsupervised,

supervised and reinforcement learning are used to train network (Alam et al., 2009). Levenberg-Marquardt (LM) and Scaled Conjugate Gradient (SCG) learning algorithms are widely used because of the shortage of back propagation training algorithms. The inputs and target values are applied to the network and the output is acquired with these learning techniques. Then the error is realized by calculating the difference between the output and target values. The weights between the hidden layers, both the input and hidden layers or both hidden and the output layers can be updated to reduce the total error. The error is then spread retrograde from the output layer to the input layer as given in following equation (Petrini, 2012);

$$w_{jk}(t+1) = w_{jk}(t) + \eta\delta_j y_j + \alpha\left(w_{jk}(t) - w_{jk}(t-1)\right)$$

Following flowchart explains what the process of developing acceptable ANN models for the estimation of global solar radiation is. The developed ANNs models are developed in respect to following these steps.

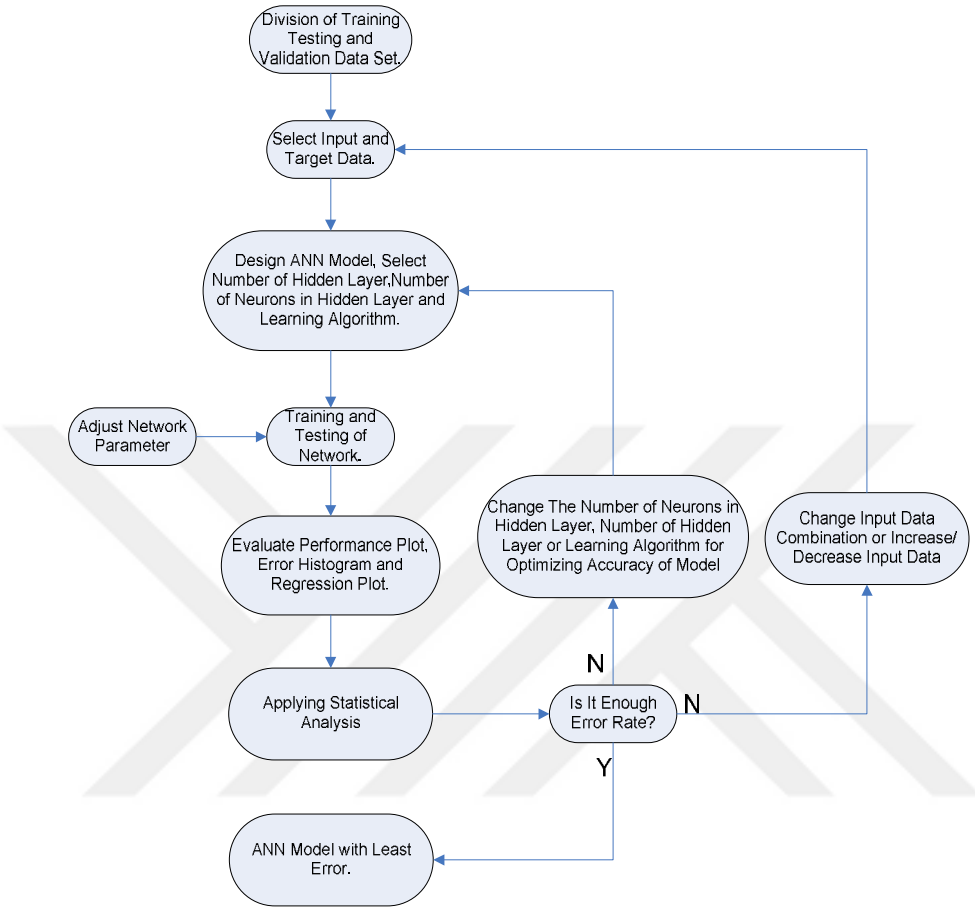


Figure 4.4. Presented ANN prediction algorithm.

4.3. Application of Proposed Models

As it is mentioned before in chapter 4, there are some type of global solar radiation models developed based on other meteorological parameters instead of using sunshine duration as just one single parameter. It is also as it is mentioned before in chapter 2, the amount of global solar radiation which reaches the Earth's surface depends on the meteorological parameters. Relation between global solar radiation and meteorological parameters can be both in negative or positive relation. According to studies in the literature global solar radiation is directly

proportional with sunshine duration. The graphical representation of relation between sunshine duration and global solar radiation for the cities of study area are shown in Figure 4.5.a, b and c.

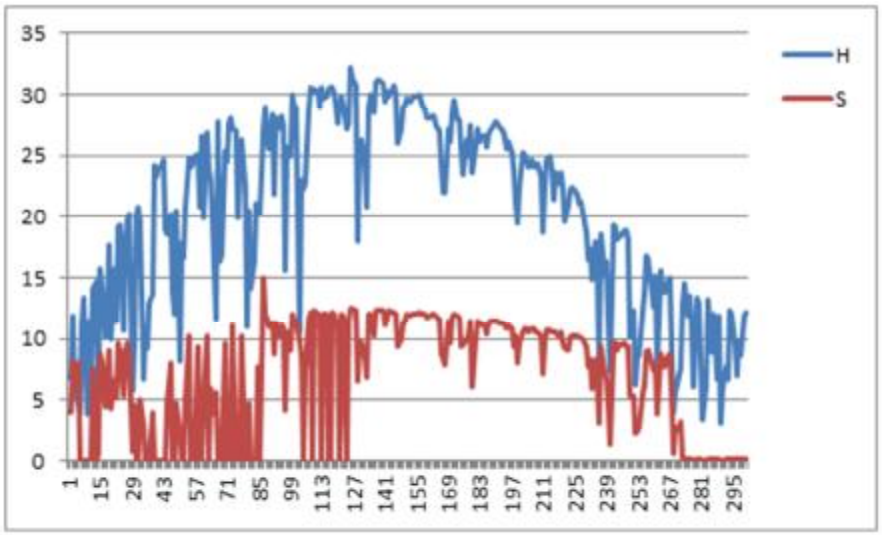


Figure 4.5.a. The graph of sunshine duration and global solar radiation in 2014 for Adana

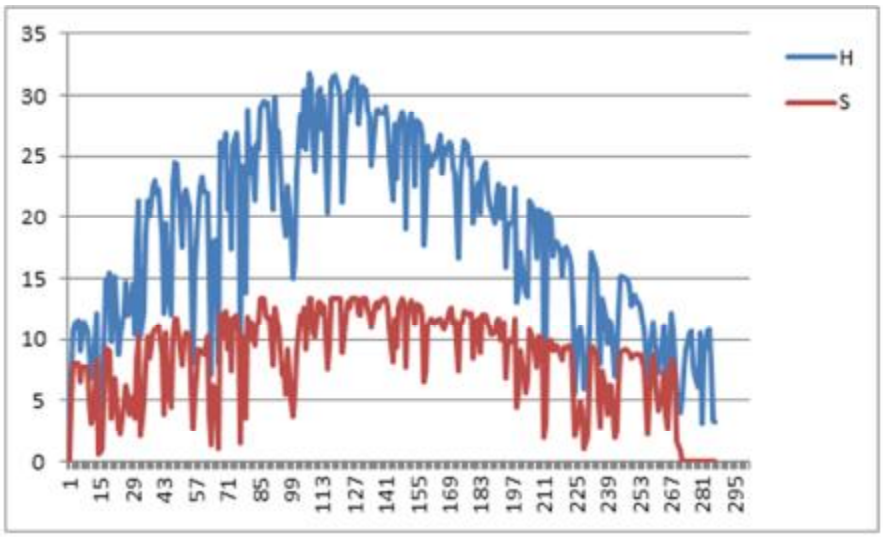


Figure.4.5.b . The graph of sunshine duration and global solar radiation in 2014 for Göksun

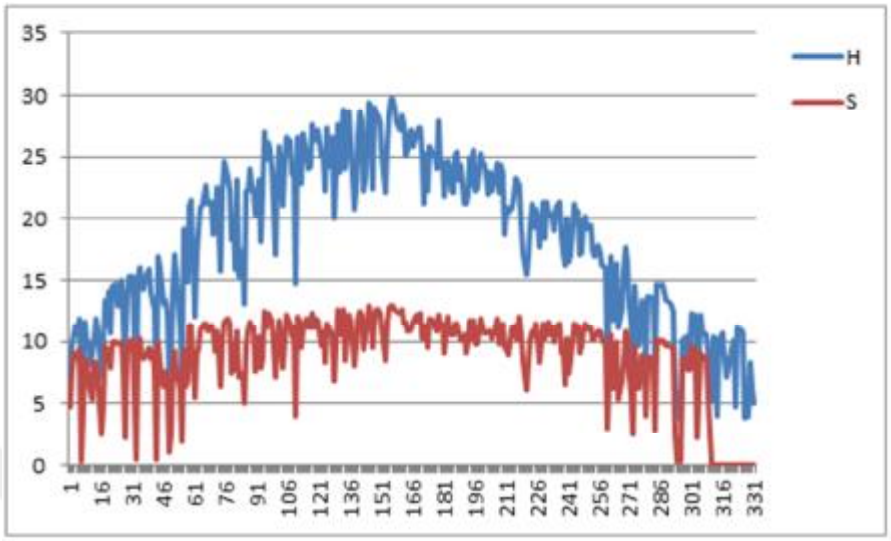


Figure 4.5.c. The graph of sunshine duration and global solar radiation in 2014 for Tarsus

Angström-Prescott method which is based on this direct proportional relation is widely used parametric model in the literature. On the other hand, disadvantage of this model is that the models developed based on Angström-Prescott models can not even close to ANN models in terms of error calculations (Khatib et al., 2012). The obtained errors from Angström-Prescott method based models between measured and calculated results of global solar radiation are higher than the errors obtained with ANN models while ANNs are known as black box modelling technique. Hence, it is important to develop a parametric model with lower errors. Global solar radiation is directly proportional with sunshine duration while it is inversely proportional with relative humidity. The relation between relative humidity and global solar radiation for the cities of study area are shown in Figure 4.6.a, b and c.

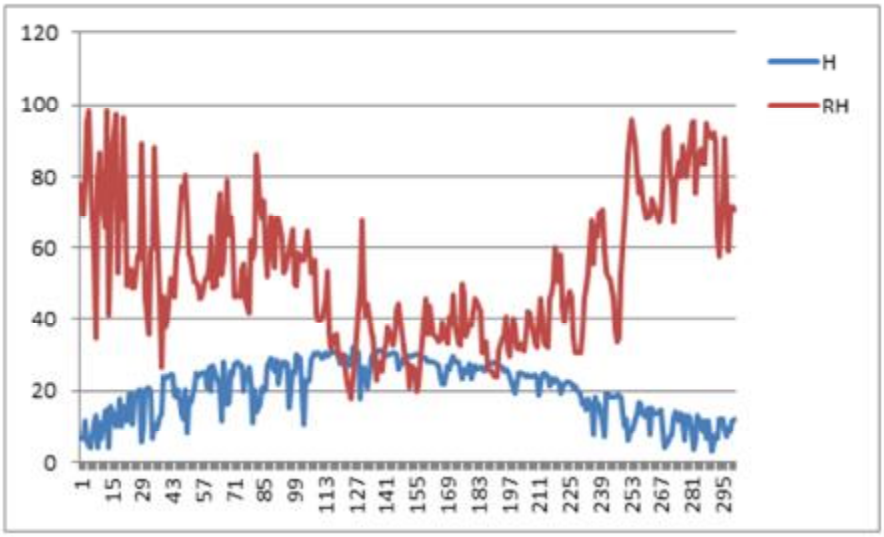


Figure 4.6.a. The graph of relative humidity and global solar radiation in 2014 for Adana

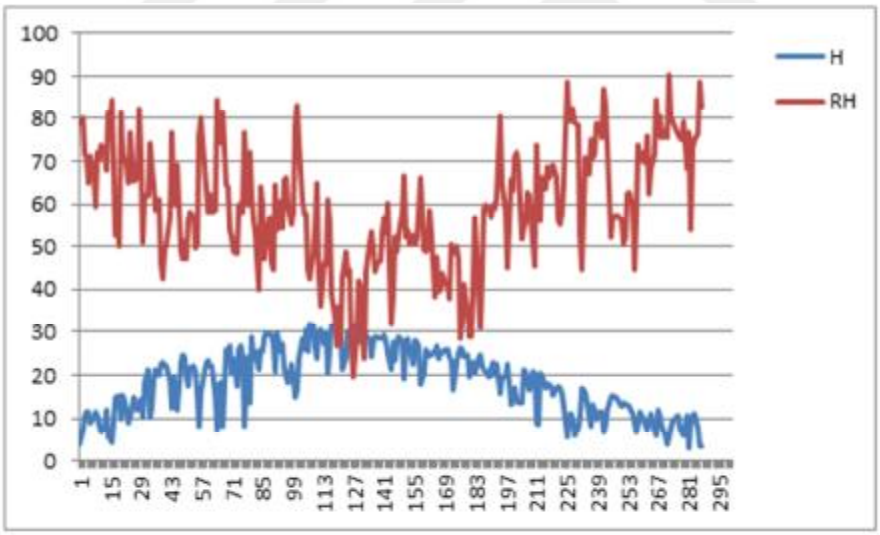


Figure 4.6.b. The graph of relative humidity and global solar radiation in 2014 for Göksun

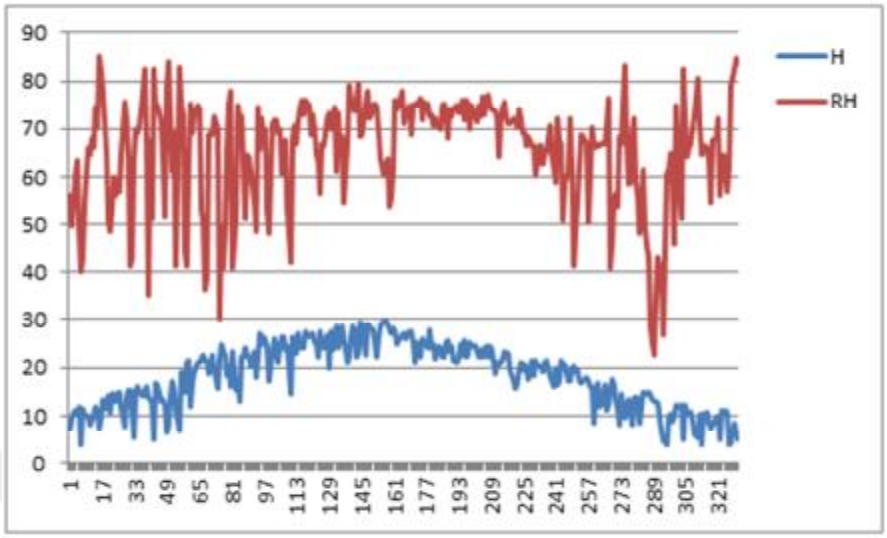


Figure 4.6.c. The graph of relative humidity and global solar radiation in 2014 for Tarsus

Swartman and Ogunlade (Swartman and Ogunlade, 1967) proposed a model which calculates solar radiation by using the ratio between sunshine duration and maximum sunshine duration and relative humidity on this basis. The Angström-Prescott model and Swartman and Ogunlade model are given consecutively to make Swartman and Ogunlade's modification on Angström-Prescott model visible;

$$H/H_0 = a + b(S/S_0)$$

$$H/H_0 = a + b\left(S/S_0\right) + cRH$$

Basically; Swartman and Ogunlade model adds relative humidity to Angström-Prescott model. The flowchart of the developing the proposed models are given below;

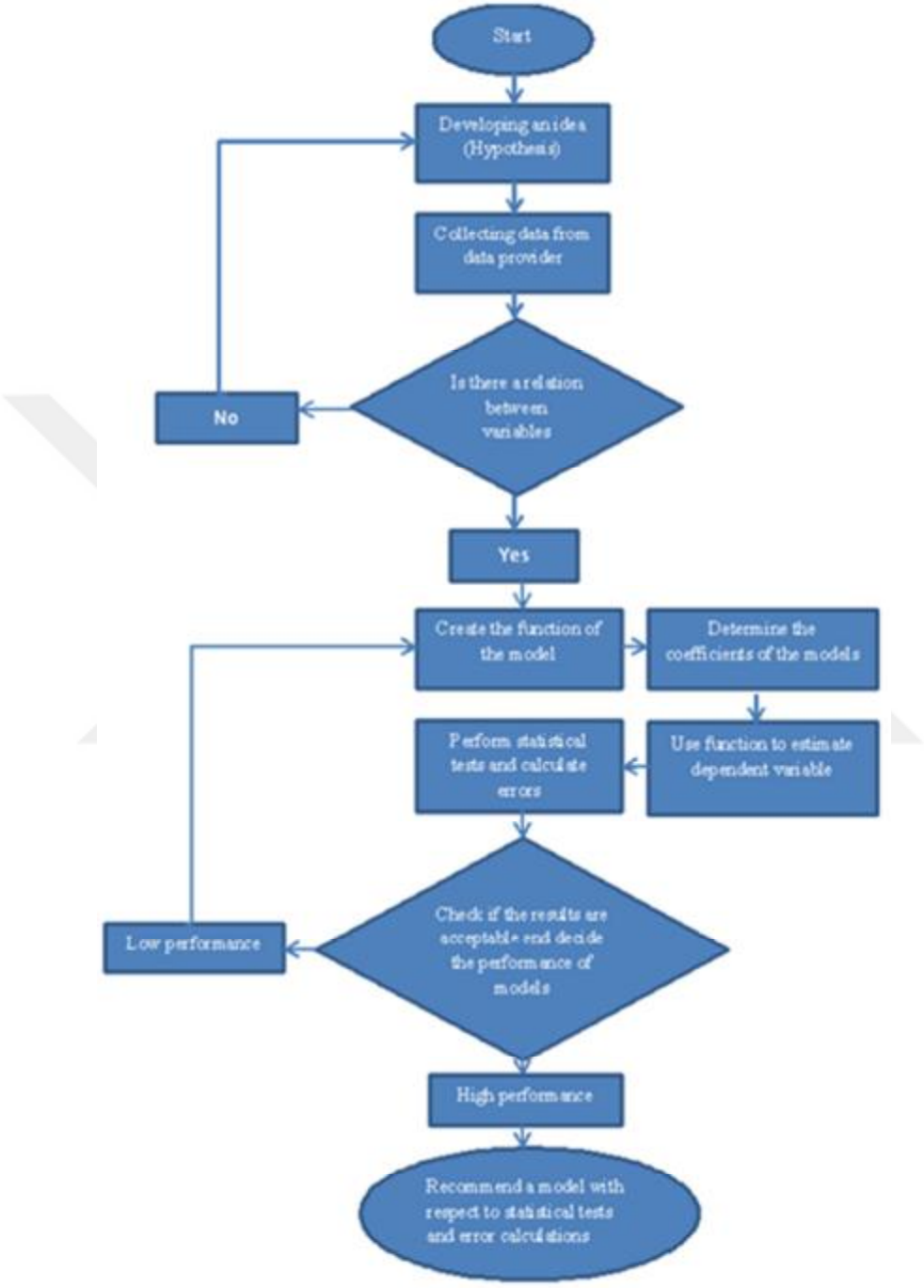


Figure 4.7. Flowchart of developing proposed models and deciding the accuracy of them

4.3.1. Proposed Model 1

Swartman and Ogunlade indeed modified Angström-Prescott model with the relative humidity. On the other hand, there are quadratic models of Angström-Prescott model to get lower errors in estimating global solar radiation in the literature (Akinoglu and Ecevit, 1990) (Bahel et al., 1987). The quadratic model which developes a nonlinear model between sunshine duration and global solar radiation is proposed by Akinoglu and Ecevit (Akinoglu and Ecevit, 1990). Therefore, it is considered to add relative humidity as a second parameter to this quadratic model of Angström-Prescott method in the proposed model, which is shown in equations 13.

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + dRH \tag{4.17}$$

4.3.2. Proposed Model 2

In order to get lower errors there are cubic models of Angström-Prescott model for the estimation of global solar radiation in the literature. Bahel et al (Bahel et al., 1987) proposed a cubic model between global solar radiation and sunshine duration. It is aimed to get lower errors than Bahel et al. model by adding relative humidity as another parameter to this model. The proposed model 2 is given by following equation

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3 + eRH \tag{4.18}$$

4.4. Statistical Tests and Error Calculations

Estimated global solar radiation values were compared with measured values taken from Turkish Meteorological Services through analysis of error, in terms of Mean Bias Error (MBE), Root Means Square Error (RMSE), Mean

Absolute Error (MAE) and Coefficient of Determination (R^2). Models are evaluated in terms of errors that are given by following equations. The MBE represents the value of the bias error and is a measure of the goodness of correlation (Rumbayan and Nagasaka, 2012).

$$MBE = \frac{1}{n}\sum_{i=1}^{n} H_{im} - H_{ic} \tag{4.19}$$

The RMSE is the fundamental measure of accuracy, as the lower the RMSE, the more accurate the estimate (Rumbayan and Nagasaka, 2012).

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(H_{im}-H_{ic})^2}{n}} \tag{4.20}$$

Similarly to the RMSE, smaller MAE values indicate better agreement between measured and calculated values (Rumbayan and Nagasaka, 2012).

$$MAE = \frac{\sum_{i=1}^{n}|H_{im}-H_{ic}|}{n} \tag{4.21}$$

The coefficient of determination (R^2) is another statistical method to test the regression relation between measured and calculated values (Hassanal et al., 2016).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(H_{im}-H_{ic})^2}{\sum_{i=1}^{n}(H_{im}-\overline{H_{ic}})^2} \tag{4.22}$$

where H_{im} is the measured values and H_{ic} is the calculated values of daily global solar radiation and n is the number of testing examples.

4.5. Summary

Modelling global solar radiation methods in the literature can be divided in to parametric and ANN models. A linear correlations between a meteorological parameter such as sunshine duration, difference between maximum and minimum air temperature, relative humidity or precipitation and global solar radiation is developed by linear models while nonlinear correlations such as quadratic, cubic, logarithmic, trigonometric or exponential correlations are developed. Developing linear or nonlinear correlations between global solar radiation and just one single meteorological parameters provides developing global solar radiation model with just a single independent variable. It is also possible to develop correlations between global solar radiation and more than one meteorological parameters. Physically it makes sense because under the atmosphere there is not just one single parameter which effects global solar radiation.

ANNs with it is currently improving structure can also provide useful models to estimate global solar radiation with a low errors. Any correlated meteorological parameters can be used as an estimators in these models. On the other hand, ANNs are black box modelling technique which means we have knowledge about input parameters, transfer functions and output parameters while we do not have a knowledge about internal working of the model. We get different result in these models for each time when we run the model. Thereby, it is more clearly to explain the relation between the output and input parameters or in other words, dependent and independent parameters with parametric models.

The main features of parametric and ANNs models which are widely used in the literature and chosen to validate in this thesis are presented in this chapter. The formulations of the error calculation methods and statistical test to have a knowledge about the models quality and acceptability are also given.

This section contains physical principle and mathematical models of proposed models consisting of both quadratic and cubic models. Basically, it is aimed to model global solar radiation based on sunshine duration which affects the

global solar radiation amount positively and relative humidity which affect the global solar radiation amount negatively together with a parametric model. The reason of using these parameters is to put two different independent variables in the model that one of them affects the dependent variable positively while other one affects negatively. The main purpose of developing these models is to get lower errors with these models.

The next chapter presents the coefficients of the developed models and error calculation results in order to compare models each other and to test the performance of the proposed models.

5. RESULTS AND DISCUSSIONS

5.1. Coefficients of Monthly Mean Daily Models

In the present part of this thesis, monthly mean daily global solar radiation on a horizontal surface and sunshine duration data for Göksun, Tarsus and Adana for the period between 2012 and 2015 were taken from Turkish State Meteorological Service. The global solar radiation has been measured with pyranometer in these stations since 2012. The data from Göksun, Tarsus and Adana is used to train and test the models. The monthly mean daily values for each data are organized as train dataset and test dataset. The dataset were then divided into two sub-data sets, one of which for 2012, 2013 and 2015 was used for calibrating and developing the models and another for the year 2014 for evaluating models. These dataset are preferred for parametric model because of the data accuracy. The most accurate global solar radiation data is obtained by pyranometers.

On the other hand, while modelling global solar radiation with ANNs, dataset is changed because of preventing the over fitting. It is impossible for the network not to memorize for 3 years monthly mean data so another data set is demanded from Turkish Meteorological Services and monthly mean daily global solar radiation and monthly average daily sunshine duration data are provided by The Turkish State Meteorological Service. Daily global solar radiation is measured by actinography and bright sunshine duration is measured by sunshine recorders for these dataset. TSMS provided the monthly average daily global solar radiation data for Adana since 2000 to 2013, for Mersin since 2000 to 2010, for Antakya since 2000 to 2010 and for Kahramanmaras since 2000 to 2008 and monthly mean daily sunshine duration for Adana from 2000 to 2013, for Mersin from 2000 to 2010, for Antakya from 2000 to 2013 and for Kahramanmaras from 2000 to 2013.

70%, 15% and 15% of dataset is used for training, testing and validation, respectively. The network is implemented with different input combinations, hidden layer number and hidden neuron numbers for several times. The reason of

several attempts, weights and biases are chosen randomly and this affects the accuracy of the model. On the other hand 'over fitting' is obstructed with the using of early stopping techniques. When the error on validation set increases for a defined number of iterations the training is stopped automatically. Some of the system parameters are given as number of epoch = 100, specified number of iterations (net.trainParam.max_fail) for preventing over fitting is 50, learning algorithm is Levenberg Marquardt and Scaled Conjugate Algorithm, transfer functions tansig and purelin.

5.1.1. Monthly Mean Angström-Prescott Based Models

One of the main objectives of this thesis is to estimate the monthly mean daily global solar radiation using sunshine duration based on Angström-Prescott method in EMR and to validate these models which are proposed in the literature for many different regions for the estimation of monthly average global solar radiation from sunshine duration and to select the model that gives more accuracy for EMR.

The Angström-Prescott coefficients of the three regression models are estimated for each station separately by curve estimation techniques with R Programming for each station one by one and for whole region together. Based on the linear, quadratic and cubic regression models of Angström-Prescott method and the data of 3 stations, the regression models are generated for each station. Linear, quadratic and cubic models generated for whole EMR as well. The coefficients of these generated models for each station one by one and for whole area are given in Table 5.1. These models are best fitted Angström-Prescott method based models and suggested for the estimation of the monthly mean daily global solar radiation in Eastern Mediterranean Region.

Coefficient a for Angström-Prescott based linear regression models changes between (-0,0678) and (-0,236) and all values are negative while coefficient b for linear regression models changes between 1,015 and 2,012 and all

these values are positive. Coefficient a for Angström-Prescott based quadratic regression models changes between 0,329 and 0,468 and all values are positive while coefficient b for quadratic regression models changes between (-0,927) and (-1,922) and all these values are negative. Coefficient c in Angström-Prescott quadratic regression models is varied as 1,980 and 3,443 and all these values are positive.

Table 5.1. Angström-Prescott method based linear, quadratic and cubic regression equations

Model type	Station	Equation
Linear Regression Models	Adana	$^{H}/_{H_0} = -0.0678 + 1.015\ (^{S}/_{S_0})$
	Tarsus	$^{H}/_{H_0} = -0.236 + 1.305(^{S}/_{S_0})$
	Göksun	$^{H}/_{H_0} = -0.544 + 2.012(^{S}/_{S_0})$
	Whole Region	$^{H}/_{H_0} = -0.294 + 1.457(^{S}/_{S_0})$
Quadratic Regression Models	Adana	$^{H}/_{H_0} = 0.329 - 0.927(^{S}/_{S_0}) + 1.980(^{S}/_{S_0})^2$
	Tarsus	$^{H}/_{H_0} = 0.468 - 1.922\ (^{S}/_{S_0}) + 3.022\ (^{S}/_{S_0})^2$
	Göksun	$^{H}/_{H_0} = 0.464 - 1.888\ (^{S}/_{S_0}) + 3.443(^{S}/_{S_0})^2$
	Whole Region	$^{H}/_{H_0} = 0.429 - 1.657(^{S}/_{S_0}) + 2.887(^{S}/_{S_0})^2$
Cubic Regression Models	Adana	$^{H}/_{H_0} = 0.336 - 1.051\ (^{S}/_{S_0}) + 2.338\ (^{S}/_{S_0})^2 - 0.262(^{S}/_{S_0})^3$
	Tarsus	$^{H}/_{H_0} = 0.362 + 0.228(^{S}/_{S_0}) - 2.399\ (^{S}/_{S_0})^2 + 3.578(^{S}/_{S_0})^3$
	Göksun	$^{H}/_{H_0} = 0.269 - 0.341\ (^{S}/_{S_0}) - 0.107\ (^{S}/_{S_0})^2 + 2.322(^{S}/_{S_0})^3$
	Whole Region	$^{H}/_{H_0} = 0.309 - 0.0023(^{S}/_{S_0}) - 1.259\ (^{S}/_{S_0})^2 + 2.814\ (^{S}/_{S_0})^3$

Coefficient a for Angström-Prescott based cubic models lie between 0,269 and 0,362. Coefficient b changes between (-1,051) and 0,228 even so it is possible for it to be positive or negative. Maximum value of coefficient c is 2,338 and

minimum value of it is (-2,399) and the value of coefficient d in cubic models change between (-0,262) and 3,578.

5.1.2 Monthly Mean ANN Model

The first step to develop the ANN model is the selection of the appropriate input variables and the second step is the determination of number of hidden neurons. These steps are employed with different learning algorithms and number of hidden layers. The input and target data is adjusted in the range from -1 to 1. Then, relevant input parameters are selected. An ANN system is selected as 4x336 and 6x336 input matrix and 1x336 output matrix is created. The input/target datasets were divided randomly into three subsets: training; validation; and testing datasets. Number of input is between 4 and 6 and number of the output is 1. Also number of hidden neurons is varied from 5 to 20. Some of the system parameters are given as number of epoch = 100, specified number of iterations (net.trainParam.max_fail) for preventing over fitting is 50, trained learning algorithms are Levenberg Marquardt and Scaled Conjugate Algorithm, transfer functions are tansig and purelin. ANN model, a simple training and test system is constructed in the MATLAB software and tested with different case studies.

Case 1; the number of inputs is selected as 4 (monthly mean sunshine duration, monthly mean temperature, altitude, month), number of output is selected as 1 (monthly mean solar radiation), number of neurons in hidden layer varies from 5 to 20 and Levenberg-Marquardt learning algorithm is used.

Case 2; the number of inputs is selected as 4 (monthly mean sunshine duration, monthly mean temperature, altitude, month), number of output is selected as 1 (monthly mean solar radiation), number of neurons in hidden layer varies from 5 to 20 and SCG learning algorithm is used.

Case 3; the number of inputs is selected as 6 (monthly mean sunshine duration, monthly mean temperature, latitude, longitude, altitude, month), number of output is selected as 1 (monthly mean solar radiation), number of neurons in

hidden layer varies from 5 to 20 and Levenberg-Marquardt learning algorithm is used.

Case 4; the number of inputs is selected as 6 (monthly mean sunshine duration, monthly mean temperature, latitude, longitude, altitude, month), number of output is selected as 1 (monthly mean solar radiation), number of neurons in hidden layer varies from 5 to 20 and SCG learning algorithm is used.

According to the statistical test results and error calculations most relevant input parameter combinations, algorithm and number of hidden layer is chosen and the weights of presented ANN models are given in Table 5.2.

Table 5.2. Weight matrices of weights going to hidden layer from network inputs (a) and going to output layer from hidden layer (b).

(a) (b)

i	Monthly mean daily air temperature	Monthly mean daily sunshine duration	Altitude	Month	Global solar radiation
w_{1i}	-0,69114	-0,85503	0,175845	0,348102	-0,22879
w_{2i}	-0,32751	0,252322	1,333405	-0,46867	-0,69902
w_{3i}	0,306473	0,447651	0,886947	0,914713	0,18256
w_{4i}	-0,36204	0,511421	0,026822	-1,2598	0,738443
w_{5i}	0,121935	-0,25801	0,125861	-1,45716	0,524603
w_{6i}	0,66644	-0,70251	0,987141	0,298461	0,514214
w_{7i}	0,039211	-0,91867	0,927994	0,038318	-0,35339
w_{8i}	0,137397	-0,58453	-0,10309	-0,97531	-0,41911
w_{9i}	-0,31463	0,925029	0,934294	-0,16749	-0,53318
w_{10i}	-0,72019	1,118929	-0,18966	0,235883	0,285442
w_{11i}	0,143293	-0,50969	1,476696	-0,20584	0,406969
w_{12i}	0,859494	0,86682	0,113081	-0,39268	0,048632
w_{13i}	0,954204	0,010668	0,190768	1,378095	-0,06414
w_{14i}	-1,40784	0,634899	0,130057	-0,29786	-0,00924
w_{15i}	-0,0709	0,476447	-1,21906	0,451816	-0,12907
w_{16i}	-1,02656	-0,70231	0,183127	0,297801	0,139117
w_{17i}	0,361926	-0,0973	0,229239	-1,17897	0,257178
w_{18i}	-0,07345	-0,61405	-0,0514	-1,01326	-0,50011
w_{19i}	0,833529	-0,63118	-0,14347	-0,67019	-0,36475
w_{20i}	-0,82114	-0,80613	0,147371	0,519869	-0,03325

Regression analysis of presented model is illustrated in Figure 5.1. The validation performance of model is given in Figure 5.2. The best validation performance is achieved at epoch 4 where the MSE value becomes the least level.

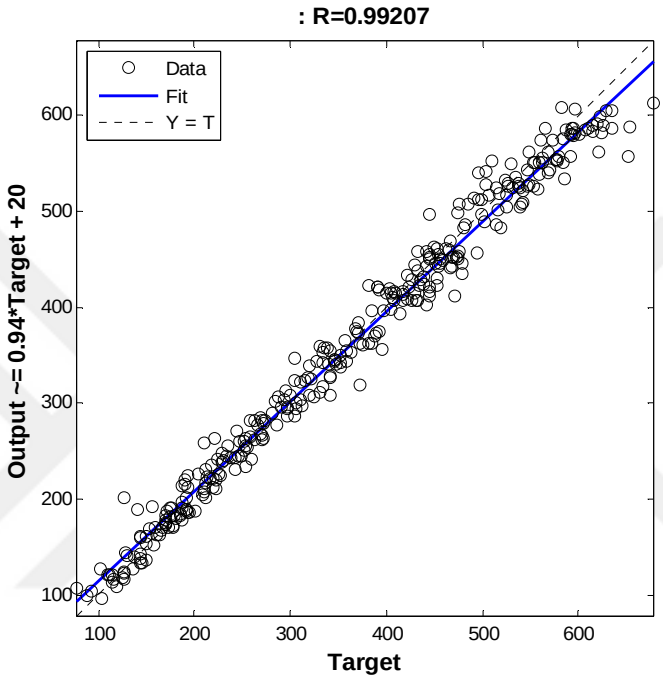


Figure 5.1. Regression plot for all.

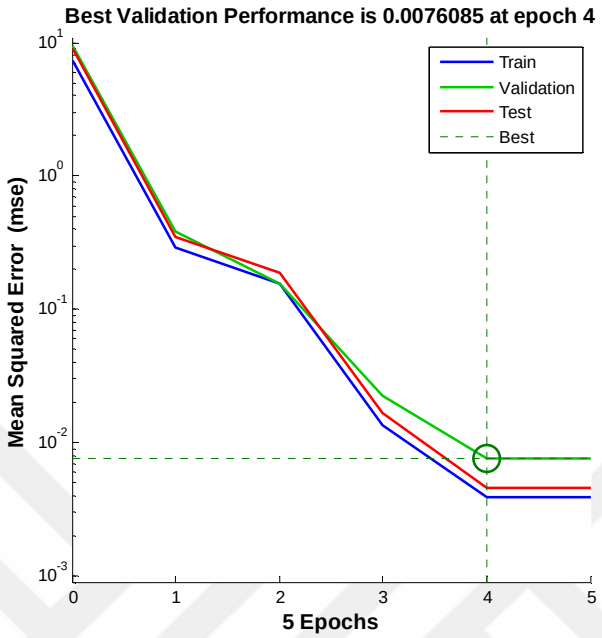


Figure 5.2. Performance plot.

5.2. Coefficients of Daily Models

In this part of this study, daily global solar radiation on a horizontal surface is modelled by parametric models and ANN model as well. The meteorological data for Göksun, Tarsus and Adana for the period between 2012 and 2015 were taken from Turkish State Meteorological Service and used to train and testing process of parametric models including Angström-Prescott linear and nonlinear models. The data obtained from the stations which global solar radiation is measured for a while with high quality equipments. The global solar radiation has been measured with pyranometer in these stations since 2012. The daily values for each data are organized as train dataset and test dataset. The dataset were then divided into two sub-data sets, one of which for 2012, 2013 and 2015 was used for calibrating and developing the models and another for the year 2014 for evaluating models.

On the other hand, while modelling global solar radiation with ANNs, dataset is changed again because of preventing the over fitting. Daily global solar radiation is measured by actinography and bright sunshine duration is measured by sunshine recorders for these dataset. TSMS provided the monthly average daily global solar radiation data for Adana since 2000 to 2013, for Mersin since 2000 to 2010, for Antakya since 2000 to 2010 and for Kahramanmaras since 2000 to 2008 and monthly mean daily sunshine duration for Adana from 2000 to 2013, for Mersin from 2000 to 2010, for Antakya from 2000 to 2013 and for Kahramanmaras from 2000 to 2013.

