IDENTIFICATION OF SITES FOR ESTABLISHING PHOTOVOLTAIC SOLAR FARMS IN PAKISTAN USING SOLAR GEOMETRY

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ABSTRACT

Utility scale Solar farms generally consist of multiple arrays of Photovoltaic (PV) Panels which collect and convert solar energy into electrical energy. Pakistan is facing a serious energy crisis. It is working on solar energy options. Therefore, it is imperative to identify most viable sites that have a high solar radiation. We utilized solar geometry and the Google Earth, a geographical information program to identify optimal sites for Pakistan. These sites should also include basic requirements for a PV plant such as availability of local grid, barren land, roads, water, and good climatic conditions. The Average solar intensity (I) was calculated by using solar geometry on a daily basis, which served as the basis for annual projections. It has been found that the best location for building a solar farm is district QilaSaifullah (I = 9.79 kWh/m2/day) in Baluchistan province. In the Khyber Pakhtunkhwa province, district Nowshera (I= 8.06 kWh/m2/day), in Sindh province, district Sukkur (I = 7.9 kWh/m2/day) and in Punjab, district Bahawalpur (I = 8.17 kWh/m2/day) have been found most suitable. This study shows that Pakistan has a good potential to install solar parks in all the provinces and provides a potential solution to address the energy crisis in Pakistan.

KEYWORDS: *Solar Farms; Energy; optimal; identification; potential sites*

INTRODUCTION

The energy requirements of the world, including Pakistan are increasing at an alarming rate. Pakistan is facing energy crisis. Renewable energy sources, including wind and solar are gaining more attention as they can be reused compared to polluting fossil fuels[1]. The fiscal growth of any country is dependent on the availability of energy from inexpensive, available and green resources[2-3]. In Pakistan, the annual electricity demand is more than the annual production due to the increases in energy requirements and mismanagement. The residents of the country are suffering because the government has started an electricity load shedding. Solar energy can provide a great opportunity for sustainable development in Pakistan[4]. Therefore, there is a need to carry out research to overcome this problem.

This research is an effort to identify the most suitable site for installing a solar farm in Pakistan and all the four provinces. Suitable solar sites are selected for all the four provinces, which are based on solar insolation calculations using solar geometry. The calculation of intensity for each day and for each month are made.

Every year, the sun sends over a billion terawatt hours of energy to the Earth. The solar radiations that reach the earth offers far more potential than any other renewable energy source. Solar energy is one of the promising choices that can satisfy increasing energydemand.

The main objectives of this study are:

- Identification of best potential sites for solar farm in all provinces of Pakistan.
- To address the energy crisis in Pakistan.
- Awareness of solar renewable energy.

ENERGY problem

Pakistan is located in one of the highest solar insolation regions on the globe. It receives an average of about 19 Mega Joules per square meter of solar energy. Pakistan covers 796,095 square kilometers of land between latitudes 24° and 36° North and longitudes 61° and 76° East. The mean global irradiation falling on a horizontal surface is about 200 - 250 Watt per m^2 per day[5]. Nowadays, it faces energy shortages, 95 percent of its electricity is generated from hydropower, the production of power from hydel dams drops in the

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Summer.In Pakistan a shortfall of 4,500 MW in the year 2011-12 and a shortfall of 5,000 MW in 2012-2013 has been recorded.[1]

Nearly 70 % of its population reside in aboutfifty thousand villages. It is not cost-effective to supply electricity from the grid to these villages, therefore a solar farm is one of the options available to provide electricity to these villages.

Solar Farm

Utility scale Solar farms generally consist of multiple arrays of Photovoltaic (PV) Panels which collect and convert solar energy into electrical energy. Antoine Becquerel first revealed Photovoltaic power and Charles Fritts created the first successful solar cell.

A suitable solar farmsite selection is a based on a set of criteria. While average insolation data offer an insight into solar energy potential on a regional scale, local, relevant conditions such as the surrounding terrain may significantly influence the solar energy potential in a specific site[6].

The selection of site for solar farm is a difficult task which has mystified the electric generation companies and the government. The calculation for each renewable energy source based on today's technology is given in the Figure 1.

