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# EVALUATING THE INCOMING SOLAR RADIATION OVER TANA BASIN IN ETHIOPIA USING ANGSTORM-PERSCOTT AND HARGREAVES MODELS

ASNAKU, TEFERA

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**ASNAKU TEFERA**

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# APPROVAL SHEET

Bahir Dar University
College Science

As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by **Asnaku Tefera** entitled **evaluating the incoming solar radiation over Tana basin north of Ethiopia using Angstrom and Hargreaves models** recommend that it be accepted as fulfilling the thesis requirement for the degree of **Master of physics (Specialization: Atmospheric physics)**

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# ABBREVIATION AND ACRONYMS

| | |
|---|---|
| GTP | Growth and Transformation Plan |
| EDI | Energy Development Index |
| EEPCO | Ethiopian electric power corporation |
| E | Solar irradiance |
| H | Splar irradiation |
| T | time duration |
| UV | Ultraviolet |
| IR | Infrared |
| $H_o$ | extraterresterial radiation |
| $I_{SC}$ | solar constant |
| d | julian day |
| IEA | International energy agency |
| CSP | concentrated solar power |
| PV | Photovoltaic |
| j | day angle |
| r | sun-earth distance |
| $\epsilon$ | relative eccentricity cottection |
| $E_o$ | extrateristerrial irradiance |
| $\delta$ | solar diclination |
| a, b | emperical constant |
| $\Phi$ | latitude |
| $\omega$ | sun set hour angle |
| n | average daily sunshine hour |
| $T_{max}$ | maximum temprature |
| $T_{min}$ | minimum temperature |
| Lat | tatitude |
| Lon | longtiude |
| CSA | Central statistical Agency of Ethiopia |

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Finally I would like to say thank staff members of National Meteorological Agency of Ethiopia, Bahir Dar branch, they help me by giving the sunshine and temperature data of Bahir Dar, Gondar, Debre Tabor and Debre Markoss stations.

# ABSTRACT

Renewable energy is considered to be one of the pivotal wedges that can combat global warming and stabilize the climate, through the reduction of carbon dioxide emissions. Solar energy is one of the most important renewable energy sources. In this study we assessed the potential of solar radiation over the Amhara region of Tana basin using the daily sunshine hours and temperature data of Bahir Dar (1985-2016), Debre Markoss, Debre Tabor and Gondar (2007-2016) obtained from National Meteorological Agency of Ethiopia. Using these data we calculate the average monthly and annually global solar radiation by using both the Angstrom-Prescott and Hargreaves empirical models. From the result, the monthly average solar radiations of the four stations calculate using the two models is maximum at spring and minimum in summer season. It also has maximum value in November. Hargreaves model gives large output of radiation than Angstrom model. In both models Bahir Dar has maximum monthly and annually radiation. So it better to install PV cell in Bahir Dar to generate more electric power.

# 1. BACK GROUND OF THE STUDY

## 1.1. INTRODUCTION

The energy consumption of the average Ethiopian is among the lowest in the world. There is a great difference between rural and urban energy use in Ethiopia, as rural areas are largely left off of the central electrical grid. Most (85%) of Ethiopian people live in rural area and they get their energy from traditional energy source like firewood, charcoal, animal dung, crop residues, kerosene and so on. Even in urban areas, half the households rely on traditional biomass (wood, dung and agricultural residues) for cooking, and in rural areas, virtually all do (except for 0.2% who use kerosene, and 1.2% charcoals) (Dalelo.A). Ethiopia has made big strides in recent years, with 48.3% of towns and villages connected to the grid as of July 2012, according to the Ethiopia Electric Power Corporation (Federal Democratic Republic of Ethiopia Ministry of Water and Energy, 2012).

The current energy consumption in Ethiopia, one that is heavily reliant on the burning of biomass has major implications for the environment. The use of traditional fuels as the main source of energy by rural households, which comprise the vast majority of Ethiopia's population, is especially an area of concern. Deforestation, land degradation, decreases in agricultural productivity, and increased greenhouse gas emissions have resulted from these patterns of unsustainable fuel consumption, and are further exacerbated by Ethiopia's growing population's increased energy demands (Gwavuya et al., 2012). Ethiopia's dependence on traditional fuel sources has resulted in the depletion of fuel wood stocks faster than they can regenerate. This pattern, paired with the country's rate of population growth, will end in environmental disaster unless changes are made in the near future. Deforestation is exacerbated by growing populations increasing energy demands, which is met by gathering more fuel wood and clearing more land for agriculture. Loss of forest cover contributes to soil erosion and the loss of nutrients necessary for agriculture. This cycle is positively reinforcing, as erosion and loss in agricultural productivity leads to the further clearing of forests for new farming plots (Howell.J, 2011).

Ethiopia has great potential (renewable energy source) to implement renewable technologies to decrease reliance on traditional fuel sources and increase rural electrification (Zereay et al., 2013). Renewable energy is energy that is generated from natural processes that are continuously replenished. The renewable energy potential includes hydropower, geothermal power, wind power and solar power. Ethiopia generates most (over 96%) of its electricity from renewable energy, mainly hydropower on the Blue Nile.

The Government of Ethiopia, under its latest Growth and Transformation Plan (GTP), envisions transitioning from a developing country to a middle-income country by 2025. Ethiopia's ability to achieve this ambitious goal in such key sectors as agriculture and industry is significantly constrained by current challenges in the power sector. Although Ethiopia is endowed with abundant renewable energy resources and has a potential to generate over 60,000 MW of electric power from hydroelectric, wind, solar and geothermal sources, currently it only has approximately 2,300 MW of installed generation capacity to serve a population of over 95 million people.

Successful projects have already begun to produce electricity. Power generation capacity improved by 230% (1,359 MWs) between 2008 and 2012, with six hydroelectric and wind power projects coming online:

- Tekeze (2009, hydroelectric, 300 MWs)
- Gibe II (2010, hydroelectric, 420 MWs)
- Tana Beles (2010, hydroelectric, 460 MWs)
- Amerti Nesha (2011, hydroelectric, 98 MWs)
- Ashegoda (2013, wind, 30 MWs)
- Adama I (2012, wind, 51 MWs)

The country began a large program to expand electricity supply in the 2010s from 2,000 MW to 10,000 MW. This was to be done mainly with renewable sources.

The three more projects—Gibe III, Adama II, And the Grand Ethiopian Renaissance Dam—are under construction. Their Combined planned output is 8,060 MWs. In 2013, The Ashegoda Wind farm expanded to 120 MWs In total, making it Africa's largest wind project that year (Hailu.S.S).

**Hydro Power** The electricity in Ethiopia's grid is now derived entirely from renewable energy. Ethiopia is often described as the water tower of northeastern Africa. It was estimated that the country has a hydropower potential of 4,000 MW (installable potential) (Dalelo.A). Hydropower accounts for most of it with some wind power added. But the gird reaches now mainly the urban population, which adds up to less than 20% of the total (GebreEgziabher.T.B). Our long-term plan is for the gird to reach all rural homesteads as well in about 20 years. In the meantime, we are pushing for fuel wood efficient stoves and biogas, with solar panel to power telecommunication technologies in rural areas.

**Gibe III** hydropower plant project is currently under construction, some 250 km south-west of Addis Ababa. The installed power will be 1,870 MW per year. The construction of two power generating plants downstream entitled the Gibe IV and Gibe V has now been planned.

**The Great Renaissance Dam,** the Grand Ethiopian Renaissance Dam will be the largest hydropower dam in Africa and among the largest in the world. When completed, it will be able to generate 6,000 MW, almost triple Ethiopia's entire national capacity (GebreEgziabher.T.B). The construction will be proposed to finalize in 2015. But it is not finished still now. The Ethiopian government is funding the entire project from domestic sources, including by getting money through selling bonds to the public.

**Wind Farms:** Ethiopia plans 800 MW of wind power. The first wind farm installation in the country was the 51 MW Adama I wind farm, built in 2011. The 120 MW Ashegoda Wind Farm opened in October 2013 and was the largest wind farm in Africa at that time. The larger 153 MW Adama II wind farm went online in May 2015, bringing Ethiopia's installed wind capacity to 324MW total (GebreEgziabher.T.B).

**The Ashegoda Wind Farm**, about 700 kms North of Addis Ababa has started generating 120 MW of electricity per year. It helps to start diversifying electricity generation, which would otherwise remain entirely from hydropower and thus susceptible to extreme weather events. Its construction was funded from both domestic and international sources (GebreEgziabher.T.B).

**The Adama Wind Farm**, which is also now operational, is about 80kms South of Addis Ababa. It produces 51MW of electricity per year.

**Geothermal:** Ethiopia has started constructing a geothermal electric power generating capacity of 1,000 MW per year in the Rift Valley. The first phase, which will produce 500 MW per year, will be completed in 2018. The second phase, which will generate another 500 MW per year, will be completed in 2021 (Teferra.M)

**Solar:** Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms (Solar World Energy Council, 2013). Solar photovoltaic are being promoted to replace fuel-based lighting and off-grid electrical needs. Ethiopia is thought to have about 5 MW of off-grid solar. Almost all current solar power is used for telecommunications. Other uses include village well pumps, health care and school lighting. A current government initiative plans to bring solar power to 150,000 households by 2015. The first large installation of solar was a village grid of 10 kW in 1985, expanded to 30 kW in 1989. A solar panel assembly plant opened in Addis Ababa in early 2013 capable of making 20 MW of panel per year.

## 1.2. STATEMENT OF THE PROBLEM

Energy is the primary and most universal measure of all kind of work by human beings and nature. Everything in the world is the expression of flow of energy in one of its forms. Access to energy is among the key elements for the economic and social developments of Ethiopia. The energy sector in Ethiopia can be generally categorized in to two major components: traditional and modern (traditional biomass usage and modern fuels i.e electricity and petroleum). As more than 85% of the country's population is engaged in the small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of Energy in Ethiopia. (Mekonnen.S.A, 2007). The energy in solar radiation can be used directly or indirectly for all of our energy needs in daily life, including heating, cooling, lighting, electrical power, transportation and even environmental cleanup (Solar World Energy Council, 2013).

The country Ethiopia has over 95 million populations. Out of them 85% are live in rural areas. And they live in traditional way because they are far from modern technology. Tana basin is one of rural areas that found west north of Ethiopia. The community people of Tana basin in Ethiopia have no sufficient access to modern energy. Due to this they are not advantageous in modern technology like internet, telephone, TV, modern stove etc. To satisfy their energy access they use traditional source of energy like wood, animal dung, agricultural residues, charcoal and kerosene. To get those traditional energy sources they cut trees around them which lead to health problem, environmental degradation and socio-economic problems, which have effects on agricultural productivity and becomes for the cause of poverty. The problems of land degradation, decreases in agricultural productivity. And this Deforestation proses is the main causes of climate change and the increment of greenhouse gases. They also spend most of their times to gather this sources and they loss most of their money to buy kerosene. In addition to that, the smoke from firewood and animal dung has an effect on the people (its impact on health).

To solve these problems most researchers studied about solar energy like sintayehu in ghinnir and sinana districts of bale zone, Habib Ibrahim in Adama and Sharew Anteneh in Ethiopia studied about assessment of solar energy, Tewolde Berhan about renewable energy in Ethiopia. Y.K. Sanusi1And M. O. Ojo, N. N. Gana and D. O. Akpootu in Kebbi, North-Western, Nigeria, Anwar Mustefa Mahmuda, Mulu Bayray Kahsaya, Asfafaw Hailesilasiec, Ftwi Yohaness Hagosd, Petros Gebraya, Hailay Kiros Kelelea, Kindeya Gebrehiwote, Hans Bauerf, Seppe Deckersg, Josse De Baerdemaekerh, Johan Driesen in North Ethiopia Griffin Salima, Geoffrey M. S. Chavula in Malawi. But no study was conducted related to solar energy around tana basin. This paper will pay particular attention to the conditions in rural areas where over 85% of the Ethiopian population currently reside especially around Tana basin.

## 1.3. SIGNIFICANCE OF THE STUDY

Solar radiation data have useful applications in different areas, such as solar water heating, wood drying, stoves, ovens, and photovoltaic, atmospheric energy balance studies, thermal load analyses on buildings, agricultural studies, and meteorological forecasting which should be reliable and readily available for design, optimization and performance evaluation of solar technologies for any particular location. The correct knowledge of global solar radiation at a given geographical location is vital to the development of many solar energy devices (INNOCENT et al., 2015).