70%, 15% and 15% of dataset is used for training, testing and validation, respectively. The network is implemented with different input combinations, hidden layer number and hidden neuron numbers for several times. The reason of several attempts, weights and biases are chosen randomly and this affects the accuracy of the model. On the other hand 'over fitting' is obstructed with the using of early stopping techniques. When the error on validation set increases for a defined number of iterations the training is stopped automatically. Some of the system parameters are given as number of epoch = 100, specified number of iterations (net.trainParam.max_fail) for preventing over fitting is 50, learning algorithm is Levenberg Marquardt and Scaled Conjugate Algorithm, transfer functions tansig and purelin.

5.2.1. Angström-Prescott Based Models

The Angström-Prescott method based linear, square and cubic equations for the estimation of daily global solar radiation are developed and listed in Table 5.3. These equations are developed and given with best fitted coefficients for the estimation global solar radiation in Eastern Mediterranean Region especially. Coefficients are determined for each station in Eastern Mediterranean Region separately and as also for whole region. The data for each city used separately while developing the equations for the stations and the data of all cities combined

while developing the equation for whole region. The coefficients a change between (-0,294) and 0,331 and b lie between 0,362 and 1,457 for Angström-Prescott linear regression equations. The coefficients a, b, c vary as 0,293-0,429; (-1,657)-(-0,091); 0,161-2,887 respectively for Angström-Prescott quadratic regression (Akınoğlu and Ecevit model) model. The coefficients a, b, c, d vary as 0,307-0,480; (-1,168)-0,044; (-1,259)-3,465 and (-2,085)-2,814 respectively for Angström-Prescott cubic regression (Bahel et al. model) model

Table 5.3. The developed equations based on Angström-Prescott linear, quadratic and cubic models for each city separated and for whole region

Model type	Station	Equation
Linear Regression Models	Adana	$^{H}/_{H_0} = 0.299 + 0.397\ (^{S}/_{S_0})$
	Tarsus	$^{H}/_{H_0} = 0.331 + 0.362(^{S}/_{S_0})$
	Göksun	$^{H}/_{H_0} = 0.269 + 0.473(^{S}/_{S_0})$
	Whole Region	$^{H}/_{H_0} = -0.294 + 1.457(^{S}/_{S_0})$
Quadratic Regression Models	Adana	$^{H}/_{H_0} = 0.378 - 0.091\ (^{S}/_{S_0}) + 0.487\ (^{S}/_{S_0})^2$
	Tarsus	$^{H}/_{H_0} = 0.422 - 0.177\ (^{S}/_{S_0}) + 0.504\ (^{S}/_{S_0})^2$
	Göksun	$^{H}/_{H_0} = 0.293 - 0.311\ (^{S}/_{S_0}) + 0.161(^{S}/_{S_0})^2$
	Whole Region	$^{H}/_{H_0} = 0.429 - 1.657\ (^{S}/_{S_0}) + 2.887(^{S}/_{S_0})^2$
Cubic Regression Models	Adana	$^{H}/_{H_0} = 0.447 - 1.206\ \left(^{S}/_{S_0}\right) + 3.465\ (^{S}/_{S_0})^2 - 2.085\ (^{S}/_{S_0})^3$
	Tarsus	$^{H}/_{H_0} = 0.480 - 1.168\left(^{S}/_{S_0}\right) + 2.975\ (^{S}/_{S_0})^2 - 1.601\ (^{S}/_{S_0})^3$
	Göksun	$^{H}/_{H_0} = 0.307 + 0.044\ (^{S}/_{S_0}) + 0.880\ (^{S}/_{S_0})^2 - 0.492\ (^{S}/_{S_0})^3$
	Whole Region	$^{H}/_{H_0} = 0.309 - 0.002\left(^{S}/_{S_0}\right) - 1.259\ (^{S}/_{S_0})^2 + 2.814\ (^{S}/_{S_0})^3$

5.2.2. Bristow and Campbell Model

Bristow and Campbell model based models are developed for each station separately and for whole region. It is aimed to develop a new global solar radiation model which depends on temperature difference for Eastern Mediterranean Region. The equations of the Bristow and Campbell model are listed in Table 5.4. The coefficients a varies as 0.653–724, while b varies as 0.022– 0.094 and the coefficient c varies 0.301-1.974. These equations with its best fitted coefficients are developed for Eastern Mediterranean Region.

Table 5.4. The developed equations based on Bristow and Campbell model for each city separated and for whole region

Station	**Equation**
Adana	$\frac{H}{H_0} = 0.653[1 - \exp(-0.0586\Delta T^{1,520})]$
Tarsus	$\frac{H}{H_0} = 0.661[1 - \exp(-0.022\Delta T^{1.974})]$
Göksun	$\frac{H}{H_0} = 0.724[1 - \exp(-0.094\Delta T^{1.097})]$
Whole Region	$\frac{H}{H_0} = 0.666[1 - \exp(-0.057\Delta T^{1.503})]$

5.2.3. Hargraves and Samani Model

Another temperature based simple model is Hargraves and Samani model which is widely used model for the stations that there is only temperature measurements are available. In this part of the study, global solar radiation equations based on Hargraves and Samani model are developed for each station separately and for whole region. Table 5.5 shows the equations based on the Hargraves and Samani model with their best fitted coefficients. According to Table 5.5, the maximum value for coefficient is 0.174 and minimum value of coefficient a is 0.151 respectively which is largely different from the values that are calculated

by Hargraves and Samani in the literature so it can be concluded that Hargraves and Samani model is site dependent model.

Table 5.5. The developed equations based on Hargraves and Samani model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.1698(T_{max} - T_{\min})^{0.5}$
Tarsus	$\frac{H}{H_0} = 0.174(T_{max} - T_{\min})^{0.5}$
Göksun	$\frac{H}{H_0} = 0.151(T_{max} - T_{\min})^{0.5}$
Whole Region	$\frac{H}{H_0} = 0.165(T_{max} - T_{\min})^{0.5}$

6.2.4. Antonanzas et al. Model

Antonanzas et al. modelled global solar radiation with both temperature difference and precipitation. Precipitation and its and previous and next day's value are handled as logical variable in this model. In this part of study, Antonanzas model is validated for the estimation of daily global solar radiation in Eastern Mediterranean Region. Developed equations for each station separately and for whole stations together are given in Table 5.6 with their best fitted coefficients. The coefficients a, b and c lie between 0.744-0.794, -0.144-(-0.056) and 1.051-1.594 respectively. The coefficients d, e, f are change between (-0.030)-(-0.001), (-0.097)-0.0002 and (-0.155)-(-0.033) respectively. The coefficient g, h and i are vary as (-0.001)-0.004, (-0.007)-(-0.005) and (-1.520)-(-0.075) respectively.

Table 5.6. The developed equations based on Antonanzas et al. model for each city separated and for whole region

Station	Equations
Adana	$\frac{H}{H_0} = 0.754(1-\exp(-0.143(\Delta T)^{1.146}(1-0.030M_{i-1}-0.054M-0.154M_{i+1}+0.0017(\Delta T)_{i+1}-0.007(\Delta T)_{i-1}-0.0757$
Tarsus	$\frac{H}{H_0} = 0.768(1-\exp(-0.056(\Delta T)^{1.594}(1-0.017-0.097M-0.033M_{i+1}+0.0026(\Delta T)_{i+1}-0.007(\Delta T)_{i-1}-1.467$
Göksun	$\frac{H}{H_0} = 0.744(1-\exp(-0.124(\Delta T)^{1.051}(1-0.001M_{i-1}+0.0002M-0.155M_{i+1}+0.0048(\Delta T)_{i+1}-0.0056(\Delta T)_{i-1}-1.515$
Whole region	$\frac{H}{H_0} = 0.794(1-\exp(-0.144(\Delta T)^{1.104}(1-0.014M_{i-1}-0.054M-0.113M_{i+1}+0.0034(\Delta T)_{i+1}-0.0074(\Delta T)_{i-1}-1.520$

5.2.5. Hunt Model

Table 5.7 shows how the coefficients of Hunt model changes for each station separately and for whole stations data together. According to the equations given in Table 5.7, the coefficients a and b of developed equations vary as 0.149–0.19 and (-1.391)-0.707 respectively.

Table 5.7. The developed equations based on Hunt et al. model for each city separated and for whole region

Station	**Equations**
Adana	$H = 0.180(T_{max}-T_{min})^{0.5}H_0 - 0.893$
Tarsus	$H = 0.190(T_{max}-T_{min})^{0.5}H_0 - 1.391$
Göksun	$H = 0.149(T_{max}-T_{min})^{0.5}H_0 + 0.290$
Whole Region	$H = 0.161(T_{max}-T_{min})^{0.5}H_0 + 0.707$

5.2.6 Abraha and Savage Model

Another global solar radiation equations based on temperature difference are developed based on Abraha and Savage model for each city separated and for whole region as well. The Abraha and Savage model best fitted coefficients are shown in Table 5.8. The given coefficients are best fitted ones for the estimation of daily global solar radiation in Eastern Mediterranean Region. The coefficient a varies as 0.148–0.170.

Table 5.8. The developed equations based on Abraha and Savage model for each city separated and for whole region

Station	Equations
Adana	$\frac{H}{H_0} = 0.75[1 - \exp(-0.152\frac{\Delta T^2}{T_m})$
Tarsus	$\frac{H}{H_0} = 0.75[1 - \exp(-0.170\frac{\Delta T^2}{T_m})$
Göksun	$\frac{H}{H_0} = 0.75[1 - \exp(-0.148\frac{\Delta T^2}{T_m})$
Whole station	$\frac{H}{H_0} = 0.75[1 - \exp(-0.169\frac{\Delta T^2}{T_m})$

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5.2.7 Annandale et al. Model

The daily global solar radiation is modelled with temperature difference and elevation of site by Annandale et al. In this part of study, best fitted equations are presented to estimate daily global solar radiation in Eastern Mediterranean Region based on Annandale et al. model. The equations with its calculated coefficient are listed in Table 5.9. According to this table the coefficient a varies as 0.145-0.174.

Table 5.9. The developed equations based on Annandale et al. model for each city separated and for whole region

Station	Equations
Adana	$H/H_0 = 0.169(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0.5}$
Tarsus	$H/H_0 = 0.174(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0.5}$
Göksun	$H/H_0 = 0.145(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0.5}$
Whole Region	$H/H_0 = 0.165(1 + 2.7x10^{-5}Z)(T_{max} - T_{\min})^{0.5}$

5.2.8. Donatelli and Campbell Model

Donatelli and Campbell modelled global solar radiation based on temperature difference. In this model daily global solar radiation is exponential function of temperature difference with its coefficients. The best fitted equations based on Donatelli and Campbell model are developed and the best fitted coefficients are determined for the estimation of daily global solar radiation in Eastern Mediterranean Region cities separately and together as whole region. Table 5.10 shows the developed equations. The coefficients a, b and c vary as 0.653-0.724, 0.267-1.419 and 1.097-1.974 respectively.

Table 5.10. The developed equations based on Donatelli and Campbell model

Station	Equations
Adana	$\frac{H}{H_0} = 0.653[1 - exp(-0.654\frac{\Delta T^{1.520}}{T_m})$
Tarsus	$\frac{H}{H_0} = 0.661[1 - exp(-0.267\frac{\Delta T^{1.974}}{T_m})$
Göksun	$\frac{H}{H_0} = 0724[1 - exp(-1.419\frac{\Delta T^{1.097}}{T_m})$
Whole region	$\frac{H}{H_0} = 0.667[1 - exp(-0.725\frac{\Delta T^{1.503}}{T_m})$

5.2.9 Goodin et al Model

Goodin et al. modelled global solar radiation based on temperature difference. Table 5.11 shows the developed equations based on Goodin et al. model for the estimation of global solar radiation in Eastern Mediterranean Region. The determined coefficients of these equations are best fitted coefficients for Eastern Mediterranean Region. The coefficients a, b and c vary as 0.597-0.655, 0.024-0.559 and 1.909-3.723.

Table 5.11. The developed equations based on Goodin et al. model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.597[1 - \exp(-0.223\left(\frac{\Delta T^{2.741}}{H_0}\right))$
Tarsus	$\frac{H}{H_0} = 0.625[1 - \exp(-0.024\left(\frac{\Delta T^{3.723}}{H_0}\right))$
Göksun	$\frac{H}{H_0} = 0.655[1 - \exp(-0.559\left(\frac{\Delta T^{1.909}}{H_0}\right))$
Whole Region	$\frac{H}{H_0} = 0.617[1 - \exp(-0.117\left(\frac{\Delta T^{2.971}}{H_0}\right))$

5.2.10. Mahmood and Hubard Model

The equations which are developed based on Mahmood and Hubard model to estimate global solar radiation in Eastern Mediterranean Region cities separately and together for whole region are given in Table 5.12. The coefficients of these equations are best fitted for the study area. According to this table the coefficient a varies as 0.003-0.004.

Table 5.12. The developed equations based on Mahmood and Hubard model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.004(T_{max} - T_{\min})^{0.69} x H_0^{0.91}$
Tarsus	$\frac{H}{H_0} = 0.004(T_{max} - T_{\min})^{0.69} x H_0^{0.91}$
Göksun	$\frac{H}{H_0} = 0.003(T_{max} - T_{\min})^{0.69} x H_0^{0.91}$
Whole Region	$\frac{H}{H_0} = 0.004(T_{max} - T_{\min})^{0.69} x H_0^{0.91}$

5.2.11 Meza and Varas Model

The equations which are developed based on Meza and Maras model for the estimation of global solar radiation on a horizontal place are given in Table 5.13. These equations are best fitted equations which are developed for each station separately and for whole stations together. According to Table 5.13 the coefficient of the model varies as 0.004-0.007.

Table 5.13. The coefficient and statistical test results of Meza and Varas model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.75[1 - \exp(-0.007\Delta T^{2.4})]$
Tarsus	$\frac{H}{H_0} = 0.75[1 - \exp(-0.007\Delta T^{2.4})]$
Göksun	$\frac{H}{H_0} = 0.75[1 - \exp(-0.004\Delta T^{2.4})]$
Whole Region	$\frac{H}{H_0} = 0.75[1 - \exp(-0.007\Delta T^{2.4})]$

5.2.12. Swartman and Ogunlade Model

The best fitted equations that are developed based on Swartman and Ogunlade model to estimate global solar radiation in Eastern Mediterranean Region cities separately and together as whole region are listed in Table 5.14. The coefficients of the model are vary as 0.298-0.416, 0.350-0.460, (-0.142)-0.033.

Table 5.14. The developed equations based on Swartman and Ogunlade model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.404 + 0.372\left(\frac{S}{S_0}\right) - 0.142RH$
Tarsus	$\frac{H}{H_0} = 0.416 + 0.350\left(\frac{S}{S_0}\right) - 0.119RH$
Göksun	$\frac{H}{H_0} = 0.298 + 0.460\left(\frac{S}{S_0}\right) - 0.033RH$
Whole Region	$\frac{H}{H_0} = 0.372 + 0.410\left(\frac{S}{S_0}\right) - 0.131RH$

5.2.13 Weiss et al Model

Best fitted equations are developed based on Weiss et al. model for the estimation of global solar radiation in Eastern Mediterranean Region cities separately and together for whole region. Table 5.15 shows the developed equations with its best fitted coefficients. According to Table 5.15, the coefficient changes between 0.287 and 0.504.

Table 5.15. The coefficient and statistical test results of Weiss et al. model for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.75[1 - \exp\left(-0.449\frac{\Delta T^2}{H_0}\right)]$
Tarsus	$\frac{H}{H_0} = 0.75[1 - \exp\left(-0.504\frac{\Delta T^2}{H_0}\right)]$
Göksun	$\frac{H}{H_0} = 0.75[1 - \exp\left(-0.287\frac{\Delta T^2}{H_0}\right)]$
Whole Region	$\frac{H}{H_0} = 0.75[1 - \exp\left(-0.432\frac{\Delta T^2}{H_0}\right)]$

5.2.14. Proposed Model 1

The developed equations with both each stations data separately and whole station data together are based on proposed model 1. The best fitted coefficients are determined for the estimation of global solar radiation in Eastern Mediterranean Region. These equations are given in Table 5.16. According to this table, the coefficient a varies as 0.301-0.445, b varies as (-0.161)-0.310, c varies as 0.158-0.486 and d varies as (-0.092) - (-0.01).

Table 5.16. The developed equations based on proposed model 1 for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0439 - 0.065\left(\frac{S}{S_0}\right) + 0.445\left(\frac{S}{S_0}\right)^2 - 0.092RH$
Tarsus	$\frac{H}{H_0} = 0.445 - 0161\left(\frac{S}{S_0}\right) + 0486\left(\frac{S}{S_0}\right)^2 - 0.037RH$
Göksun	$\frac{H}{H_0} = 0.301 + 0.310\left(\frac{S}{S_0}\right) + 0.158\left(\frac{S}{S_0}\right)^2 - 0.010RH$
Whole Region	$\frac{H}{H_0} = 0.438 + 0.001\left(\frac{S}{S_0}\right) + 0.370\left(\frac{S}{S_0}\right)^2 - 0.090RH$

5.2.15 Proposed Model 2

The best fitted coefficients of developed equations based on proposed model 2 are determined for the estimation of global solar radiation in Eastern Mediterranean Region. Best fitted equations which are determined with each station data separately and whole stations data together are given in Table 5.17. According to Table 5.17, the coefficient a varies as 0.331-0.531, b varies as (-1.217)-0.021, c varies as 0.924-3.527, d varies as (-2.164)-(-0.529) and e varies as (-0.113)-(-0.029).

Table 5.17. The coefficient and statistical test results of Proposed model 2 for each city separated and for whole region

Station	**Equations**
Adana	$\frac{H}{H_0} = 0.525 - 1.217\left(\frac{S}{S_0}\right) + 3.527\left(\frac{S}{S_0}\right)^2 - 2.164\left(\frac{S}{S_0}\right)^3 - 0.112RH$
Tarsus	$\frac{H}{H_0} = 0.531 - 1.181\left(\frac{S}{S_0}\right) + 3.055\left(\frac{S}{S_0}\right)^2 - 1.678\left(\frac{S}{S_0}\right)^3 - 0.078RH$
Göksun	$\frac{H}{H_0} = 0.331 + 0.021\left(\frac{S}{S_0}\right) + 0.924\left(\frac{S}{S_0}\right)^2 - 0.529\left(\frac{S}{S_0}\right)^3 - 0.029RH$
Whole Region	$\frac{H}{H_0} = 0.496 - 0.771\left(\frac{S}{S_0}\right) + 2.363\left(\frac{S}{S_0}\right)^2 - 1.336\left(\frac{S}{S_0}\right)^3 - 0.113RH$

5.2.16 Daily ANN Model

In this part of the study, feed-forward, back-propagation, multilayer perceptron neural network is developed to predict the daily global solar radiation using the data of 11 years. The data between 1997 and 2005 are used for training and the data between 2005 and 2007 are used for testing process. Firstly, the input and output data normalized in range of (-1, 1) or (0, 1) in order to prevents the possibility of the learning algorithm from confusing. The normalization range is specified according to the activation function that will be used in network. Then the

appropriate input variables are determined to ensure optimum accuracy of the model. After that, hidden neuron number is determined to develop the ANN model. Models are trained with different learning algorithms, input combinations and neuron numbers in hidden layer. The performances of the combinations are completely evaluated by using statistical error estimation methods. The input and target datasets are randomly divided as training, validation, and testing datasets. Some of the model parameters utilized during the training stage is adjusted as; minimum performance gradient is $10x10^{-9}$, maximum number of epochs to train is 1000, maximum validation failure is 50 and learning rate is varied between 0.1 and 0.4. Since the random values are assigned to the weights in every training process, the model is trained about 50 times.

The best inputs of the neural network were determined as daily mean air temperature, daily mean relative humidity, daily mean sunshine duration, daily mean maximum possible sunshine duration, day of the year, latitude, longitude, altitude and calculated value of daily extraterrestrial solar radiation. 9 years data was used for training and 2 years data was used for testing the model. The most accurate results were obtained with LM learning algorithm. Tansig and purelin transfer functions are trained. The weights and biases value of presented ANN model is given in Table 5.18 (a): From input layer to hidden layer (b): From hidden layer to output layer

Table 5.18. The weights and biases value of presented ANN model (a): From input layer to hidden layer (b): From hidden layer to output layer

(a)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
w_{1i}	0.493	0.142	0.215	-0.081	-0.191	-0.248	-1.223	-1.111	1.300
w_{2i}	-1.797	0.372	0.505	-0.197	-0.583	2.603	1.803	-3.738	-2.992
w_{3i}	-14.891	-1.421	5.384	-11.07	-9.227	1.784	2.116	1.800	-3.023
w_{4i}	-0.543	-0.326	-0.334	0.091	0.232	0.328	1.988	-2.870	-2.779
w_{5i}	0.098	0.565	-0.041	-0.017	-0.083	-0.505	-3.825	-0.470	-0.143
w_{6i}	0.028	0.475	-0.045	-0.005	-0.058	-0.484	0.029	-0.433	1.511
w_{7i}	-0.804	-0.152	-0.071	0.197	0.404	0.267	-1.066	1.396	-2.030
w_{8i}	-0.355	0.099	0.043	-0.054	-0.105	0.974	-0.241	0.483	0.006
w_{9i}	0.580	0.448	0.181	-0.066	-0.137	-0.380	-4.126	-1.005	3.139
w_{10i}	0.538	0.416	0.184	-0.063	-0.145	-0.394	0.638	0.133	1.034
w_{11i}	-0.043	-0.379	0.108	0.006	0.052	0.231	0.095	0.208	-0.145
w_{12i}	0.788	0.618	-0.155	0.012	0.078	-1.292	-0.199	-0.111	0.148
w_{13i}	0.643	12.73	-0.173	-0.127	-0.226	0.008	0.019	0.133	-0.047
w_{14i}	-0.738	-0.167	-0.259	0.181	0.392	0.302	2.117	-2.816	-1.450
w_{15i}	0.580	-0.098	-0.155	-0.292	-0.865	-0.203	-2.163	1.818	0.273

(b)

i	1	2	3	4	5	6	7	8
w_{j1}	-10.05	0.225	-0.039	-8.469	5.121	5.398	-6.339	1.001
i	9	10	11	12	13	14	15	-
w_{j1}	6.017	-5.985	7.087	0.848	1.260	8.497	-0.555	-

Regression analysis, which provides statistical investigation of relationships between output and target values, is illustrated in Figure 5.3. The validation performance of estimation of daily global solar radiation in Eastern Mediterranean Region model is shown in Figure 5.4. The best validation performance is achieved at epoch 399 where the MSE value becomes the least level.

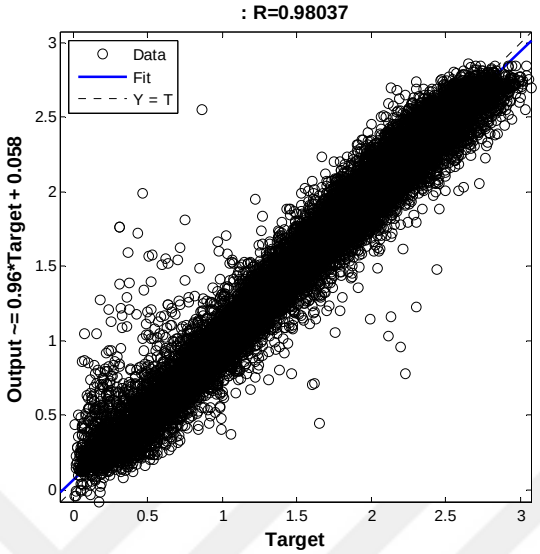


Figure 5.3. Regression analysis of estimation of daily global solar radiation for Eastern Mediterranean Region

Regression plot shows the description of the statistical relationship between input parameters and the output parameter

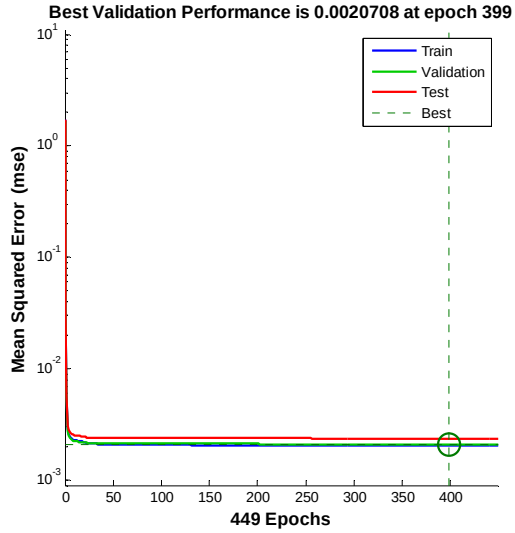


Figure 5.4. The validation performance of estimation of daily global solar radiation for Eastern Mediterranean Region

The accuracy of the ANN models is shown by MSE (Mean Squared Error). MSE value of an accurate model should close to zero. In this case , it equals to 0.0020708 and it means desired outputs and ANN outputs become very close to each other

5.3. CMSAF Generated Data

The amount of solar radiation on the ground is depends on the state of the sky. When the sky is free of clouds larger amounts of radiation are received at ground level. Therefore state of the sky is one of the most usual indicators for modelling global solar radiation. The Satellite Application Facility on Climate Monitoring (CM SAF) was started operation in January 2004 and comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice) (http://www.cmsaf.eu).

The CM SAF provides meteorological data for a long term. The surface incoming solar radiation (SIS) which is providing by CMSAF is achieved by using the Heliosat method. Heliosat model is based on cloud index what is observed by the sensor which determines the clear sky. The relation between global solar radiation and cloud albedo is given below;

$$SIS = SIS_{CLS} - (1 - CAL)$$

SIS is the solar surface irradiance, SIS_{CLS} the clear sky irradiance and CAL is the effective cloud albedo.

5.4 Statistical Test and Error Calculation Results

The coefficient of determination is the squared value of the correlation coefficient (R) between calculated value with the model and measured value of global solar radiation. The range of R^2 is from 0 to 1 for. When R^2 equals the '0', it means chosen independent variable is not suitable for the estimation of global solar radiation. When R^2 equals to '1', it means global solar radiation can be estimated with chosen parameter without any error.

The MAE measures the mean error between calculated and measured values of global solar radiation without considering their direction. The RMSE measures the quadratic mean error between calculated and measured values of global solar radiation. MBE is a system error for whole dataset and non-dimensional. Obtaining both negative and positive value of MBE are possible and negative value of MBE mean calculated values are smaller then measured values in total.

5.4.1 Comparison of Monthly Mean Models

In this part of study comparison of monthly mean daily global solar radiation models which are developed with Eastern Mediterranean Region data for the estimation of global solar radiation are compared each other with statistical test R2 and error calculation methods such as Mean Bias Error (MBE), Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE). In order to visualize the errors and how fit is the equations, graphical representation of calculated value of global solar radiation and measured value of it is given as well for each city separated and for whole region.

5.4.1.1 Angström Prescott Model Based Models

In order to show the accuracy of the models, error calculations and statistical test of Angström-Prescott model based equations are given in this part for each city separately and for whole region. Because of widely usage of linear,

quadratic and cubic regression models that are derived models which are based on Angström-Prescott model, these three developed models are compared each other.

5.4.1.1.(1) Angström Prescott Model

Table 5.19 shows error calculation and statistical test results of developed Angström-Prescott linear model with the data of each city separately and whole data together. The minimum and maximum MAE values are 3.379 and 5.755, respectively. RMSE value is varied as 4.129 and 9.203. According to Table 5.19, R^2 values lie between 0.354 and 0.738. MBE values change between 0.402 and 1.081. Errors are a bit high but the value of R^2 denotes the strength of the linear association between sunshine duration and global solar radiation especially for Adana station and the worst results are obtained for Göksun station.

The results indicate that Angström-Prescott linear regression model is not best fitted equation for the estimation of monthly mean daily global solar radiation in Eastern Mediterranean Region but it is acceptable. In order to illustrate the errors between measured and calculated values Figure 5.5.a, b, c and d is given below.

Table 5.19. The statistical test results of Angström-Prescott model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.493	3.379	4.129	0.738
Göksun	1.081	6.806	9.203	0.354
Tarsus	0.402	5.905	9.203	0.563
Whole Region	0.471	5.755	7.195	0.497

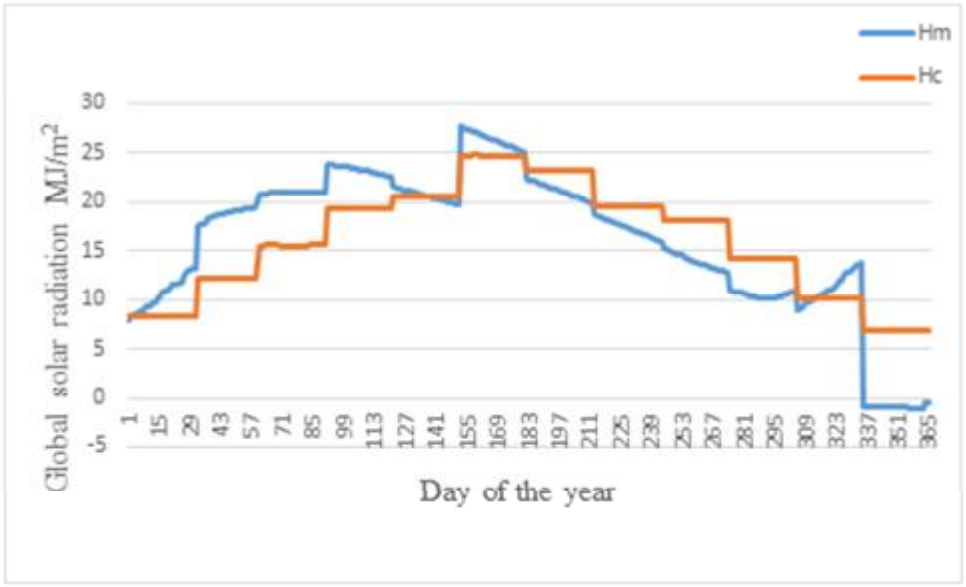


Figure 5.5.a. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 with Angström-Prescott based model for Adana.

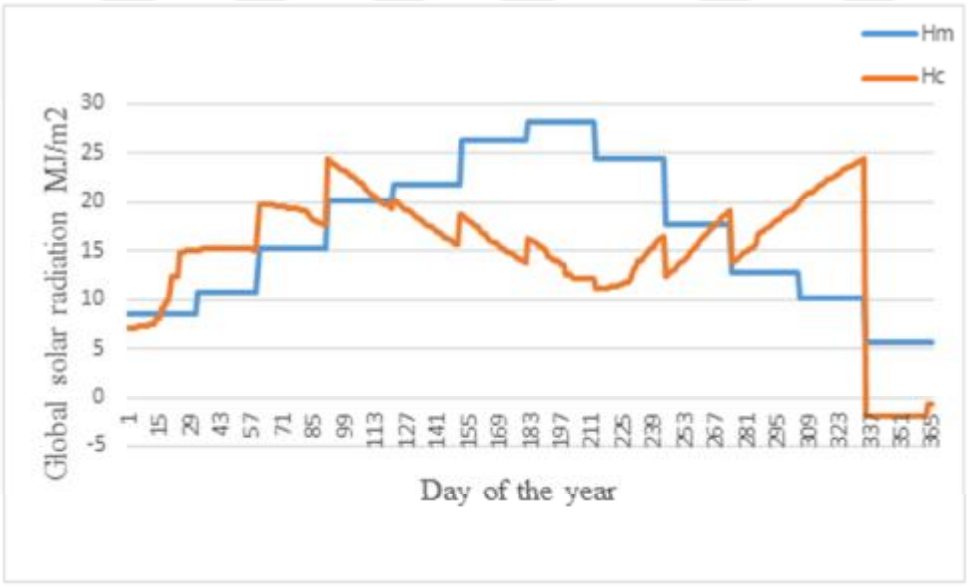


Figure 5.5.b. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 with Angström-Prescott based model for Göksun.

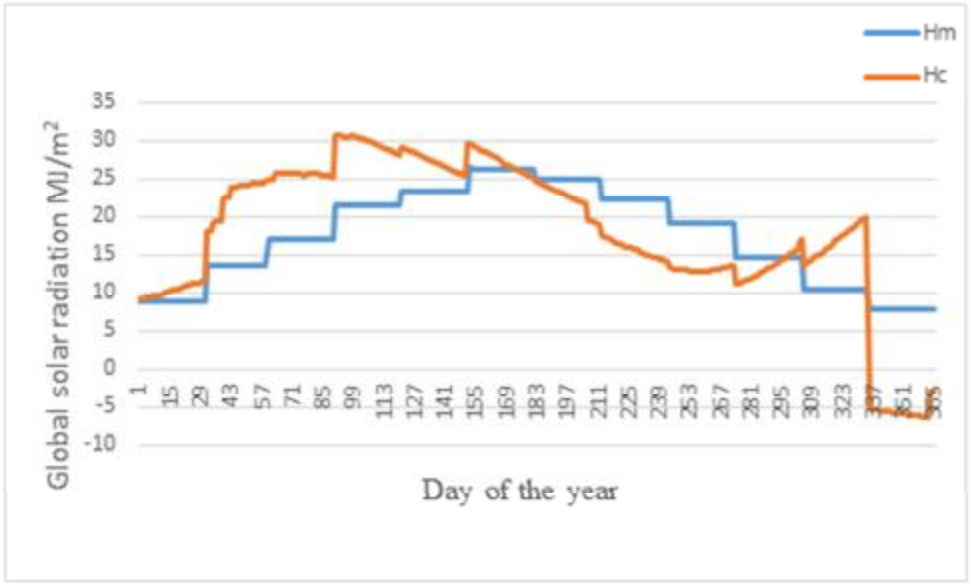


Figure 5.5.c. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 with Angström-Prescott based model for Tarsus.



Figure 5.5.d. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott model for Whole Region.

5.5.1.1.(2). Angström Prescott Quadratic Model (Akınoğlu and Ecevit Model)

Table 5.20 shows the results of developed Angström-Prescott quadratic model with the data of each city separately and together for whole region. The minimum and maximum MAE values are 2.108 and 4.711, respectively. RMSE value is varied as 2.519 and 6.044. According to Table 5.20, R^2 values lie between 0.361 and 0.821. MBE values change between (-0.456) and 0.144. These errors are lower than the errors obtained with Angström-Prescott linear regression model. So, Angström-Prescott quadratic model is more preferable than Angström-Prescott linear regression model for the estimation of monthly mean daily global solar radiation in Eastern Mediterranean Region. Figure 5.6.a, b, c and d shows the illustration of the errors between measured and calculated values.

Table 5.20. The statistical test results of Akınoğlu and Ecevit model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.041	2.108	2.519	0.821
Göksun	0.144	4.711	6.044	0.361
Tarsus	-0.456	3.558	4.307	0.618
Whole Region	-0.257	3.984	5.097	0.501

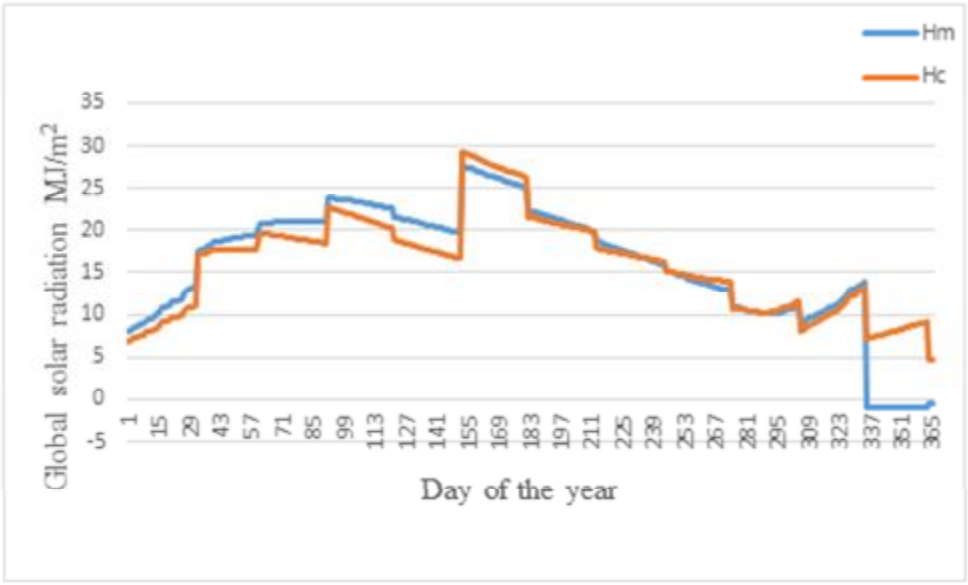


Figure 5.6.a. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Adana.