The locations with the highest solar radiations are not always necessarily feasible sites for the errection of solar farms. Many other factors has an important role in the utility solar farms site selection. They can be categorized into: economic, and ecological factors.

Solar farms are used to create energy at the utility level, which is added to the national grid. PV arrays have been generating power for utilities since the first megawatt-scale solar farm was built in Sacramento, California, in 1984.

The government of Punjab, Pakistan has established the Quid-e-Azam solar park in Bahawalpur. In the first phase of this park, 100MW solar farm has been developed and will then be expanded to 1500MW in the later phases.

METHODOLOGY

The Solar radiation map of Pakistan was studied and potential sites were identified after that Google Earth was used to inspect the shortlisted sites for the final selection. Solar geometry was used to calculate the solar insolations for the shortlisted sites and final selections were made and validated. The overall solar potential for Pakistan is summarized in Figure 2 which shows the direct normal solar irradiation for the entire country. The following points were ensured in the shortlisting of the sites.

Proximity to the roads, grid and population, High insolation,Leveled terrain,Water availability, low rainfall and no archeology.

Table 1 shows the data analysis, check sheet that was used to determine the four locations where (×) shows absence and (✓) shows the presence of the each criteria of determining suitable location. In this manner all other locations wereexamined extensively and the results were obtained Chirat and Zhob were dropped. Next, by using solar geometry the three average radiations for all these sites were determined. These three types of solar intensities are: Normal intensity (In), Direct/Horizontal surface intensity (Idh) and Inclined surface intensity (Idi).

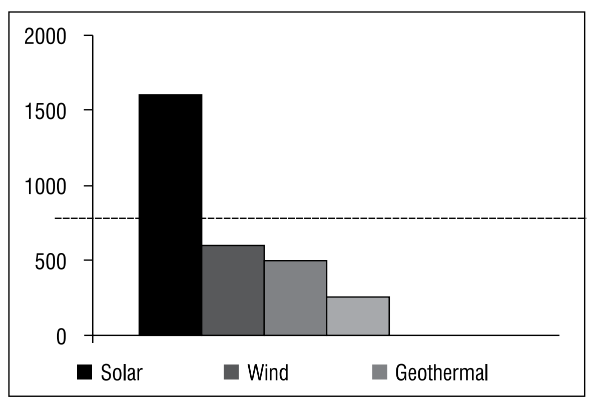

Figure 1: The Potential for Renewable Energy Resources2 (Exa Joule)

After that average of these was used to find average I direct. Next, the comparison of the I values was made and it was investigated that whether the site selection is validated or not by the use of solar geometry. This procedure resulted in the identification of four sites.

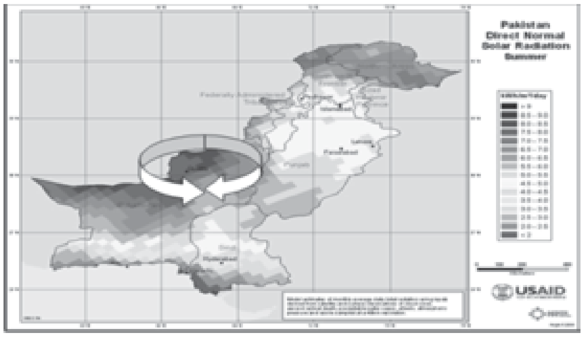

Figure 2: Pakistan Direct Normal Solar Radiation Map developed by USAID and NREL

One for each four provinces. However, QilaSaiffullah, Baluchistan emerged as the most suitable site in Pakistan.

Table 1: Check Sheet Determining suitable locations

Criteria	Qila-Saifullah	Sukkur	Nowshera	Bahalpur	Zhob	Chirat
1. High radiation	✓	✓	✓	✓	✓	✓
2. Proximity to roads	✓	✓	✓	✓	✓	✓
3. Proximity to the Grid	✓	✓	✓	✓	✓	×
4. Leveled Terrain	✓	✓	✓	✓	×	×
5. No Danger of flooding	✓	✓	✓	✓	✓	✓
6. Water availability	✓	✓	✓	✓	✓	×
7. Proximity to residential areas	✓	✓	✓	✓	✓	✓
8. Low Rain Fall	✓	✓	×	✓	✓	×
9. No Archaeology	✓	✓	✓	✓	✓	✓

Solar Astronomy

If the direct solar radiation is not blocked by clouds, it is considered as sunshine which is a combination of bright light and radiant heat. When it is blocked by the clouds, it is termed as diffused light. Hence radiation is I direct + I diffuse. According to the World Meteorological Organization 'sunshine duration' mean the cumulative time during which an object receives direct irradiance from the Sun.