So, the result of this study is providing information on estimated global solar radiation of the past thirty two years of the study area (Bahir Dar), and ten years for (Debre Markoss, Debre tabor and Gondar) have vital importance for production of the global solar radiation in the future and encourages the community people and interested organizations to use PV cell solar energy devices for electrifications instead of grid systems and areas that have no grid system. Furthermore, the document of this study is to encourage other researchers to do more researches especially on application of solar energy to electrified rural areas.

## 1.4. RESEARCH OBJECTIVE

### 1.4.1. General Objective

The general objective of this study is to assessment the global solar radiation over tana basin in Ethiopia.

### 1.4.2 Specific Objective

The specific objective of this study is

- To estimate the amount of solar radiation in Bahir Dar, Gondar, Debre Tabor and Debre Markoss

# 2. LITERATURE REVIEW

## 2.1. THE SUN

The sun is a vast and hot sphere of gas: the temperature in the interior of the sun is approximated to be around 15 million kelvins, its diameter is 1.4 million kilometers and its mass is 2.0 * $10^{30}$ kilograms (Kauko.H, 2008). The Sun is about 150 million kilometers from the Earth, and because the Earth is about 6300 km in radius. Sun is the seat of thermonuclear processes and produces a vast amount of energy. The energy emitted by the sun is called solar energy or solar radiation. Despite the considerable distance between the sun and the earth, the amount of solar energy reaching the earth is substantial. It is the earth's primary natural source of energy. Other sources are: the geothermal heat flux generated by the earth's interior, natural terrestrial radioactivity, and cosmic radiation, which are all negligible relative to solar radiation (Luqman et al., 2015).

## 2.2. ENERGY EMITTED FROM THE SUN

Solar energy is a renewable resource, and is environmentally friendly. Unlike fossil fuels that are only found in selected regions of the world, solar energy is available just about everywhere on earth (world energy council, 2004). The main source of solar energy is the sun (Griffin et al., 2012). This celestial body emits electromagnetic energy determined by solar output, sun-earth positioning, latitude, time of the year and time of the day. Between the top of the atmosphere and the earth's surface, the incident radiation from the sun experiences attenuation caused by water vapour and gaseous and dust particles, through reflection, absorption and scattering. The solar flux at the earth's surface is given as the sum of incident and diffuse radiation (Salima et al., 2012).

The sun consists mainly of helium and hydrogen; by mass approximately 80% is hydrogen and 20% is helium. The energy of the sun emerges from fusion reactions where four hydrogen nuclei fuse into one helium nucleus in the hot interior of the sun. In this reaction, the mass of the reactants is more than the mass of the products, and thus energy is released by Einstein law. The energy moves by radiation and convection to the surface of the sun, from which it radiates to the surrounding space (Kauko.H, 2008).

The Sun emits many forms of electromagnetic radiation in varying quantities. As shown in the following Figure2. 1 bellow, about 43 percent of the total radiant energy emitted from the Sun is in the visible parts of the spectrum. The bulk of the remainder lies in the near-infrared (49 percent) and ultraviolet section (7 percent). Less than 1 percent of solar radiation is emitted as x-rays, gamma waves, and radio waves.

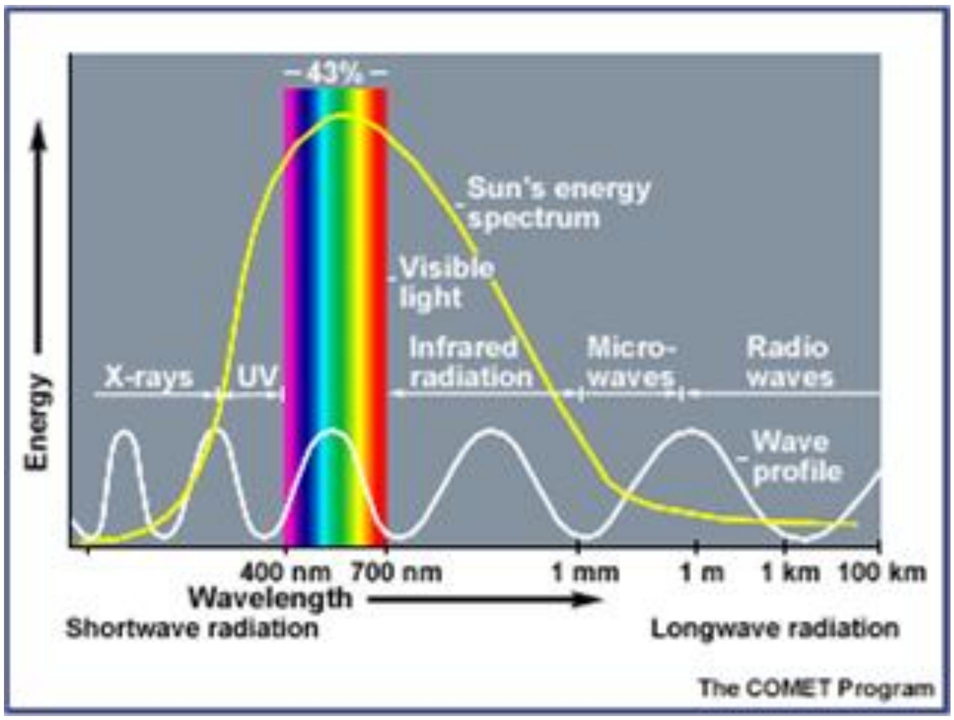


Figure2. 1:The transfer of energy from the Sun across nearly empty space

Once the Sun's energy reaches Earth, it is intercepted first by the atmosphere. As shown in Figure2. **2** a small part of the Sun's energy is directly absorbed, particularly by certain gases such as ozone and water vapor. Some of the Sun's energy is reflected back to space by clouds and Earth's surface.

Most of the radiation, however, is absorbed by Earth's surface. When the radiation is absorbed by a substance, the atoms in the substance move faster and the substance becomes warm to the touch. The absorbed energy is transformed into heat energy. This heat energy plays an important role in regulating the temperature of Earth's crust, surface waters, and lower atmosphere.

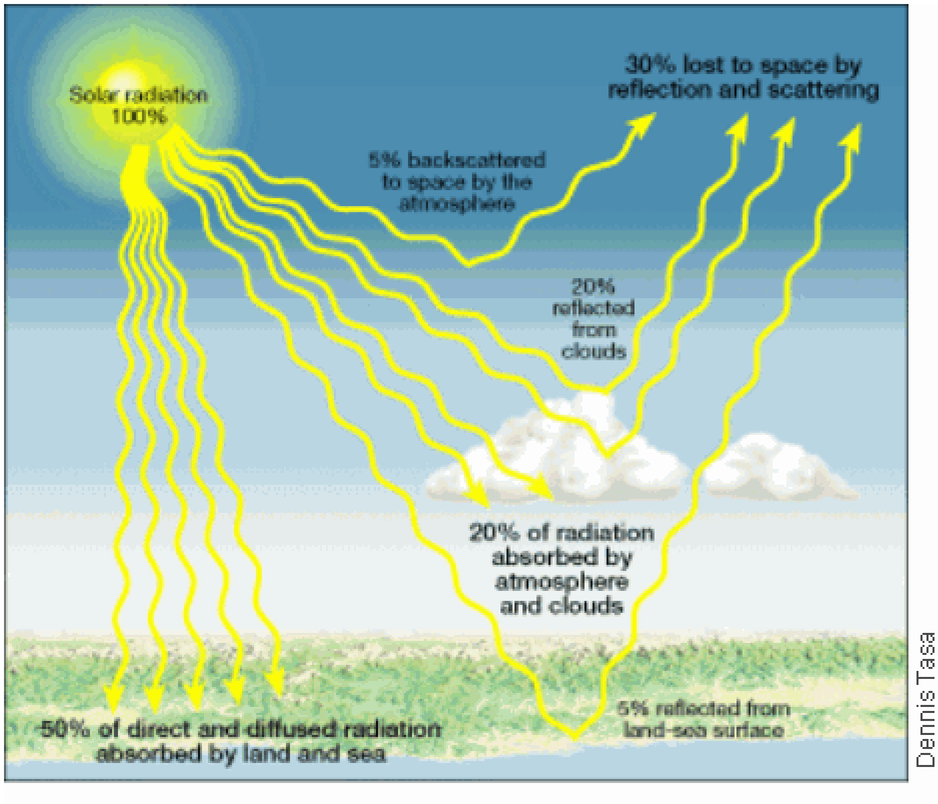


Figure2. 2: Atmospheric impacts on solar electromagnetic spectrum

Every surface on Earth absorbs and reflects energy at varying degrees, based on the surface's color and texture. Dark-colored objects absorb more visible radiation; light-colored objects reflect more visible radiation. Shiny or smooth objects reflect more, while dull or rough objects absorb more. Differences in reflection impact temperature, weather, and climate. Scientists use the term albedo to describe the percentage of solar radiation reflected back into space by an object or surface. A perfectly black surface has an albedo of 0 (all radiation is absorbed). A perfectly white surface has an albedo of 1.0 (all radiation is reflected).

Different features of Earth have different albedos. For example, land and ocean have low albedos (typically from 0.1 to 0.4) and absorb more energy than they reflect. Snow, ice, and clouds have high albedos (typically from 0.7 to 0.9) and reflect more energy than they absorb. Earth's average albedo is about 0.3. In other words, about 30 percent of incoming solar radiation is reflected back into space and 70 percent is absorbed.

| Type of surface | Albedo (%) |
|---|---|
| Ocean | 10-40 |
| Forest | 6 – 18 |
| Cities | 14 – 18 |
| Grass | 7 – 25 |
| Soil | 10 – 20 |
| Grassland | 16 – 20 |
| Desert (sand) | 35 – 45 |
| Ice | 20 – 70 |
| Cloud (thin, thick stratus) | 30, 60 – 70 |
| Snow (old) | 40 – 60 |
| snow (fresh) | 75 – 95 |

Table2.1: surface type and its albedo

### 2.2.1. THE SOLAR SPECTRUM

The distribution of solar radiation as a function of the wavelength is called the solar spectrum, which consists of a continuous emission with some superimposed line structures. The Sun's total radiation output is approximately equivalent to that of a blackbody at 5776 K (Randy, J. Ellingson, 2014). The radiation from the sun can be separated into three major energy regions. Figure2. **1** shows that, the high frequency (short wave length) energy in the radiation spectrum is labeled "ultraviolet" or "UV" and is detected by the human body primarily in terms of sunburn. The medium frequency energy radiation band in the solar spectrum is the visible band. The low frequency (long wave length) radiation band is the "infrared" or "IR" region. The amount of ultraviolet energy in the solar spectrum is small, essentially negligible in terms of useful heating effect. The visible band comprises about 47 to 48 percent of useful radiation for heating and the "near" infrared band makes up the balance. The intensity will vary with latitude, elevation and time of year because the amount of radiation that is absorbed and scattered by the atmosphere depends on the thickness of the atmosphere through which solar radiation must penetrate.

### 2.2.2. SOLAR CONSTANT

The luminosity of the Sun is about 3.86 x $10^{26}$ watts. This is the total power radiated out into space by the Sun. Most of this radiation is in the visible and infrared part of the electromagnetic spectrum, with less than 1 % emitted in the radio, UV and X-ray spectral bands. The sun’s energy is radiated uniformly in all directions. Because of atmospheric impacts and sun-earth distance, only 0.000000045% of this power is intercepted by our planet. This still amounts to a massive 1.75 x$10^{17}$ watts. For the purposes of solar energy capture, we normally talk about the amount of power in sunlight passing through a single square meter face-on to the sun, at the Earth's distance from the Sun. The intensity of the sun's energy on a surface varies with distance from the sun. At the average earth-sun distance, out in space, the intensity of solar energy has been determined to be 1377 W/$m^2$ with a variability of about three percent. The value of 1377 W/$m^2$.is called the "solar constant". The solar constant is defined as the total irradiance of the sun at the mean orbital distance of the Earth. The solar constant is a fundamental quantity in atmospheric physics since it represents the amount of solar energy arriving at the top of the atmosphere (Ajao et al, 2013).

As shown in Figure2. **4** bellow, due to the earth's elliptical orbit around the sun, the distance from the earth to the sun changes during the year so that the energy reaching the outer atmosphere of the earth varies by ±3% from 1335 to 1418 W/$m^2$. In addition to the variability in solar radiation that reaches the outer atmosphere around earth due to seasons, there are very large variations in the amount of solar energy available at a particular location on the earth's surface. Radiation reaching the earth's surface is of primary interest to terrestrial applications and the intensity will vary considerably with latitude season of the year, and local weather conditions. Variation in the total luminosity of the Sun itself also another factors for small variation in the solar constant.