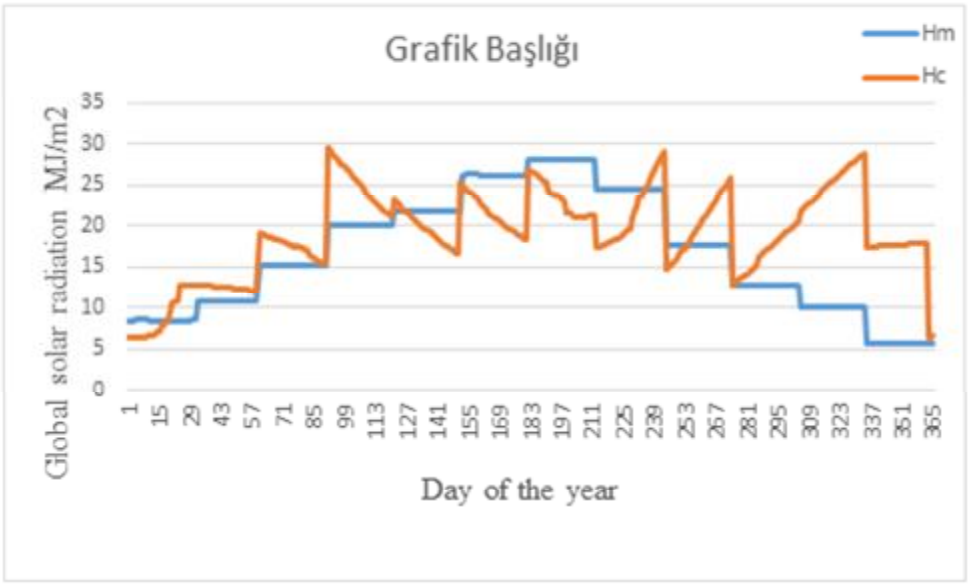


Figure 5.6.b. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Göksun.

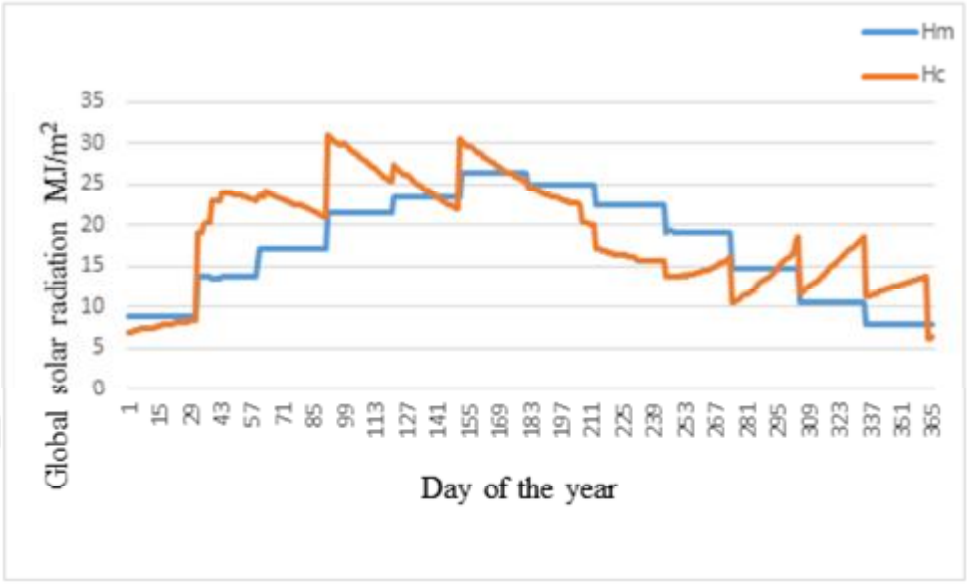


Figure 5.6.c. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Tarsus.

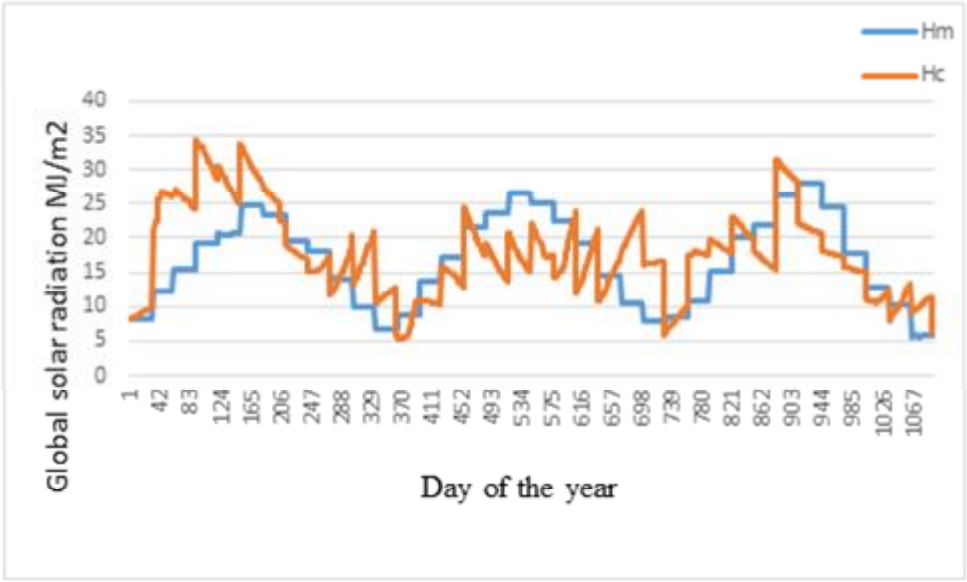


Figure 5.6.d. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Whole Region.

5.4.1.1.(3) Angström Prescott Cubic Model (Bahel et al. Model)

The calculated errors and statistical test result of the models developed based on angstrom-Prescott cubic model for the estimation of monthly mean daily global solar radiation in Eastern Mediterranean Region are shown in Table 5.21. The minimum and maximum MAE values are 2.124 and 4.347 respectively. RMSE value is varied as 2.537 and 5.589. According to Table 5.21, R^2 values lie between 0.425 and 0.819. MBE values change between 0.010 and 0.418.

Angström-Prescott cubic models give the results as good as results obtained with Angström-Prescott quadratic model. There is not remarkable difference between Angström-Prescott cubic model and Angström-Prescott quadratic model. So, because of the complexity of the model, it is not preferable for the stations or whole region except Göksun station while there is Angström-Prescott quadratic model is available.

Table 5.21. The statistical test results of Bahel et al. model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.010	2.124	2.537	0.819
Göksun	0.418	4.347	5.589	0.425
Tarsus	0.030	3.235	3.923	0.644
Whole Region	0.090	3.600	4.703	0.541

In order to illustrate the difference between calculated value of monthly mean global solar radiation and measured value of monthly mean global solar radiation, Figure 5.7.a, b, c and d are given below. All the graphical representation are done by the year of 2014 which the data of the year are chosen as test dataset it means the dataset is not used while training the models based on Angström-Prescott model.

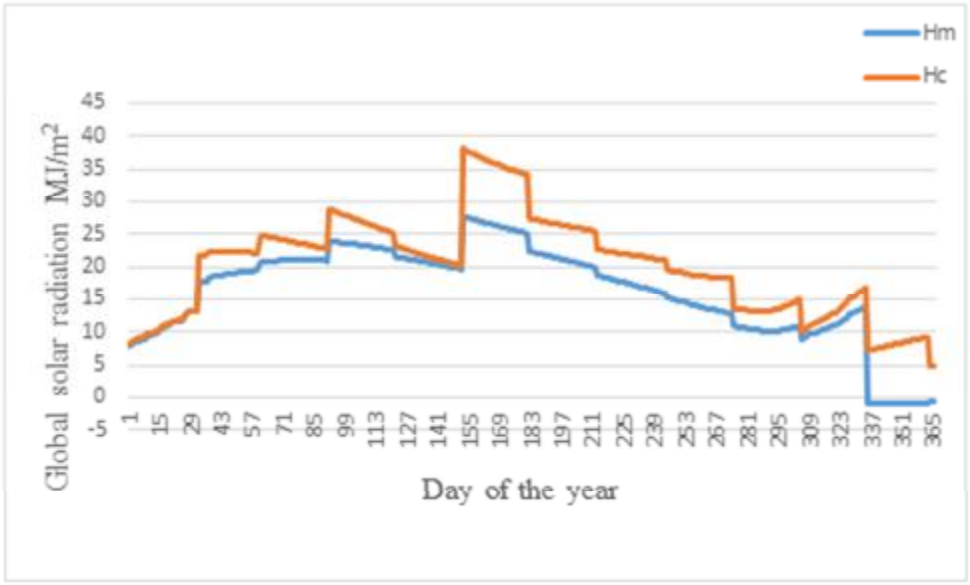


Figure 5.7.a. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Adana.

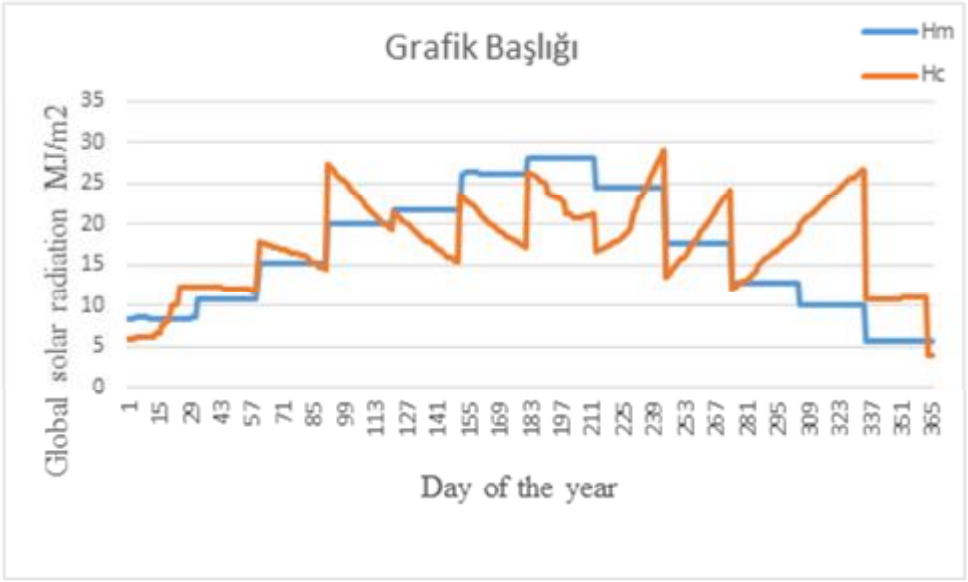


Figure 5.7.b. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Göksun.

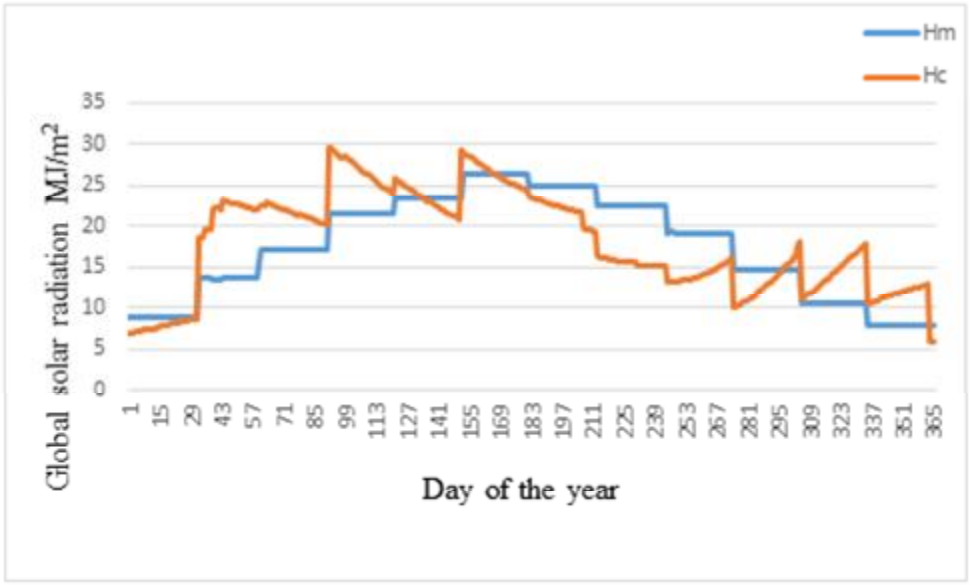


Figure 5.7.c. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Tarsus.

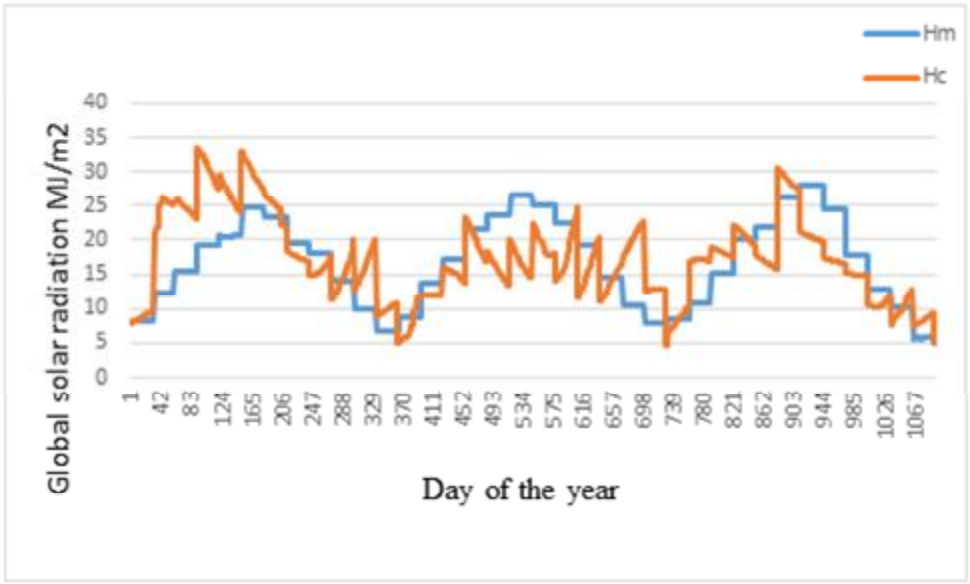


Figure 5.7.d. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Whole Region.

5.4.1.2. ANN Model

MAE, MBE, RMSE and R^2 values are given in Table 5.22 and comparison of measured and estimated values are given in Figures 6.8.a, b and c. The results indicate that using the ANN model is an applicable choice for modelling global solar radiation. The minimum and maximum MAE values are 0.450 and 0.502 respectively. RMSE value is varied as 0.504 and 1.573. According to Table 5.22, R^2 values lie between 0.983 and 0.998. MBE values change between (-0.454) and 0.249. These errors are lower than the errors obtained with Angström-Prescott linear, quadratic and cubic regression model. So, ANN model is more preferable than Angström-Prescott linear, quadratic or cubic regression model for the estimation of monthly mean daily global solar radiation in Eastern Mediterranean Region. Figure 5.8.a, b, c and d shows the illustration of the errors between measured and calculated values.

Table 5.22. Statistical results of monthly mean daily global solar radiation with ANN.

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.249	0.450	0.863	0.983
Mersin	-0.454	0.454	1.573	0.998
Kahramanmaraş	-0.346	0.458	1.200	0.986
Antakya	0.145	0.502	0.504	0.994

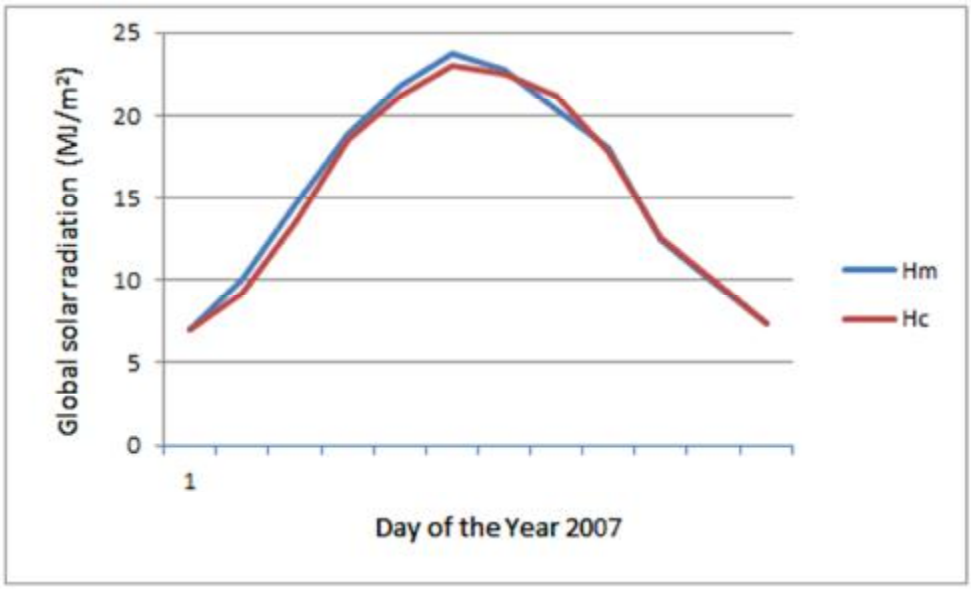


Figure 5.8.a. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2007 based on ANN model for Adana.

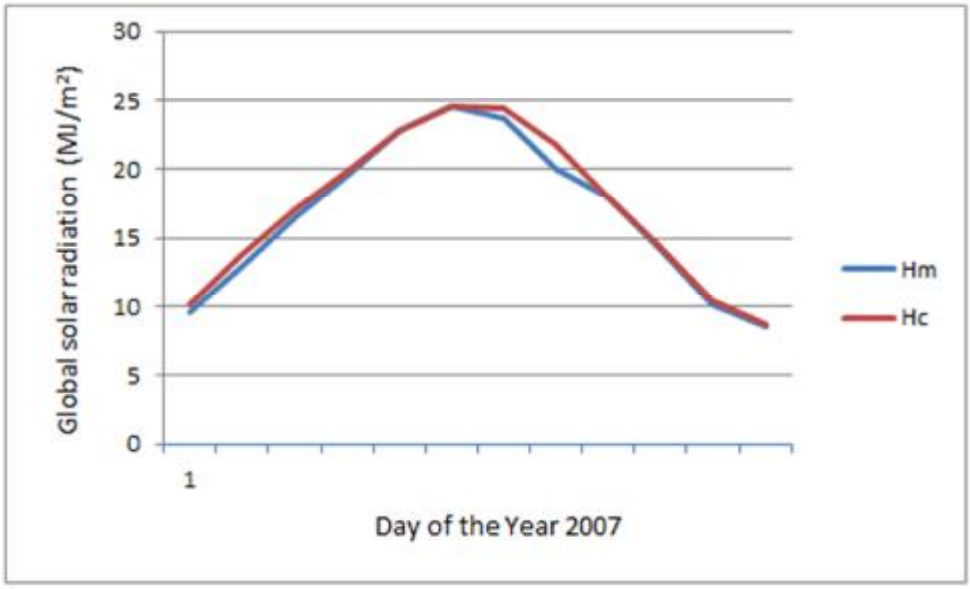


Figure 5.8.b. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2007 based on ANN model for Mersin.

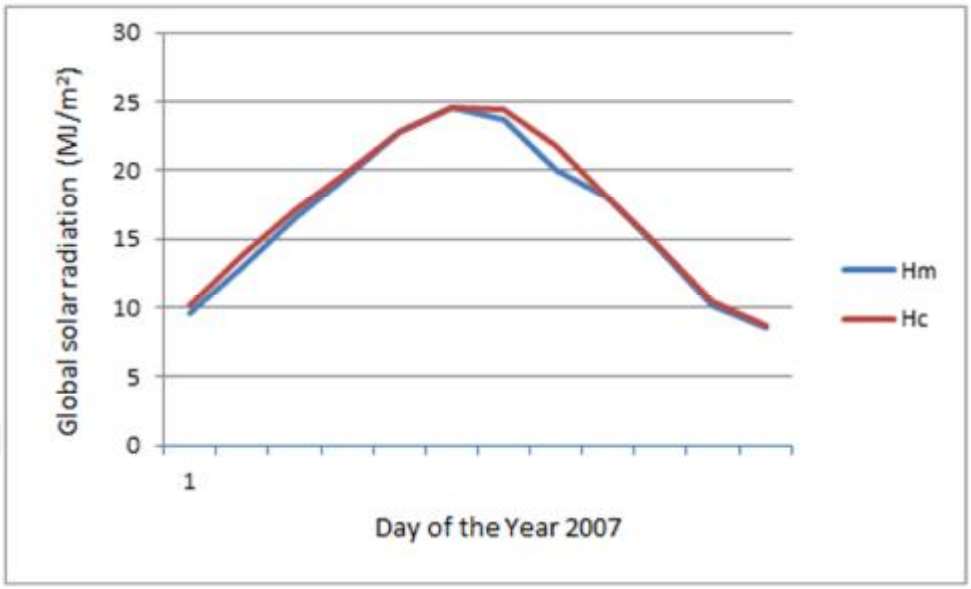


Figure 5.8.c. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2007 based on ANN model for Kahramanmaras.

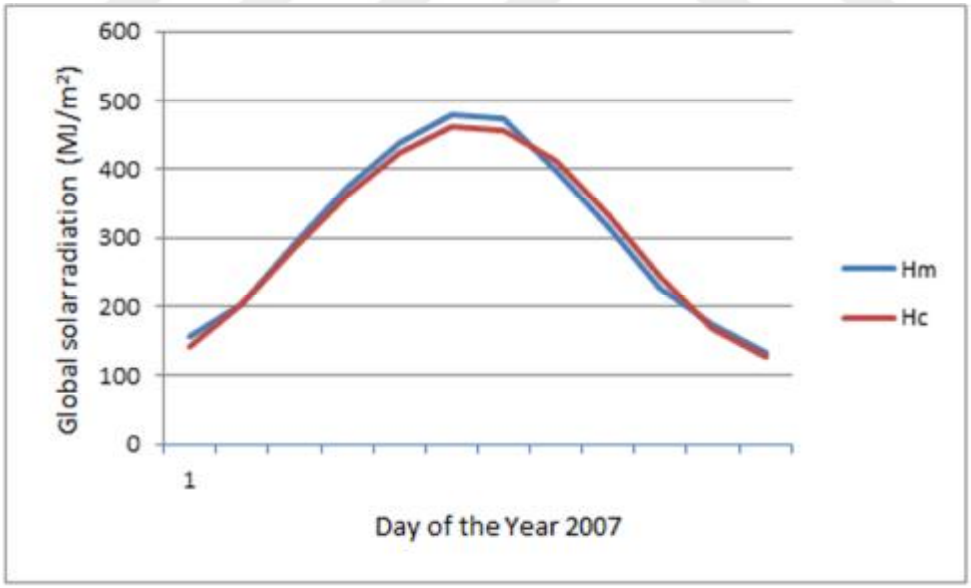


Figure 5.8.d. Graphical representation of measured and estimated values of monthly mean daily global solar radiation along the year of 2014 based on ANN model for Antakya.

5.4.2. Comparison of Daily Models

In this part of study comparison of daily global solar radiation models which are developed with Eastern Mediterranean Region data for the estimation of global solar radiation are compared each other with statistical test R^2 and error calculation methods such as Mean Bias Error (MBE), Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE). In order to visualize the errors and how fit is the equations, graphical representation of calculated value of global solar radiation and measured value of it is given as well for each city separated and for whole region.

5.4.2.1. Angström-Prescott Model

Table 5.23 shows the results of developed Angström-Prescott linear model with the data of each city separately and together for whole stations. The minimum and maximum MAE values are 1.039 and 2.831, respectively. RMSE value is varied as 1.354 and 3.807. According to Table 5.23, R^2 values lie between 0.719 and 0.955. MBE values change between 0.044 and 0.652. It is obviously clear that daily models based on of Angström-Prescott linear model gives better results than all monthly mean daily models. Angström-Prescott models can be highly recommended model for the estimation of global solar radiation in Eastern Mediterranean Region. The results indicate that there is a good relationship between sunshine duration and global solar radiation. Figure 5.9.a, b, c and d given in order to show the graphical representation of calculated and measured values of global solar radiation. On the other hand, errors are getting higher in developed models with whole stations data together.

Table 5.23. The statistical test results of Angström-Prescott model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.044	1.039	1.354	0.954
Göksun	0.164	1.159	1.632	0.955
Tarsus	0.037	1.209	1.631	0.940
Whole Region	0.652	2.831	3.807	0.719

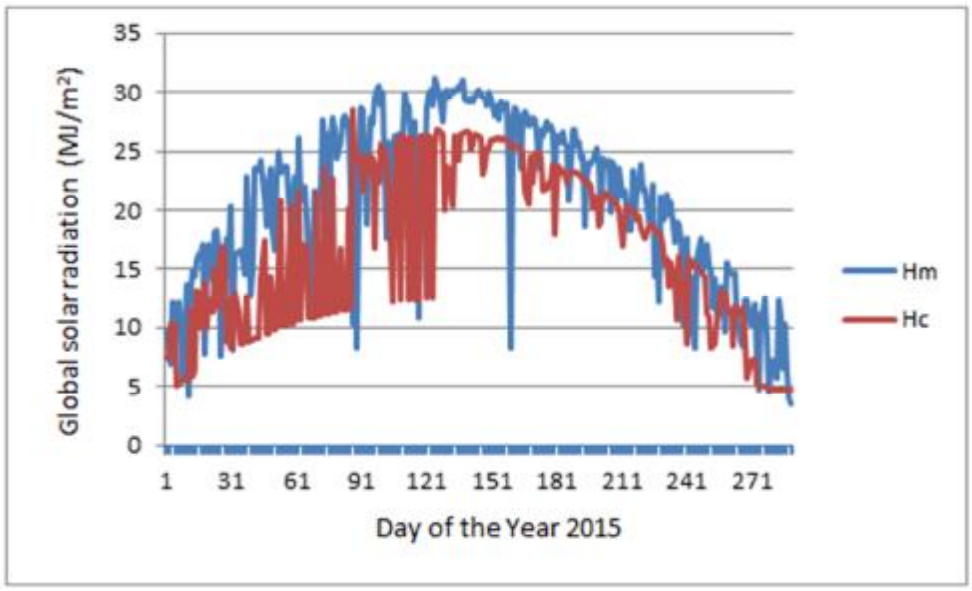


Figure 5.9.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott model for Adana.

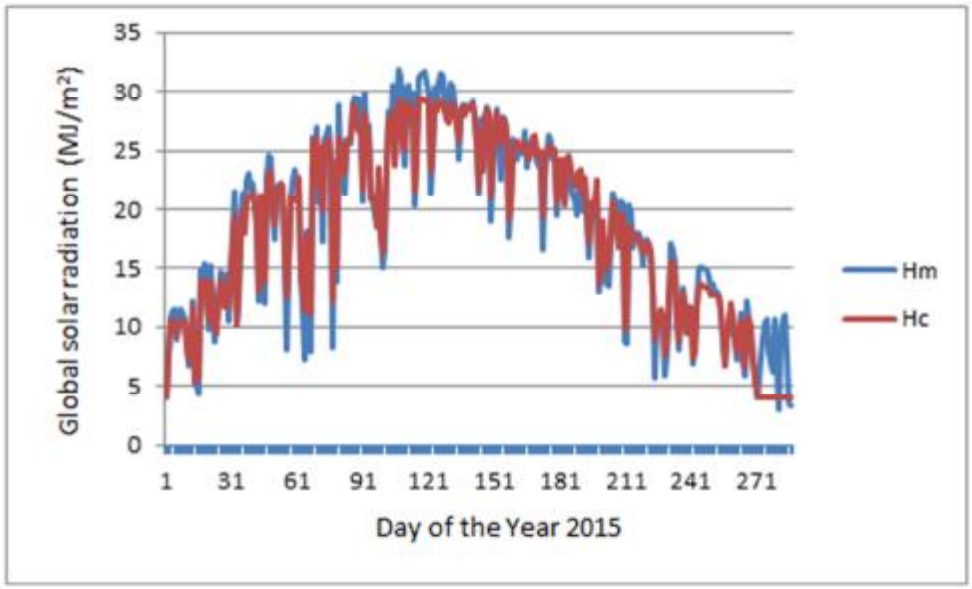


Figure 5.9.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott model for Göksun.

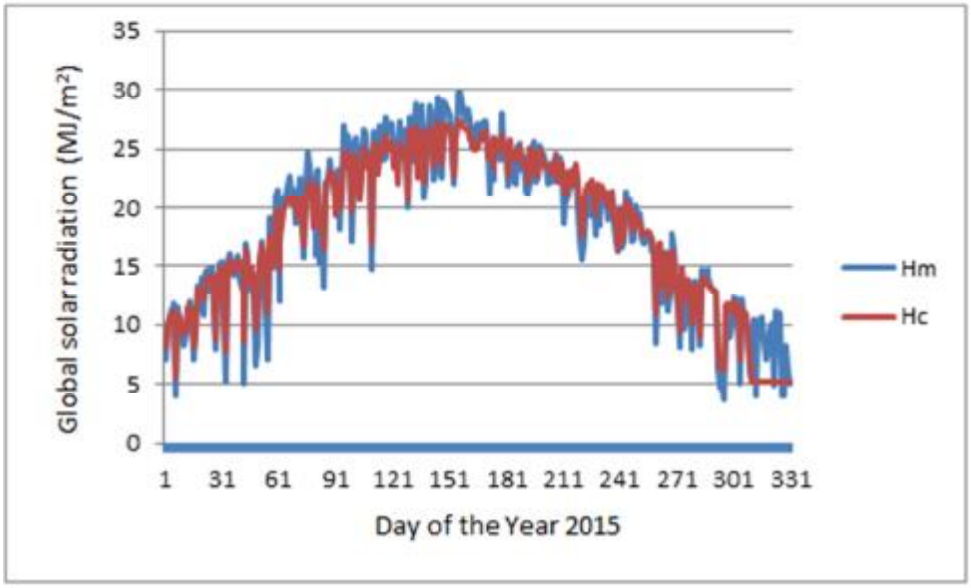


Figure 5.9.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott model for Tarsus.

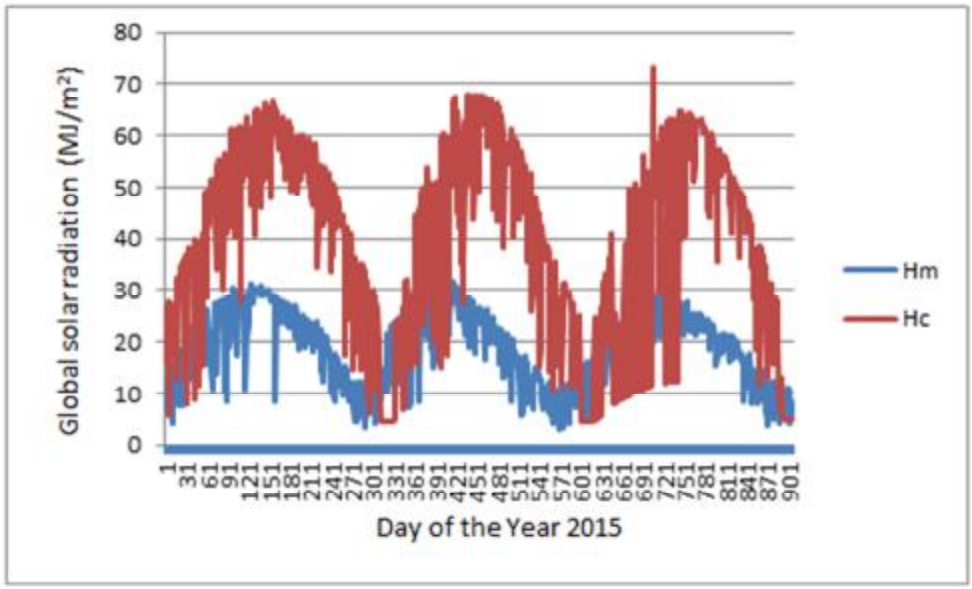


Figure 5.9.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott model for Whole Region.

5.4.2.2. Angström-Prescott Quadratic Model (Akınoğlu and Ecevit Model)

Table 5.24 shows the error calculation and statistical test results of developed Angström-Prescott quadratic model with the data of each city separately and together for whole region. The minimum and maximum MAE values are 0.937 and 2.068, respectively. RMSE value is varied as 1.240 and 2.962. According to Table 5.24, R^2 values lie between 0.836 and 0.963. MBE values change between -7.816 and 0.303. Angström-Prescott quadratic model also gives better results for daily global solar radiation estimation than monthly mean daily global solar radiation estimation. However, it also indicates that model for whole station is not as preferable as each station separately. This model can be highly recommended for each stations but using Angström-Prescott linear model is favourable because of the model's simplicity. Figure 5.10.a, b, c and d are given to illustrate the difference between calculated and measured values of daily global solar radiation in the year of 2014.

Table 5.24. The statistical test results of Akınoğlu and Ecevit model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.263	0.937	1.240	0.963
Göksun	0.208	1.098	1.551	0.960
Tarsus	0.303	1.167	1.551	0.951
Whole Region	0.574	2.068	2.962	0.836

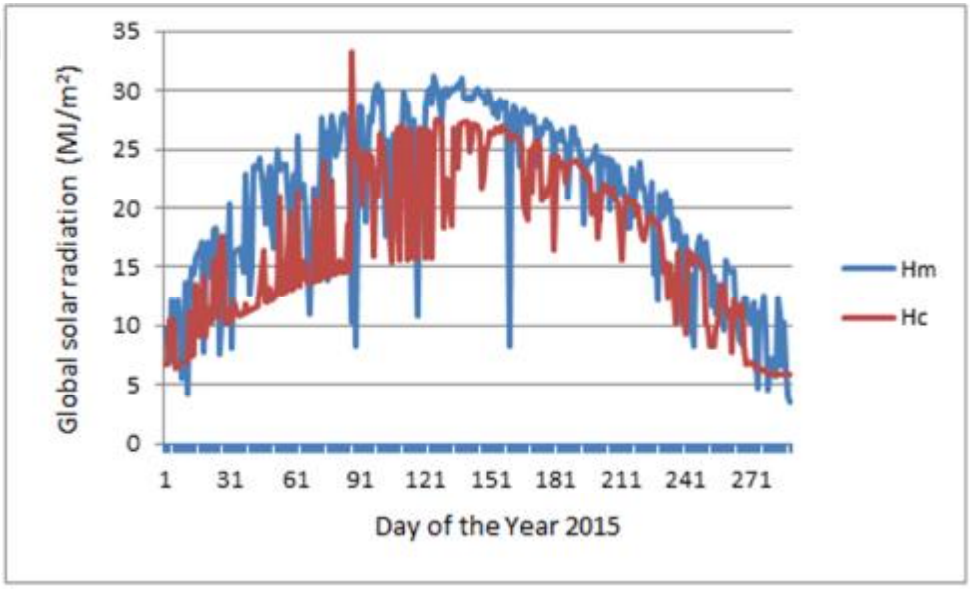


Figure 5.10.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Adana.

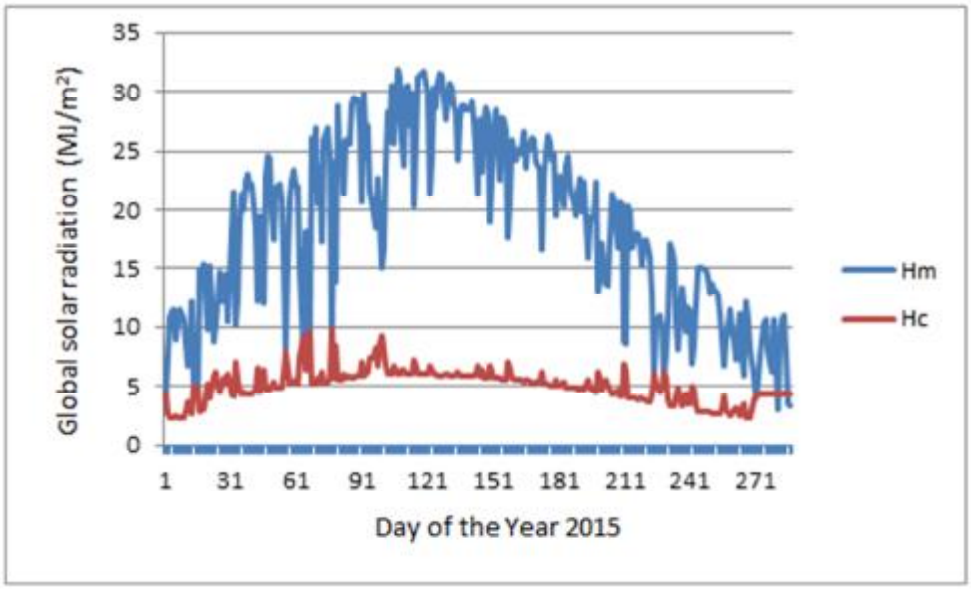


Figure 5.10.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Göksun.

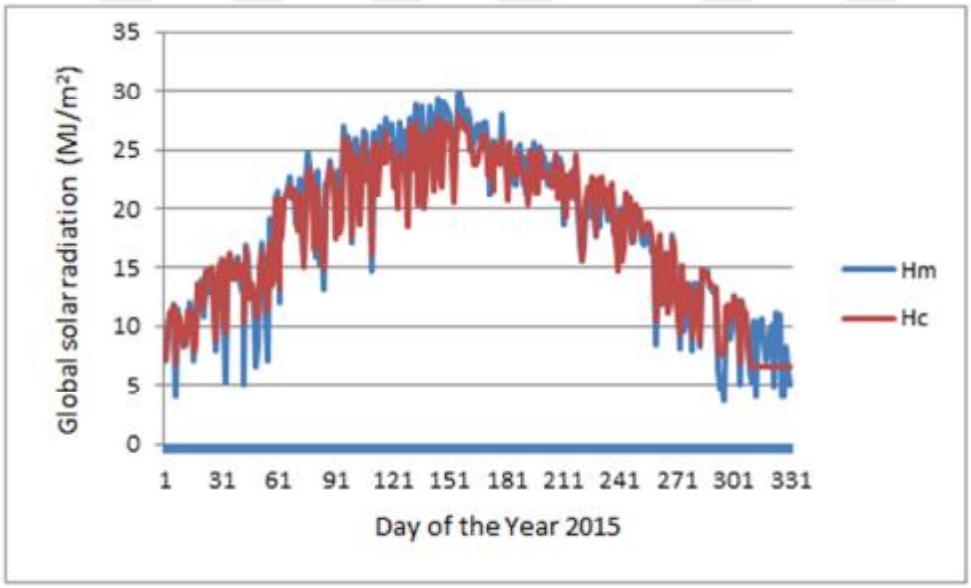


Figure 5.10.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Tarsus.