The solar energy radiation on the earth depends on the location. During the day, the intensity of radiation is high. At sunset, the radiation intensity decreases. At a high altitude the energy content is somewhat higher. The length of atmosphere that solar radiation passes through varies with the time of day and month of the year due to Earth tilt and rotation. The Earth's axis is tilted at 23.47 degrees from the vertical to the plane of the Earth's orbit around the sun. This tilt is responsible for the seasonal variations in weather.

Solar Radiation Measurement

Researchers record sunlight using a sunshine recorder, pyranometer, or pyrheliometer[12]. These are quite expensive. This data has been practically collected and available for more than twenty years in developed countries. Another method of estimation of solar insolation is cloud cover data in which data is acquired through satellite images.

However, solar radiation measurements are not easily available in many developing countries, including Pakistan because of the high cost of the measurement equipment.

Several empirical models exist which measure the solar radiation using different parameters. Some model uses sunshine duration. In this paper, solar intensity is calculated by applying empirical formulas

Sun Shine's Hour Method

The solar PV Panel works only when there is sunshine. First of all the sun's declination angle was found by using the formula for declination as given below,

$$d = 23.47 \sin \{360(284 + N)\}/365 \qquad \text{Eq. 1}$$

where,

d = Sun's declination angle

N = days of the year counted from

January 1 to December 31

By putting values of N=1,2,3...365, the declination angle values were obtainedusing Microsoft Excel.

After calculating the declination angle, the hour angle at sunset for each day was calculated using the formula as given below,

$\cos (h) = -\tan (l), \tan (d)(1)$ Eq. 2

where, l= latitude angle and d = declination angle

By putting values in the above formula, h was calculated.

Time at sunset t, is given by

$t = h/15$ Eq. 3

Where, t is the hours after solar noon

Time at sun − set = h/15 Eq. 4

Time at sun − rise = (12)-(sun − set time) Eq. 5

Since from normal observation, it has been noted that 21st of June is the largest and 21st of December is the smallest day in terms of sun shine hours. From this it is obvious that 21st of each month is of much importance.

Therefore, the declination for 21st of each month was found and similarly the sun shine hours were also calculated.

To get an average data for the whole day, the hour angle was calculated after every 15 minuteinterval of time from sun rise to sun set.

After each 15 minutes the change in hour angle is 3.75˚, as derived below.

It is known that

60 minutes = 15° Eq. 5

$15\,\text{minutes} = \frac{15°}{60}$ Eq. 6

15 minutes = 3.75° Eq. 7

Now if 3.75° is added to hour angle at the sunrise time it will give the total hour angle after 15 minutes from the sunrise time.

For example, if the hour angle at the sunrise time is -77.56, then by adding 3.75°, it will give hour angle after 15 minutes. Similarly hour angle after each 15 minutes can be determined simply by adding 3.75˚ after an interval of 15 minutes. Finally, at noon time hour angle will be 0˚. After noon, it will increase in the positive direction and will reach a maximum limit at the sun set.

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Altitude Angle

It is an angle in a vertical plane between the sun rays and the projection of sun rays on a horizontal plane. The formula for calculating the altitude angle at a particular location, time and date is given below.

Sinβ = cosl x cosh x cosd + sinl x sond Eq. 8

Where, β = altitude angle Eq. 9

$$L = \frac{1}{Sin\beta} \qquad \text{Eq. 10}$$

Air mass is actually a measure of the path the radiation has to travel in the earth's atmosphere. Thus, for altitude angle,

All the above mentioned values had been found for the 21st of each month and hour angle is also found after each 15 minutes. Thus, the values of L, h, β, and are available after each 15 minutes for the 21st of each month.