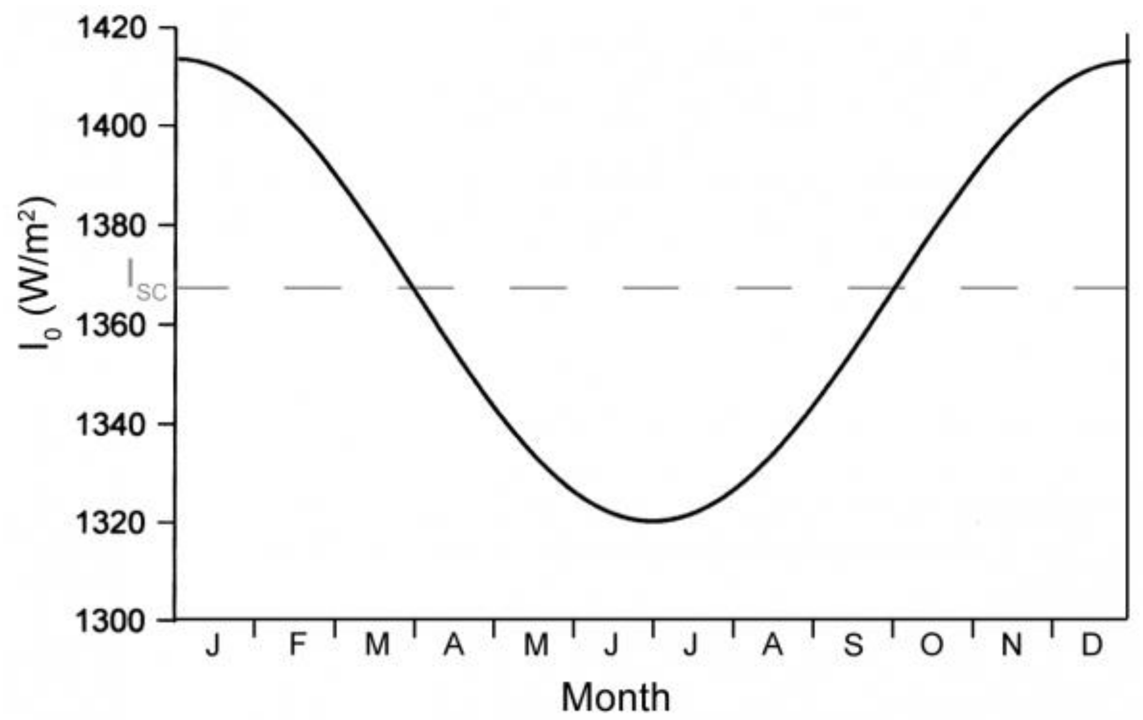

Figure2. 3: The variation of solar constant with day length.

## 2.2.3. EXTRATERRESTRIAL RADIATION

The incident spectral solar radiation outside the earth's atmosphere is called "extraterrestrial"; the extraterrestrial radiation is defined as the radiation that passes perpendicularly through an imaginary surface just outside the earth's atmosphere. The intensity of extraterrestrial solar radiation is varies from day to day because of the change in distance between the Earth and Sun and because of the Sun activity (Radosavljević.J & Đorđević., 2001). The extraterrestrial radiation, $H_0$ (W/m$^2$), on each day of the year is given by (Saleh.S, 2014).

$$H_0 = I_{SC} * [1 + 0.034 \cos (\frac{2\pi}{365} d)] \qquad 2.1$$

where $I_{SC}$ is the solar constant and d is the day number (starting from the 1st of January). The solar constant is an estimate of the average annual extraterrestrial radiation, having a generally accepted numerical value of 1377 W/m$^2$ (Kauko.H, 2008).

### 2.2.4. GLOBAL SOLAR RADIATION

Two components of solar radiation come to the Earth surface. One component comes directly from the Sun (direct solar radiation) and the other originates from dispersing of direct solar radiation in the atmosphere. The direct solar radiation represents a component of global solar radiation that comes directly to the earth in a bright and clear day (Griffin et al., 2012). The radiation that reflects from surroundings (so called albedo) is of importance for some surfaces that are inclined under some angle to the horizontal surface. This radiation is (diffuse solar radiation). Diffuse solar radiation is a part of the sunlight that passes through the atmosphere and is consumed, scattered or reflected by water vapor, dust particles or pollution (Mousavi et al., 2017). This Global solar radiation consists of direct and diffuse solar radiation is mainly diffuse and comes to the receiving surface under different angles. (Radosavljević.J. & D., 2001).

## 2.3. SOLAR ENERGY REACHES ON THE EARTH'S SURFACE

At any one time, the earth intercepts approximately 180 $x10^6$GW. The amount of solar radiation intercepted by the earth is called extraterrestrial radiation. As it makes its way towards the ground, it is depleted when passing through the atmosphere. On average, less than half of extraterrestrial radiation reaches ground level. Even when the sky is very clear with no clouds, approximately 20 % to 30 % of extraterrestrial radiation is lost during the down welling path**.** The role of the clouds is of paramount importance: optically thin clouds allow a small proportion of radiation to reach the ground; optically thick clouds create obscurity by stopping the radiation downwards. In clear skies, aerosols and water vapor are the main contributors to depletion.

The spectral distribution of extraterrestrial radiation is such that about half of it lies in the visible part of the electromagnetic spectrum. It produces daylight and is well perceived by the human vision system. Other parts of it are in the near-infrared and ultraviolet ranges. This spectral distribution is modified as the radiation crosses the atmosphere downwards; changes are mainly due to gases and aerosols. Several quantities are necessary to describe radiation. It is recalled that power is energy divided by a time interval. Irradiance (E) is defined as a power received per area; unit is watt per square meter ($W\ m^{-2}$). Irradiation (H) is the energy received per area; unit is joule per square meter ($J\ m^{-2}$).

The conversion from irradiation into irradiance is performed by dividing irradiation by the duration of the measurement. Reciprocally, irradiance is converted into irradiation by multiplying by time duration. If T is the duration of measurement:

$$E = H/T$$

The irradiation received at ground level on a horizontal flat surface consists of a direct component, i.e., the part of the irradiation that is coming from the sun's direction, and of a diffuse component, originating from the sky vault, clouds and neighboring objects. The sum of these components is called global irradiation. This decomposition may be of importance for several solar energy conversion systems

Since the Earth's cross sectional area is 127,400,000 $km^2$, the total Sun's power it intercepted by the Earth is $1.740\times10^{17}$ Watts but as it rotates, no energy is received during the night and the Sun's energy is distributed across the Earth's entire surface area, most of which is not normal to the Sun's rays for most of the day, so that the average insolation is only one quarter of the solar constant or about 342 Watts per square meter. Taking into account the seasonal and climatic conditions the actual power reaching the ground generally averages less than 200 Watts per square meter. Thus the average power intercepted at any time by the earth's surface is around $127.4 \times 10^6 \times 10^6 \times 200 = 25.4 \times 10^{15}$ Watts or 25,400 Tera Watts. Integrating this power over the whole year the total solar energy received by the earth will be:

25,400 TW X 24 X 365 = 222,504,000 Tera Watt hours (TWh)

To put this into perspective, the total annual electrical energy (not the total energy) consumed in the world from all sources in 2011 was 22,126 TWh (International Energy Agency (IEA)). Thus the available solar energy is over 10,056 times the world's consumption.

## 2.4. VARIABILITY OF SOLAR ENERGY ON THE EARTH'S SURFACE

Solar radiation has to pass through the atmosphere before reaching the earth's surface. The amount of power received at a given geographical site varies in time: between day and night due to the earth's rotation and between seasons because of the Earth's orbit. And at a given time it also varies in space, because of the changes in the obliquity of the solar rays with longitude and latitude. Accordingly, the amount of power received at a given location and time depends upon the relative position of the sun and the earth. This is why both sun-earth geometry and time play an important role in solar energy conversion and photo energy systems (Habib.H, 2015). Attenuation of the Earth's atmosphere and surface albedo also affects the amount of solar radiation on the earth surface.

### 2.4.1. THE APPARENT MOTION OF THE SUN

Resulting from the motion of the earth around the sun and its own axis, the position of the sun in the sky varies both daily and annually, as seen from the perspective of any point on the earth's surface. As shown in Figure2. **4** the earth travels in space on an elliptical orbit around the sun, with its axis tilted – which further more causes the seasonal variations in the sun's path across the sky. Simultaneously the earth makes 24-hour full circles around its axis, causing the sun to rise and set every day.

The earth describes an elliptical orbit with the sun at one of the foci (Figure2. **4**). The eccentricity of the earth's orbit is very small (0.01675); this means that the orbit is almost circular. The mean distance between the sun and the earth is approximately equal to 1.496 x $10^8$km.This distance is called 1 astronomical unit (ua).

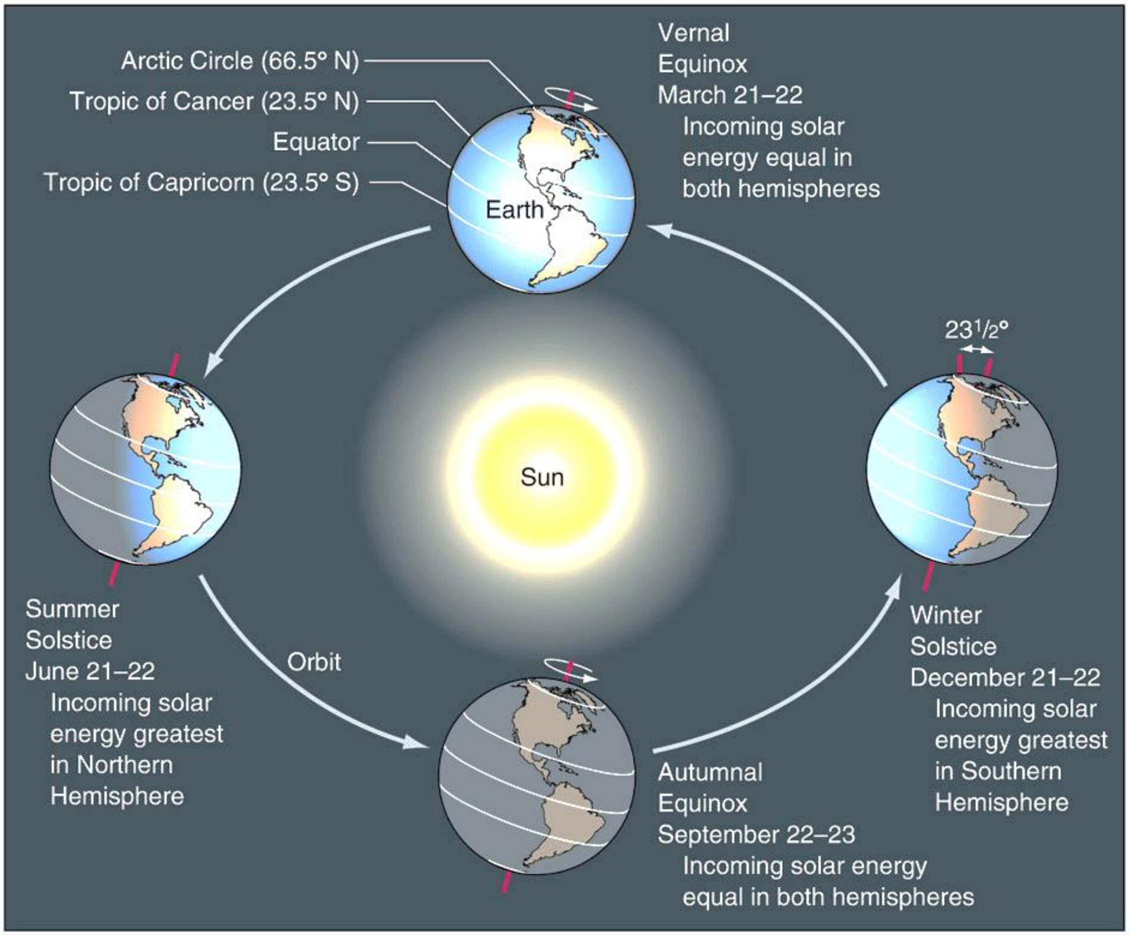


Figure2. 4: Scheme showing the earth's orbit around the sun.

In Figure2. **4** it can be noted that the equatorial plane of the earth inclines by 0.40928 rad (23.45°) on the plane containing the earth's orbit. This is equivalent to saying that the axis of the earth's daily rotation passing by the two poles is inclined by this angle with respect to the orbit plane. Because of this inclination, the northern hemisphere is closer to the sun in July than the southern hemisphere is and the sun over heads on the northern hemisphere. This defines the astronomical summer which begins on 21-22 June, known as the summer solstice, and which ends three months later. Conversely, the northern hemisphere is farther from the sun than the southern hemisphere during the astronomical winter, which begins on 21-22 December, a date known as the winter solstice and the sun over heads on the southern hemisphere.