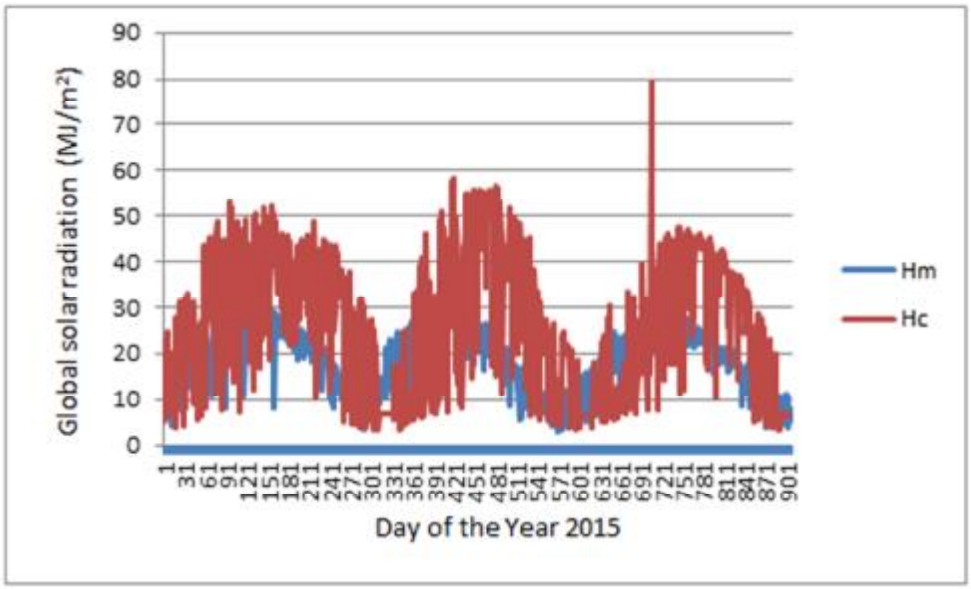


Figure 5.10.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott quadratic model for Whole Region.

5.4.2.3. Angström-Prescott Cubic Model (Bahel et al. Model)

The statistical test result and calculated errors of Angström-Prescott cubic models for daily global solar radiation estimation are given in Table 5.25. The minimum and maximum MAE values are 0.935 and 1.923, respectively. RMSE value is varied as 1.182 and 2.778. According to Table 5.25, R^2 values lie between 0.850 and 0.965. MBE values change between (-0.027) and 1.543. Angström-Prescott cubic model gives good results than Angström-Prescott linear and quadratic models. Figure 5.11.a, b, c and d shows the graphical representation of the model.

Table 5.25. The statistical test results of Bahel et al. model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.077	0.935	1.182	0.965
Göksun	0.199	1.082	1.519	0.961
Tarsus	-0.027	1.073	1.426	0.954
Whole Region	0.368	1.923	2.778	0.850

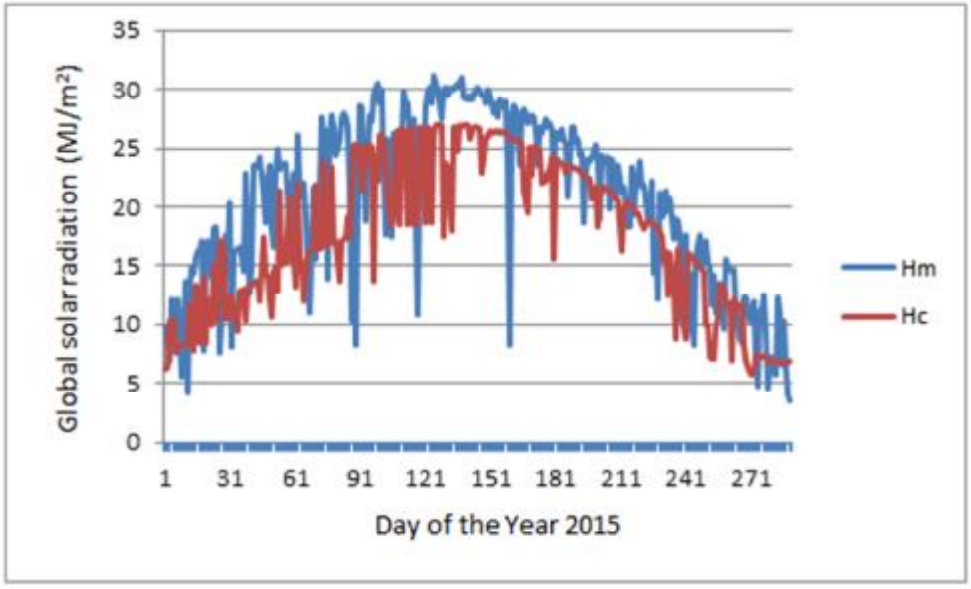


Figure 5.11.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Adana.

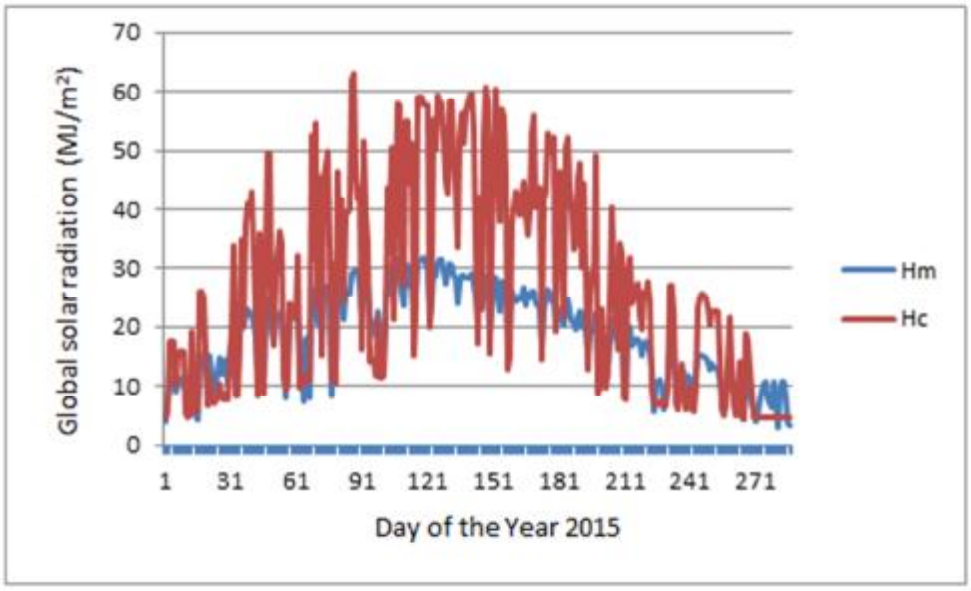


Figure 5.11.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Göksun.

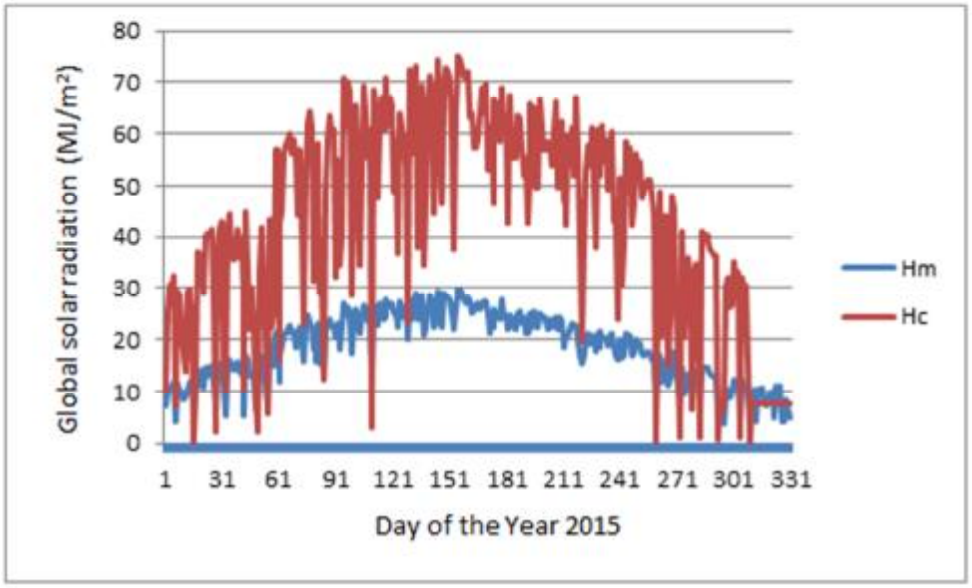


Figure 5.11.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Tarsus.

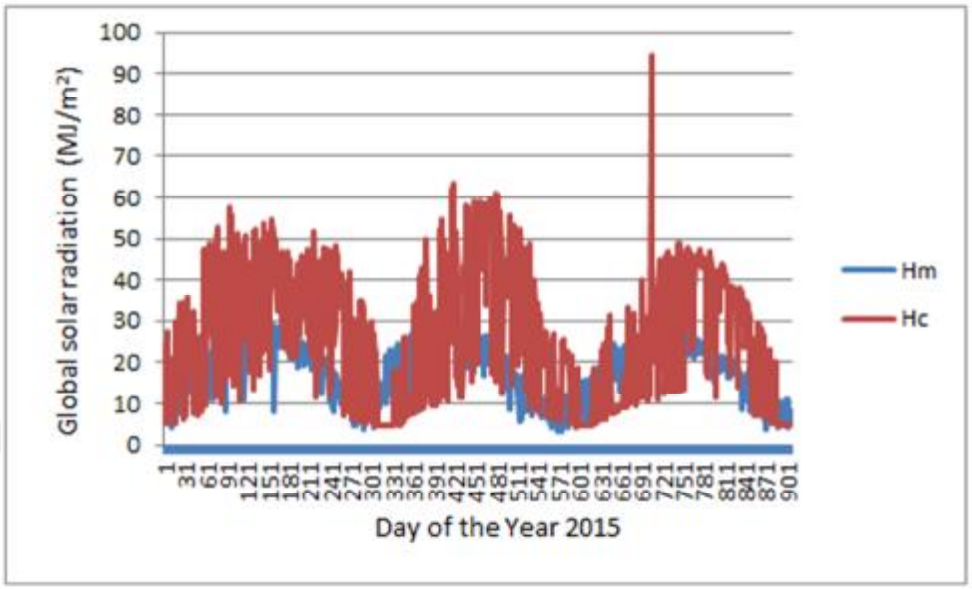


Figure 5.11.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Angström-Prescott cubic model for Whole Region.

5.4.2.4. Bristow Campbell Model

The errors and statistical test result of developed model based on Bristow and Campbell model are given in Table 5.26. The minimum and maximum MAE values are 2.033 and 2.665, respectively. RMSE value is varied as 2.651 and 3.654. According to Table 5.26, R^2 values lie between 0.748 and 0.865. MBE values change between -0.085 and 0.653. The illustrations of the difference between calculated and measured value along the year of 2014 are given in Figure 5.12.a, b, c and d.

According to numerical results and graphical representation of the model, Bristow-Campbell model is favourable for each city and for whole station. It can be useful for the stations which only temperature measurement is available.

Table 5.26. The statistical test results of Bristow and Campbell model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.653	2.141	2.723	0.841
Göksun	0.339	2.665	3.654	0.748
Tarsus	-0.085	2.163	2.81	0.865
Whole Region	0.308	2.033	2.651	0.856

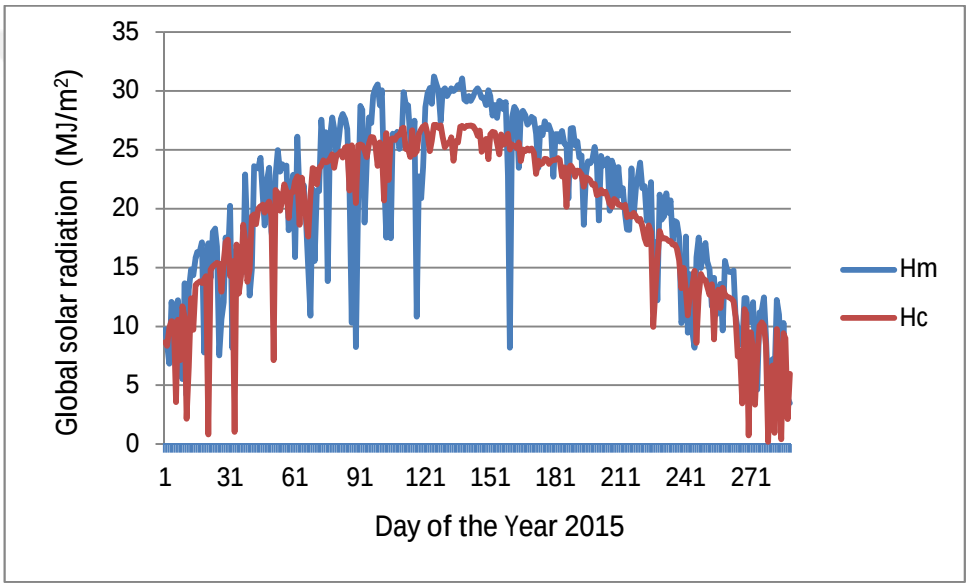


Figure 5.12.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Bristow-Campbell model for Adana.

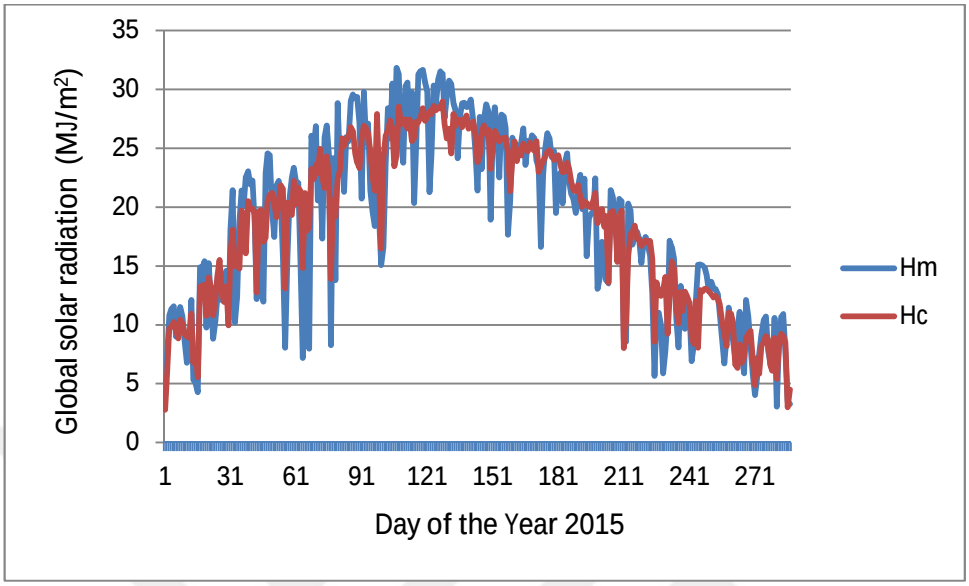


Figure 5.12.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Bristow-Campbell model for Göksun.

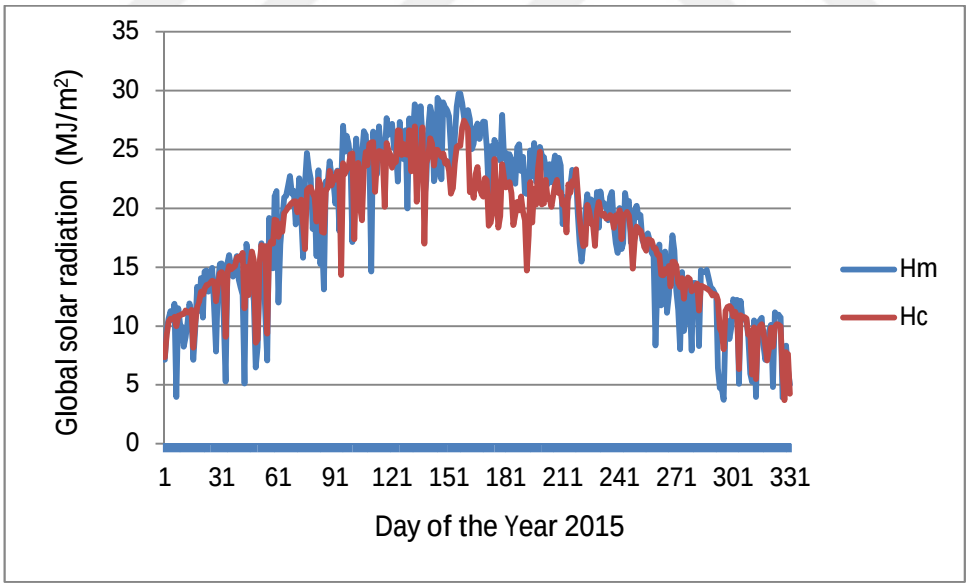


Figure 5.12.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Bristow-Campbell model for Tarsus.

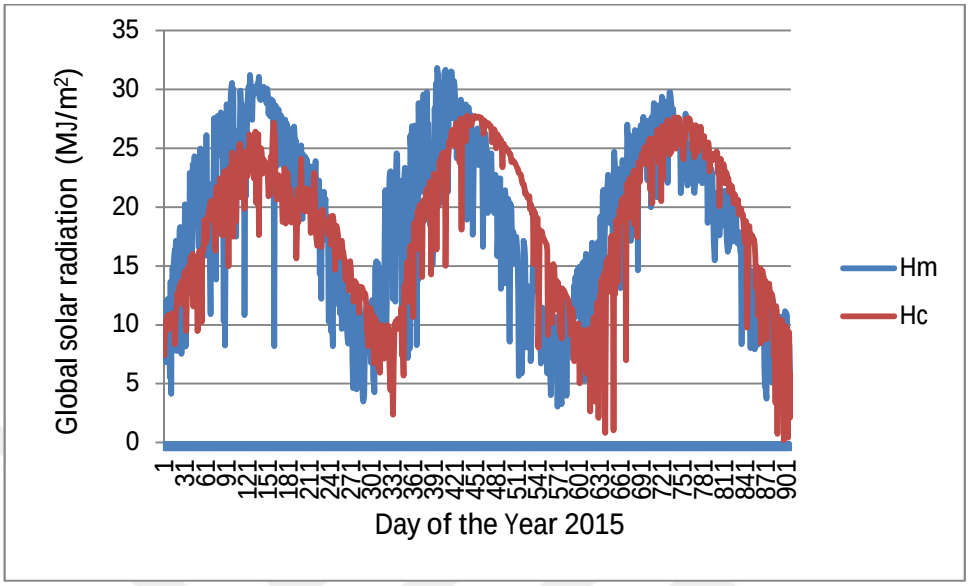


Figure 5.12.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Bristow-Campbell model for Whole Region.

5.4.2.5. Hargraves and Samani Model

Table 5.27 indicates the calculated errors and statistical test results of the Hargraves and Samani model based developed model. The minimum and maximum MAE values are 2.158 and 2.678, respectively. RMSE value is varied as 2.848 and 3.462. According to Table 5.27, R^2 values lie between 0.766 and 0.861. MBE values change between 0.039 and 0.873.

There is not such a big difference between Bristow-Campbell and Hargraves-Samani model based models so this model is also acceptable for daily solar radiation estimation in Eastern Mediterranean Region but a bit worse than Bristow-Campbell model. Bristow-Campbell model has advantages because of better results and there is no other superiority of Hargraves-Samani models to Bristow-Campbell model. Figure 5.13.a, b, c and d are given to show the difference between calculated and measured values of global solar radiation in year of 2014.

Table 5.27. The statistical test results of Hargraves and Samani model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.873	2.264	2.855	0.832
Göksun	0.039	2.158	2.848	0.861
Tarsus	0.525	2.286	2.944	0.827
Whole Region	0.426	2.678	3.462	0.766

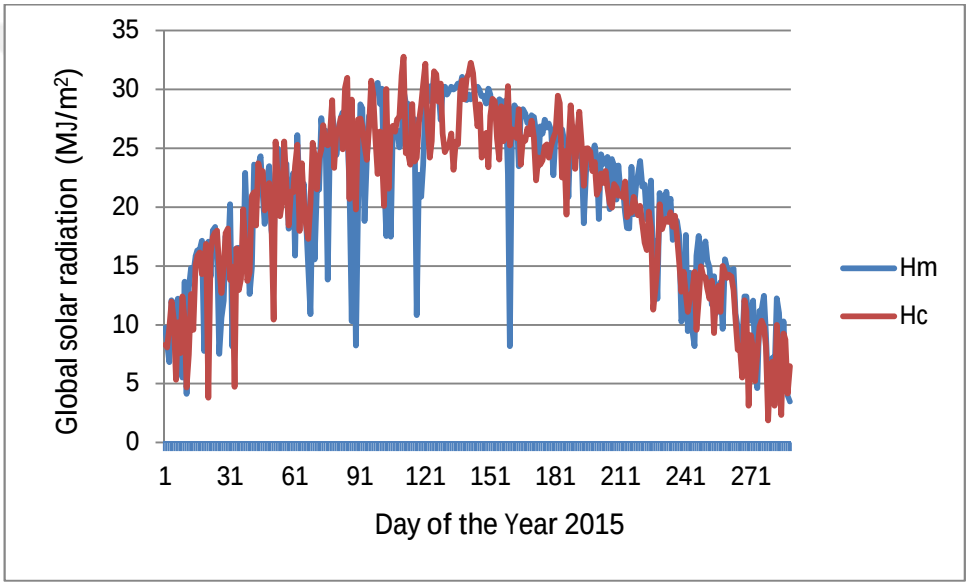


Figure 5.13.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hargraves-Samani model for Adana.

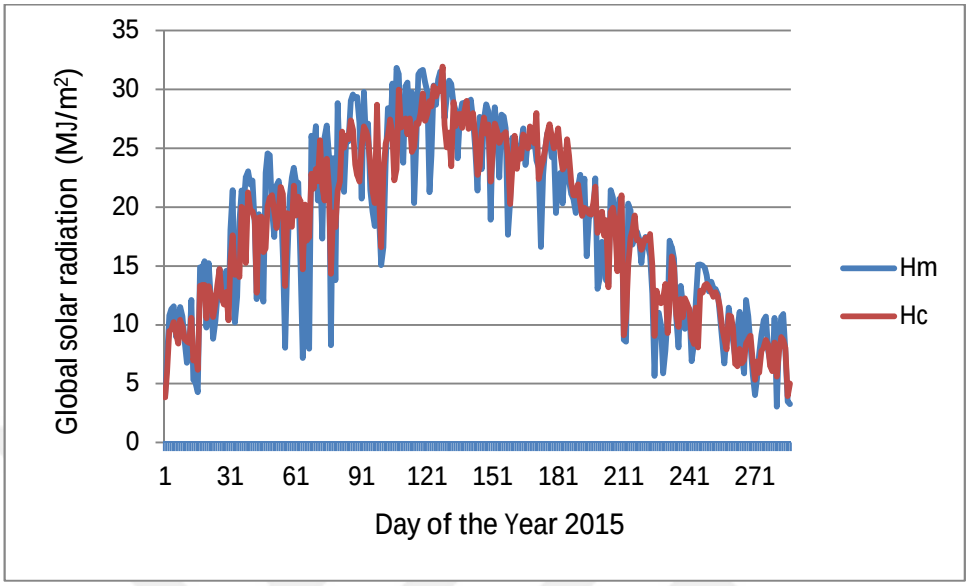


Figure 5.13.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hargraves-Samani model for Göksun.

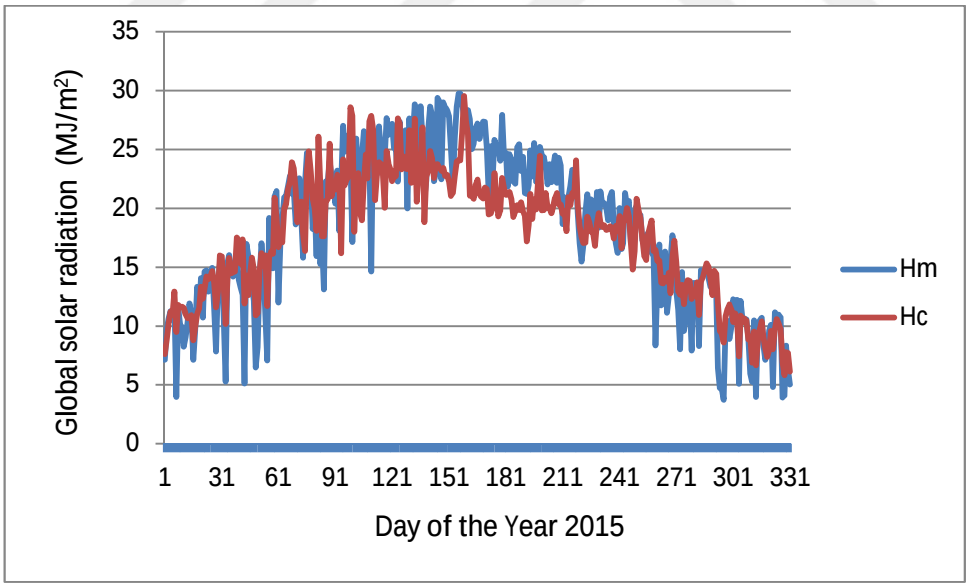


Figure 5.13.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hargraves-Samani model for Tarsus.

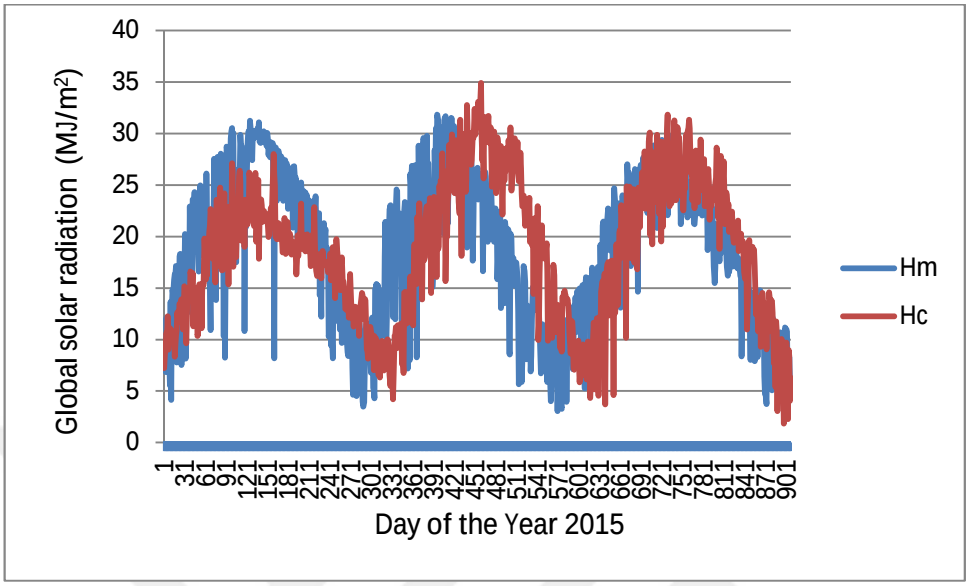


Figure 5.13.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Hargraves-Samani model for Whole Region.

5.4.2.6. Antonanzas et al. Model

Statistical test result and calculated errors of Antonanzas et al. model based developed models are given in Table 5.28. According to this table, MAE values lies between 1.675 and 2.092, RMSE values change between 2.172 and 2.850 and MBE values varies between -0.081 and 0.321. R^2 values lies between 0.837 and 0.892. According to statistical test and error calculation results of the model, Antonanzas model better fits than Bristow and Campbell model and Hargraves and Samani model for whole stations separately and together in the study area. Graphical representation of the calculated and measured values are given in Figure 5.14.a, b, c and d.

Table 5.28. The statistical test results of Antonanzas et al model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.321	1.675	2.172	0.885
Göksun	-0.081	1.924	2.507	0.892
Tarsus	0.284	1.711	2.234	0.890
Whole Region	0.141	2.092	2.850	0.837

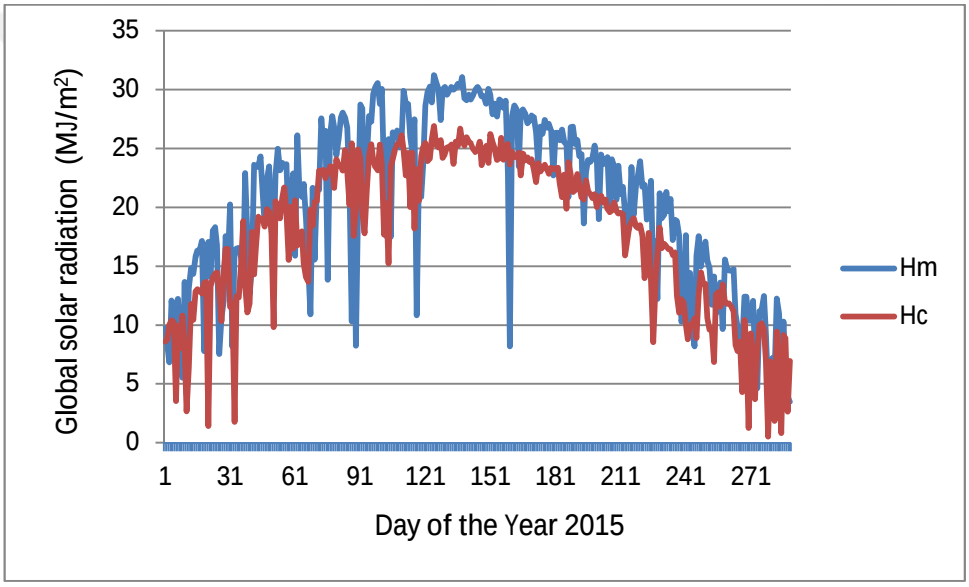


Figure 5.14.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Antonanzas et al. model for Adana.

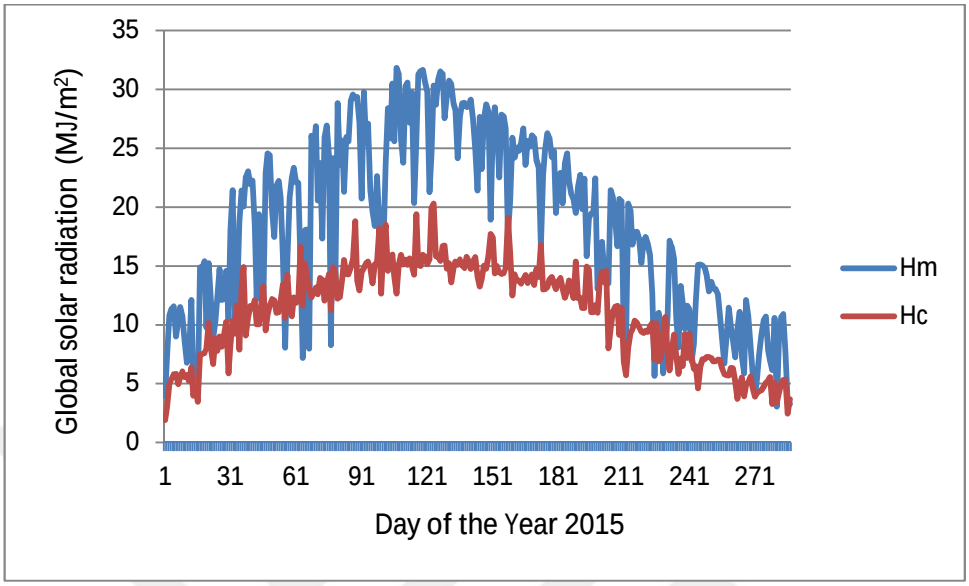


Figure 5.14.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Antonanzas et al. model for Göksun.

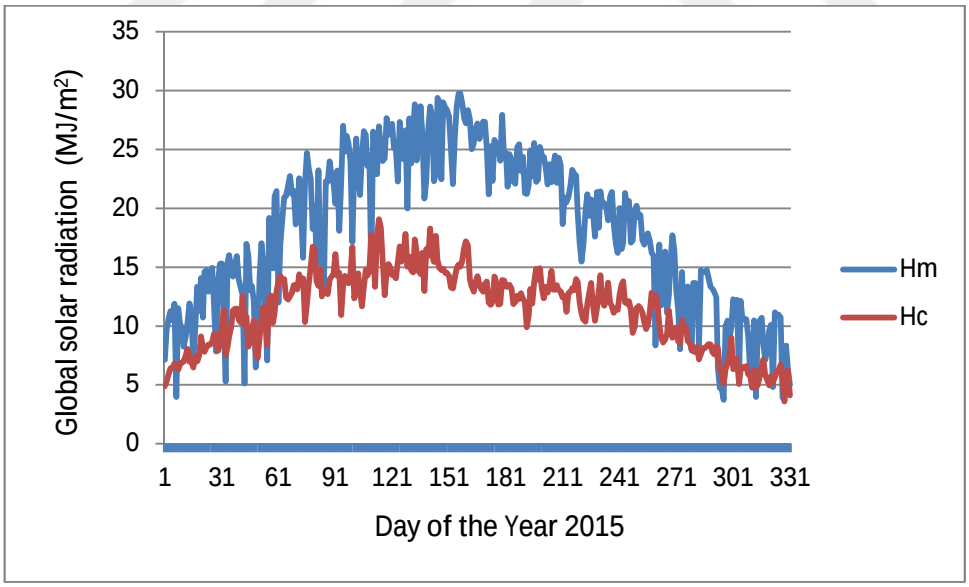


Figure 5.14.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Antonanzas et al. model for Tarsus.

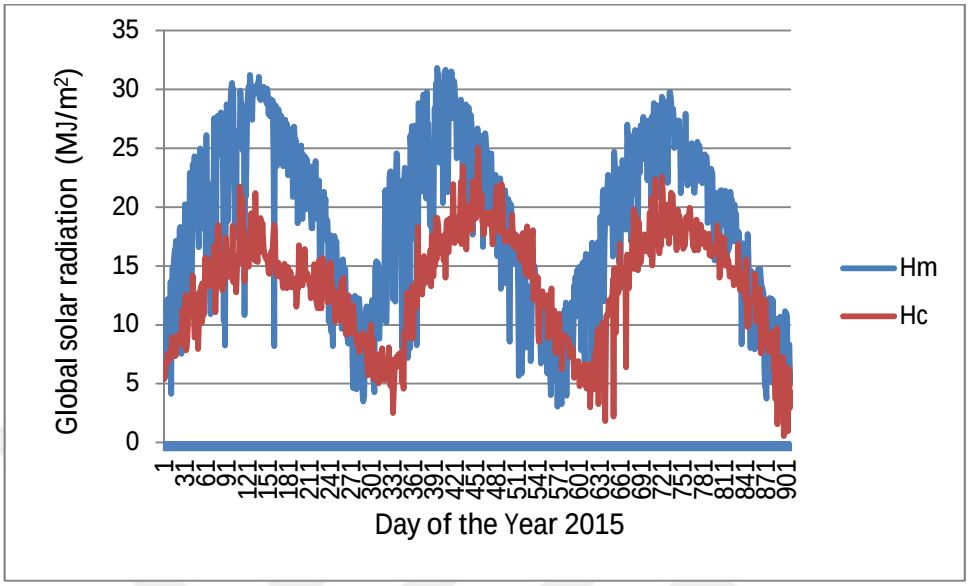


Figure 5.14.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Antonanzas et al. model for Whole Region.

5.4.2.7. Hunt Model

Table 5.29 shows the Hunt model results. The MAE value varied as 2.149-2.638. The RMSE values are lie between 2.729 and 3.424. The R^2 values are change between 0.766 and 0.861. MBE values lie between 0.005 and 0.713. That is to say, the Hunt model results are worse than the Antonanzas et al model results but close to Bristow-Campbell and Hargraves-Samani model. So it can be accepted to estimate daily global solar radiation with Hunt model in Eastern Mediterranean Region. Figure 5.15.a, b, c and d illustrates the calculated and measured values of daily global solar radiation with Hunt model based developed model in Eastern Mediterranean Region.