The equation for the depleted normal radiation is

$$In = 1082e^{\wedge}(-0.182\,\mathrm{L})\frac{\mathrm{w}}{\mathrm{m}^{\wedge}2} \quad \text{Eq. 11}$$

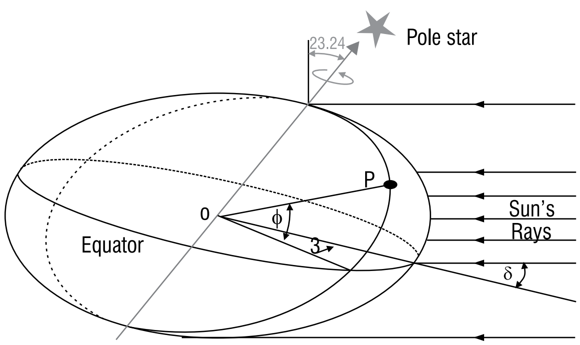

Figure 3a: The declination angle (δ), latitude (φ) and the hour angle (ω) for point P.7

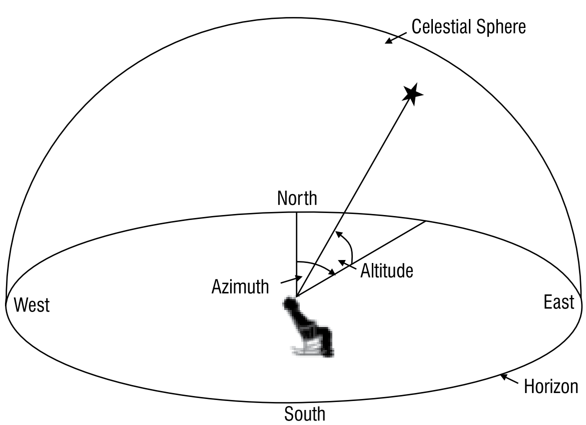

Figure 3b: Direct solar Radiation on a horizontal surface

The formula for direct solar radiation is given by

$I_D = I_n \cos\theta$ Eq. 12

where

I_n = Solar normal radiation

I_D = Direct solar radiation

Solar Geometry

The radiation reaching the Earth depends on the solar geometry. The concept of time is very important in this calculation.

Latitude

In Figure 3, ***O*** is the center of the Earth and any point ***P*** on the surface, ***OP*** isthe radius. The elevation angle of point Pabove the equator is its latitude. The latitude is called Northern latitude if north of the equator and southern latitude if south of it.

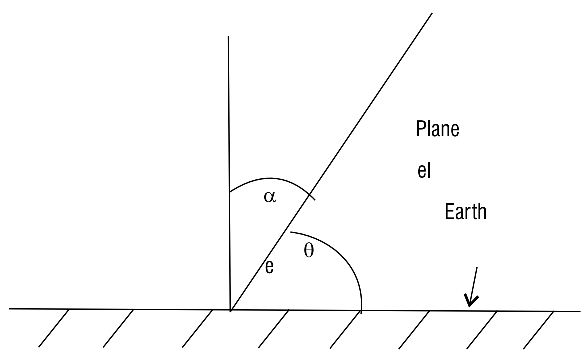

Figure 4: Direct solar Radiation on a inclined surface.

Altitude angle

The altitude angle illustrates the elevation of the sun in the sky. It is the angular height of the sun in the sky measured from the horizontal.It is represented by ***β***

ϴ = Panel installation angle = 90° - Φ Eq. 14

The I_n is calculated for all the 12 months of the year separately.