Lastly, the daily rotation of the earth on itself induces the notion of a mean solar day divided into 24 h of 60 min each. The time parameters (year, day, and hour) are essential in order to compute the apparent position of the sun in the sky and, accordingly, the radiation at ground level that may be exploited.

## 2.4.2. SUN-EARTH DISTANCE

The mean distance between the earth and the sun, $r_0$, is 1 ua (Figure2. **4**). This value is reached for spring and fall equinox. The actual distance varies during the year depending on the number of the days in the year d: it is maximum for summer solstice (1.017 ua) and minimum for winter solstice (0.983 ua). A number of mathematical expressions of this distance are available; they are usually expressed in terms of Fourier series type of expansion. The following expression is adopted from the European Solar Radiation Atlas (2000).

$$j = d2\,\pi/365.2422 \qquad \text{2.2}$$

d ranges from 1 (1st January) to 365, or 366 in case of a leap year. Whatever the year, it is convenient to define the day angle j, in rad, as

The day angle is almost zero on 1st January (0.0172), equal to π on 1st July and 2π on 31st December. The sun-earth distance r is then given by

$$\left(\frac{r}{r_0}\right)^2 = 1 + \epsilon \qquad \text{2.3}$$

Where ϵ can be set to

$$\epsilon = 0.03344\cos(j - 0.049) \qquad \text{2.4}$$

With an accuracy sufficient for solar engineering, ϵ is called the relative eccentricity correction. As the amount of solar radiation intercepted by the earth depends upon the sun-earth distance, the extraterrestrial irradiance $E_0$ is computed from the solar constant $I_{SC}$ using the relative correction ϵ

$$E_0 = I_{SC}\,(1 + \epsilon) \qquad \text{2.5}$$

The relative correction ϵ is comprised between −0.03 and +0.03. A consequence of the large distance between the sun and the earth is that despite its formidable size, the sun appears as a small spot to an observer on the earth. The solid angle under which the sun appears is equal to 0.68 $x10^{-4}$ sr. The sunrays can be considered as parallel as they hit the top of the earth's atmosphere.

## 2.4.3. SOLAR DECLINATION

Declination is the angular distance from the sun north or south to the earth's equator. As schematically illustrated in fFigure2. **4**, the maximum and minimum declination angle values of the earth's orbit produce seasons (Mousavi et al., 2017). As it can be seen in Figure2. 4 the direction of the solar rays is not always parallel to the equatorial plane. The angle composed by the direction to the sun and the equatorial plane is called the solar declination, represented by δ. solar declination angle is the angle between the line of sun-earth's centers and Equatorial plane. The convention for counting the declination is the same as that for latitudes. Latitudes Φ are counted positive in the northern hemisphere and negative in the southern hemisphere. As shown in Figure2.**5** bellow, solar declination δ is positive for the summer solstice and negative for the winter solstice. By convention, longitudes are counted positive east of the meridian 0 rad and negative west of this meridian.

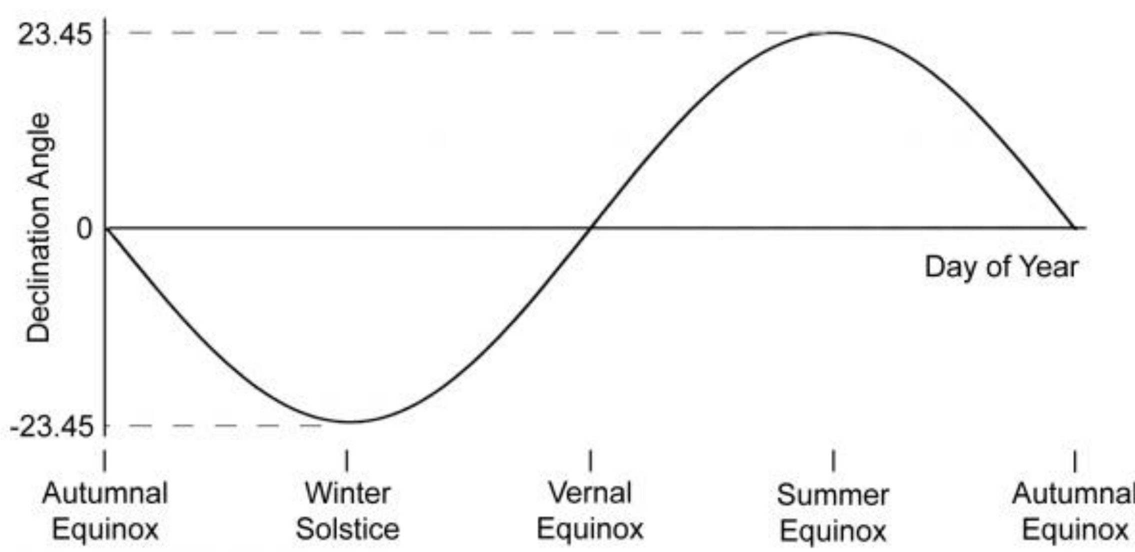


Figure2.5: the variation of solar declination angle with seasons

The solar declination varies from -23.45 degree to +23.45 degree. The sun can be only overhead between the tropic of Cancer ($23.5^0$N) & tropic of Capricorn ($23.5^0$ S). At tropic of Cancer ($23.5^0$ N), the sun is overhead at noon time, June 21, Where $\delta = 23.5^0$ (Summer Solstice). At tropic of Capricorn ($23.5^0$ S), the sun is overhead at noon time, Dec. 21, where $\delta = -23.5^0$ (Winter Solstice). At the Equator ($0^0$), the sun is overhead at noon at March 21 and Sept. 21, (Equinoxes). These extremes are reached at respectively the winter and summer solstices (Habib.H, 2015). At equinoxes, the declination is 0. A mean daily value is accurate enough for solar radiation estimation. Thus δ can be computed from d. using the day length d δ can be calculated as:

$$\delta = 23.45\sin\left(360 \times \tfrac{284+d}{365}\right) \ldots\ldots 2.6$$

where'd' is Julian day length starting from January first to December 31.

## 2.4.4. MONTHLY VARIATIONS

The monthly variation is due to earth's rotation about the sun and to seasonal changes in weather, which affect the cloud cover. In the winter the sun is lower in the sky than in the summer and the resultant larger incident angle between the sun and earth's a line perpendicular to a horizontal surface reduces the amount of radiation Intercepted by the earth's surface. The sun is shown at a higher angle, say during the summer months, and a larger amount of energy is intercepted.

## 2.4.5. DAILY VARIATIONS

The total amount of solar radiation reaching a horizontal surface on earth varies from day to day, primarily because of atmospheric phenomena. Clouds, dust, and other particulate matter in the atmosphere cause variations in radiation absorption and scatter.

### 2.4.6. HOURLY VARIATIONS

Hourly variations in available solar energy at a given location are principally due to the earth's rotation although cloudiness can have significant effects. Early morning and at the time of sunset, sun is at a very low angle and the solar rays must pass through a large thickness of atmosphere. The intensity of the energy received is therefore low. The hourly peak in radiation occurs at noon, when the sun is at the highest angle and is passing through the minimum thickness of the atmosphere. Since winter days are shorter than summer days, the period during which solar energy can be collected varies with season.

## 2.5. SOLAR ENERGY AND PV CELL

Solar energy can be used to generate electricity using photovoltaic solar cells and concentrated solar power. It can be used to heat buildings directly by passive solar building designs, or cooking and heating food with the help of solar ovens (VECAN.D, 2011). Photovoltaic is the direct conversion of light into electricity at the atomic level (SERISP, 1982). The "photovoltaic effect" is the basic physical process through which a PV cell converts sunlight into electricity.

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel Prize in physics (National Solar Power Reasearch Institute, Inc., 12/21/98). The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications (Knier.G, 2008).

In Ethiopia the first PV systems were installed in the mid-1980s - these systems were installed for rural home lighting and for school lighting. The largest of these was a 10.5kWp system installed in 1985 in Central Ethiopia which served 300 rural households through a micro grid in the village. This system was later upgraded to 30kWp in 1989 to provide power for the village water pump and grain mill (Ethio Resource Group Freiburg (Germany), 2012).

Since 222,504,000 TWh solar energy reaches on the Earth surface, which converted into electrical energy by photovoltaic cell, with low conversion efficiency of only 10% the available energy will be 22,250,400 TWh or over a thousand times the consumption. Using the same low conversion efficiency, the entire world's electricity demand could be supplied from a solar panel of 127,000 $km^2$.

It is estimated that a total of some 5.3MWp of PV is now in use in Ethiopia. The main area of application for PV is now off-grid telecom systems (particularly for mobile and landline network stations) which account for 87% of total installations. PV systems are also used in social institutions including health stations, schools and for water pumping. Some thirty thousand residential customers are also electrified with PV in rural areas.
Now a day, the monthly household power consumption of Ethiopia is approximately 300-400 KWh. The solar radiation reaches on the earth surface over Tana basin is over 2.5KWh/$m^2$day.A PV cell with an area of 30 -40 $m^2$ and efficiency 10-15% generates an electric power over 225-2160 KWh, which covers the household power consumptions. So it is better to that the people use suns energy as energy source for household applications by covering their homes with PV cells to converting suns energy to electric power and they save their money.

### 2.5.1. How do Photovoltaic Work?

The solar cell is composed of a P-type semiconductor and an N-type semiconductor. Sunlight is composed of photons, or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When solar light (photons) hitting the cell produces two types of electrons, negatively and positively charged electrons in the semiconductors. Negatively charged (-) electrons gather around the N-type semiconductor while positively charged (+) electrons gather around the P-type semiconductor. When we connect loads such as a light bulb, electric current flows between the two electrodes.

There are different types of solar cells; the most common group is the silicon cells. The silicon cell with highest efficiency is the mono-crystalline cell, where the atoms are symmetric placed within the structure. Commercial silicon cells have an efficiency of 14 - 17 %. A less expensive alternative is the polycrystalline cell, where the structure is less symmetric and less complex. Here the efficiency is about 13 - 15 %.

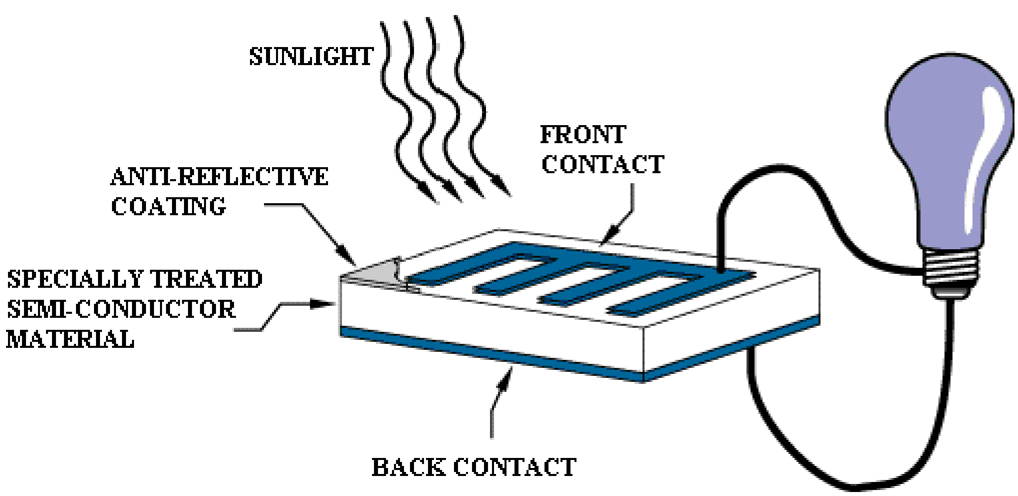


Figure2. 6: Circuit diagram of solar cell

The above diagram Figure2. **6** illustrate the operation of a basic photovoltaic cell, also called a solar cell. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive (P-type) on one side and negative (n-type) on the other. From bellow we see that a number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

Multiple modules can be wired together to form an array. In general, the larger the area of a module or array; the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

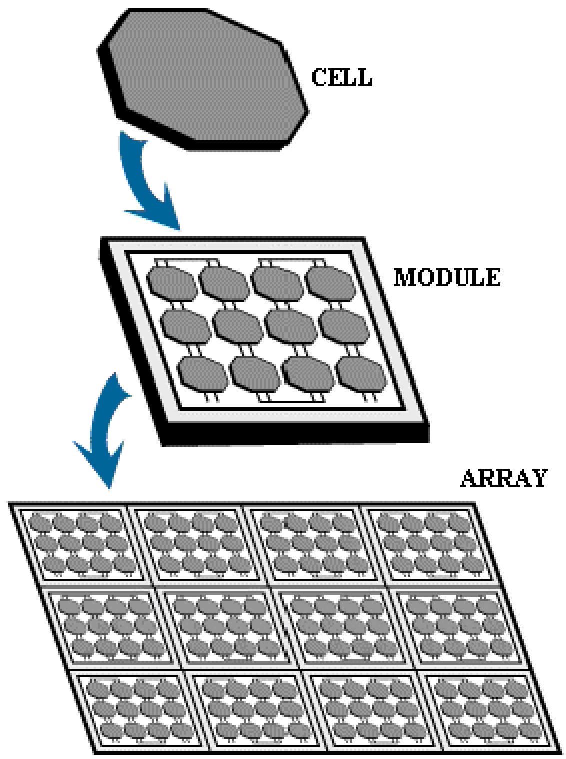


Figure2.7: combination of solar cell to form modules and array.