Table 5.29. The statistical test results of Hunt model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.713	2.149	2.729	0.832
Göksun	0.005	2.159	2.849	0.861
Tarsus	0.265	2.157	2.804	0.827
Whole Region	0.174	2.638	3.424	0.766

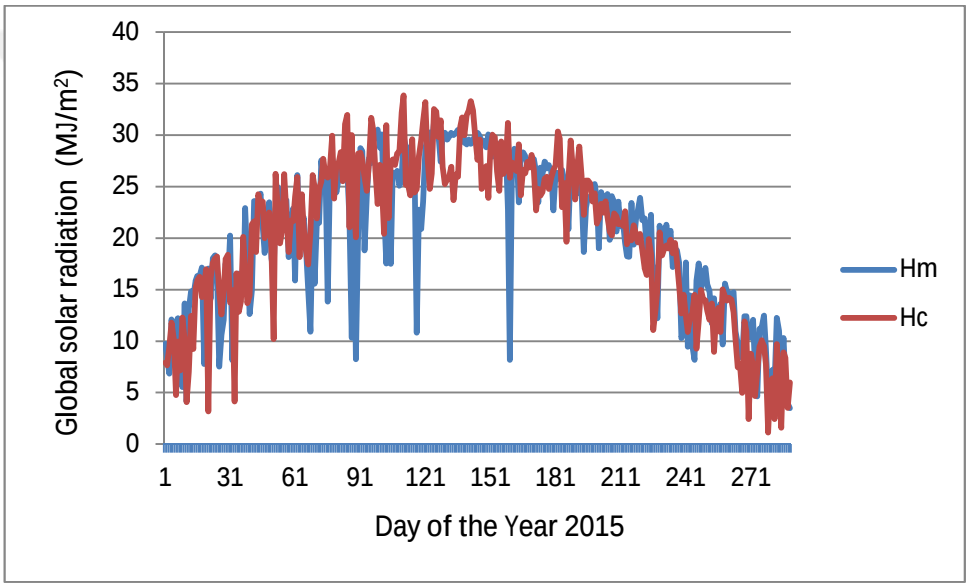


Figure 5.15.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hunt model for Adana.

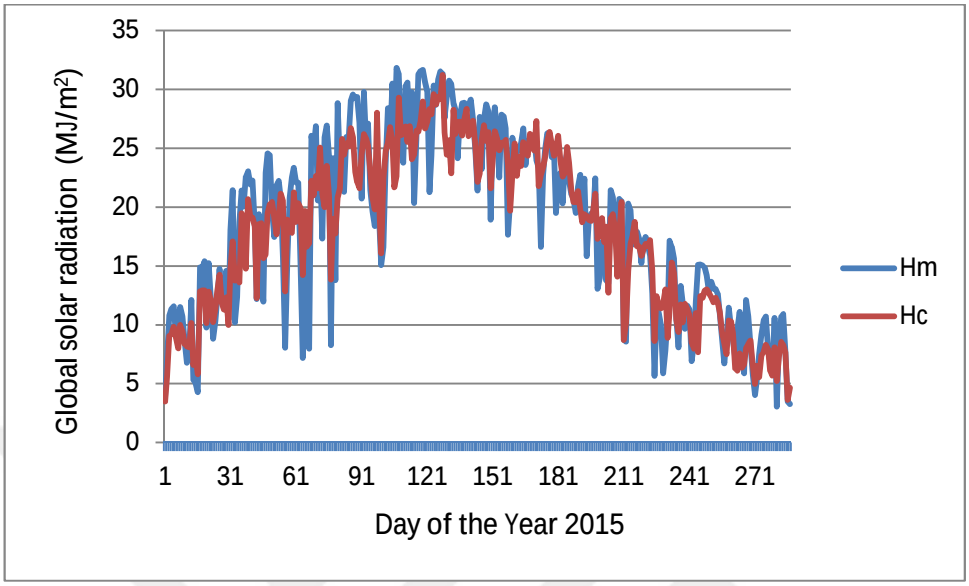


Figure 5.15.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hunt model for Göksun.

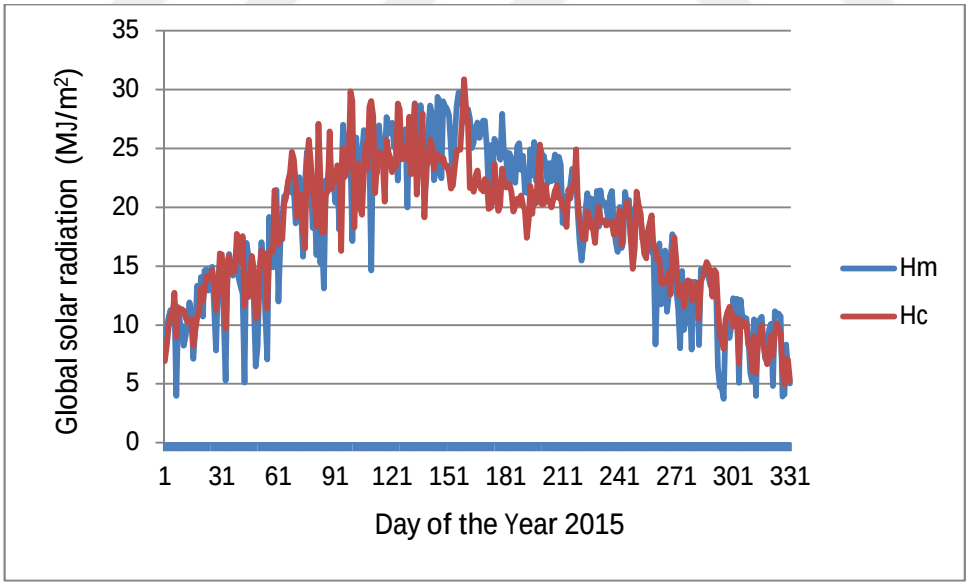


Figure 5.15.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Hunt model for Tarsus.

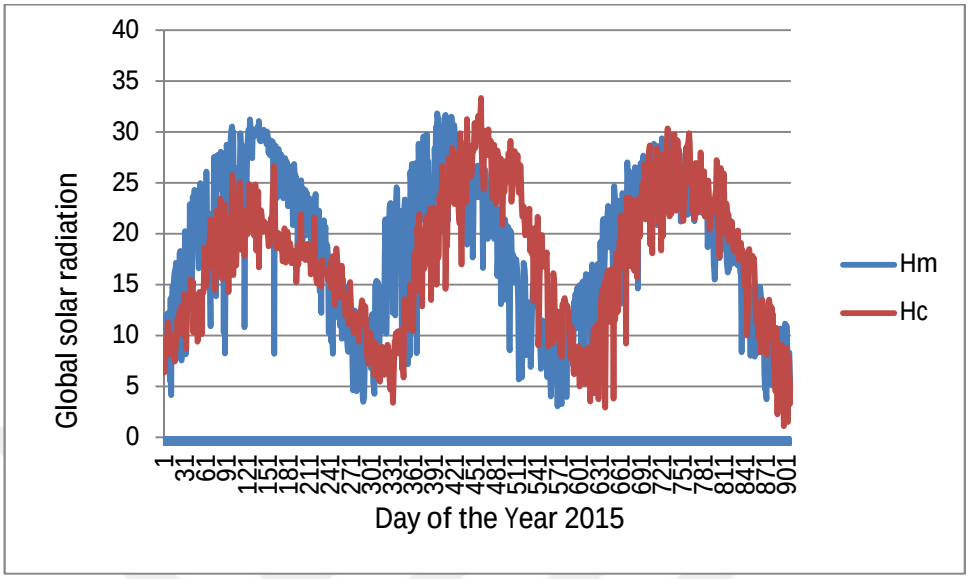


Figure 5.15.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Hunt model for Whole Region.

5.4.2.8. Abraha and Savage Model

The Abraha and Savage based models' error calculation and statistical test results are shown in Table 5.30. The MAE value varies as 2.369–2.689. The RMSE values lie between 3.166-3.783. R^2 values change between 0.717-0.865. MBE value varies as (-1.115) - 0.267. These results are worse than all models mentioned before except the Angström-Prescott model based models developed for monthly mean daily global solar radiation. The illustration of calculated and measured values of daily global solar radiation are given in Figure 5.16.a, b, c and d.

Table 5.30. The statistical test results of Abraha and Savage model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.267	2.494	3.357	0.717
Göksun	-1.115	2.434	3.270	0.865
Tarsus	-0.064	2.369	3.166	0.775
Whole Region	-0.495	2.689	3.783	0.743

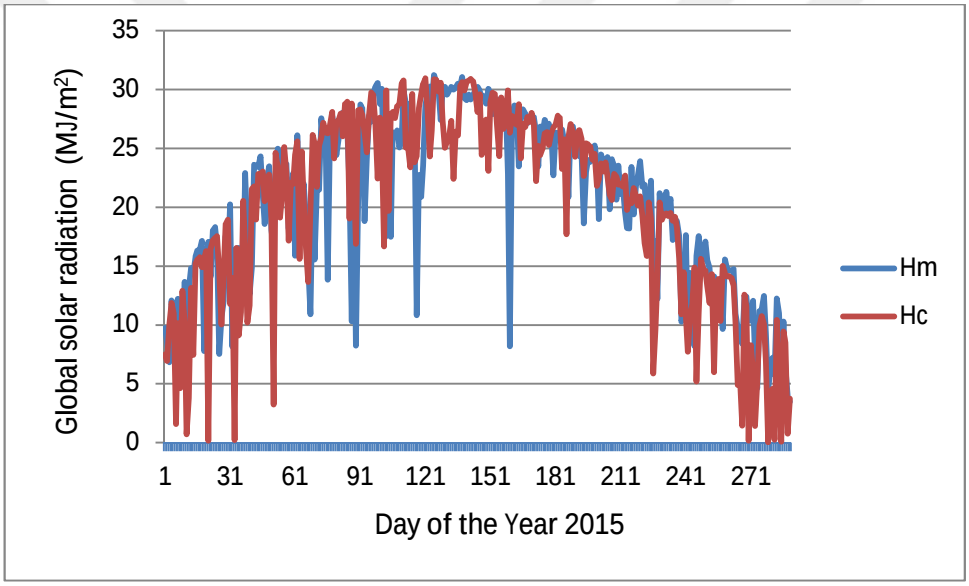


Figure 5.16.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Abraha and Savage model for Adana.

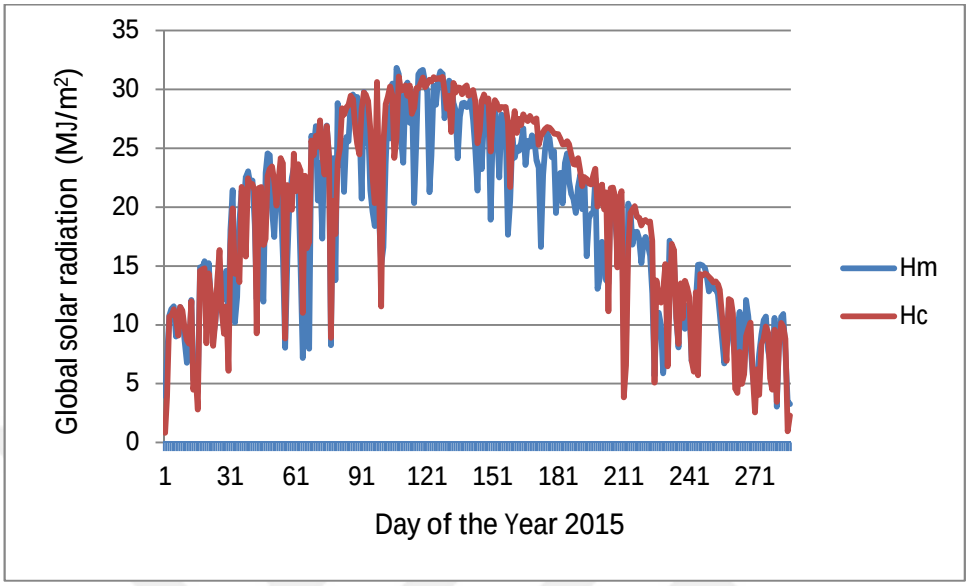


Figure 5.16.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Abraha and Savage model for Göksun.

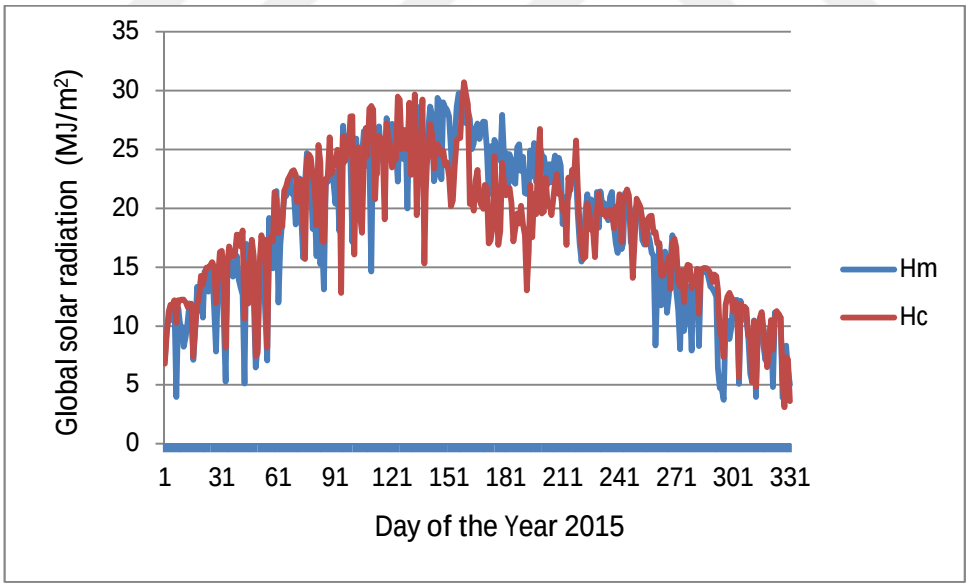


Figure 5.16.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Abraha and Savage model for Tarsus.

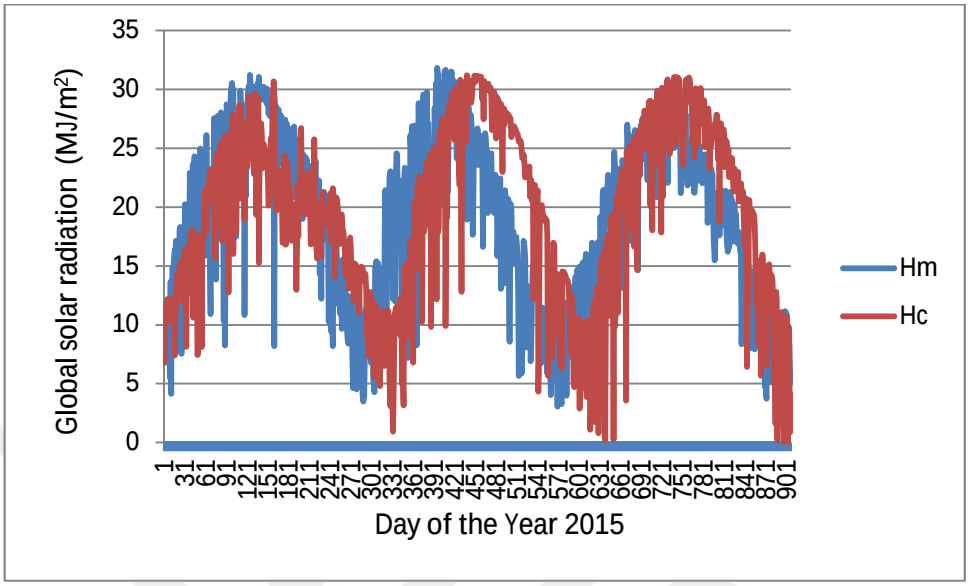


Figure 5.16.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Abraha and Savage model for Whole Region.

5.4.2.9. Annandale et al. Model

The calculated errors and statistical test results of Annandale model are listed in Table 5.31. According to this table MAE values change between 2.158 and 2.678. RMSE values lies between 2.848 and 3.462. R^2 values are between 0.766 and 0.861. MBE values vary as 0.039-0.873. According to these results Annadale et al model is suitable for the estimation of daily global solar radiation in Eastern Mediterranean Region. Graphical representation of calculated and measured values of global solar radiation are given in Figure 5.17.a, b, c and d.

Table 5.31. The statistical test results of Annandale et al model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.873	2.264	2.855	0.832
Göksun	0.039	2.158	2.848	0.861
Tarsus	0.525	2.286	2.944	0.827
Whole Region	0.426	2.678	3.462	0.766

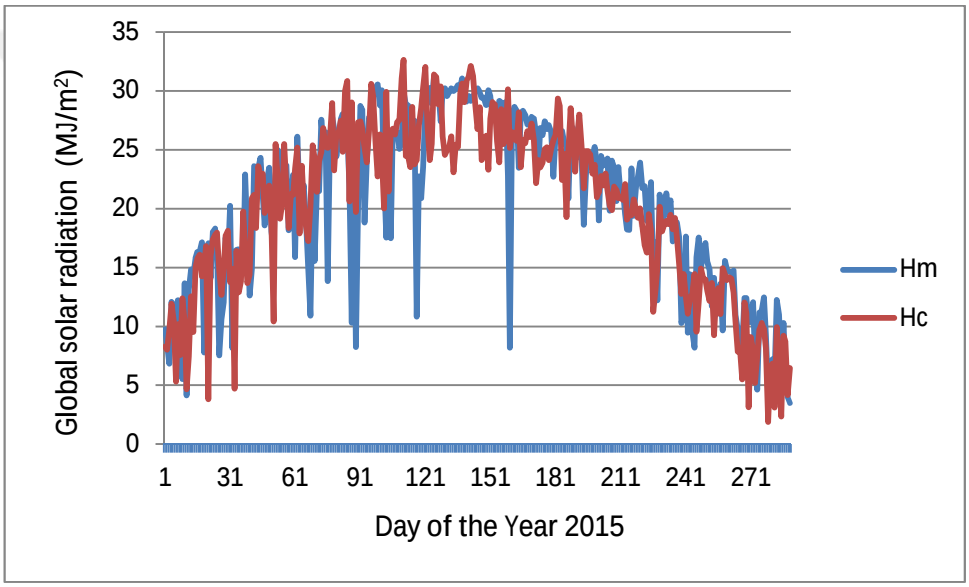


Figure 5.17.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Annandale et al. model for Adana.

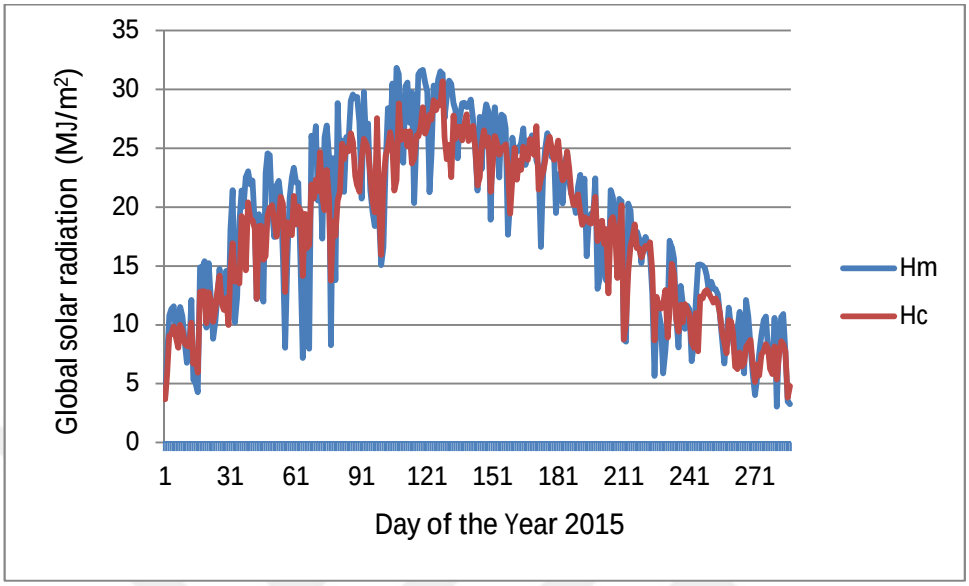


Figure 5.17.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Annandale et al. model for Göksun.

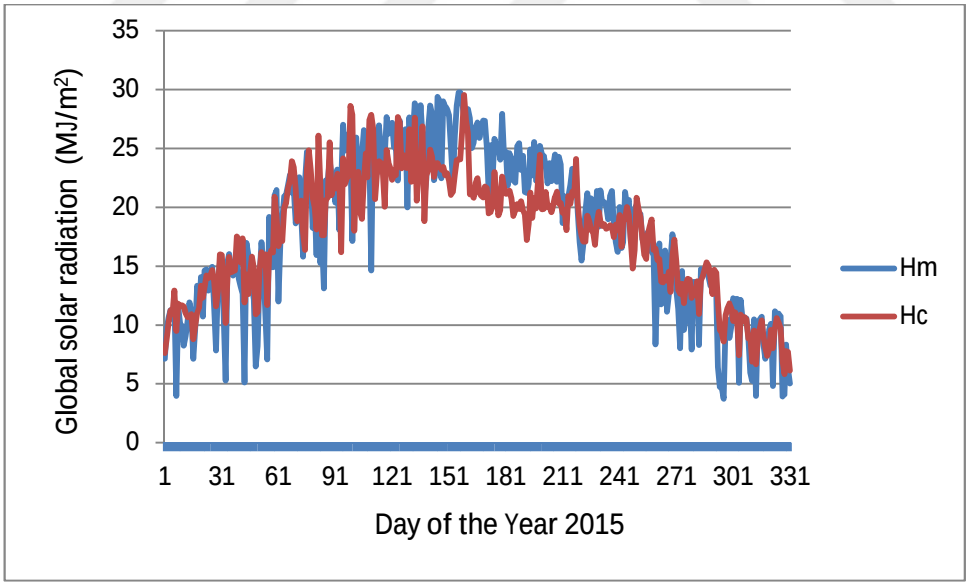


Figure 5.17.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Annandale et al. model for Tarsus.

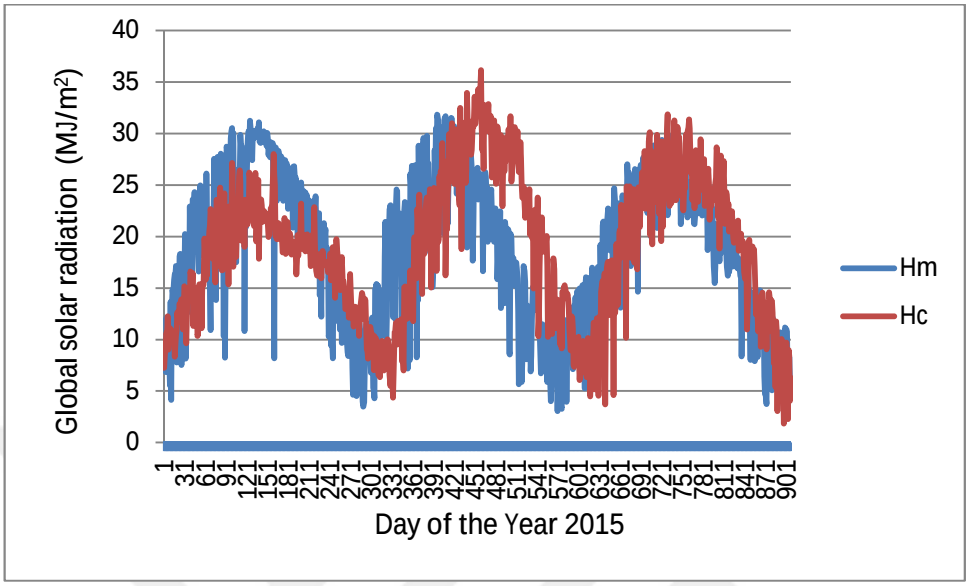


Figure 5.17.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Annandale et al. model for Whole Region.

5.4.2.10. Donatelli and Campbell Model

The Donatelli and Campbell based models' error calculation and statistical test results are shown in Table 5.32. The statistical test results are change between 2.015-2.361 for MAE, 2.630-3.130 for RMSE, 0.806-0.866 for R^2 and 0.139-0.479 for MBE. Donatelli and Campbell models give acceptable and good results for each station separately and for whole stations together so using this model to estimate daily global solar radiation in Eastern Mediterranean Region is favourable. The illustration of measured and calculated values are given in Figure 5.18.a, b, c and d.

Table 5.32. The statistical test results of Donatelli and Campbell model

Station	Statistical test results			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.479	2.076	2.651	0.844
Göksun	0.139	2.180	2.804	0.866
Tarsus	0.256	2.015	2.630	0.858
Whole Region	0.251	2.361	3.130	0.806

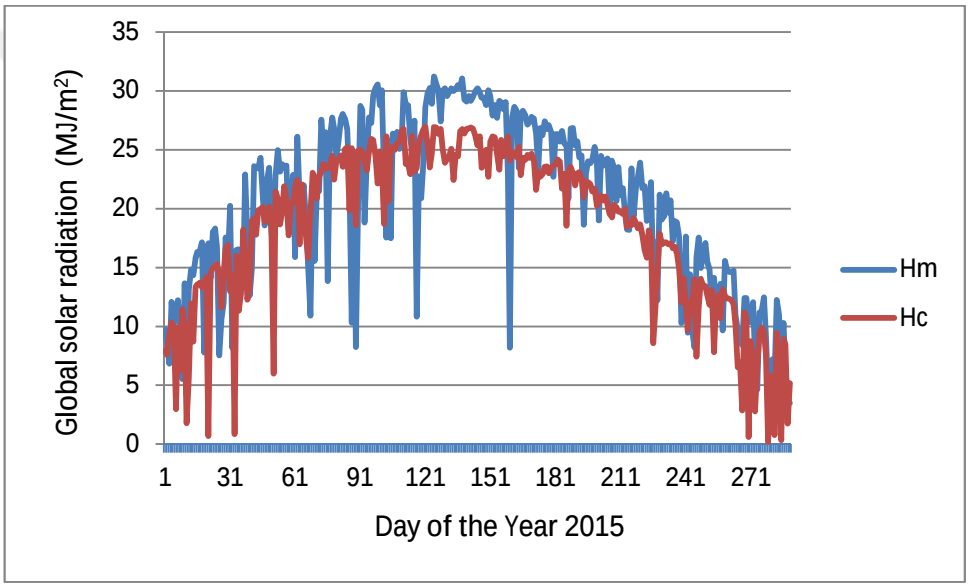


Figure 5.18.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Donatelli and Campbell model for Adana.

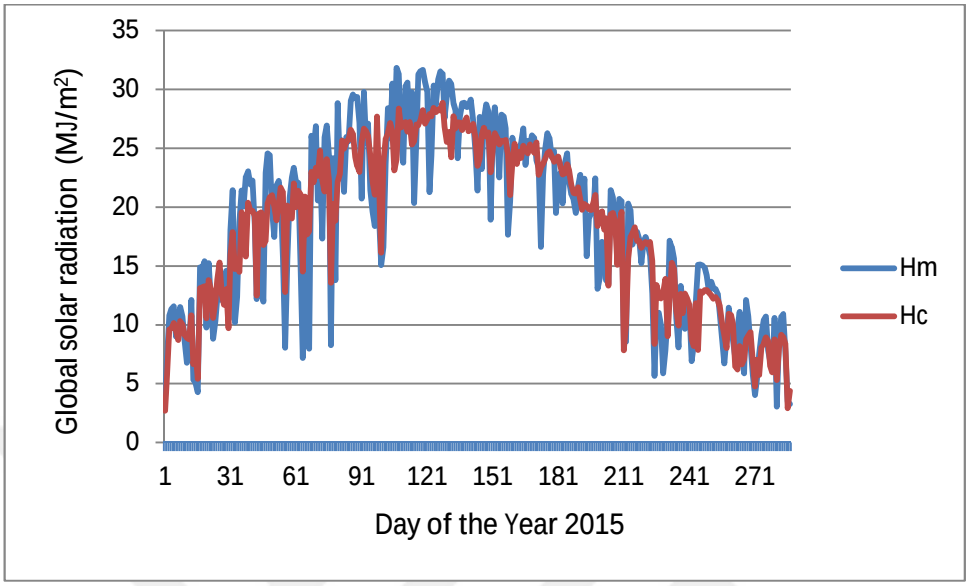


Figure 5.18.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Donatelli and Campbell model for Göksun.

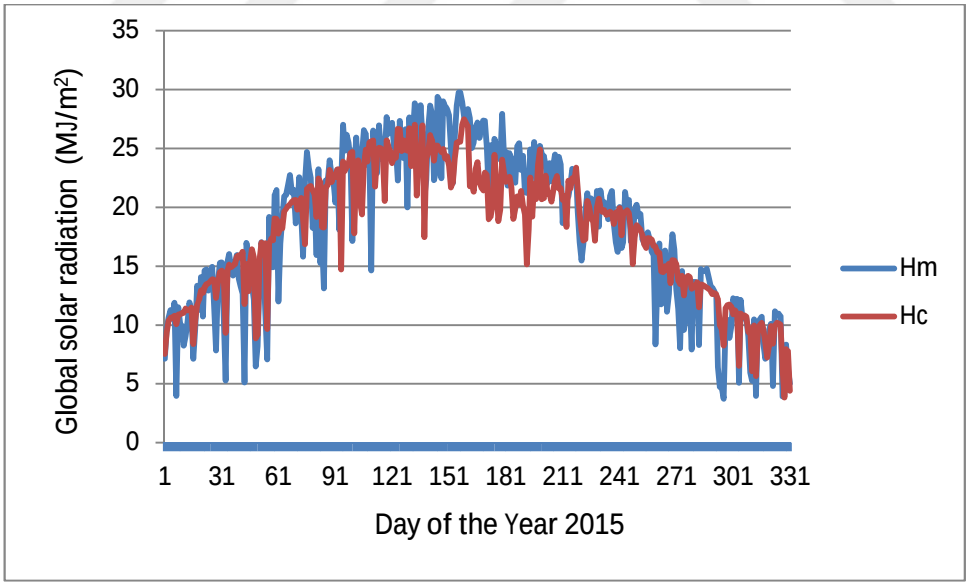


Figure 5.18.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Donatelli and Campbell model for Tarsus.

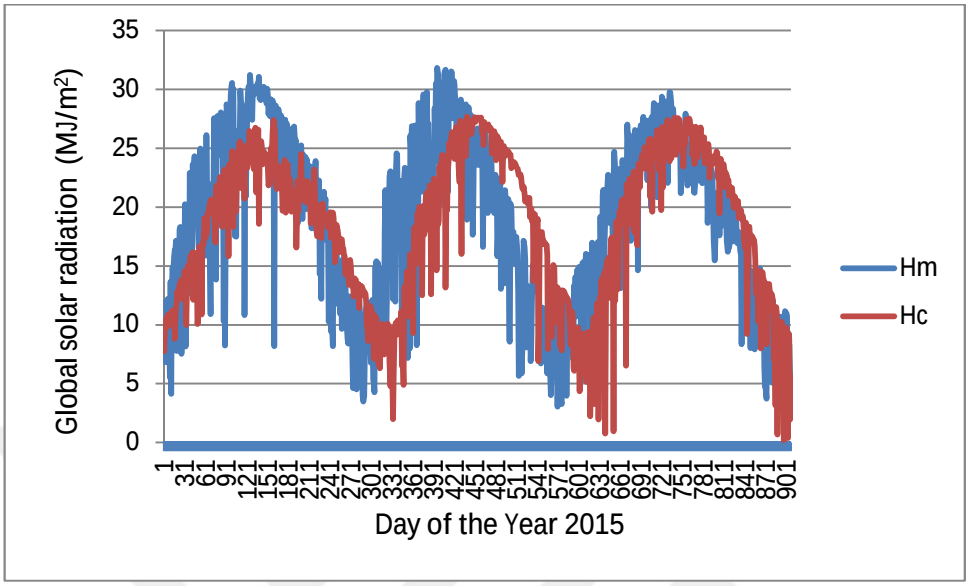


Figure 5.18.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Donatelli and Campbell model for Whole Region.

5.4.2.11. Goodin et al Model

Table 5.33 shows the statistical test and error calculation results of Goodin et al model. According to Table 5.33, MAE values vary as 2.258-2.737. RMSE values change between 2.934 and 3.484. R^2 values lie between 0.769-0.859 and MBE values lie between 0.020-0.657. Gooding et al. model based developed models are also acceptable and suitable for the estimation of global solar radiation in Eastern Mediterranean Region but does not have a superiority to other temperature difference based models developed in this study before. The calculated and measured values of daily global solar radiation are illustrated in Figure 5.19.a, b, c and d.

Table 5.33. The statistical test results of Goodin et al model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.657	2.464	3.094	0.790
Göksun	0.020	2.357	2.945	0.859
Tarsus	0.349	2.258	2.934	0.819
Whole Region	0.472	2.737	3.484	0.769

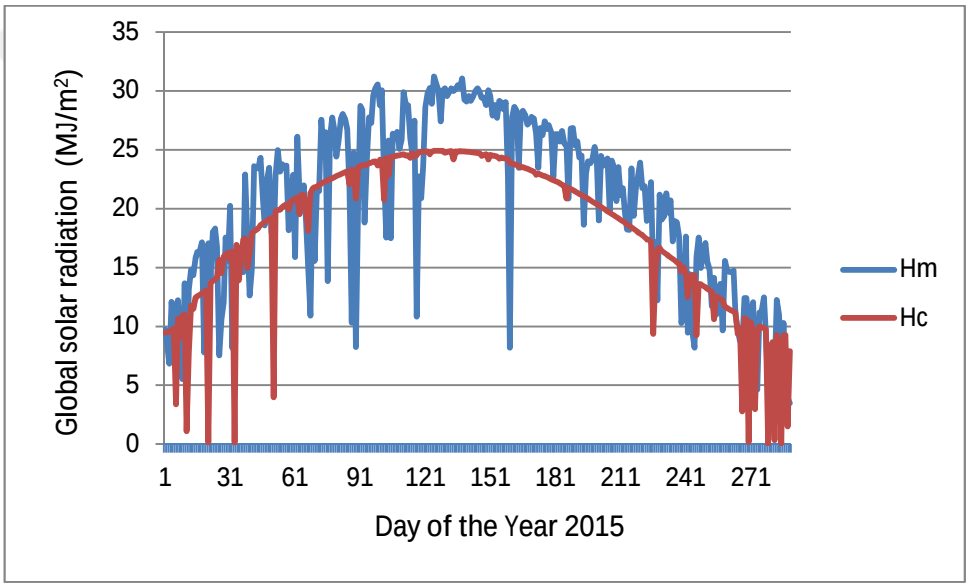


Figure 5.19.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Goodin et al. model for Adana.

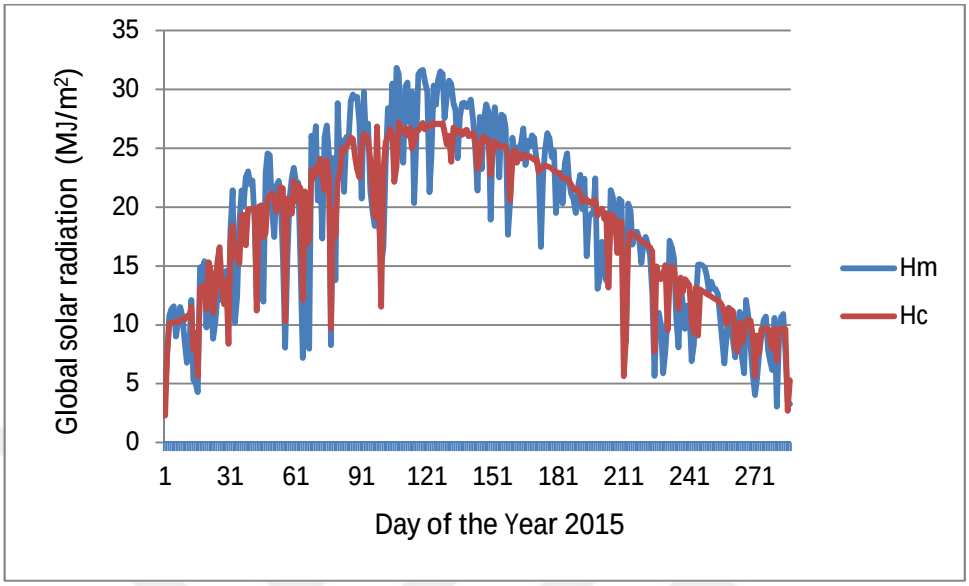


Figure 5.19.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Goodin et al. model for Göksun.

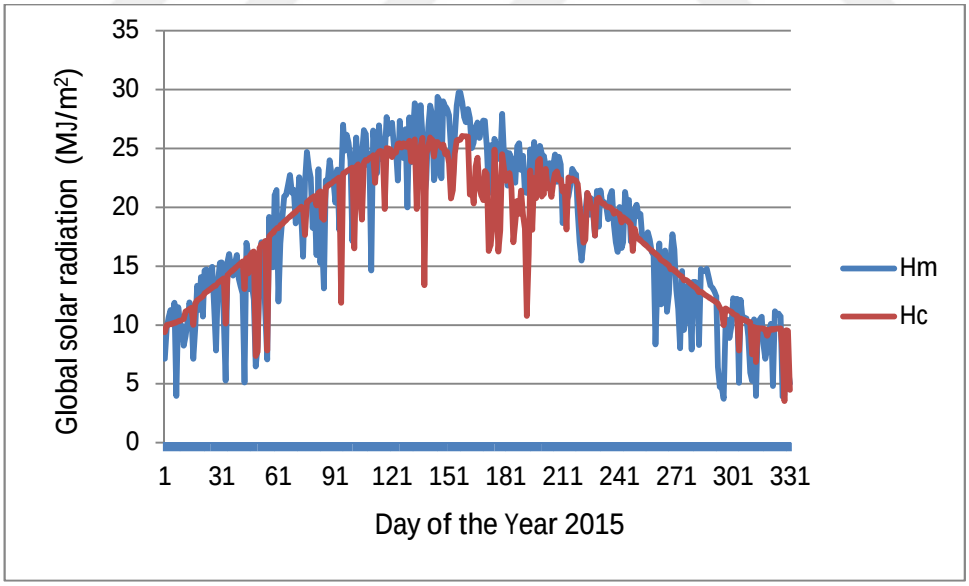


Figure 5.19.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Goodin et al. model for Tarsus.