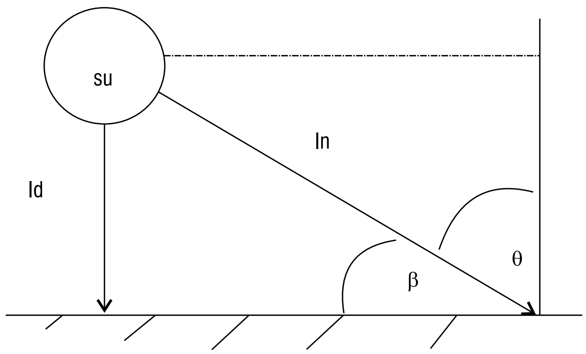

Figure 5: Direct solar Radiation on a horizontal surface

Then, Direct (horizontal surface) intensity I_{DH} was calculated as,

I_{DH} = In,cos θ = In. sin β Eq. 14

IDI = In (cosβ.cosα.cosΦ= sinβ.sinΦ Eq. 15

Azimuth angle = α = tan − [sin(h)/(sin(φ).cos(h) − cos(h) − cos(φ). tan(d))] Eq. 16

Finally, the Inclined surface intensity I_{DH} is given by,

By putting equation (14) into the equation (15), the

Table 2: Increase in the solar intensity with Height.

				Solar Attitude Angle, Degrees						
Height	10	20	25	30	35	40	50	60	70	80
Above Mean										
Sea Level, m										
				Percentage Increase in Solar Intensity						
1000	17.5	14	13	12	10	10	9	8	8	8
1500		26	23	20	15	17	16	15	15	15
2500		40	35	32	30	28	26	24	23	22
3000		42	37	33	32	30	28	27	26	25

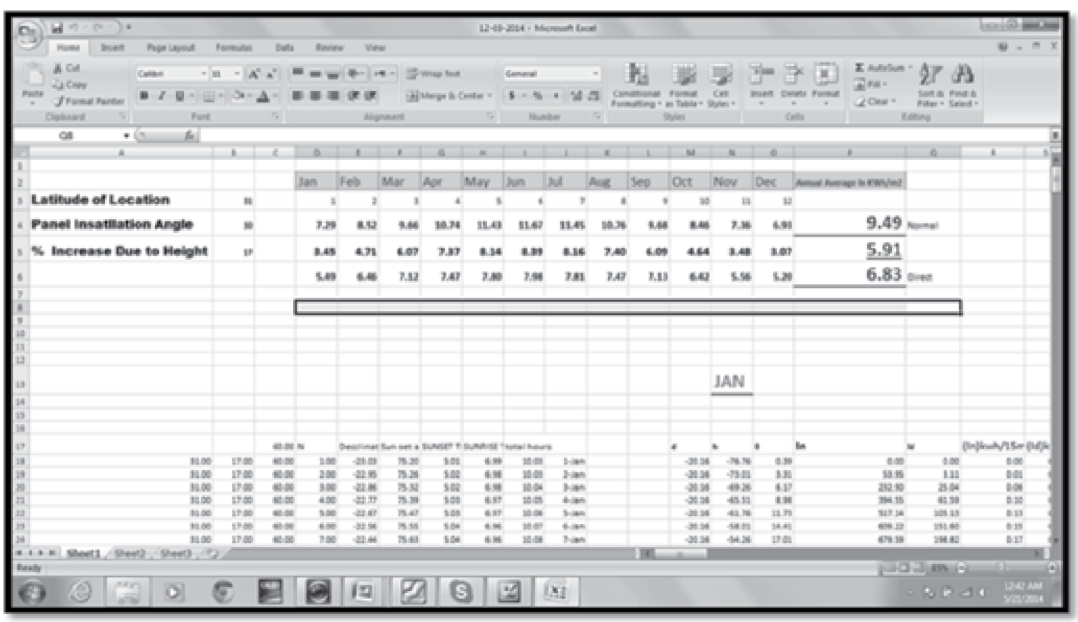

Figure 6: Print screen of solar radiation calculator in Microsoft Excel

was calculated

A print screen of the solar radiation calculator in Microsoft Excel is shown in figure 9, where by entering the latitude and elevation of a particular location, gives daily solar insolation of that location. A percent increase in the height was determined from a Table 2[9].

For example, for 21 Jan

N=21, d=-20.16,

h=0,

I_n*=0.24 KWh/m2,*

$I_{inclined}$*=0.22,*

$I_{horizontal}$*=0.15,*

I_{direct}*=0.15*

Sunset=5:15,

Sunrise=6:05

RESULTS

Potential sites in each province

One of the objectives of this paper is to specify suitablesites for the development of utility solar farms in Pakistan. The selected sites for each province with details are given below.