The current and power output of photovoltaic modules is approximately proportional to the sunlight intensity. This implies that the efficiency of solar panel depends on the weather condition, time of the day and the site of installation of the system. Consideration of the site of installation brings about installing a solar panel in a place where it will be able to capture enough sunlight (Ajao et al, 2013).

# 3. METHODOLOGY

## 3.1. STUDY AREA

Lake Tana, the main source of the Blue Nile River, is the largest lake in Ethiopia and the third largest in the Nile Basin. It is approximately 84 km long, 66 km wide and is located in the country's north-west highlands (Lat 12° 0' North, Lon 37° 15' East). There are 37 islands in the lake, upon which some 20 monasteries from the 16th and 17th century exists. As shown in Figure3. **1** bellow, Lake tana located at latitude12.1667 and longitude of 37.3333 degree. The Lake Tana Basin significantly contributes to the livelihoods of tens of millions of people in the lower Nile River basin. The lake is also a natural reservoir for the eighty-megawatt runoff power station at Tis Abay. The largest city on the lake shore, Bahir Dar, is the capital of the Amhara Province and is home to Bahir Dar University (BDU).

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), Bahir Dar Special Zone has a total population of 221,991, of whom 108,456 are men and 113,535 women; 180,174 or 81.16% are urban inhabitants, the rest of population are living at rural kebeles around Bahir Dar. At the town of Bahir Dar there are 155,428 inhabitants; the rest of urban population is living at Meshenti, Tis Abay and Zege towns which are part of Bahir Dar Special Zone. The Lake Tana basin comprises an area of 15,096 $km^2$ including the lake area The mean annual rainfall of the catchment area is about 1280 mm. The main rainy season between June and September. The air temperature shows large diurnal but small seasonal changes with an annual average of 20 °C. The basin has significance national importance due to its high potentials for irrigation, hydroelectric power development, high value crops and livestock production, and ecotourism. The lake is a natural freshwater lake which covers 3000 - 3600 $km^2$ area at an elevation of 1800 m. The lake is shallow with a maximum depth of 15 m. The main tributaries of the Lake Tana are Gilgel Abay, Gumera, Ribb and Megech rivers (Setegn.SG , R. Srinivasan , B. Dargahi, 2008).

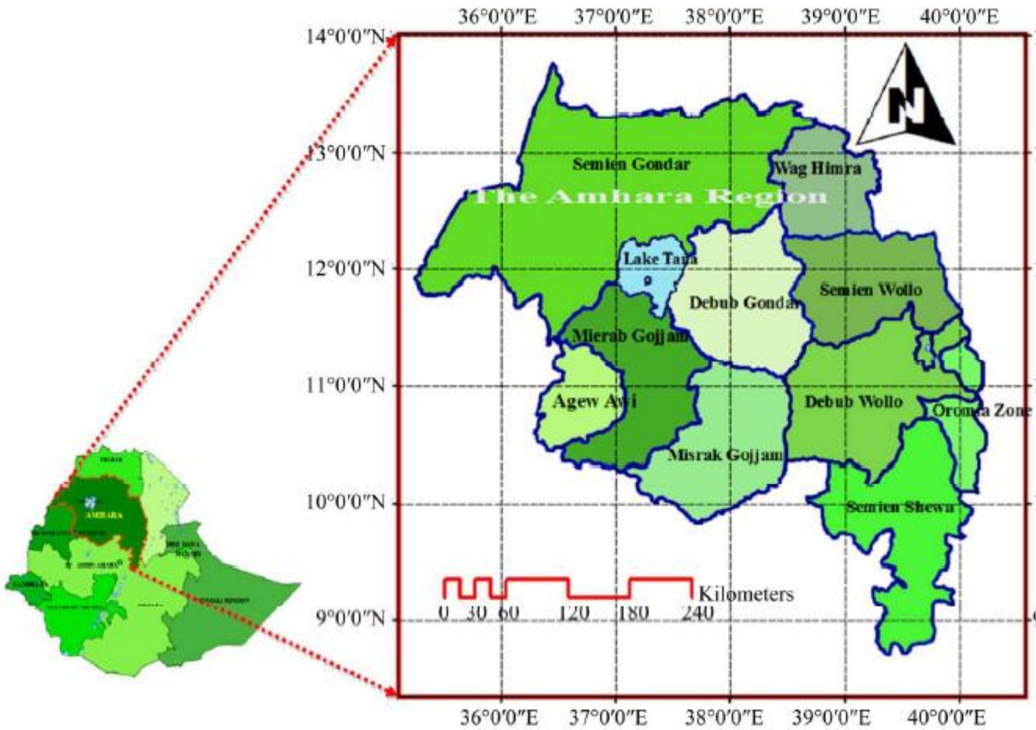


Figure3. 1: Geographical map of Amhara region with Lake Tana basin

## 3.2. DATA TYPE AND SOURCE

Ethiopian metrological agency has the responsibility to collect the daily and the monthly mean data for sunshine hours, Maximum Temperature Tmax, and Minimum Temperature Tmin. So we got those measured data from Ethiopian metrological agency. The data obtain covered a period of thirty two years (1985 - 2016) for Bahir Dar stations at Latitude 11.59 and longitude of 37.888, ten years (2007-2016) for Gondar stations at Latitude 12.6 and longitude of 37.46, for Debre Markoss stations at Latitude 10.33 and longitude of 37.73 and Debre Tabor stations at Latitude 11.85 and longitude of 38.02

## 3.3. METHOD

Since solar radiation data can't get directly from Ethiopian metrological agency of Bahir Dar branch, there are many methods to estimate the global solar radiation depends on the type of data that we have. For this research work, we gate sunshine duration, Maximum Temperature Tmax, and Minimum Temperature Tmin data of Bahir Dar (1985-2016), Debre Markoss (2007-2016), Debre Tabor (2007-2016) and Gondar (2007-2016) from Ethiopian metrological agency and using Angstrom –Prescott model (equation) and Hargreaves model convert to global solar radiation data.

Angstrom –Prescott method of estimating global solar radiation using sunshine duration given as (UDO.SO, 2001)

$$\frac{H}{H_o} = a + b\left(\frac{n}{N}\right) \quad \text{……………………………………………………………} 3.1$$

Where H Incoming daily global solar radiation (MJ $m^{-2}$ $d^{-1}$)

$H_0$ is Daily extra-terrestrial radiation (MJ $m^{-2}$ $d^{-1}$) which is determined using equation defined by Duffi and Beckman (1991)

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360d}{365}\right)\right]\left[\cos\Phi\cos\delta\sin\omega\frac{2\pi\omega}{360}\sin\Phi\sin\delta\right] \quad \text{……......} 3.2$$

Where Φ = latitude in degree

δ = Solar declination angle in degree given by $\delta = 23.45\sin(360\frac{284+d}{365})$

d is the Julian day number (the number of days of the year starting from the first of January),

$I_{sc}$ = solar constant with a value of 1367 $Wm^{-2}$,

ω is sunset hour angle which given as

$$\omega = \cos^{-1}(-\tan\Phi\tan\delta) \quad \text{………………………………………………...} 3.3$$

'a' and 'b' Empirical constant which is given by

$$a = 0.1 + 0.24\left(\frac{n}{N}\right) \quad \text{………………………………………………………....} 3.4$$

And $$b = 0{:}37 + 0{:}08\left(\frac{n}{N}\right) \quad \text{……….………..……………………………………} 3.5$$

n is the monthly average daily number of hours of bright sunshine, N is the monthly average daily maximum number of hours of possible sunshine (or day length) which is given by

$$N = \frac{2}{15}\omega \qquad 3.6$$

Hargreaves model is the other models that used to calculate solar radiation using maximum and minimum temperature data. Which is given by:

$$\frac{H}{H_o} = a(\sqrt{T_{max} - T_{min}}) \qquad 3.7$$

Where $T_{max}$ and $T_{min}$ are the monthly average maximum and minimum temperature at the given area.

So, mat lab plot of solar radiation verses year and solar radiation verses month were enough to estimate the global solar radiation at a given area.

# 4. RESULT AND DISCUSSION

Monthly Average Sunshine Hours "n" (hrs.), Maximum Temperature "tmax" ($^{o}$C) and Minimum Temperature "tmin" ($^{o}$C) of Bahir Dar from1985-2016, Gondar, Debre Markoss and that of Debre Tabor from 2007-2016 are given in Table4. **1** bellow. All the other parameters i.e the daily and monthly data's are put in appendix part.

Table4. 1: The monthly mean sunshine hour, maximum temperature and minimum temperature of a) Debre Tabor, b) Debre Markoss, c) Gondar and d) Bahir Dar.

| Month | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 23.1 | 24.8 | 25.2 | 25.4 | 22.5 | 22.4 | 19.9 | 19.9 | 20.8 | 22 | 22.4 | 22.3 |
| Tmin | 7.2 | 9.4 | 10.5 | 10.5 | 10.5 | 10.5 | 10 | 10.1 | 9.4 | 8.7 | 8.2 | 7.7 |
| SS | 8.8 | 9.2 | 7.4 | 7.9 | 5.8 | 6.4 | 4.3 | 4.7 | 6.4 | 7.5 | 7.7 | 8.5 |

A

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 24.5 | 25.9 | 26.1 | 26.4 | 24.1 | 21.9 | 19.5 | 19.5 | 20.8 | 23 | 23.3 | 22.6 |
| Tmin | 8.4 | 10.7 | 12.6 | 12.6 | 12.7 | 11.5 | 11.4 | 11.2 | 10.7 | 11 | 9.2 | 8.8 |
| SS | 8.1 | 9.2 | 8 | 7.5 | 6.7 | 5.2 | 3.2 | 3.9 | 5.2 | 8.6 | 8.7 | 9.4 |

B

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 28.5 | 30.2 | 29.5 | 30.7 | 29.1 | 25.9 | 23.6 | 23.6 | 25.1 | 27 | 27.7 | 27.8 |
| Tmin | 12.2 | 13.8 | 13.8 | 15.8 | 16 | 14.6 | 14 | 13.8 | 13.2 | 14 | 12.6 | 12.3 |
| SS | 9.1 | 8.9 | 7.3 | 7.9 | 7 | 3.8 | 3.9 | 4.7 | 6.1 | 7.5 | 8.5 | 8.4 |

C

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 27 | 29 | 30 | 30 | 29 | 27 | 24 | 24 | 26 | 27 | 27 | 27 |
| Tmin | 8 | 10 | 13 | 15 | 15 | 15 | 14 | 14 | 14 | 14 | 11 | 9 |
| SS | 10 | 10 | 9 | 9 | 8 | 7 | 5 | 5 | 6 | 9 | 10 | 10 |

D

From Table4. **1** above we see that from the four stations, the maximum monthly average temperature recorded in Gondar and Bahir Dar during spring, the minimum one in Debre Tabor and Debre Markoss during winter. In addition to that all stations have minimum sunshine duration in summer and the maximum sunshine duration in spring.