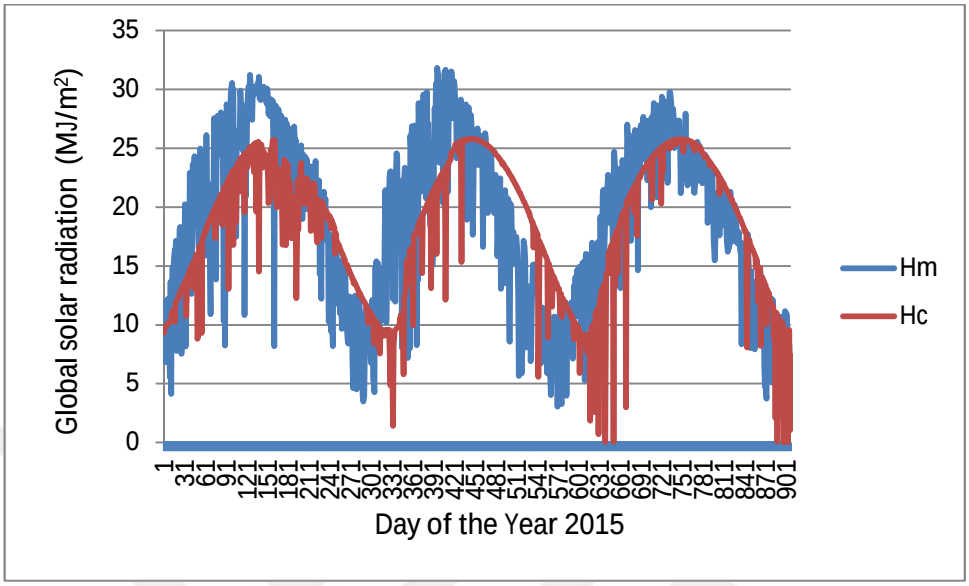


Figure 5.19.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Goodin et al. model for Adana.

5.4.2.12. Mahmood and Hubard Model

The statistical test result and calculated errors of Mahmood and Hubard model is shown in Table 5.34. According to this table MAE values change between 2.884 and 4.298. RMSE values change between 3.759 and 5.314. R^2 values lie between 0.766 and 0.845. MBE values change between 0.569-1.344. Mahmood and Hubard model based developed models are also acceptable and suitable but does not have superiority to other models developed based on temperature difference. The calculated and measured values of daily global solar radiation are illustrated in Figure 5.20.a, b, c and d.

Table 5.34. The statistical test results of Mahmood and Hubard model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	1.344	3.092	3.759	0.838
Göksun	0.569	4.060	4.729	0.845
Tarsus	0.748	2.884	3.806	0.840
Whole Region	0.949	4.298	5.314	0.766

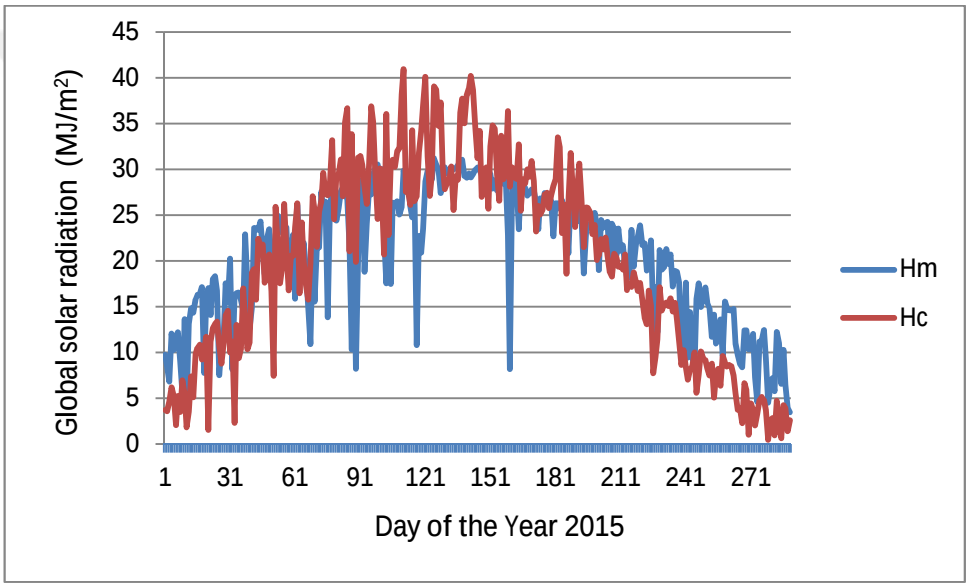


Figure 5.20.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Mahmood and Hubard model for Adana.

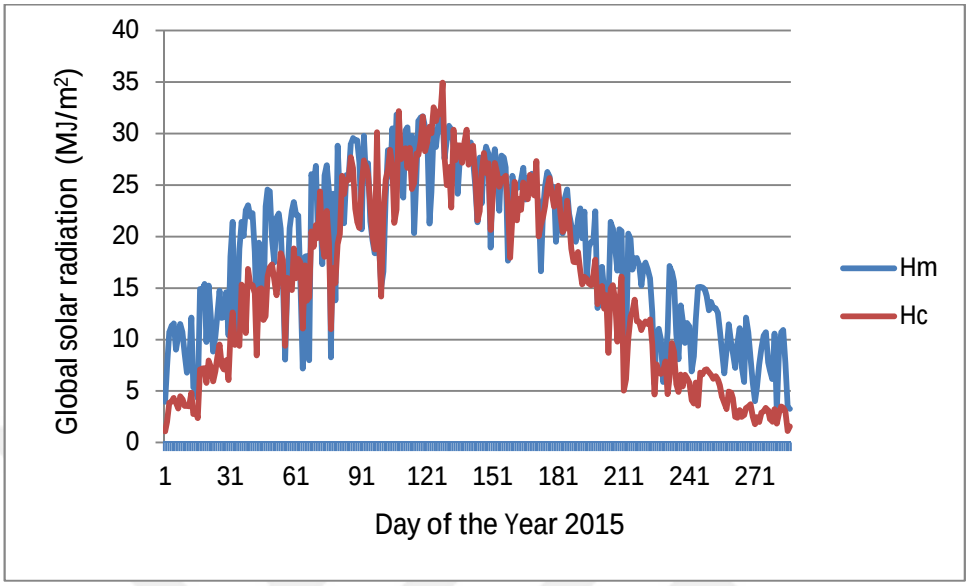


Figure 5.20.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Mahmood and Hubard model for Göksun.

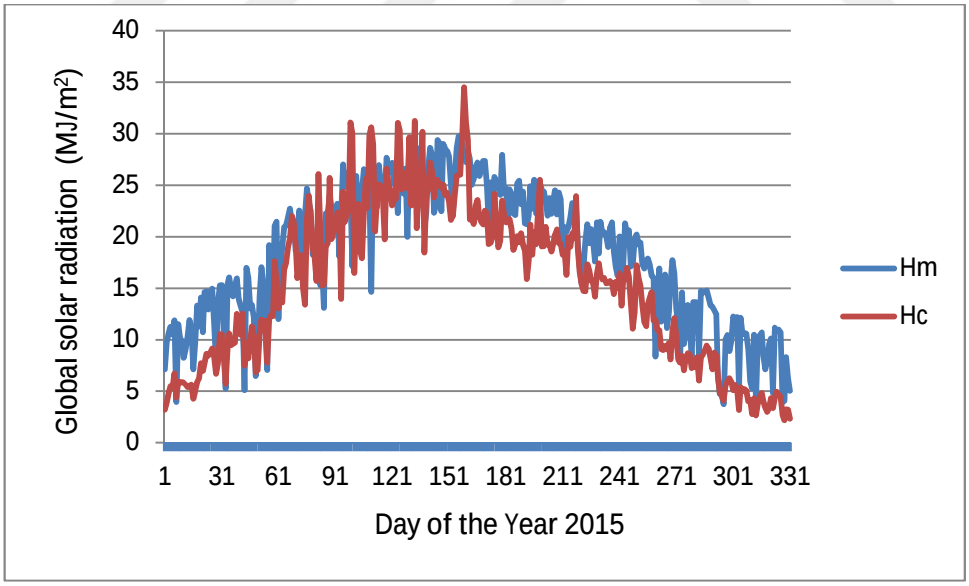


Figure 5.20.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Mahmood and Hubard model for Tarsus.

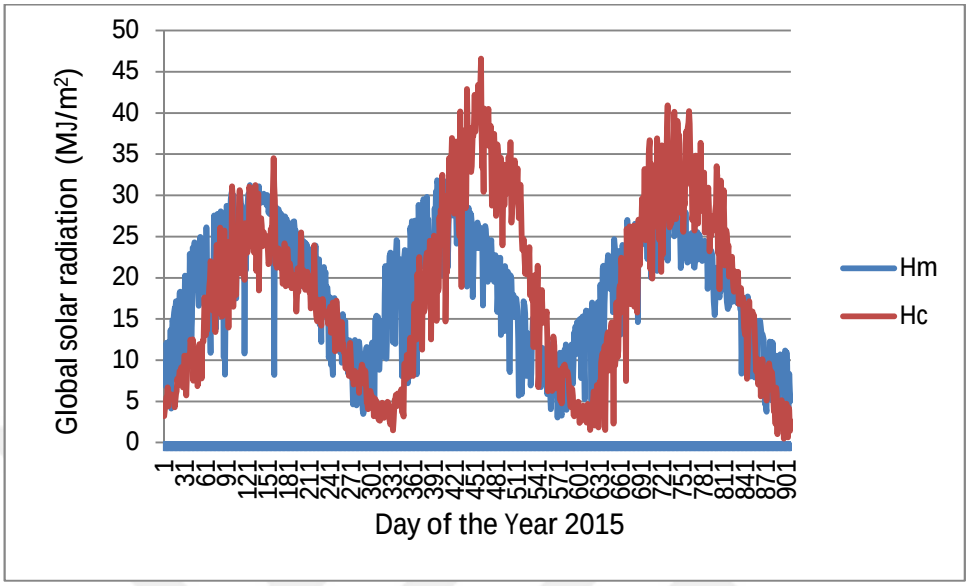


Figure 5.20.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Mahmood and Hubard model for Whole Region.

5.4.2.13 Meza and Varas Model

The statistical test results and calculated errors of Meza Varas model is shown in Table 5.35. MAE values of the model change between 2.144-2.964. RMSE values change between 2.946 and 4.265. R^2 values lie between 0.745-0.814 and MBE values lie between -0.662 and 0.018. These models are acceptable but do not have superiority to other temperature based models as well. The graphical representation of the models are given in Figure 5.21.a, b, c and d.

Table 5.35. The statistical test results of Meza and Varas model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.018	2.964	4.265	0.745
Göksun	-0.662	2.586	3.626	0.814
Tarsus	-0.068	2.144	2.946	0.806
Whole Region	-0.437	2.412	3.482	0.769

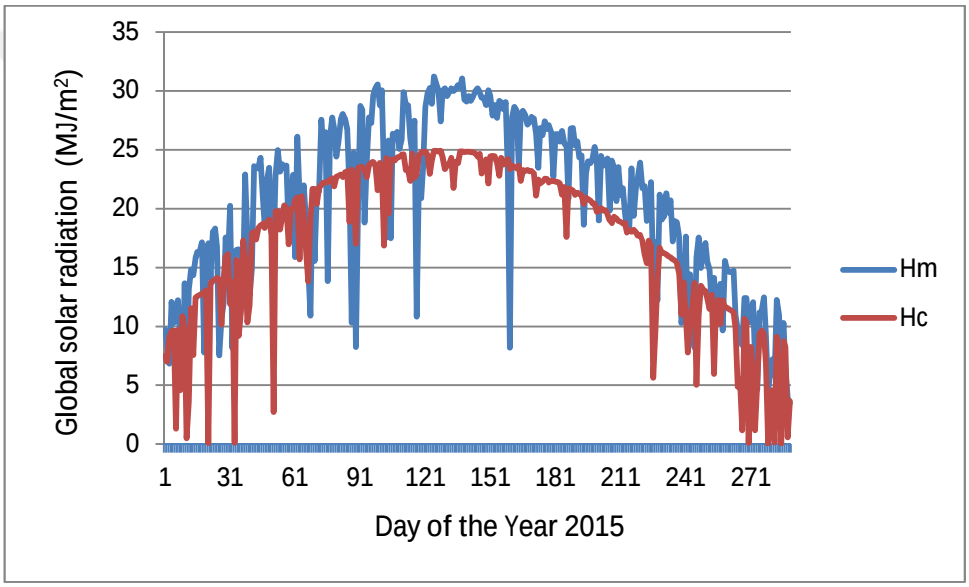


Figure 5.21.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Meza and Varas model for Adana.

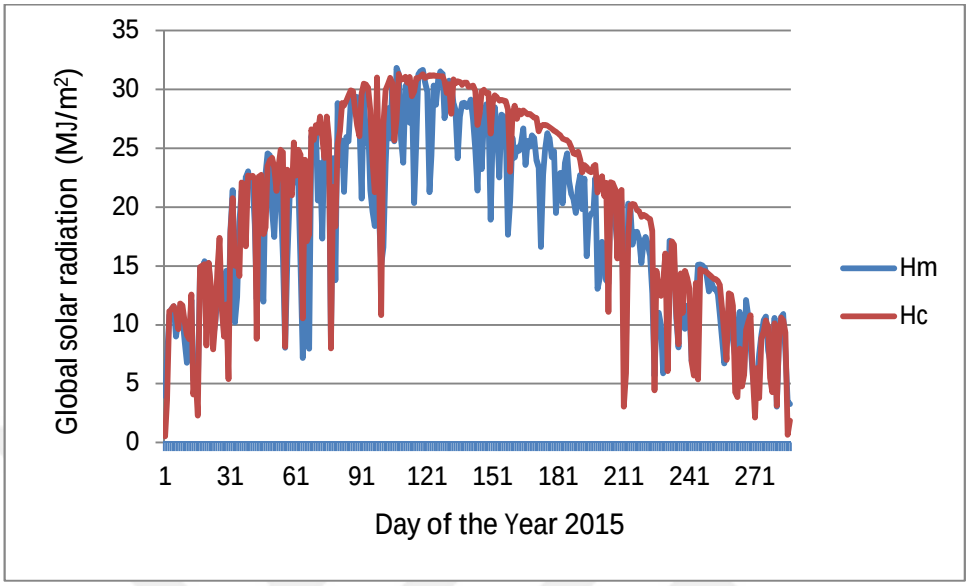


Figure 5.21.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 with model developed based on Meza and Varas model for Göksun.

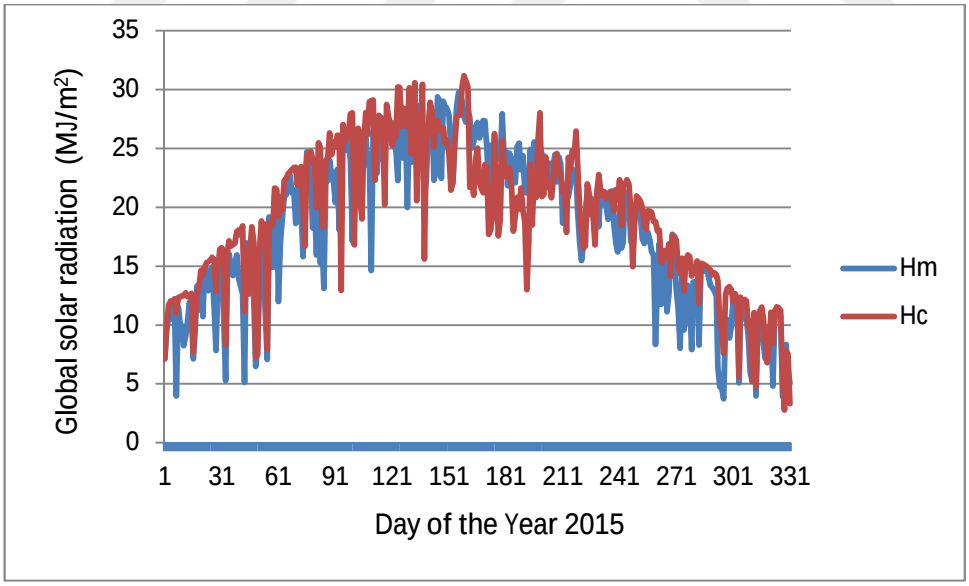


Figure 5.21.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Meza and Varas model for Tarsus.

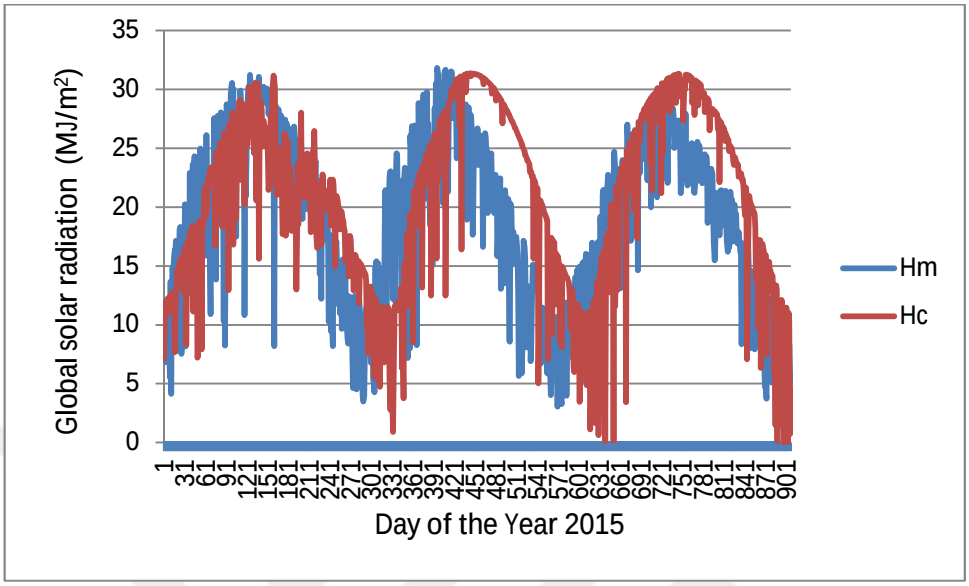


Figure 5.21.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Meza and Varas model for Whole Region.

5.4.2.14. Swartman and Ogunlade Model

The error calculations and statistical test results of Swartman and Ogunlade based model are listed in Table 5.36. The MAE values of the model vary as 1.054-2.291. The RMSE values of the model change between 1.353 and 2.973. R^2 values change between 0.829-0.955. MBE values change between 0.122 and 0.501. According to errors and statistical test result, developed models based on Swartman and Ogunlade models have superiority to all models developed in this study for each station separately and whole together. These results indicates that modelling global solar radiation with sunshine duration and relative humidity together provides better results than modelling global solar radiation with any other meteorological parameters. The graphical representation of calculated and measured values are given in Figure 5.22.a, b, c and d.

Table 5.36. The statistical test results of Swartman and Ogunlade model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.163	1.054	1.353	0.955
Göksun	0.150	1.160	1.623	0.955
Tarsus	0.122	1.223	1.658	0.939
Whole Region	0.501	2.291	2.973	0.829

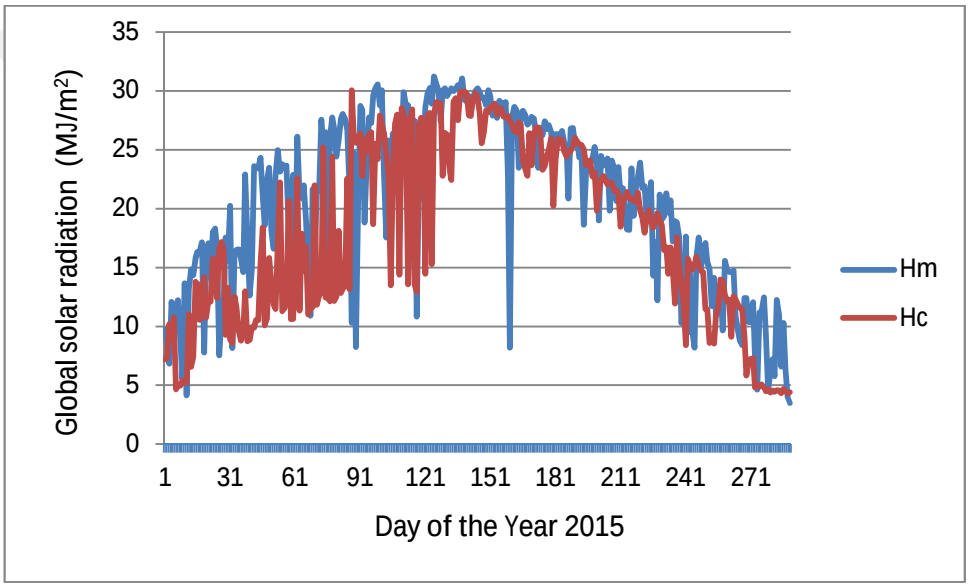


Figure 5.22.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Swartman and Ogunlade model for Adana.

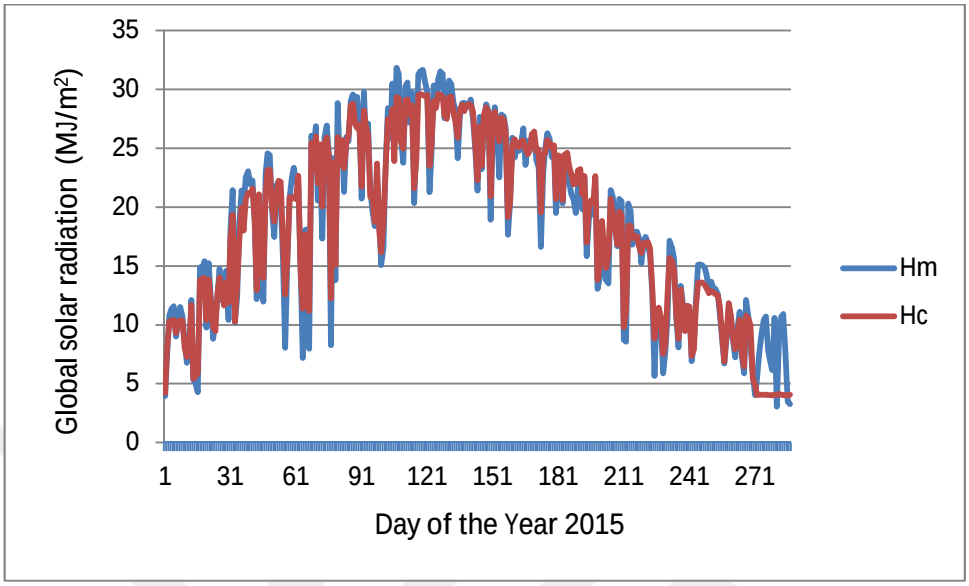


Figure 5.22.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Swartman and Ogunlade model for Göksun.

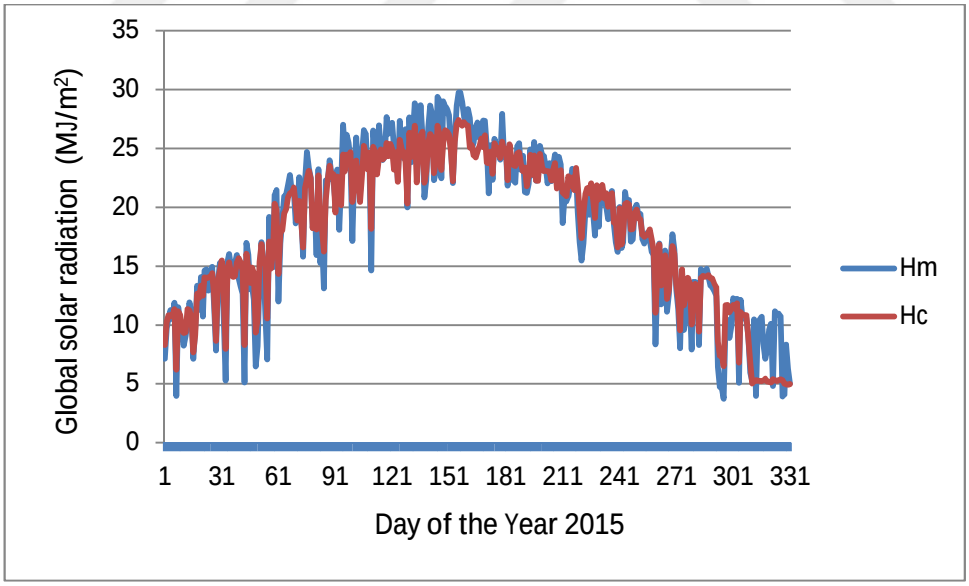


Figure 5.22.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Swartman and Ogunlade model for Tarsus.

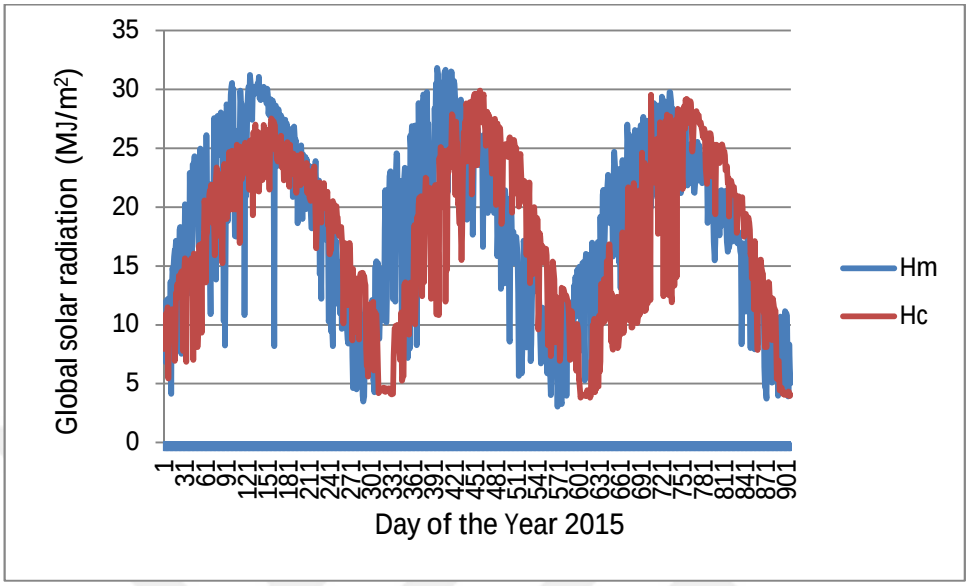


Figure 5.22.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Swartman and Ogunlade model for Whole Region.

5.4.2.15. Weiss et al. Model

Table 5.37 shows the statistical test results and calculated errors of Weiss et al model. According to Table 5.37, MAE values of the model change between 2.385 and 3.525. RMSE values change between 3.169 and 4.476. R^2 values lie between 0.499-0.843. MBE values change between -0.919 and 0.491. Developed models based on Weiss et al. model are proper but not preferable compared with other models developed in this study. The calculated and measured values of daily global solar radiations are illustrated in Figure 5.23.a, b, c and d.

Table 5.37. The statistical test results of Weiss et al model

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.491	3.525	4.476	0.499
Göksun	-0.919	2.413	3.169	0.843
Tarsus	-0.128	2.385	3.193	0.771
Whole Region	-0.342	3.243	4.328	0.638

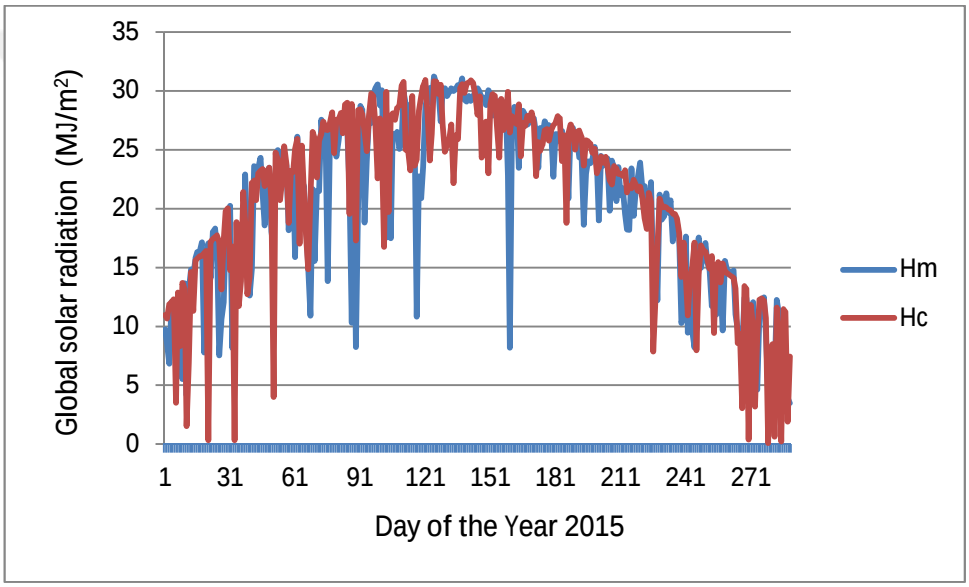


Figure 5.23.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Weiss et al. model for Adana.

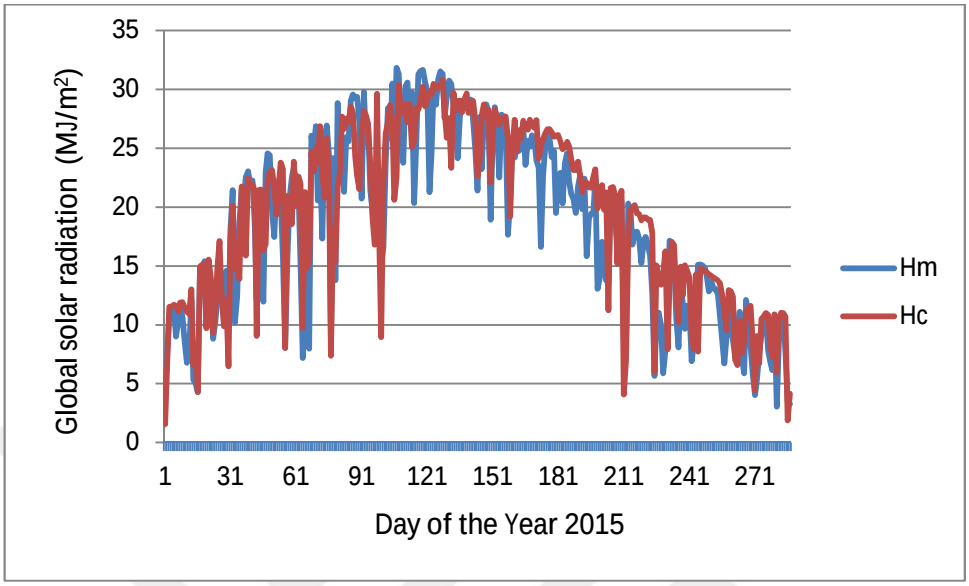


Figure 5.23.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Weiss et al. model for Göksun.

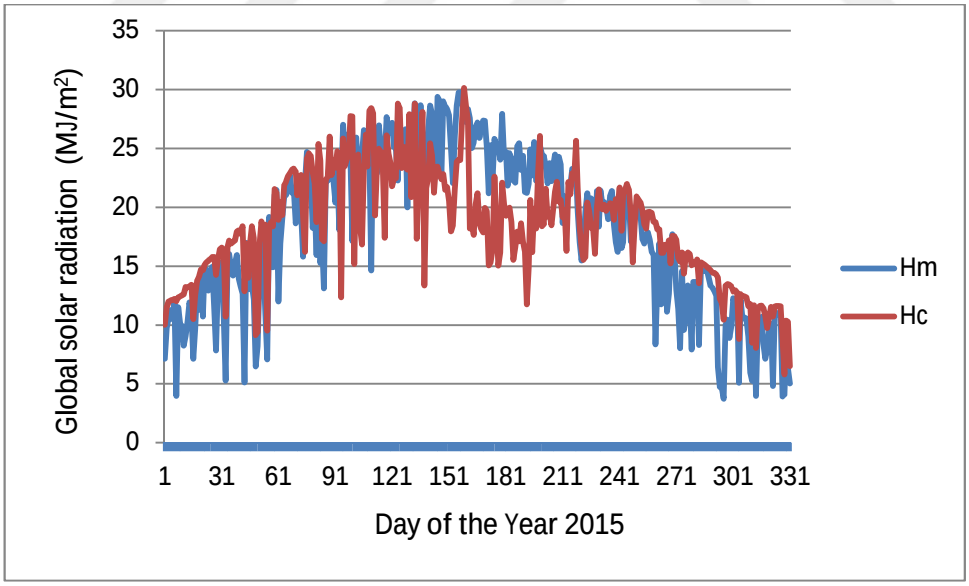


Figure 5.23.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Weiss et al. model for Tarsus.

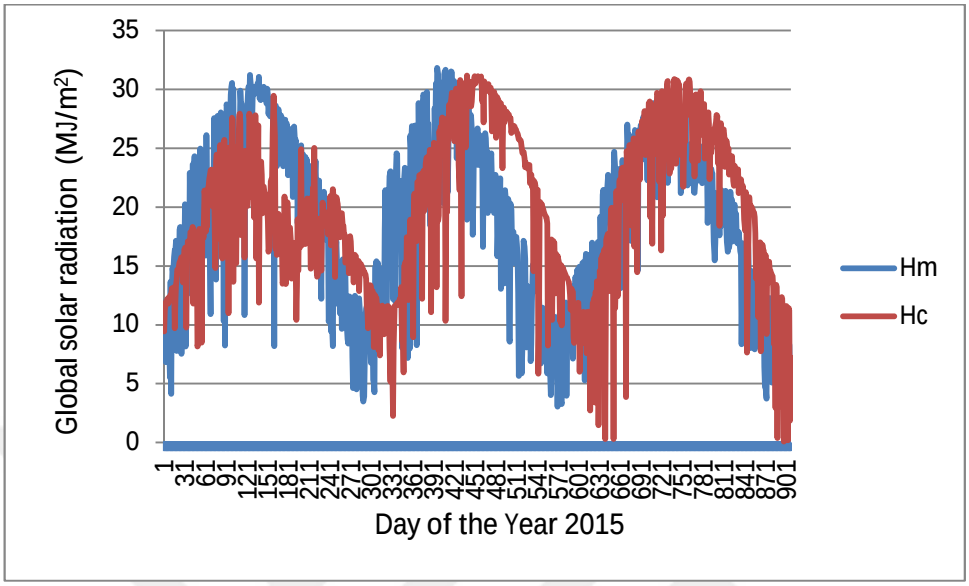


Figure 5.23.d. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Weiss et al. model for Whole Region.

5.4.2.16. Proposed Model 1

The calculated errors and statistical test result of Proposed Model 1 are given in Table 5.38. According to this table, MAE values change between 0.958 and 1.924. RMSE values change between 1.248 and 2.569. R^2 values lie between 0.874 and 0.964. MBE values change between 0.203 and 0.477. Proposed Model 1 developed in this study following Swartman and Ogunlade Model and it gives better results for each station separately and for Whole Region, the errors are lower and coefficient of determination is stronger than Swartman-Ogunlade based models. So, Proposed Model 1 highly recommended for the estimation of daily global solar radiation in Eastern Mediterranean Region. The illustrations of the errors between measured and calculated values are given by Figure 5.24.a, b, c and d.

Table 5.38. The statistical test results of Proposed model 1

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.322	0.958	1.248	0.964
Göksun	0.203	1.097	1.549	0.960
Tarsus	0.320	1.192	1.569	0.950
Whole Region	0.477	1.924	2.569	0.874

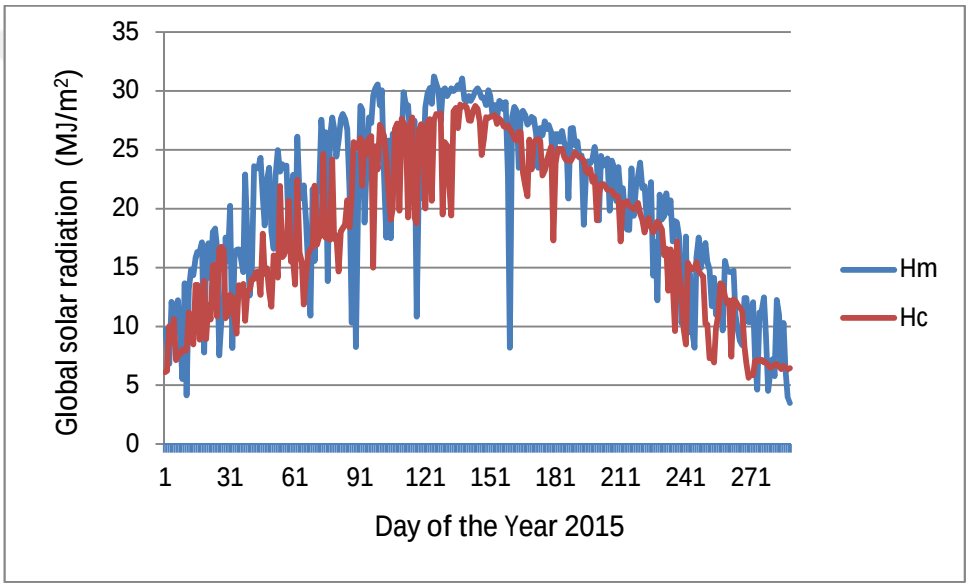


Figure 5.24.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 1 for Adana.