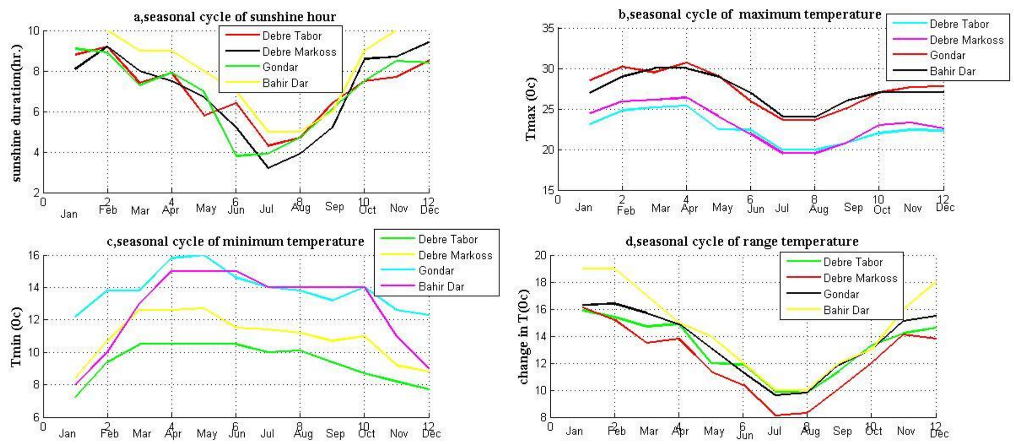


figure 4. 1seasonal cycles of a) sunshine, b) maximum temperature, c) minimum temperature and d) temperature range of the four stations.

As we see from figure 4. **1** all of the stations have long period of sunshine duration and maximum temperature around spring. Because around those seasons almost all the day, the sky is clear (no or less cloud covers the atmosphere). So the solar radiation reaches on the earth for long period of time. Around winter also have long period of sunshine duration and maximum temperature. And their short period of sunshine duration is occurring in summer season (June-August). This is due to cloud coverage i.e in summer the cloud covers the atmosphere most or all over the day and the sun shine on the earth for short period of time per day and the maximum temperature becomes decreases.

The minimum temperatures have large value in summer and small value in winter, most of the energies emitted from the sun is reflected, absorbed or scattered back to space. Only a small part of it reaches to the earth. Once the energy reach to earth it is absorbed not reflect nor scattered. So, the temperature throughout the day is almost constant and the change between them is small in summer. But in spring the reverse is true. In those months less cloud is in the sky and most of sun energies reach on the earth at the day time and it increases the temperature. At nigh the earth remitted those energies as long wave radiation back to space and becomes cool (has less temperature). These two conditions give out large temperature difference between them in spring and minimum temperature difference in summer.

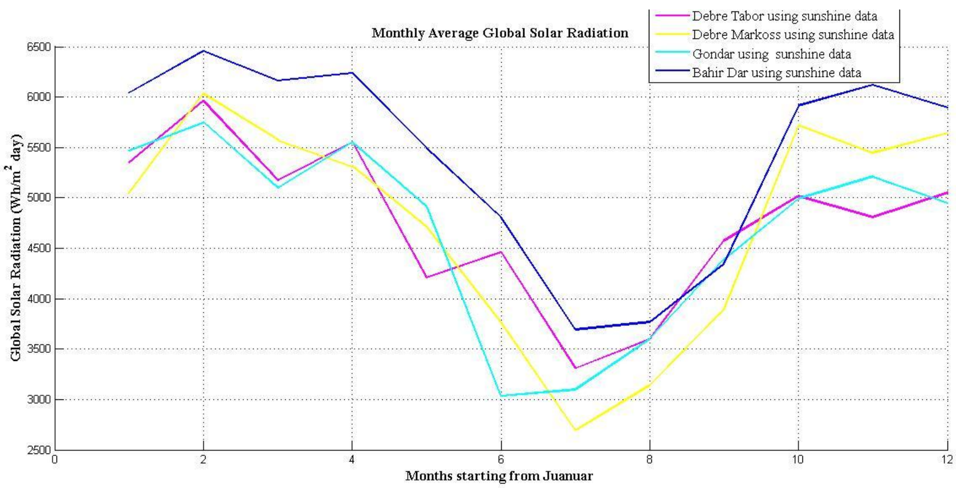


Figure 4. 2: The monthly average Global solar radiation of Debre Tabor, Debre Markoss, Gondar (2007-2016) and Bahir Dar (1985-2016) calculated using the Angstrom model.

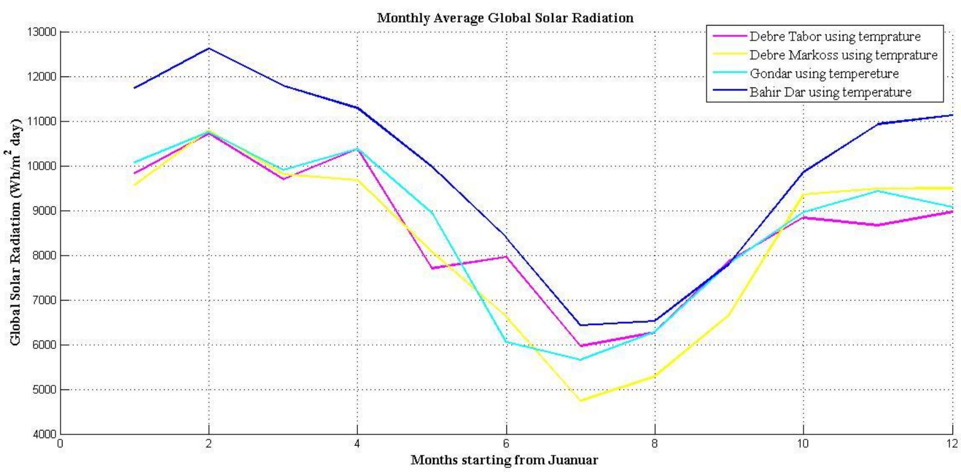


Figure4.3: The monthly average Global solar radiation of Debre Tabor, Debre Markoss, Gondar (2007-2016) and Bahir Dar (1985-2016) calculated using the Hargreaves models.

Figure 4.2 and Figure 4.3 show the monthly average solar radiation of Debre Tabor, Debre Markoss, Gondar (2007-2016) and Bahir Dar (1985-2016) calculated using the Angstrom and Hargreaves model. As we have seen above the last maximum average monthly global solar radiation of each station is occur in February and their least minimum value are occurred in July. But in general, the four stations have maximum radiation in spring and minimum is summer season. Why in summer the radiation is minimum? The reason is that in summer season the sky covered with clouds so the period of sunshine hour is short, most of the radiations from the sun back scattered, absorbed and reflect to space, so the amount of solar radiation reaches on the Earth surface are small in summer. In spring around February, March and April there is clear sky and most of the radiation emitted from the sun reach to the earth surface. Due to this and such like reasons the radiation is maximum in those months. From the two graphs given above Bahir Dar has the largest radiation in both models. This may be surface albedo and industries in the city.

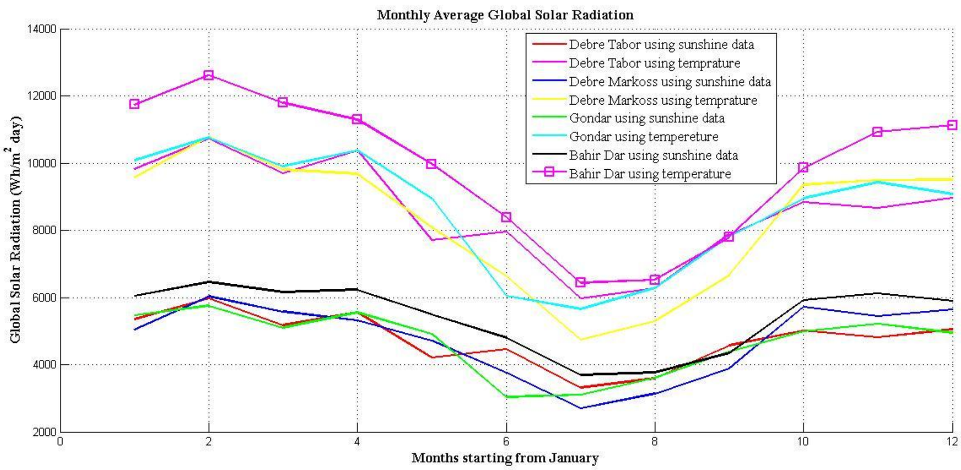


Figure4.4: The monthly average Global solar radiation of Debre Tabor, Debre Markoss, Gondar (2007-2016) and Bahir Dar (1985-2016) calculated using both Angstrom and Hargreaves models.

From Figure4.4, we see that the plots of the two models have the same trained for each month but Hargreaves models give the large value of solar radiation than the Angstrom models for all stations. This difference in magnitude is that sunshine data is smaller than the change in temperature data. As we see from Table4. **1** data of sunshine duration is less than that of the change in temperature. So solar radiation calculated using temperature data is large.

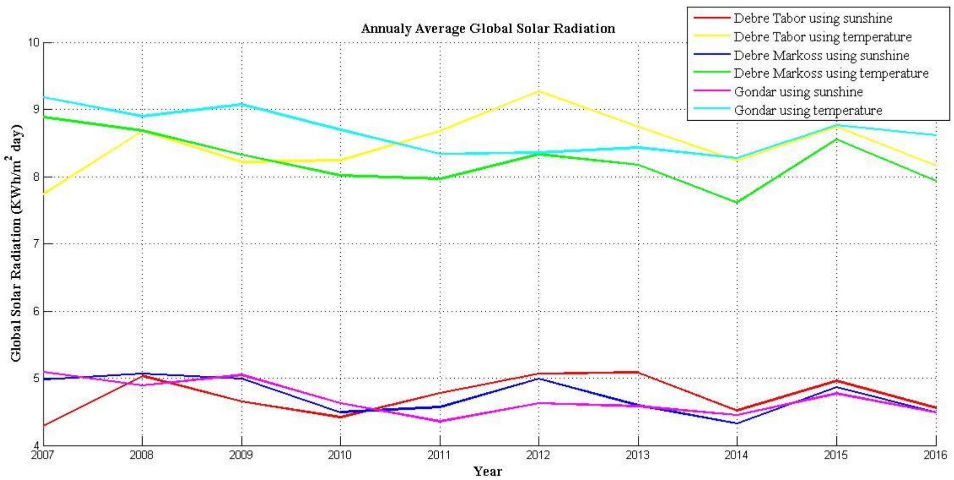


Figure 4. 5: Annually average Global solar radiation of Debre Tabor, Debre Markoss and Gondar (2007-2016) calculated using Angstrom and Hargreaves models.

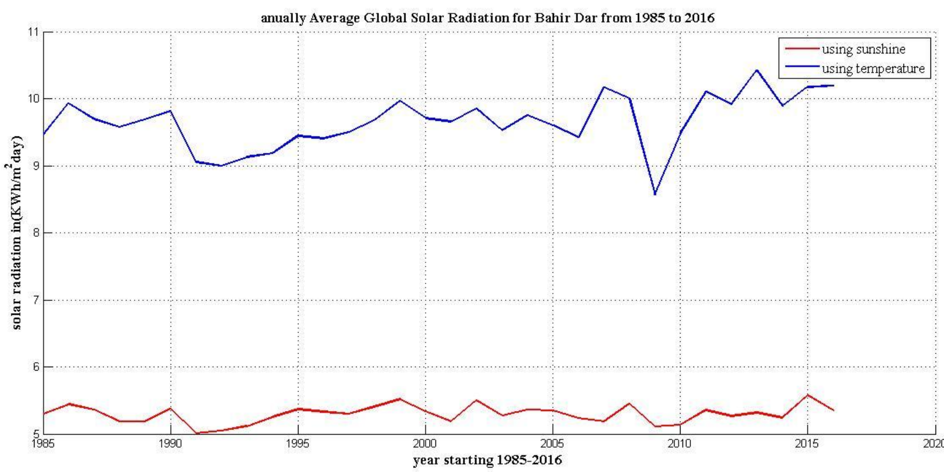


Figure 4.6: Annually average Global solar radiation of Bahir Dar (1985-2016) calculated using both the Angstrom and Hargreaves model.

The annually solar radiation of Debre Tabor, Debre Markoss and Gondar (2007-2016) (Figure 4.5) calculated using Angstrom and Hargreaves models. Since the data of Bahir Dar covers 32 years, and the rest three stations data covers ten years, it is better to plot the three stations (Debre Tabor, Debre Markoss and Gondar) in one plane and Bahir Dar in the other plane. From these graphs we see that; Debre Tabor has maximum radiation in 2013 (5.09KWh/m$^2$day) and (9.3KWh/m$^2$day) for Angstrom and Hargreaves model respectively and minimum in 2007 (4.3KWh/m$^2$day) and around (7.7KWh/m$^2$day). Debre Markoss has minimum radiation in 2014 (4.33KWh/m$^2$day) and (7.6KWh/m$^2$day) for Angstrom and Hargreaves model respectively and maximum in 2008 (5.05KWh/m$^2$day) for Angstrom models and in 2007 (8.9KWh/m$^2$day) for Hargreaves model. Gondar has maximum radiation in 2007 (5.1KWh/m$^2$day) and (9.2KWh/m$^2$day) Angstrom and Hargreaves model respectively minimum in 2011 (4.36KWh/m$^2$day) for Angstrom model and in 2014 (8.25KWh/m$^2$day) for Hargreaves model. Similar to that of the monthly plot, the Hargreaves model gives maximum annually radiation than that of the Angstrom model.

Figure 4.6 shows the annually solar radiation of Bahir Dar show the annually solar radiation of Bahir Dar calculated by using the two models. From the graph above we see that the maximum solar radiation of Bahir Dar occur in 2015 around (5.6 Kwh/m$^2$day) for Angstrom model and in 2013 around (10.5 KWh/m$^2$day) for Hargreaves model. And their minimum values occur in 1991 (5 KWh/ m$^2$day) for Angstrom model and in 2009 (8.6 KWh/ m$^2$day) for Hargreaves model. In this plot also Hargreaves model give large radiation.

The annual variation of solar radiation in four cities may be due to urbanization, industrialization, human activities and atmospheric conditions. Sometimes large amount of greenhouse gases emitted from industries and other places and sometimes the greenhouse gases emission is reduced. Due to these and such like activities the amount of solar radiation absorbed by earth varies year to year.

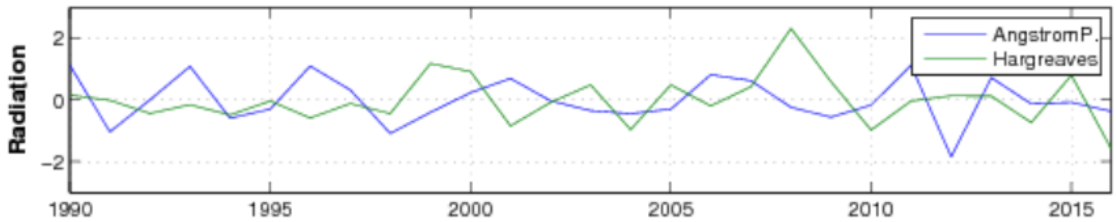


Figure4.7: The annually anomalous of radiation of Debre Markoss using two models for spring season.

From Figure4.7 we see that the annually anomalous of radiation of Debre Markoss on spring season has maximum value in 2008 for Hargreaves model and in 2011 for the Angstrom models. Its minimum is in 2012 for Angstrom models and in 2016 for Hargreaves model.

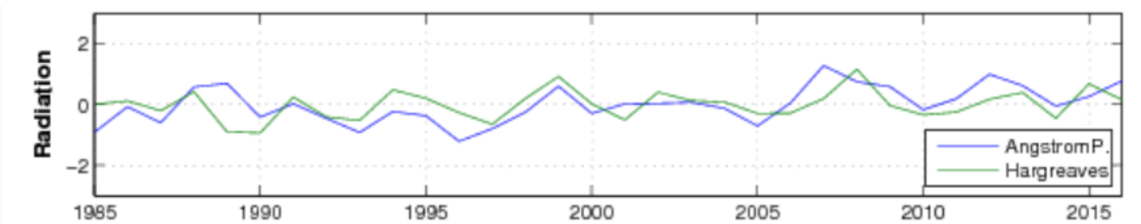


Figure4.8 The annually anomalous of radiation of Bahir Dar using two models for spring season.

Figure4.8 shows the anomalous of solar radiation for Bahir Dar using the two models in spring season. The radiation is maximum in 2007 for Angstrom models, in 2008 for Hargreaves model and its minimum is in 1996 for Angstrom models and in 1990 for Hargreaves model.

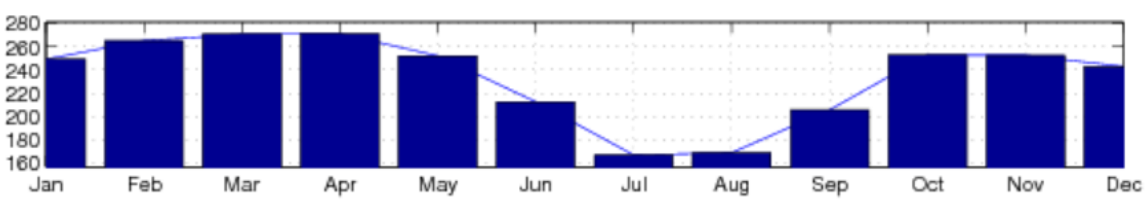


Figure4.9 : Solar radiation of observed data over Tana basin

Figure4.9 shows the plot of observed radiation data. As we see above the last maximum radiation is occur in March and April and its least minimum is in June and July. When we compare it with Figure 4.2 and Figure 4.3 that plot using models, they have the same trend. Their maximum and minimum values occur approximately in the same season. So, it is possible to use these models to assess the solar radiation where areas that can't gate radiation data directly.

As we see from Figure4.9 the least minimum radiation is around 170Wh/m$^2$day and the maximum is 270Wh/m$^2$day. Averaged it will be 220Wh/m$^2$day. By using PV cells of whose efficiency 10% and area of installation 1m$^2$, we can get around 660Wh power in one month which is enough to cover the energy demand of home application.

# 5. CONCLUSION

The energy consumption of the average Ethiopian is among the lowest in the world. The current energy consumption in Ethiopia, one that is heavily reliant on the burning of biomass has major implications for the environment. Ethiopia has great potential (renewable energy source) to implement renewable technologies to decrease reliance on traditional fuel sources and increase rural electrification. Solar energy is the most abundant permanent renewable energy resource on earth and it is available for use in its direct and indirect form. Solar radiation is an energy emitted from the sun in the form of electromagnetic radiation in varying quantities. The amount of power received at a given location and time on the earth affected by different parameters of the atmosphere and Earth mechanics. The amount of solar radiation intercepted by the earth is called extraterrestrial radiation. Two components of solar radiation come to the Earth surface. One component comes directly from the Sun *(*direct solar radiation*)* and the other originates from dispersing of direct solar radiation in the atmosphere is (diffuse solar radiation).

The whole year the total solar energy received by the earth will be 222,504,000 TWh which is over 10,056 times the world's consumption. Photovoltaic cell is a device that converts solar energy in to electricity. The current and power output of a PV cell depends on its size and is proportional to the intensity of sunlight striking the surface of the cell.

From this study, we calculate the amount of monthly average global solar radiation of Bahir Dar (1985-2016), Gondar, Debre Markoss, and Debre Tabor (2007-2016) by using both the Angstrom-Prescott and Hargreaves empirical equations from sunshine and temperature data which obtain from Ethiopian metrological agency. As we see above all of the cities have its own maximum value in spring and minimum in summer both in two models. But Hargreaves empirical model gives maximum solar radiation than that of Angstrom-Prescott model. And the monthly and annually GSR of Bahir Dar is greater than the other three cities both in the two models.

# 6. RECOMMENDATION

Generally, rural electrification program through solar energy technologies need to be strengthened in the future given their paramount importance in empowering women economically and altering traditional gender relations. As a matter of fact PV electricity is the most viable option for power supply in areas where grid electricity is not reachable due to difficult topography, poor infrastructure and the resultant inaccessibility. Private investors and NGOs need to be encouraged to participate in the process of expanding PV based off-grid power into the rural areas.

Tana basin has an annual average solar radiation of about 3-12 $kWh/m^2$/day according to the radiation contour map of Bahir Dar, Debre Tabor, Gondar and Debre Markoss. This shows that Tana basin is a very suitable area for harnessing this free source of energy and this resource should be utilized effectively for the benefit of those residing in this particular location and its environs.

Some researchers have been done on renewable energy sources. But not enough especially on its application hasn’t been done around Tana basin in Ethiopia. So I would like to say that, researchers and scientists will study about them and encourage the people to use this source as household energy.

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# APPENDIX

A, Annually average Global Solar Radiation of Debre Tabor H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for ten years (2007-2016)

| Year | n(hr.) | tmax(0c) | tmin(0c) | Φ(0) | N | A | b | Ho | H(KWh/m2day) | 10H1(KWh/m2day) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 6.227 | 22.7504 | 9.57799 | 11.85 | 12.001 | 0.226 | 0.412 | 0.9808 | 4.2810375 | 0.7731625 |
| 2008 | 7.529 | 21.9822 | 9.50273 | 11.85 | 12.001 | 0.252 | 0.421 | 0.9808 | 5.034008333 | 0.867925 |
| 2009 | 6.32 | 22.7499 | 9.95153 | 11.85 | 12.001 | 0.228 | 0.413 | 0.9808 | 4.652945455 | 0.821609091 |
| 2010 | 6.452 | 22.1619 | 8.68223 | 11.85 | 12.001 | 0.23 | 0.413 | 0.9808 | 4.416883333 | 0.824441667 |
| 2011 | 7.025 | 22.1087 | 8.81432 | 11.85 | 12.001 | 0.241 | 0.417 | 0.9808 | 4.777290909 | 0.8673 |
| 2012 | 7.564 | 23.4697 | 9.33379 | 11.85 | 12.001 | 0.252 | 0.421 | 0.9808 | 5.064208333 | 0.9268 |
| 2013 | 7.604 | 21.8382 | 9.2645 | 11.85 | 12.001 | 0.254 | 0.421 | 0.9808 | 5.082109091 | 0.873672727 |
| 2014 | 6.572 | 22.9271 | 9.56023 | 11.85 | 12.001 | 0.231 | 0.414 | 0.9808 | 4.51873 | 8.23479 |
| 2015 | 7.376 | 22.9065 | 9.97281 | 11.85 | 12.001 | 0.248 | 0.419 | 0.9808 | 4.956141667 | 0.874058333 |
| 2016 | 6.7 | 22.4583 | 9.80833 | 11.85 | 12.001 | 0.235 | 0.415 | 0.9808 | 4.555175 | 0.816775 |

b, Monthly average Global Solar Radiation of Bahir Dar H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for Bahir Dar 1985-2016

| month | N | Tmax | tmin | Φ | δ | ω | D | a | b | Ho | H | H1 | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 9.53 | 26.9 | 8.45 | 11.59 | -20.92 | 85.5 | 17 | 0.3006 | 0.4369 | 0.867 | 5.7747 | 1.1203 | 11.4006 |
| February | 9.65 | 28.5 | 10.21 | 11.59 | -12.95 | 87.3 | 47 | 0.299 | 0.4363 | 0.945 | 6.2465 | 1.2093 | 11.6395 |
| March | 9.1 | 29.8 | 12.95 | 11.59 | -2.418 | 89.5 | 75 | 0.283 | 0.431 | 1.017 | 6.2234 | 1.1838 | 11.9338 |
| April | 9.04 | 30.1 | 14.63 | 11.59 | 9.415 | 91.95 | 105 | 0.2769 | 0.429 | 1.056 | 6.2607 | 1.1503 | 12.2598 |
| May | 8.22 | 29.2 | 15.41 | 11.59 | 18.79 | 94 | 135 | 0.2573 | 0.4224 | 1.053 | 5.6238 | 1.0072 | 12.5336 |
| June | 6.95 | 27.3 | 14.51 | 11.59 | 23.09 | 95.02 | 162 | 0.2316 | 0.4139 | 1.041 | 4.7724 | 0.8616 | 12.6687 |
| July | 4.62 | 24.3 | 14.2 | 11.59 | 21.18 | 94.56 | 198 | 0.1879 | 0.3993 | 1.042 | 3.4808 | 0.6209 | 12.6078 |
| august | 4.61 | 24.5 | 14.06 | 11.59 | 13.46 | 92.81 | 228 | 0.1895 | 0.3998 | 1.048 | 3.5462 | 0.6405 | 12.375 |
| Septemb | 6.46 | 25.6 | 13.53 | 11.59 | 2.217 | 90.45 | 258 | 0.2285 | 0.4128 | 1.026 | 4.6121 | 0.8135 | 12.0607 |
| October | 8.59 | 26.6 | 13.53 | 11.59 | -9.599 | 88.01 | 288 | 0.2756 | 0.4285 | 0.962 | 5.667 | 0.9579 | 11.735 |
| Novemb | 9.5 | 26.8 | 11.28 | 11.59 | -18.91 | 85.97 | 318 | 0.2989 | 0.4363 | 0.883 | 5.8324 | 1.0397 | 11.4628 |
| Decembe | 9.73 | 26.6 | 9.003 | 11.59 | -23.05 | 84.99 | 344 | 0.3061 | 0.4387 | 0.841 | 5.7445 | 1.0811 | 11.3325 |