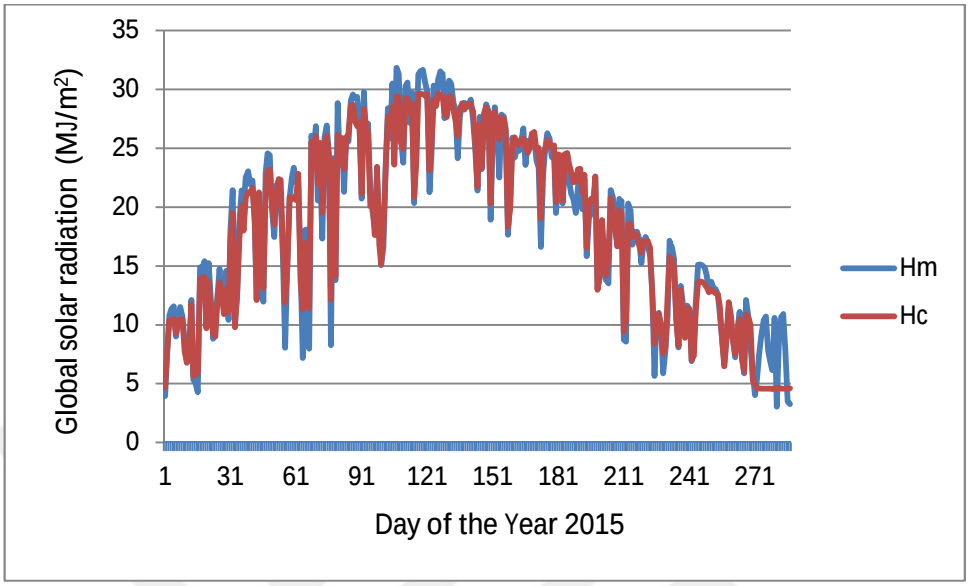


Figure 5.24.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 1 for Göksun.

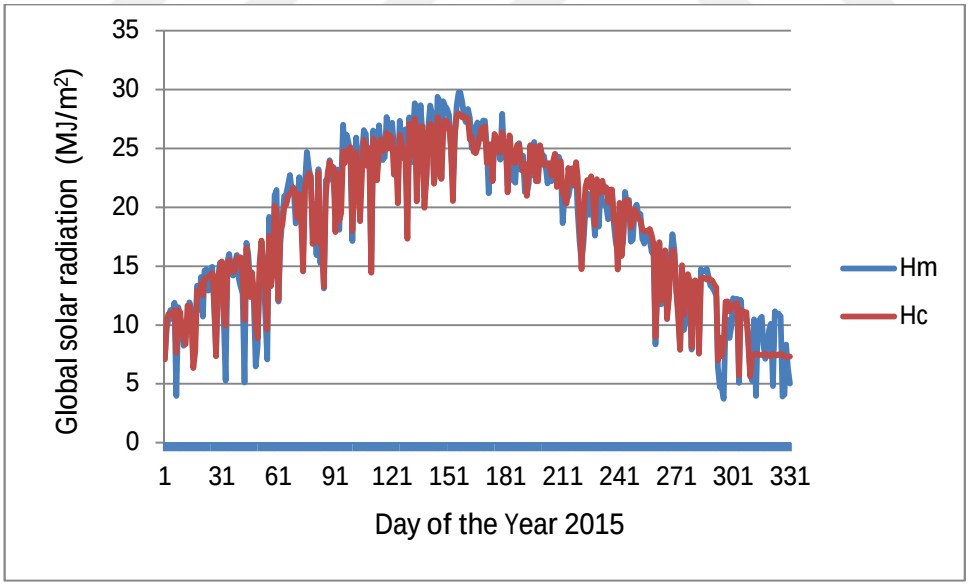


Figure 5.24.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 1 for Tarsus.

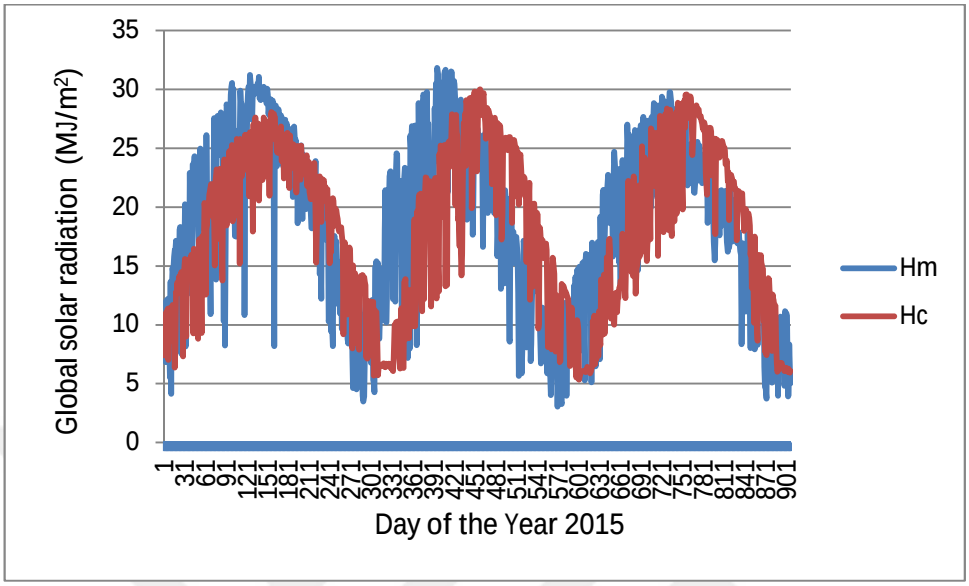


Figure 5.24.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 1 for Whole Region.

5.4.2.17 Proposed Model 2

The calculated errors and statistical test results of Proposed Model 2 is shown in Table 5.39. The MAE values of proposed model 2 change between 0.947-1.710. RMSE values change between 1.183 and 2.369. R^2 values lie between 0.890 and 0.965. MBE values vary as (-0.007)-0.290. Proposed Model 2 also has superiority to any other models developed based on any meteorological parameters. It is also recommended for the estimation of daily global solar radiation in Eastern Mediterranean Region. Proposed Model 2 gives better results than Proposed Model 1 but Proposed Model is simpler than Proposed Model 2. The difference between calculated values with Proposed Model 2 and measured values of daily global solar radiation for the year of 2014 are illustrated in Figure 5.25.a, b, c and d.

Table 5.39. The statistical test results of Proposed model 2

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Adana	0.142	0.947	1.183	0.965
Göksun	0.184	1.086	1.513	0.961
Tarsus	-0.007	1.074	1.428	0.955
Whole Region	0.290	1.710	2.369	0.890

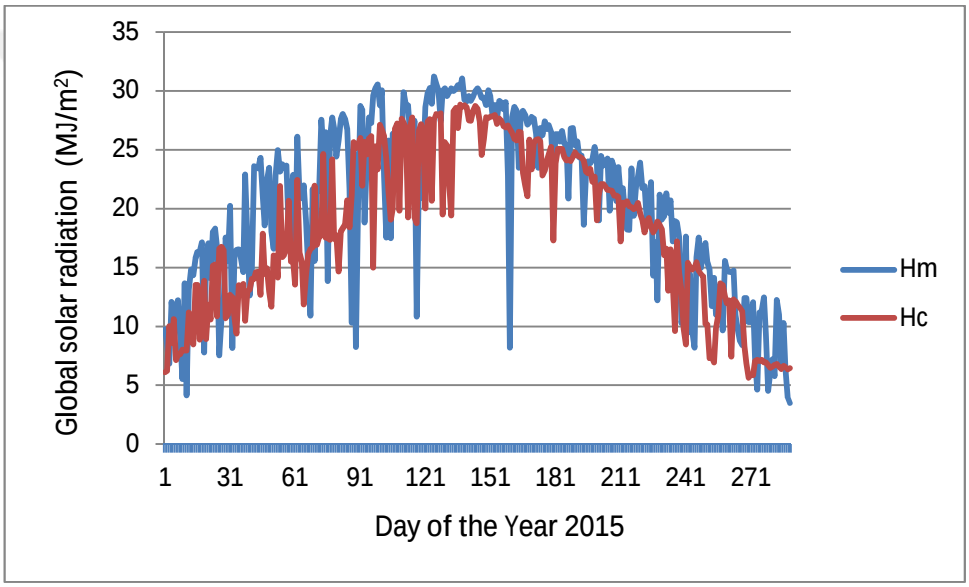


Figure 5.25.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 2 for Adana.

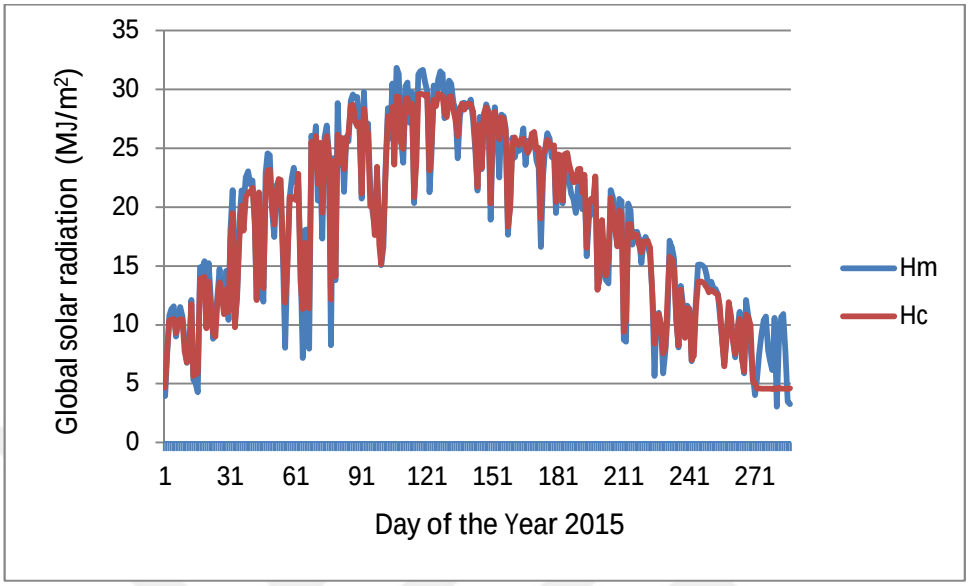


Figure 5.25.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 2 for Göksun.

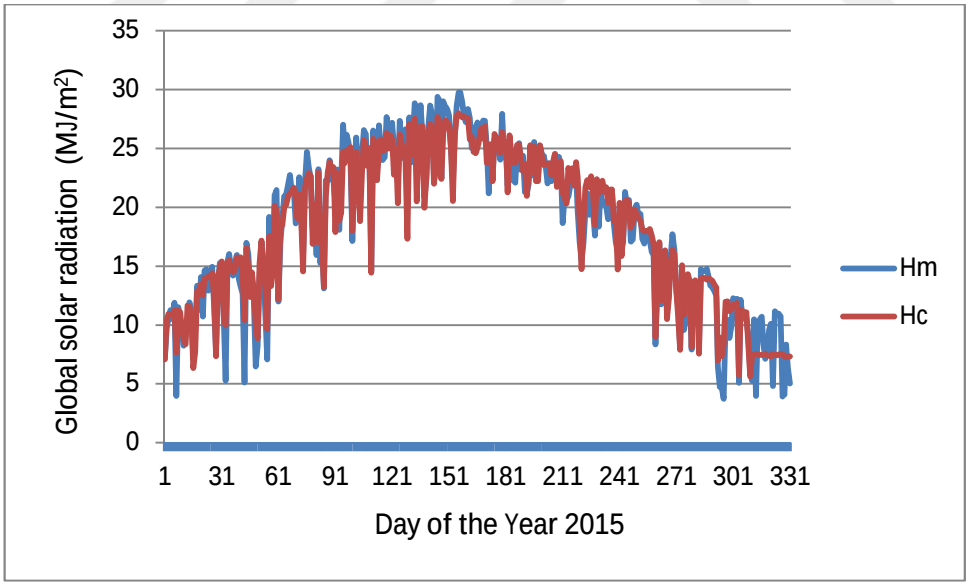


Figure 5.25.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 2 for Tarsus.

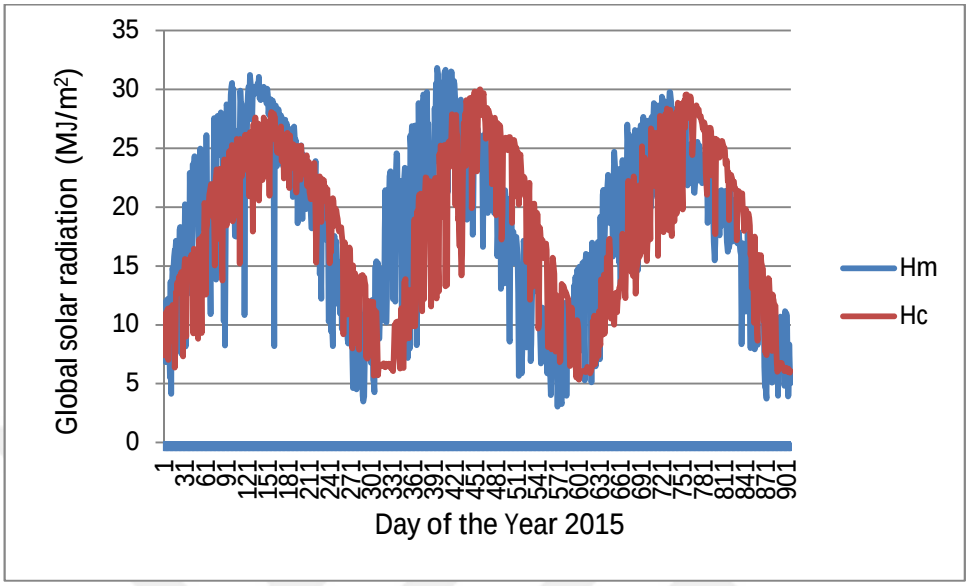


Figure 5.25.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2014 based on Proposed Model 2 for Whole Region.

5.4.2.18 ANN Model

The best inputs of the neural network were determined as mean temperature, relative humidity, sunshine duration, maximum possible sunshine duration, day of the year, latitude, longitude, altitude and calculated value of extraterrestrial solar radiation. 9 years data was used for training and 2 years data was used for testing the model. The most accurate results were obtained with LM learning algorithm. Tansig and purelin transfer functions are trained

MAE, MBE, RMSE and R^2 values are given in Table 5.40 and comparison of measured and estimated values are given in Figures 6.26. a, b and c. The results indicate that using the ANN model is an applicable choice for modelling global solar radiation. The ANN model is trained with whole dataset of region. The MAE value is -0.429. RMSE value is 1.487 varied as 0.504. According to Table 52, R^2 value is 0.961 and MBE value is (-0.429). These errors are very low. In order to these low errors, ANN model can be alternative to model global solar radiation

with parametric models. Figure 5.26.a, b, c and d shows the illustration of the errors between measured and calculated values.

Table 5.40. Statistical results of daily global solar radiation with ANN.

Station	**Statistical test results**			
	MBE	**MAE**	**RMSE**	**R^2**
Whole Region	-0.429	0.997	1.4879	0.961

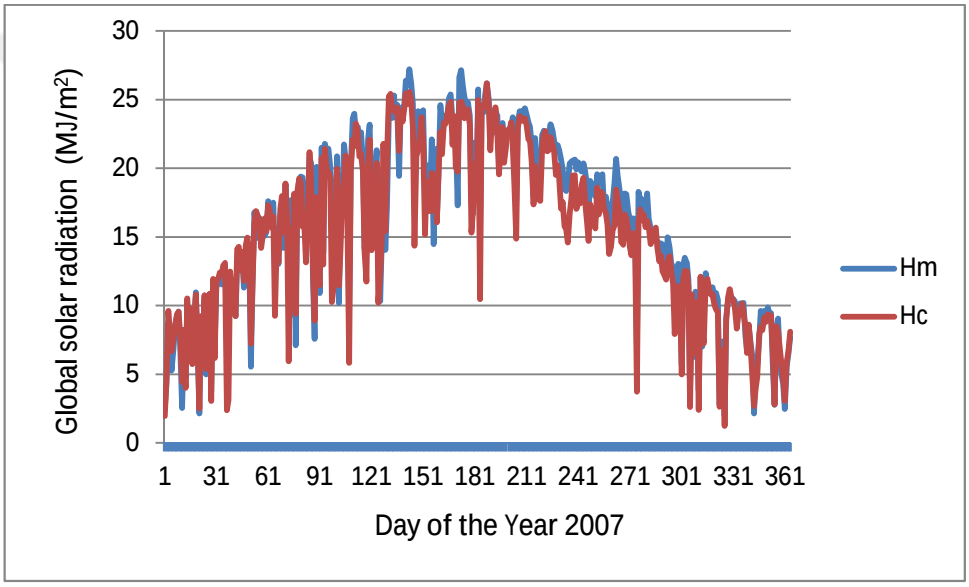


Figure 5.26.a. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2007 with model developed with ANN for Adana.

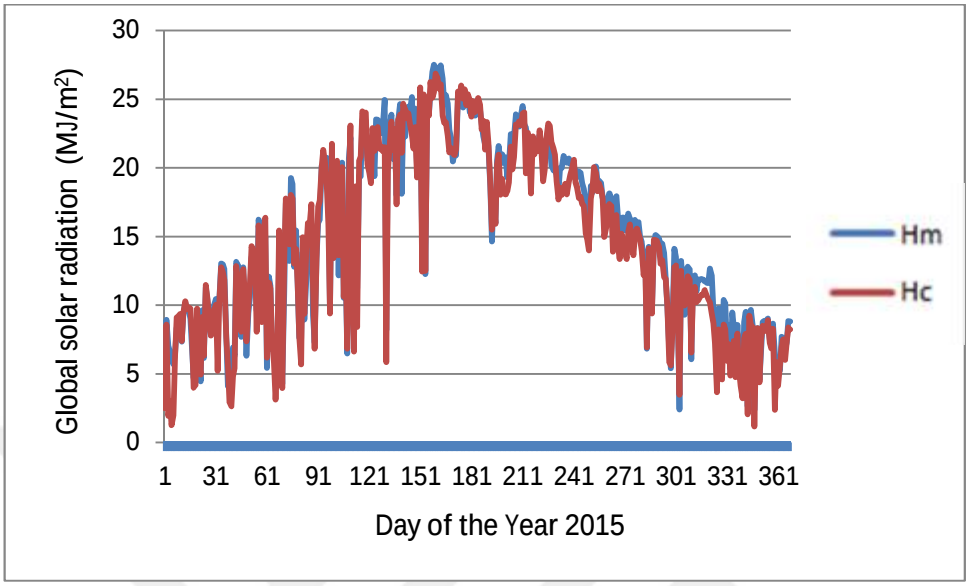


Figure 5.26.b. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2007 with model developed with ANN for Mersin.

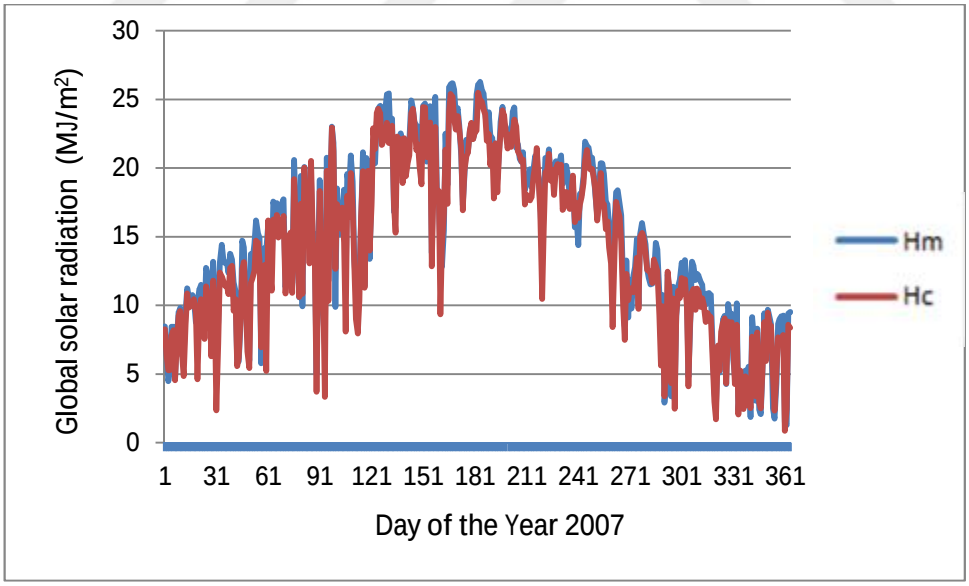


Figure 5.26.c. Graphical representation of measured and estimated values of daily global solar radiation along the year of 2007 with model developed with ANN for Kahramanmaras.

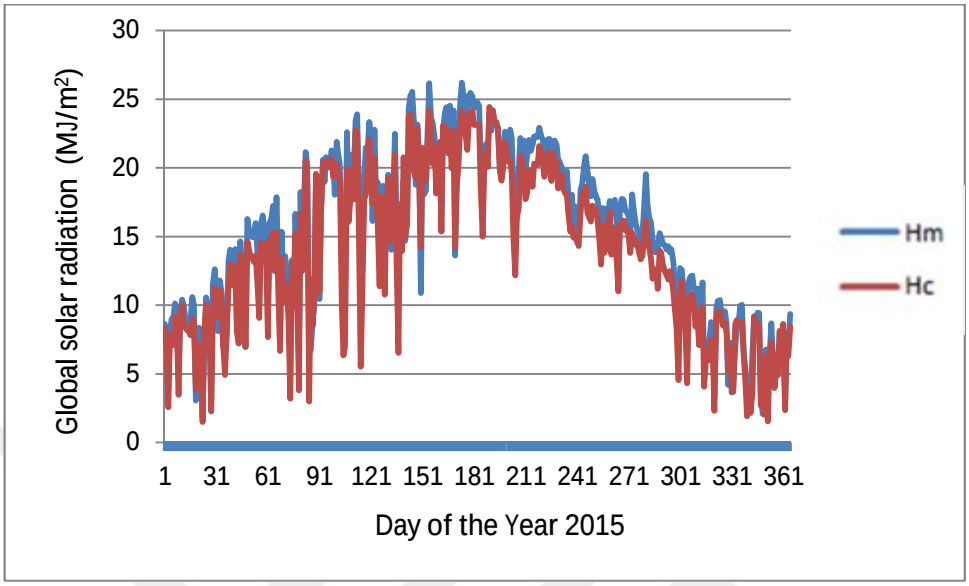


Figure 5.26.d. Graphical representations of measured and estimated values of daily global solar radiation along the year of 2007 with model developed with ANN for Antakya.

5.4.2.19. CMSAF Model

In order to compare CMSAF Satellite model, the data which is downloaded from CMSAF official website for stations which are in the field of interest of this study. The measured values of global solar radiation data and the CMSAF's data are compared by same statistical test result and error calculation methods which are used in this study. Table 5.41 shows the statistical results of CMSAF model. The MAE values of CMSAF model change between 1.890 and 3.278. RMSE values change between 2.791 and 4.753. R2 values lie between 0.714 and 0.934. MBE values vary as (-2.862)-0.0029. CMSAF Models generated database are suitable for Eastern Mediterranean Region. Errors between CMSAF data and measured data can be seen on the graphs given in Figure 5.27.a, b and c. It is not possible to calculate errors for Whole Region because there is no Whole Region database provided by CMSAF.

Table 5.41. The statistical test results of CMSAF model

Station	Statistical test results			
	MBE	MAE	RMSE	R^2
Adana	2.149	2.188	2.751	0.811
Göksun	0.391	1.370	1.892	0.834
Tarsus	1.611	1.742	2.266	0.934

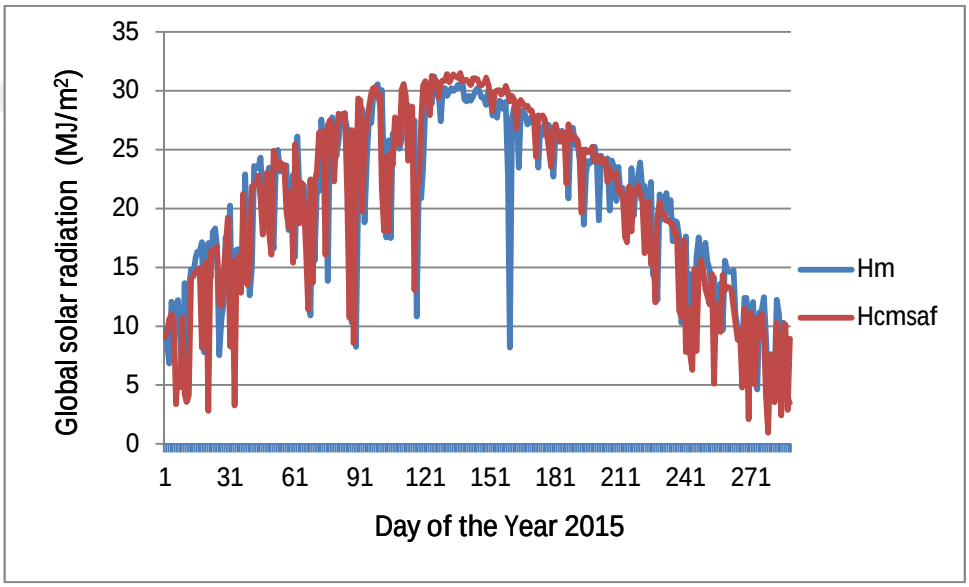


Figure 5.27.a. Graphical representation of measured daily global solar radiation and CMSAF daily global solar radiation data along the year of 2014 for Adana.

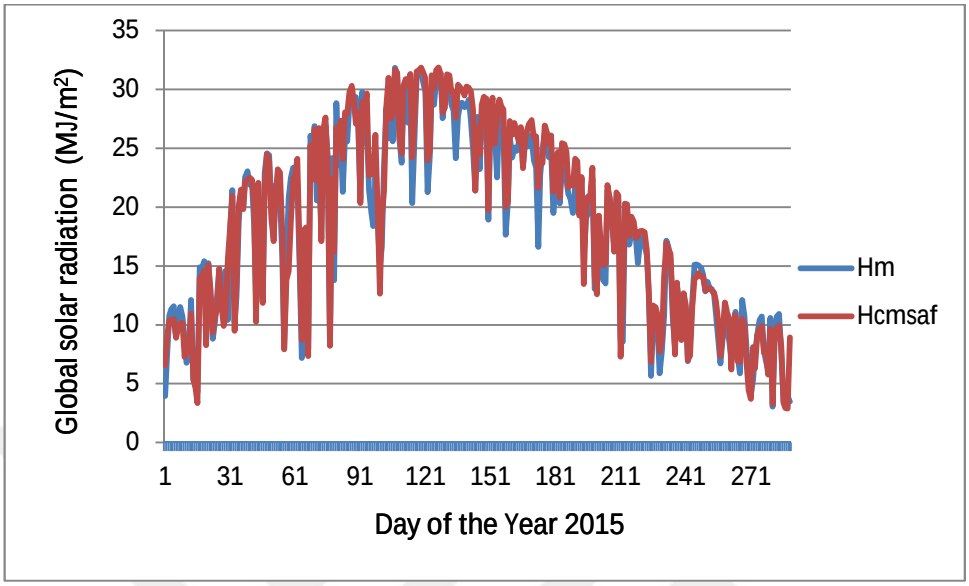


Figure 5.27.b. Graphical representation of measured daily global solar radiation and CMSAF daily global solar radiation data along the year of 2014 for Göksun.

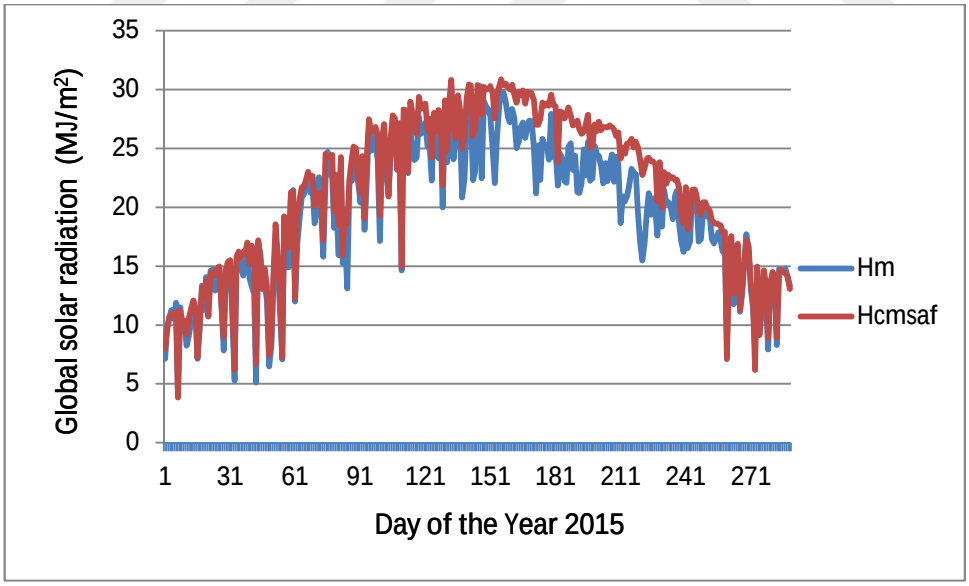


Figure 5.27.c. Graphical representation of measured daily global solar radiation and CMSAF daily global solar radiation data along the year of 2014 for Tarsus.

5.5. Summary

This chapter demonstrates the results of parametric models which are based on different meteorological parameters. Results illustrate the performance of each model separately.

Many models which are already existed in the literature are validated and evaluated. Angström-Prescott widely used models are trained for monthly mean daily global solar radiation modelling and daily mean global solar radiation modelling. Also, ANN modelling technique is trained for monthly mean daily and daily global solar radiation modelling. ANN models give more accurate results. On the other hand; to find an alternative to ANN modelling techniques for developing a consistent model, different meteorological parameters are handled as an estimators for daily global solar radiation. Modelling global solar radiation based on sunshine duration is a good alternative according to statistical test results. However sunshine duration is not being measured in some meteorological stations. In order to prevent the restrictive meteorological measurements in these stations, many different models developed for modelling global solar radiation with different kind of meteorological parameters. It is observed that temperature difference is another good option to use as an estimator for daily global solar radiation. Statistical test results are performed to visualize the models performances.

In order to obtain better results and minimize the errors which are obtained by parametric models, two new parametric models are performed and low errors are obtained with these parametric models. These errors approximate the errors obtained with ANN methods. Sunshine duration and relative humidity handled together as estimators for daily global solar radiation in developed models.

The next chapter presents the main results and concluded remarks of this thesis.

6. CONCLUSIONS AND RECOMMENDATIONS

Sunshine duration, temperature and relative humidity can be measured in all around the world with measurement devices which are not expensive. There is no need to specialist to use these devices while the station is in operation as well. However, it is difficult to measure global solar radiation in all meteorological stations because of the cost of the devices and their need of calibration and maintenance. On the other hand, there is short term or long term missing data in the database of stations which global solar radiation measurement is being made in. In this case, modelling global solar radiation is becoming an important issue. It is seen that there are too many studies in the literature that global solar radiation is modelled in order to eliminate the need of global solar radiation measurement. According to error calculation of the results of the models, it can be seen that these models are very useful to create a database for the stations which global solar radiation is not being made and to fill the gaps in the stations which global solar radiation measurement is being made but still with lack. In order to visualize the whole models validated in this thesis results for whole region which are obtained for each model separated are given in following table;

One of the main objectives of this thesis is to calculate the global solar radiation from sunshine duration. A general model is needed to estimate global solar radiation due to the rare availability of global solar radiation measurement in Eastern Mediterranean Region. Based on the radiation data and sunshine hours data, linear, quadratic and cubic equations are generated and also investigation on monthly mean daily regression models have been obtained for the region. Statistical test results show that Angström Prescott linear, quadratic and cubic models best suits in Adana which most professional meteorological measurements being made in. In general models, model accuracy is getting lower. A comparison of the estimated and measured values is shown by figures. According to results seen from the figures, models which are generated for each city separately are more

accurate than the models which are generated for whole region. However, general models are also acceptable with obtained positive R^2 values. Best fitted Angström-Prescott based model to estimate monthly mean daily global solar radiation for whole region is cubic model which is also known as Bahel model with a with 0.090 MBE, 3.60 MAE, 4.703 RMSE and 0.541 R^2.

Table 6.1. The comparison of whole trained models

Station	**MBE**	MAE	RMSE	**R^2**
ANN	**-0.429**	0.997	1.4879	**0.961**
Proposed model 2	**0.290**	1.710	2.369	**0.890**
Proposed model 1	**0.477**	1.924	2.569	**0.874**
Bristow - Campbell	**0.308**	2.033	2.651	**0.856**
Bahel et al.	**0.368**	1.923	2.778	**0.850**
Antonanzas et al	**0.141**	2.092	2.850	**0.837**
Akınoğlu and Ecevit	**0.574**	2.068	2.962	**0.836**
Swartman-Ogunlade	**0.501**	2.291	2.973	**0.829**
Donatelli-Campbell	**0.251**	2.361	3.130	**0.806**
Meza-Varas	**-0.437**	2.412	3.482	**0.769**
Goodin et al	**0.472**	2.737	3.484	**0.769**
Hunt	**0.174**	2.638	3.424	**0.766**
Hargraves-Samani	**0.426**	2.678	3.462	**0.766**
Annandale et al	**0.426**	2.678	3.462	**0.766**
Mahmood-Hubard	**0.949**	4.298	5.314	**0.766**
Abraha and Savage	**-0.495**	2.689	3.783	**0.743**
Angström-Prescott	**0.652**	2.831	3.807	**0.719**
Weiss et al	**-0.342**	3.243	4.328	**0.638**

In order to obtain lower errors than errors obtained with Angström-Prescott model based parametric models, an ANN model is developed for modelling monthly mean global solar radiation with high accuracy for Mersin, Adana, Kahramanmaras and Antakya. Measured data of monthly average daily global solar radiation is compared with the calculated data by different ANN models. A number of various input parameters are introduced and tested in the structure of ANN model. In order to determine the optimal general ANN model different combination of input parameters are trained with different number of hidden layers and different algorithms. The obtained results indicate that the most relevant combinations of input variables are monthly mean temperature, monthly mean sunshine duration, month and altitude. On the other hand, it is determined that the most proper neuron the numbers in hidden layer is 20. Effects of these input parameters and the number of neurons are tested by using statistical analyses methods namely MAE, MBE, RMSE R^2 and R (only used for training stage). The validation results indicate that the developed ANN model can be alternative to the traditional Angström-Prescott based estimation models with satisfactory accuracy. The minimum and maximum MAE values are 0.450 and 0.502 respectively. RMSE value is varied as 0.504 and 1.573. R^2 values lie between 0.983 and 0.998. MBE values change between (-0.454) and 0.249. These errors are lower than the errors obtained with Angström-Prescott linear, quadratic and cubic regression model. On the other hand, ANN results change in each time model trained. This is the reason of searching most accurate parametric model. Briefly, ANN gives accurate results than Angström-Prescott based models but because of its 'black box' methods which it is know outputs and inputs but not known the internal working principe, a parametric model which closes to accuracy of ANN model is searched in this thesis.

As another main objective of this thesis, Angstrom-Prescott method which is not used to develop models for the study area before is used and new daily global solar radiation equations are developed for these stations. Furthermore, an ANN

model is developed by using long term data of study area. A comparison between these models is made by statistical error calculation methods. It is shown in this thesis that all developed Angström-Prescott model based daily global solar radiation models gives satisfactory results for each city separately. However, these results are getting lower for general models. These results can be supported by R^2 value of the models as well.

The MBE value for whole region with Angström-Prescott cubic model is 0.368, MAE is 1.923, RMSE is 2.778 and R^2 is 0.850 while the MAE value is 0.997, RMSE value is 1.487, R^2 value is 0.961 and MBE value is (-0.429) for ANN model. Modelling daily global solar radiation with more than one parameter by using ANN gives accurate results than parametric models based on errors and R^2 values.

Another main objective of this thesis is to calculate the global solar radiation from various meteorological variables such as air temperature, relative humidity and precipitation. A general formula can be useful to model global solar radiation for filling gaps of existing time series and to model it due to the rare availability of global solar radiation measurement and lack of database in Eastern Mediterranean Region. Based on the radiation data and other meteorological data, 12 different models which are based on other meteorological parameters than sunshine duration are evaluated and all the coefficients of these models are determined to reach the accurate results. On the other hand, two novel models for modelling global solar radiation from sunshine duration and relative humidity are proposed. According to the all error calculation's results such as MBE, MAE and RMSE and graphics that are drawn to compare model results with ground measurements, best results are obtained with Proposed Model 1 and Proposed Model 2 both for each station separately and for whole study area. However, Proposed Model 1 is simplier than Proposed Model 2. Therefore, Proposed Model 1 is suggested for modelling daily global solar radiation in Eastern Mediterranean Region. This equations with given coefficients can be used for modelling the

global solar radiation in areas where the global solar radiation measurement is not available and for filling gaps in database where the global solar radiation measurement is available but with missing data for a while. However Proposed Model 1 also gives lower errors than the models suggested before and evaluated in this thesis such as Angström-Prescott based models, so these model is also suggested to be trained in other studies.