C, Annually average Global Solar Radiation of Bahir Dar H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for Bahir Dar 1985-2016

| Year | N | tmax | tmin | Φ | d | a | B | 10000* Ho | 1000*H | 10000*H1 | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 7.88 | 26.4 | 12.49 | 11.59 | 12 | 0.2581 | 0.4227 | 0.982 | 5.29916 | 0.9457 | 181.25 |
| 1986 | 8.21 | 26.8 | 12.12 | 11.59 | 181 | 0.2656 | 0.4252 | 0.982 | 5.44084 | 0.9932 | 12.0008 |
| 1987 | 8.08 | 27.3 | 13 | 11.59 | 181 | 0.2628 | 0.4243 | 0.982 | 5.35989 | 0.9694 | 12.0008 |
| 1988 | 7.76 | 27 | 12.49 | 11.59 | 181 | 0.2567 | 0.4222 | 0.982 | 5.1844 | 0.9577 | 12.0008 |
| 1989 | 7.77 | 26.2 | 11.25 | 11.59 | 181 | 0.2566 | 0.4222 | 0.982 | 5.18252 | 0.9686 | 12.0008 |
| 1990 | 8.12 | 27.1 | 12.52 | 11.59 | 181 | 0.2635 | 0.4245 | 0.982 | 5.38077 | 0.982 | 12.0008 |
| 1991 | 7.61 | 25.7 | 11.81 | 11.59 | 181 | 0.2548 | 0.4216 | 0.982 | 5.00831 | 0.9053 | 12.0008 |
| 1992 | 7.53 | 26.3 | 12.94 | 11.59 | 181 | 0.2514 | 0.4205 | 0.982 | 5.04414 | 0.8999 | 12.0008 |
| 1993 | 7.67 | 26.4 | 12.97 | 11.59 | 181 | 0.2547 | 0.4216 | 0.982 | 5.11869 | 0.9127 | 12.0008 |
| 1994 | 7.87 | 26.8 | 13.47 | 11.59 | 181 | 0.2586 | 0.4229 | 0.982 | 5.25432 | 0.9187 | 12.0008 |
| 1995 | 8.09 | 27.1 | 13.65 | 11.59 | 181 | 0.2631 | 0.4244 | 0.982 | 5.37026 | 0.9445 | 12.0008 |
| 1996 | 8.02 | 27.1 | 13.6 | 11.59 | 181 | 0.2619 | 0.424 | 0.982 | 5.32878 | 0.9408 | 12.0008 |
| 1997 | 7.98 | 27.7 | 13.8 | 11.59 | 181 | 0.2608 | 0.4236 | 0.982 | 5.30006 | 0.9497 | 12.0008 |
| 1998 | 8.14 | 27.3 | 13.33 | 11.59 | 181 | 0.2643 | 0.4248 | 0.982 | 5.40453 | 0.9675 | 12.0008 |
| 1999 | 8.33 | 27 | 12.58 | 11.59 | 181 | 0.268 | 0.426 | 0.982 | 5.51858 | 0.9966 | 12.0008 |
| 2000 | 8.05 | 27.1 | 12.77 | 11.59 | 181 | 0.2623 | 0.4241 | 0.982 | 5.34478 | 0.971 | 12.0008 |
| 2001 | 7.81 | 27.1 | 12.22 | 11.59 | 181 | 0.2585 | 0.4228 | 0.982 | 5.19008 | 0.9657 | 12.0008 |
| 2002 | 8.3 | 27.9 | 13.41 | 11.59 | 181 | 0.2664 | 0.4255 | 0.982 | 5.50015 | 0.9858 | 12.0008 |
| 2003 | 7.92 | 28.3 | 13.55 | 11.59 | 181 | 0.2599 | 0.4233 | 0.982 | 5.27523 | 0.9525 | 12.0008 |
| 2004 | 8.07 | 27.6 | 13.19 | 11.59 | 181 | 0.2626 | 0.4242 | 0.982 | 5.35925 | 0.9754 | 12.0008 |
| 2005 | 8.06 | 27 | 12.9 | 11.59 | 181 | 0.2625 | 0.4242 | 0.982 | 5.34799 | 0.9609 | 12.0008 |
| 2006 | 7.87 | 26.8 | 12.89 | 11.59 | 181 | 0.2588 | 0.4229 | 0.982 | 5.23897 | 0.9423 | 12.0008 |
| 2007 | 7.77 | 26.8 | 10.33 | 11.59 | 181 | 0.2568 | 0.4223 | 0.982 | 5.18555 | 1.0167 | 12.0008 |
| 2008 | 8.21 | 26.8 | 11.86 | 11.59 | 181 | 0.2652 | 0.4251 | 0.982 | 5.44897 | 1.0001 | 12.0008 |
| 2009 | 7.69 | 24.3 | 11.73 | 11.59 | 272 | 0.256 | 0.422 | 0.967 | 5.10712 | 0.856 | 11.929 |
| 2010 | 7.69 | 27.1 | 12.52 | 11.59 | 181 | 0.2549 | 0.4216 | 0.982 | 5.13551 | 0.9483 | 12.0008 |
| 2011 | 8.07 | 27 | 11.46 | 11.59 | 181 | 0.2626 | 0.4242 | 0.982 | 5.357 | 1.0103 | 12.0008 |
| 2012 | 7.9 | 27.6 | 12.41 | 11.59 | 181 | 0.2595 | 0.4232 | 0.982 | 5.26565 | 0.9914 | 12.0008 |
| 2013 | 7.99 | 28.8 | 11.87 | 11.59 | 181 | 0.2612 | 0.4237 | 0.982 | 5.31885 | 1.0427 | 12.0008 |
| 2014 | 7.88 | 27.8 | 12.42 | 11.59 | 181 | 0.259 | 0.423 | 0.982 | 5.24326 | 0.9891 | 12.0008 |
| 2015 | 8.35 | 28.6 | 13.78 | 11.59 | 181 | 0.267 | 0.4257 | 0.982 | 5.57308 | 1.0175 | 12.0008 |
| 2016 | 8.07 | 28.3 | 12.51 | 11.59 | 181 | 0.2628 | 0.4243 | 0.982 | 5.35513 | 1.0191 | 12.0008 |

d, Annually average Global Solar Radiation of Debre Markoss H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for Debre Markoss 2007-2016

| Year | n(hr.) | tmax(0c) | tmin(0c) | Φ(0) | ω(0) | N | a | B | Ho | H(KWh/m2day) | H1 (KWh/m2day) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 7.35 | 23.527 | 10.44 | 10.33 | 90.01 | 12.001 | 0.25 | 0.42 | 0.986 | 4.975233333 | 0.884675 |
| 2008 | 7.5 | 22.962 | 10.67 | 10.33 | 90.01 | 12.001 | 0.25 | 0.42 | 0.986 | 5.0645 | 0.868058 |
| 2009 | 7.39 | 22.658 | 10.86 | 10.33 | 90.01 | 12.001 | 0.25 | 0.42 | 0.986 | 4.991241667 | 0.832173 |
| 2010 | 6.53 | 23.444 | 11.11 | 10.33 | 90.01 | 12.001 | 0.23 | 0.41 | 0.986 | 4.490708333 | 0.801458 |
| 2011 | 6.59 | 23.11 | 10.32 | 10.33 | 90.01 | 12.001 | 0.23 | 0.41 | 0.986 | 4.5716 | 0.796733 |
| 2012 | 7.38 | 22.607 | 11.07 | 10.33 | 90.01 | 12.001 | 0.25 | 0.42 | 0.986 | 4.9934 | 0.832933 |
| 2013 | 6.7 | 23.11 | 10.81 | 10.33 | 90.01 | 12.001 | 0.24 | 0.42 | 0.986 | 4.595958333 | 0.817 |
| 2014 | 6.11 | 22.679 | 10.78 | 10.33 | 90.01 | 12.001 | 0.22 | 0.41 | 0.986 | 4.32356 | 0.76127 |
| 2015 | 6.95 | 23.556 | 11.18 | 10.33 | 90.01 | 12.001 | 0.24 | 0.42 | 0.986 | 4.86675 | 0.8555 |
| 2016 | 9.83 | 23.233 | 8.693 | 10.33 | 86.42 | 11.523 | 0.3 | 0.44 | 0.899 | 6.0954 | 1.0438 |

e, Annually average Global Solar Radiation of Gondar H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for Gondar2007-2016

| Year | n(hr.) | tmax(0c) | tmin(0c) | Φ(0) | N | A | B | Ho | H(KWh/m2day) | 10H1(KWh/m2day) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 7.69 | 27.1229 | 13.649 | 12.6 | 12.001 | 0.243 | 0.418 | 0.9782 | 5.088636364 | 0.917972727 |
| 2008 | 7.31 | 27.2698 | 13.589 | 12.6 | 12.001 | 0.248 | 0.419 | 0.9782 | 4.889633333 | 0.889891667 |
| 2009 | 7.56 | 27.3733 | 13.76 | 12.6 | 12.001 | 0.253 | 0.421 | 0.9782 | 5.048016667 | 0.907508333 |
| 2010 | 6.85 | 26.6813 | 12.48 | 12.6 | 12.001 | 0.238 | 0.416 | 0.9782 | 4.627525 | 0.869325 |
| 2011 | 6.36 | 27.5216 | 13.532 | 12.6 | 12.001 | 0.229 | 0.413 | 0.9782 | 4.354441667 | 0.833608333 |
| 2012 | 6.85 | 27.4528 | 14.496 | 12.6 | 12.001 | 0.239 | 0.416 | 0.9782 | 4.628258333 | 0.835358333 |
| 2013 | 6.74 | 27.814 | 14.165 | 12.6 | 12.001 | 0.236 | 0.415 | 0.9782 | 4.580109091 | 0.843190909 |
| 2014 | 6.54 | 27.4933 | 14.116 | 12.6 | 12.001 | 0.233 | 0.414 | 0.9782 | 4.451175 | 0.827091667 |
| 2015 | 7.13 | 27.4247 | 13.863 | 12.6 | 12.001 | 0.245 | 0.418 | 0.9782 | 4.770281818 | 0.876690909 |
| 2016 | 7 | 27.3504 | 13.739 | 12.6 | 12.001 | 0.24 | 0.417 | 0.9782 | 4.715341919 | 0.866737542 |

F, Monthly average Global Solar Radiation of Debre Tabor H by Calculated using Angstrom models, H1calculated using Hargreaves model and other meteorological data for ten years (20072016

| Month | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmax | 23.1 | 24.8 | 25.2 | 25.4 | 22.5 | 22.4 | 19.9 | 19.9 | 20.8 | 21.9 | 22.4 | 22.3 |
| Tmin | 7.2 | 9.4 | 10.5 | 10.5 | 10.5 | 10.5 | 10 | 10.1 | 9.4 | 8.7 | 8.2 | 7.7 |
| N | 8.8 | 9.2 | 7.4 | 7.9 | 5.8 | 6.4 | 4.3 | 4.7 | 6.4 | 7.5 | 7.7 | 8.5 |
| Φ | 11.9 | 11.9 | 11.9 | 11.9 | 11.85 | 11.9 | 11.9 | 11.85 | 11.9 | 11.9 | 11.9 | 11.85 |
| D | 17 | 47 | 75 | 105 | 135 | 162 | 198 | 228 | 256 | 288 | 318 | 344 |
| Δ | -20.9 | -13 | -2.4 | 9.41 | 18.79 | 23.1 | 21.2 | 13.46 | 2.22 | -9.6 | -18.9 | -23 |
| Ω | 85.4 | 87.2 | 89.5 | 92 | 94.09 | 95.1 | 94.7 | 92.88 | 90.5 | 88 | 85.9 | 90.01 |
| N | 11.4 | 11.6 | 11.9 | 12.3 | 12.55 | 12.7 | 12.6 | 12.38 | 12.1 | 11.7 | 11.5 | 11.32 |
| Ho | 0.86 | 0.94 | 1.02 | 1.06 | 1.054 | 1.04 | 1.04 | 1.049 | 1.03 | 0.96 | 0.88 | 0.837 |
| A | 0.28 | 0.29 | 0.25 | 0.25 | 0.212 | 0.22 | 0.18 | 0.191 | 0.23 | 0.25 | 0.26 | 0.28 |
| B | 0.43 | 0.43 | 0.42 | 0.42 | 0.407 | 0.41 | 0.4 | 0.4 | 0.41 | 0.42 | 0.42 | 0.43 |
| H | 5.33 | 5.94 | 5.19 | 5.53 | 4.619 | 4.49 | 3.31 | 3.617 | 4.59 | 5.02 | 4.83 | 5.054 |
| H1 | 0.96 | 1.07 | 0.97 | 1.04 | 0.803 | 0.8 | 0.6 | 0.625 | 0.79 | 0.88 | 0.87 | 0.847 |