On the other hand, Bristow and Campbell model with its best fitted coefficients is best suited for the region while daily global solar radiation is modelled with temperature difference with 0.308 MBE, 2.033 MAE, 2.651 RMSE and 0.856 R^2. Modelling global solar radiation with temperature difference is another important option for the region because of rare availability of sunshine duration measurement. So, Bristow and Campbell model based developed models can be alternative for the stations in the study area which sunshine duration measurement is not available. However, Proposed Model 1 best fits following ANN model for the stations which sunshine duration measurement is available with the MBE values change between 0.203 and 0.477, MAE values change between 0.958 and 1.924, RMSE values change between 1.248 and 2.569 and finally R^2 values lie between 0.874 and 0.964. MBE. Therefore, Proposed Model 1 is offered for modelling daily global solar radiation in Eastern Mediterranean Region.

REFERENCES

Abdalla, YAG., 1994. New correlation of global solar radiation with meteorological parameters for Bahrain. International Journal of Solar Energy, 16, 111–120.

Abraha, MG., Savage, MJ., 2008. Comparison of estimates of daily solar radiation from air temperature range for application in crop simulations. *Agricultural and Forest Meteorology*, 148, 401–16.

Adaramola, MS., 2012. Estimating global solar radiation using common meteorological data in Akure, Nigeria. Renewable Energy, 47, 38–44

Agbo, GA., Ibeh, GF., Ekpe, JE., 2012. Estimation of global solar radiation at Onitsha with regression analysis and artificial neural network models. Research Journal of Recent Sciences, 1, (6), 27-31.

Ahmad, I., Al-Hamadani, N., Ibrahim, K., 1983. Solar radiation maps for Iraq. Sol Energy, 31, (1), 29–44,

Ahmed, F., Ulfat, I., 2004. Empirical models for the correlation of monthly average daily global solar radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan. Turkish J Phys, 28, (5), 301–7.

Ahrens, CD, Meteorology Today: An Introduction to Weather, Climate, and the Environment, 2012, Cengage Learning, UK, 640”

Akinoğlu, B., Ecevit, A., 1990. A further comparison and discussion of sunshine-based models to estimate global solar radiation. Energy, 15, (10), 865–72.

Akpabio, LE., Etuk, SE., 2003. Relationship between global solar radiation and sunshine duration for Onne, Nigeria. Turkish Journal of Physics, 27, 161–7.

Aksoy, B., 1997. Estimated monthly average global radiation for Turkey and its comparison with observations. Renewable Energy, 10, (4), 625–33.

Alam, S., Kaushik, SC., Garg, SN., 2009. Assessment of diffuse solar energy under general sky condition using artificial neural network. Applied Energy, 86,554-564.

Allen, R., 1997. Self-calibrating method for estimating solar radiation from air temperature. Journal of Hydrologic Engineering, 2, 56–67.

Almorox, J., Benito, M., Hontoria, C., 2005. Estimation of monthly Angström–Prescott equation coefficients from measured daily data in Toledo, Spain. Renewable Energy, 30, 931–6.

Almorox, J., Hontoria, C., 2004. Global solar radiation estimation using sunshine duration in Spain. Energy Conversion and Management, 45, (9/10), 1529–35

Alsaad, M., 1990. Characteristic distribution of global solar radiation for Amman, Jordan. Sol Wind Technol, 7, (2–3), 261–6.

Ampratwum, DB., Dorvlo, ASS., 1999. Estimation of solar radiation from the number of sunshine hours. Applied Energy, 63, 161–7.

Amrouche B., Le Pivert X., 2014. Artificial neural network based daily local forecasting for global solar radiation. Applied Energy, 130, 333-341

Angström, A., 1924. Solar and terrestrial radiation. Quart J Roy Meteor Soc, 50, 121–6.

Annandale, JG., Jovanic, NZ., Benade, N., Allen, RG., 2002. Software for missing data error analysis of Penman–Monteith reference evapotranspiration. *Irrigation Science,* 21, 57–67.

Aras, H., Balli, O., Hepbasli, A., 2006. Estimating the horizontal diffuse solar radiation over the Central Anatolia Region of Turkey. Energy Conversion & Management 47, 2240-9.

Aras, H., Balli, O.,Hepbasli, A., 2006 b. Global solar radiation potential, Part1,model development. Energy Sour Part B,Econ Plan Policy, 1, (3), 303–15

Atsu, SS., Dorvlo, S., Jervase, AJ., Al-Lawati, A., 2002. Solar radiation estimation using artificial neural networks. Applied Energy, 71, 307-319

Ayana, HB, 2011 Solar energy resources as an important part of renewable energy resources in terms of Turkey. Project for the Degree of MSc in Energy, Environmental Technology and Economics, City University, London. (Unpublished)

Bahel, V., Bakhsh, H., Srinivasan, R., 1987. A correlation for estimation of global solar radiation. Energy, 12, (2),131–5.

Bahel, V., Srinivasan, R., Bakhsh, H., 1986. Solar radiation for Dhahran, Saudi Arabia. Energy, 11, (10), 985–9,

Bakirci K., 2009. Estimation of solar radiation by using ASHRAE clear sky model in Erzurum, Turkey. Energy Sources Part A 31, (3), 208–16.

Bakirci, K., 2000. Models of solar radiation with hours of bright sunshine, A review, Renewable and Sustainable Energy Reviews, 13, 2580-8

Bakirci, K., 2007. Estimation of global solar radiation on horizontal surface. Journal of Thermal Science and Technology 27, (1), 7–11 [in Turkish].

Bakirci, K., 2008. Correlations for estimation of solar radiation on horizontal surface. Journal of Energy Engineering, 134, (4), 130–4.

Barbaro, S., Cannata, G., Coppolono, S., Leone, C., Sinagra, E.,1981. Diffuse solar radiation statistics forItaly. Sol Energy, 26, 429–35.

Bayat, K., Mirlatifi, SM., 2009. Estimation of daily global solar radiation using regression models and artificial neural network. Agriculture's Science and Natural Resources Magazine, 16, 3 [inPersian].

Behrang, MA, Assareh, E., Noghrehabadi, EA., Ghanbarzadeh, A., 2011. New sunshine-based models for predicting global solar radiation using PSO (particle swarm optimization) technique. Energy, 36, (5), 3036–49

Behrang, MA., Assareh, E., Ghanbarzadeh, A., Noghrehabadi AR., 2010. The potential of different artificial neural network (ANN) techniques in daily global solar radiation modeling based on meteorological data. Solar Energy, 84, (8), 1468-80.

Benghanem, M., Mellit, A., Alamri, SN., 2009. ANN-based modelling and estimation of daily global solar radiation data, A case study. Energy Conversion and Management, 50, (7), 1644-55.

Bennett, I., 1965. Monthly maps of mean daily insolation for United States. Sol. Energy 9, (3), 145–59

Benson, RB., Paris, MV., Sherry, JE., Justus, CG., 1984. Estimation of daily and monthly direct diffuse and global solar radiation from sunshine duration measurements. Solar Energy, 32, (4), 523–35.

Besharat, F., Dehghan, AA., Faghih, AR., 2013. Empirical models for estimating global solar radiation, A review and case study. Renewable and Sustainable Energy Reviews, 21, 798-821

Boukelia, TE., Mecibah, MS., Meriche, IE., 2014. General models for estimation of the monthly mean daily diffuse solar radiation (Case study, Algeria). Energy Conversation and Management, 81, 211–9.

Bristow, KL., Campbell, GS., 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology, 31, 59–166.

Chegaar, M., Chibani, A., 2001. Global solar radiation estimation in Algeria. Energy Conversion and Management, 42, 967–73.

Chelbi, M., Gagnon, Y., Waewsak, J., 2015. Solar radiation mapping using sunshine duration-based models and interpolation techniques, Application to Tunisia. Energy Conversion and Management , 101, 203-15.

Chen, R., Ersi, K.,Yang, J., Lu, S., Zhao, W., 2004. Validation of five global radiation models with measured daily data in China. Energy Conversion and Management, 45,1759–69.

Donatelli, M., Campbell, GS., 1998. A simple model to estimate global solar radiation. In, Proceedings of the fifth European society of agronomy congress, Nitra, Slovak Republic,133–4

Duffie, JA, Beckman WA, Solar Engineering of Thermal Processes, 2013, John Wiley & Sons, New York, 936

Duzen, H., Aydin, H., 2012. Sunshine-based estimation of global solar radiation on horizontal surface at Lake Van region (Turkey). Energy Conversion and Management 58, 35-46

Elagib, NA., Mansell, MG., 2000. New approaches for estimating global solar radiation across Sudan. Energy Conversion and Management 41, 419–34

El-Metwally, M., 2004. Simple new methods to estimate global solar radiation based on meteorological data in Egypt. Atmospheric Research, 69, 217–39.

El-Metwally, M., 2005. Sunshine and global solar radiation estimation at different sites in Egypt. Journal of Atmospheric and Solar-Terrestrial Physics, 67, 1331–42.

Elminir, HK., Yosry A., Farag IY., 2007. Prediction of hourly and daily diffuse fraction using neural network, as compared to linear regression models. Energy, 32, (8), 1513-23.

El-Sebaii, AA., Al-Ghamdi, AA., Al-Hazmi, FS., Faidah, A., 2009. Estimation of global solar radiation on horizontal surfaces in Jeddah, Saudi Arabia. Energy Policy, 37,3645–9.

El-Sebaii, AA., Al-Hazmi, FS., Al-Ghamdi, AA., Yaghmour, SJ., 2010. Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Applied Energy 87, 568–76.

El-Sebaii, AA., Trabea, AA., 2003. Estimation of horizontal diffuse solar radiation in Egypt. Energy Conversation Management, 44, 2471–82

Ener, R., Hammer, S., Akınoğlu, BG., 2013. Estimation of daily global solar irradiation by coupling ground measurements of bright sunshine hours to satellite imagery. Energy, 58, 417–25

Ener, RS., Hammer, A., Akinoglu, BG., 2013. Coupling satellite images with surface measurements of bright sunshine hours to estimate daily solar irradiation on horizontal surface. Renewable Energy, 55, 212-19

Ertekin, C., Yaldiz, O., 2000. Comparison of some existing models for estimating global solar radiation for Antalya (Turkey). Energy Conversation and Management, 41, (4), 311-30

Fadare, DA., 2009. Modelling of solar energy potential in Nigeria using an artificial neural network model. Applied Energy, 86, (9),1410-22.

Fadare, DA., 2010. The application of artificial neural networks to mapping of wind speed profile for energy application in Nigeria. Applied Energy 87, 934-942.

Gana, NN., Rai, JK., Momoh, M., 2014. Estimation of global and diffuse solar radiation for Kebbi, North-Western, Nigeria. International Journal of Scientific & Engineering Research, 5, 1654-61

Gariepy, J., 1980. Estimation of global solar radiation. International report, Service of meteorology, Government of Quebec, Canada

Glover, J., McCulloch, JSG., 1983. The empirical relation between solar radiation and hours of sunshine. Q J R Meteorol Soc, 84, (360), 172–5.

Goodin, DG., Hutchinson, JMS., Vanderlip, RL., Knapp, MC., 1999. Estimating solar irradiance for crop modelling using daily air temperature data. Agronomy Journal 1999;91,845–51.

Gopinathan, K., Soler, A., 1992. A sunshine dependent global insolation model for latitudes between 60N and 70N. Renewable Energy, 2, (4–5), 401–4.

Gopinathan, KK., 1988 a. A general formula for computing the coefficients of the correlations connecting global solar radiation to sunshine duration, Sol. Energy 41, 499–502

Gopinathan, KK., 1988 b. A simple method for predicting global solar radiation on a horizontal surface. Sol Wind Technol, 3, (5), 581–3.

Gopinathan, KK., 1988 c. Computing the monthly mean daily diffuse radiation from clearness index and percent possible sunshine. Solar Energy, 41, (4), 379–85

Gopinathan, KK., 1988 d. The distribution of global and sky radiation throughout Lesotho. Solar&Wind Technology, 5, 581

Hargreaves, GH., Samani, ZA., 1982. Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering, 108, (IR3), 223–30.

Harris, NC, Solar Energy Systems Design, 1985,John Wiley and Sons Inc, US, 784

Hasni, A., Sehli, A., Draoui, B., Bassou, A., Amieur, B., 2010. Estimating global solar radiation using artificial neural network and air temperature data in a semi-arid environment. Renewable Energy, 35, (9), 2131-35.

Hasni, A., Sehli, A., Draoui, B., Bassou, A., Amieur, B., 2012. Estimating global solar radiation using artificial neural network and climate data in the south-western region of Algeria. Energy Procedia, 18, 531-7.

Hassana, GE., Youssefa, ME., Alia, MA., Mohamed, ZE., Shehatab, AI.,2016. Performance assessment of different day-of-the-year-based models for estimating global solar radiation - Case study, Egypt. Journal of Atmospheric and Solar-Terrestrial Physics, 149, 69–78

Hay, JE., 1979. Calculation of monthly mean solar radiation for horizontal and inclined surfaces. Sol Energy, 23, (4), 301–7.

Hinrichsen K., 1994. The Angström formula with coefficients having a physical meaning. Sol Energy, 52, (6), 491–5.

http://www.cmsaf.eu (Date viewed, 22.11.2016)

http://www.eie.gov.tr/eie-web/english/solar/solarTurkey_e.html (Date viewed, 22.11.2016)

http://www.enerji.gov.tr/tr-TR/Sayfalar/Gunes (Date viewed, 22.11.2016)

http://www.mgm.gov.tr (Date viewed, 22.11.2016)

http://www.physicalgeography.net/fundamentals/7f.htm (Date viewed, 22.11.2016)

Hunt, L., Kuchar, L., Swanton, C., 1998. Estimation of solar radiation for use in crop modelling. Agric. For. Meteorology, 91, 293–300

Ibrahim, SMA., 1985. Diffuse solar radiation in Cairo, Egypt. Energy Conversion and Management, 25, (1), 69–72.

Iqbal, M., 1979. Correlation of average diffuse and beam radiation with hours of bright sunshine. Solar Energy, 23, (2), 169–73.

Jain, P., 1986. Global irradiation estimation for Italian locations. Sol Wind Technol 3, (4), 323–8.

Jain, P., 1990. A model for diffuse and global irradiation on horizontal surfaces. Sol Energy, 45, (5), 301–8.

Jain, S., Jain, P., 1988. A comparison of the Angstrom-type correlations and the estimation of monthly average daily global irradiation. Sol Energy, 40, (2), 93–8.

Jiang, Y., 2009. Estimation of monthly mean daily diffuse radiation in China. Applied Energy 2009;86,1458–64.

Jin, Z., Yezheng, W., Gang, Y., 2005. General formula for estimation of monthly average daily global solar radiation in China. Energy Conversion and Management 46, 257-68

Karakoc, E., Sensoy, S., Kose, E., Balta, I., Träger-Chatterjeer, C., 2010. Comparison of CM-SAF SIS and surface radiation data in Turkey for the year 2006. Analele Universităţii din Oradea Fascicula, Protecţia Mediului, 15, 652-656

Katiyar, AK., Pandey, CK., 2010. Simple correlation for estimating the global solar radiation on horizontal surfaces in India. Energy, 35, (12), 5043–8

Kémajou, A., Léopold, MBA., Meukam, P., 2012. Application of artificial neural network for predicting the indoor air temperature in modern building in humid region. British Journal of Applied Science & Technology, 2, (1), 23-34.

Khatib, T., Mohamed, A., Sopian, K., 2012. A review of solar energy modelling techniques. Renewable and Sustainable Energy Reviews, 16, (5), 2864-69.

Khogali, A., Ramadan, M., Ali, Z., Fattah, Y., 1983. Global and diffuse solar irradiance in Yemen(Y.A.R.). Sol Energy, 31, (1), 55–62.

Kiliç, A, Öztürk, A, Solar energy, solar radiation and flate-plate collectors (in Turkish), 1984, SEGEM, Ankara, 135

Koca, A., Oztop, HF., Varol, Y., Koca, GO., 2011. Estimation of solar radiation using artificial neural networks with different input parameters for Mediterranean region of Anatolia in Turkey. Expert Systems with Applications, 38, (7), 8756-62.

Kriesel D. A Brief Introduction to Neural Networks 2007. available at http://www. dkriesel.com. (Date viewed, 22.11.2016)

Kung Y., 1998. Digital Neural Networks. PTR Prentice-Hall

Lewis, G., 1983. Estimates of irradiance over Zimbabwe. Solar Energy, 31, 609–612.

Lewis, G., 1992. An empirical relation for estimating global irradiation for Tennessee,

Lewis, G., 1995. Estimates of monthly mean daily diffuse irradiation in the south-eastern United States. Renewable Energy, 6, 983–8.

Li, H., Ma, W., Lian, Y., Wang , X., Zhao, L., 2011. Global solar radiation estimation with sunshine duration inTibet,China. Renewable Energy, 36, (11), 3141–5.

Li, H., Ma, W., Wang, X., Lian, YW., 2011. Estimating monthly average daily diffuse solar radiation with multiple predictors, a case study. Renewable Energy, 36, 1944–8.

Li, MF., Liu, HB., Guo, PT., Wu, W., 2010. Estimation of daily solar radiation from routinely observed meteorological data in Chongqing, China. Energy Conversion and Management, 51, 2575-79

Lippmann, R.P., 1997. An Introduction to Computing with Neural Nets. ASSP Magazine IEEE, 4, 4-22.

Louche, A.,Notton, G.,Poggi, P.,Simonnot, G., 1991. Correlations for direct normal and global horizontal irradiation on a French Mediterranean site. Sol Energy, 46, (4), 261–6.

Luhanga, P., Andringa, J., 1990. Characteristics of solar radiation at Sebele, Gaborone, Botswana. Sol Energy, 44, (2), 77–81

Maduekwe, A., Chendo, M., 1995. Predicting the components of the total hemispherical solar radiation from sunshine duration measurements in Lagos, Nigeria. Renew Energy, 6, (7), 807–12

Maghrabi, AH., 2009. Parameterization of a simple model to estimate monthly global solar radiation based on meteorological variables, and evaluation of existing solar radiation models for Tabouk, Saudi Arabia. Energy Conversion and Management, 50, 2754–60.

Mahmood, R., Hubbard, KG., 2002. Effect of time of temperature observation and estimation of daily solar radiation for the Northern Great Plains, USA. Agronomy Journal, 94, 723–33.

Maitha, HAS., Ali HA., Hassan ANH., 2011. Using MATLAB to Develop Artificial Neural Network Models for Predicting Global Solar Radiation in Al Ain City – UAE, Engineering Education and Research Using MATLAB, InTech, Available from, http://www. intechopen.com/books/ engineering-education-and-research-usingmatlab/using-matlab-to-developartificial neural-network-models-for-predicting-global-solar-radiation-in-al. (Date viewed, 22.11.2016)

Mecibah, MS., Boukelia, TE., Tahtah, R., Gairaa, K., 2014. Introducing the best model for estimation the monthly mean daily global solar radiation on a horizontal surface (Case study,Algeria). Renewable and Sustainable Energy Reviews, 36, 194–202

Meza, F., Varas, E., 2000. Estimation of mean monthly solar global radiation as a function of temperature. Agricultural and Forest Meteorology, 100, 231–241

Mousavi, R., Sabziparvar, AA,, Niaz, AM., Ebrahimi A., Heydari, PM., 2015. Calibration of the Angström-Prescott solar radiation model for accurate estimation of reference evapotranspiration in the absence of observed solar radiation. Theoretical and Applied Climatology, 119, (1), 43–54

Mubiru, J., Banda, EJKB., 2007. Performance of empirical correlations for predicting monthly mean daily diffuse solar radiation values at Kampala, Uganda. Theor Appl Climatol, 88, 27–31.

Mubiru, J., Banda, EJKB., 2008. Estimation of monthly average daily global solar irradiation using artificial neural networks. Solar Energy, 82, (2),181-7.

Newland, FJ., 1989. A study of solar radiation models for the coastal region of South China. Sol Energy, 43, (4), 227–35.

Notton, G., Paoli, C., Ivanova, L., Vasileva S., Nivet ML., 2013. Neural network approach to estimate 10-min solar global irradiation values on tilted planes. Renewable Energy, 50, 576-84.

Ododo, JC., Sulaiman, AT., Aidan, J., Yuguda, MM., Ogbu, FA., 1995. The importance of maximum air temperature in the parameterisation of solar radiation in Nigeria. Renewable Energy, 6, 751–63.

Ögelman, H., Ecevit, A., Tasdemiroğlu, E., 1984. A new method for estimating solar radiation from bright sunshine data. Sol Energy, 33, (6), 619–25.

Önal, G, Doğan Z, 2010. Enerjide Temiz Kömür, Dünya Enerji Konseyi Türk Milli Komitesi Türkiye 10. Enerji Kongresi, 2010 http://www.dektmk.org.tr/pdf/enerji_kongresi_10/guvenonal.pdf (Date viewed, 22.11.2016)

Ozgoren, M., Bilgili, M., Sahin, B., 2012. Estimation of global solar radiation using ANN over Turkey. Expert Systems with Applications, 39, (5), 5043-51.

Page, JK., 1961. The estimation of monthly mean values of daily total short-wave radiation on vertical and inclined surfaces from sunshine records for latitudes 40N–40S. In, Proceedings of UN conference on new sources of energy, 378–90.

Pandey, CK., Katiyar, AK., 2009. A comparative study to estimate daily diffuse solar radiation over India. Energy, 34,1792–6.

Paulescu, M, Paulescu, E, Gravila, P, Badescu V, Weather Modeling and Forecasting of PV Systems Operation, 2013, Springer, London, 358.

Petrini, M., 2012. Improvements to the back propagation algorithm. Annals of the University of Petroşani, Economics, 12,185-192.

Pidwirny, M, Atmospheric Effects on Incoming Solar Radiation, Fundamentals of Physical Geography, 2nd Edition. Date Viewed,

Poudyal, KN., Bhattarai BK., Balkrishnal S., Berit, K., 2012.Estimation of global solar radiation using sunshine duration in Himalaya Region. Research Journal of Chemical Sciences, 2, (11), 20-25

Prescott, JA, 1940. Evaporation from water surface in relation to solar radiation. Trans R Soc Aust, 64, 114–48.

Qin J., Chen Z., Yang K., Liang S., Tang W., 2011. Estimation of monthly-mean daily global solar radiation based on MODIS and TRMM products. Applied Energy, 88, 2480-2489

Radosavljević, J., Đorđević, A., 2001. Defining of the intensity of solar radiation on horizontal and oblique surfaces on earth. Working and Living Environmental Protection, 2, (1), 77 – 86.

Rahimi, I., Bakhtiari, B., Qaderi K., Aghababaie, M., 2012. Calibration of Angstrom Equation for Estimating Solar Radiation using Meta-Heuristic Harmony Search Algorithm (Case study, Mashhad-East of Iran). Energy Procedia, 18, 644-651

Rahimikhoob A., 2010. Estimating global solar radiation using artificial neural network and air temperature data in a semi-arid environment, Renewable Energy, 35, 2131–2135

Raja, IA., 1994. Insolation-sunshine relation with site elevation and latitude. Sol. Energy, 53, (1), 53–56

Raja, IA., Twidell, JW., 1990. Distribution of global insolation over Pakistan. Sol Energy, 44, (2), 63–71.

Rehman, S., 1998. Solar radiation over Saudi Arabia and comparisons with empirical models. Energy, 23, (12), 1077–82.

Rehman, S., Mohandes, M., 2008. Artificial neural network estimation of global solar radiation using air temperature and relative humidity. Energy Policy, 36, (2), 571-6.

Rensheng, C., Shihua, L., Ersi, K., Jianping, Y., Xibin, J., 2006. Estimating daily global radiation using two types of revised models in China. Energy Conversion and Management, 47, (7–8), 865–78

Reyes, J., Rosen, M., 2007. Creating Sustainable Communities a Guide for Developers and Communities http://www.state.nj.us/dep/opsc/sdtguide.html (Date viewed, 22.11.2016)

Rietveld, MR., 1978. A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. Agricultural Meteorology 19, 243–52.

Robaa, SM., 2009. Validation of the existing models for estimating global solar radiation over Egypt. Energy Conversion and Management, 50, (1), 184-93

Rojas, R, Neural Networks, 1996, Springer-Verlag, Berlin, 453

Rumbayan, M., Nagasaka, K., 2012. Solar Irradiation estimation with neural network method using meteorological data in Indonesia. International Journal of Technology, 2, 110-120.

Said, R.,Mansor, M., Abuain, T., 1998. Estimation of global and diffuse radiation at Tripoli. Renewable Energy, 14, (1–4), 221–7.

Samuel, T., 1991. Estimation of global radiation for Sri Lanka. Sol Energy 47, (5), 333–7

Şen, Z, Solar Energy Fundamentals and Modeling Techniques, Atmosphere, Environment, Climate Change and Renewable Energy, 2008, Springer, London, 276

Sensoy S, Demircan M, Balta I. Climate of Turkey, Turkish State Meteorological Service website. http://www.mgm.gov.tr/FILES/iklim/turkiye_iklimi.pdf, (Date viewed, 22.11.2016)

Sfetsos, A., Coonick, AH., 2000. Univariate and multivariate forecasting of hourly solar radiation with artificial intelligence techniques, Solar Energy, 68, (2), 169-78.

Singh, OP., Srivastava, SK., Gaur, A., 1996. Empirical relationship to estimate global radiation from hours of sunshine. Energy Conversation and Management, 37, (4), 501–4.

Soler, A., 1990. Monthly specific Rietveld's correlations. Solar and Wind Technology, 7, 305–8.

Sözen, A., Arcaklioğlu, E., Özalp, M., 2004. Estimation of solar potential in Turkey by artificial neural networks using meteorological and geographical data. Energy Conversion and Management, 45, (18,19), 3033-52.

Sproul AB., 2002. Vector Analysis of Solar Geometry. Proceedings of Solar 2002 Australian and New Zealand Solar Energy Society, 1-10

Srivastava, RC., Pandey, H., 2013. Estimating Angstrom–Prescott coefficients for India and developing a correlation between sunshine hours and global solar radiation for India. Renewable Energy, 1, 11–7.

Srivastava, S., Singh, O., Pandey, G., 1993. Estimation of global solar radiation in Uttar Pradesh (India) and comparison of some existing correlations. Sol Energy 51, (1), 27–9

Suehrcke H., Bowden RS., Hollands, KGT., 2013. Relationship between sunshine duration and solar radiation. Solar Energy, 92, 160–171

Supit, I., Van Kappel, RR., 1998. A simple method to estimate global radiation. Solar Energy, 63,147–60.

Swartman, RK., Ogunlade, O., 1967. Solar radiation estimates from common parameters. Solar Energy, 11, 170–2.

Tarhan, S., Sari, A., 2005. Model selection for global and diffuse radiation over the Central Black Sea(CBS) region of Turkey. Energy Conversation Management, 46, (4), 605–13.

Taşdemiroğlu, E., Sever, R., 1991. An improved correlation for estimating solar radiation from bright sunshine data for Turkey. Energy Conversation Management, 31, (6), 599–600.

Tiris, M.,Tiris, C., Türe, IE., 1996. Correlations of monthly-average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze,Turkey.Energy Conversation and Management, 37, (9), 1417–21.

Tiwari, GN, Dubey, S, Fundamentals of Photovoltaic Modules and their Applications, 2009, RSC Publishing, UK, 422

Toğrul, IT., Onat, E., 2000. A comparison of estimated and measured values of solar radiation in Elazig, Turkey. Renewable Energy, 20, (2), 243–52.

Toğrul, IT., Toğrul, H., 2002. Global solar radiation over Turkey, comparison of predicted and measured data. Renewable Energy,25, 55–67.

Toğrul, IT., Toğrul, H., Evin,D., 2000. Estimation of monthly global solar radiation from sunshine duration measurement in Elazig. Renewable Energy, 19, (4), 587–95.

Trabea, A., 1999. A multiple linear correlation for diffuse radiation from global solar radiation and sunshine data over Egypt. Renewable Energy, 17,411–20.

Trabea, AA., Shaltout, MAM., 2000. Correlation of global solar radiation with meteolological parameters over Egypt. Renewable Energy, 21, 297–308.

U.S.A. Energy Conversation and Management, 33, (12), 1097–9.

Ulgen, K., Hepbasli, A., 2002. Comparison of solar radiation correlations for Izmir, Turkey. Int J Energy Res, 26, (5), 413–30.

Ulgen, K., Hepbasli, A., 2004. Solar radiation models. Part 2,comparison and developing new models. Energy Source, 26, (5), 521–30

Ulgen, K., Hepbasli, A., 2009. Diffuse solar radiation estimation models for Turkey's big cities. Energy Conversation and Management, 50, 149–56.

Ulgen, K., Ozbalta, N., 2000. Measured and estimated global radiation on horizontal surface for Bornova, Izmir. XII. National Thermal Science and Technical Congress, Izmit, Turkey, 113–18 [in Turkish].

Urraca, R., Antonanzas, J., Martinez-de-Pison, FJ., Antonanzas-Torres, F., 2015. Estimation of solar global irradiation in remote areas. Journal of Renewable and Sustainable Energy, 7, 231-6.

Veeran, P., Kumar, S., 1993. Analysis of monthly average daily global radiation and monthly average sunshine duration at two tropical locations. Renewable Energy, 3, (8), 935–9.

Weiss, A., Hays, CJ., Hu, Q., Easterling, WE., 2001. Incorporating bias error in calculating solar irradiance, implications for crop yield simulations. *Agronomy Journal*, 93, 1321–6

WMO, 2010. CIMO guide to meteorological instruments and methods of observation . In, Measurement of Radiation, World Meteorological Organization, WMO-No. 8 (2010 update), seventh ed. Geneva, Switzerland, 157–198

Wong, LT., Chow, WK., 2001. Solar radiation model, Applied Energy, 69, 191-224.

Yildiz, M., Oz, S., 1994. Evaluation of the solar energy potential of Turkey. In, Proceedings of the 6th National Energy Congress; 250–60 [in Turkish].

Yohanna, JK., Itodo, IN., Umogbai, VI., 2011. A model for determining the global solar radiation for Makurdi, Nigeria. Renewable Energy, 36, (7), 1989–92.

Zabara, K., 1986. Estimation of the global solar radiation in Greece. Sol Wind Technol, 3, (4), 267–72.

Zhao, N., Zeng, X., Han, S., 2013. Solar radiation estimation using sunshine hour and air pollution index in China. Energy Conversion and Management, 76, 846-51

CURRICULUM VITAE

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APPENDIX

APPENDIX A: Global Solar Radiation Measurement Stations of Turkish State Meteorological Services

Table A.1 The stations which global solar radiation measurement is available

City	Province	Station
ADANA	YÜREĞİR	Adana Bölge
ADANA	YÜREĞİR	Çukurova Tarım Arş. (TAGEM)
AFYONKARAHİSAR	MERKEZ	Afyonkarahisar Bölge
AĞRI	DOĞUBEYAZIT	Doğubeyazıt
AĞRI	MERKEZ	Ağrı
AKSARAY	MERKEZ	Aksaray
AMASYA	MERZİFON	Merzifon Meydan
ANKARA	ÇAMLIDERE	Çamkoru
ANKARA	ÇUBUK	Esenboğa Meydan
ANKARA	KAZAN	Sarayköy Toprak
ANKARA	KEÇİÖREN	Ankara Bölge
ANKARA	KEÇİÖREN	9. (Ankara) Bölge
ANTALYA	ELMALI	Elmalı
ANTALYA	ELMALI	Elmalı
ANTALYA	MURATPAŞA	Antalya Meydan
ARTVİN	MERKEZ	Artvin
AYDIN	İNCİRLİOVA	İncir Arş.(TAGEM)
AYDIN	MERKEZ	Aydın
BALIKESİR	BANDIRMA	Bandırma Meydan
BALIKESİR	BURHANİYE	Burhaniye
BALIKESİR	DURSUNBEY	Yayla Orman
BALIKESİR	MERKEZ	Balıkesir Meydan
BARTIN	AMASRA	Amasra

BAYBURT	AYDINTEPE	Aydıntepe
BİNGÖL	SOLHAN	Solhan
BİTLİS	TATVAN	Nemrut Kayak Merkezi
BOLU	MERKEZ	Batı Karadeniz Orman Arş.
BOLU	MERKEZ	Bolu
BURSA	OSMANGAZİ	Bursa
BURSA	YENİŞEHİR	Yenişehir Meydan
ÇANAKKALE	MERKEZ	Çanakkale
ÇANKIRI	BAYRAMÖREN	Bayramören
DENİZLİ	ÇARDAK	Çardak Meydan
DENİZLİ	HONAZ	Honaz
DENİZLİ	KALE	Kale
DİYARBAKIR	ERGANİ	Ergani
DİYARBAKIR	BAĞLAR	Diyarbakır Meydan
ELAZIĞ	PALU	Palu
ERZİNCAN	MERKEZ	Erzincan Meydan
ERZİNCAN	TERCAN	Tercan
ERZURUM	PALANDÖKEN	Palandöken Kayak Merkezi
ERZURUM	PASİNLER	Toprak Su Arş. (TAGEM)
ERZURUM	TORTUM	Tortum
ERZURUM	YAKUTİYE	Erzurum Meydan
ESKİŞEHİR	SİVRİHİSAR	Sivrihisar
ESKİŞEHİR	TEPEBAŞI	Eskişehir Havaalanı
GAZİANTEP	OĞUZELİ	Gaziantep Oğuzeli Meydan
GİRESUN	DERELİ	Kümbet Yaylası
GÜMÜŞHANE	MERKEZ	Gümüşhane
HAKKARİ	MERKEZ	Hakkari

ISPARTA	GÖNEN	Süleyman Demirel Meydan
ISPARTA	MERKEZ	Isparta
İSTANBUL	BAKIRKÖY	Atatürk Havaalanı
İSTANBUL	ÇEKMEKÖY	Ömerli
İSTANBUL	PENDİK	Sabiha Gökçen Meydan
İSTANBUL	SANCAKTEPE	Samandıra Meydan
İZMİR	BORNOVA	Bornova Orman
İZMİR	BORNOVA	Zeytincilik Arş.(TAGEM)
İZMİR	ÇİĞLİ	Çiğli Havaalanı
İZMİR	GAZİEMİR	Adnan Menderes Havaalanı
İZMİR	KEMALPAŞA	Kemalpaşa
İZMİR	KEMALPAŞA	Ovacık
İZMİR	MENEMEN	Menemen
KAHRAMANMARAŞ	GÖKSUN	Göksun
KARABÜK	KARATEPE	Karatepe
KARAMAN	MERKEZ	Karaman
KARS	MERKEZ	Kars
KARS	MERKEZ	Kars Meydan
KASTAMONU	MERKEZ	Kastamonu
KASTAMONU	PINARBAŞI	Pınarbaşı
KAYSERİ	BÜNYAN	Bünyan
KAYSERİ	DEVELİ	Develi
KAYSERİ	KOCASİNAN	Erkilet Meydan
KAYSERİ	PINARBAŞI	Pınarbaşı
KIRKLARELİ	MERKEZ	Kırklareli
KIRKLARELİ	VİZE	Yumurtatepe

KİLİS	MERKEZ	Kilis
KONYA	AKŞEHİR	Akşehir
KONYA	BEYŞEHİR	Beyşehir
KONYA	KARATAY	Bahri Dağdaş Arş. (TAGEM)
KONYA	KULU	Kulu
MALATYA	BATTALGAZİ	Meyvecilik Arş.(TAGEM)
MALATYA	MERKEZ	Malatya
MARDİN	MERKEZ	Mardin
MERSİN	ÇAMLIYAYLA	Meyvecilik Arş. (TAGEM)
MERSİN	TARSUS	Tarsus
MERSİN	TOROSLAR	Arslanköy
MUĞLA	DALAMAN	Dalaman Meydan
MUĞLA	MERKEZ	Muğla
MUŞ	MALAZGİRT	Malazgirt
NEVŞEHİR	GÜLŞEHİR	Kapadokya Meydan
NİĞDE	MERKEZ	Niğde
NİĞDE	ULUKIŞLA	Ulukışla
ORDU	ÜNYE	Ünye
RİZE	ARDEŞEN	Yeşiltepe
RİZE	İKİZDERE	Cimil
RİZE	MERKEZ	Rize
SAMSUN	BAFRA	Toprak Su Arş.(TAGEM)
SAMSUN	TEKKEKÖY	Karadeniz Arş. (TAGEM)
SİNOP	AYANCIK	Akören Köyü
SİNOP	MERKEZ	Sinop
SİVAS	DİVRİĞİ	Divriği

SİVAS	GEMEREK	Gemerek
SİVAS	SUŞEHRİ	Suşehri
ŞANLIURFA	BOZOVA	Bozova
ŞANLIURFA	CEYLANPINAR	Ceylanpınar Tigem
ŞANLIURFA	HARRAN	Koruklu GAP Toprak Su (TAGEM)
ŞIRNAK	MERKEZ	Şırnak
TEKİRDAĞ	ÇORLU	Çorlu Meydan
TEKİRDAĞ	MERKEZ	Tekirdağ
TOKAT	MERKEZ	Tokat
TOKAT	MERKEZ	Toprak ve Su Arş. (TAGEM)
TUNCELİ	OVACIK	Ovacık
VAN	MERKEZ	Van Bölge
YOZGAT	BOĞAZLIYAN	Boğazlıyan