Khyber Pakhtunkhwa Province

Khyber Pakhtunkhwa (KP) province is in the north-west of Pakistan. This province has an area of 74,521 km². The latitude of KP is 33.916 and longitude is 71.8. From the solar insolation map of Pakistan as shown in Figure 4, it can be observed that the average solar insolation for KP is 5 to 6 kWh/m^2/day. Pervaz et. al has For Peshawar data has collected[8]. For KP the selected location is Jalozai, Nowshera. Table 3 shows the Insolation of Jalozai. District Nowshera has a total 1,748 km² area. Jalozai is at a distance of 35 Km from Peshawar, which is the provincial capital of KP.

- Vast land, mostly barren
- Elevation from sea level is 396m
- Normal solar insolation is 8.06 KWh/m2/day
- Solar insolation on a horizontal surface is approximately bout 5.0 kWh/m2/day
- Solar insolation on inclined surface is approximately 5.78 KWh/m2/day

Sindh Province

The Sindh province of Pakistan is located on the western corner of South Asia. In figure (4), it can be observed that the average solar radiation for this province is about 3 to 5.5 KWh/m^2/day.

In this study the recommended location for building utility solar farm in Sindh province is Sukkur which is one of the main cities of Sindh. Its situation is on the west bank of river Indus. The city of Sukkur is the capital of Sukkur division. Throughout the year the sunshine is abundant.

The details for this site are:

The latitude is 27.705N and Longitude is 68.847 E

Elevation from sea level is 47 m

Normal solar insolation is 7.9 kWh/m^2/day

Solar insolation on a horizontal surface is 4.5 kWh/m^2/day

Solar insolation on inclined surface is 5.2 kWh/m^2/day

Punjab province

The Punjab province of Pakistan is the second largest province in terms of area of about 205,344 Km^2, its population exceeds 82 million. The province is a fertile region while it contains the Thal and Cholistan deserts. From the solar radiation map of Pakistan as shown in

Table 3: Insolation of Jalozai

Type of insolation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg KWh/m2
Insolation on Normal surface	6.07	7.13	8.18	9.19	9.87	10.13	9.89	9.21	8.2	7.07	6.07	5.67	8.06
Insolation on horizontal surface	2.75	3.81	5,03	6.22	6.96	7.2	6.98	6.25	5.05	3.75	2.74	2,39	4.93
Insolation on Inclined surface	4.65	5.46	6.04	6.34	6.62	6.78	6.64	6.35	6.05	5.42	4.65	4,33	5.78

Table 4: Insolation of QilaSaifullah

Type of insolation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg KWh/m2
Insolation on Normal surface	7.29	8.52	9.66	10.74	11.43	11.67	11.45	10.76	9.68	8.46	7.36	6.93	9.49
Insolation on horizontal surface	3.45	4.71	6.07	7.37	8.14	8.39	8.16	7.39	6.09	4.64	3.48	3.07	5.914
Insolation on Inclined surface	5.49	6.46	7.12	7.46	7.79	7.98	7.81	7.47	7.13	6.42	5.56	5.2	6.83

figure 4, it can be observed that the average solar insolation for Punjab province is 5.5 to 6 kWh/m^2/day. For this province the Bahawalpur region is recommended for building the solar farm due to immense solar resources and vast land.

- The latitude is and longitude 71.68 E
- Elevation is 118 m above sea level
- Normal solar insolation is $8.17x\frac{\text{kWh}}{m2xday}$
- Solar insolation on a horizontal surface is $5.15x\frac{\text{kWh}}{m2xday}$
- Solar insolation on inclined surface is $5.88x\frac{\text{kWh}}{m2xday}$
- 6th biggest city in Punjab.

Baluchistan province

Baluchistan is the largest province, territory wise shown in Figure 7-9. It has a low population and consists of large barren lands. The average daily global insolation in Baluchistan is about 20 MJ/m2 per day. The annual mean sunshine duration is 8 to 8.5 hours a day. It is the most feasible location for installing a solar farm in Pakistan is Baluchistan due to the high solar intensity. The details of solar resources and the best location for Baluchistan is Qila Saifullah. Qilla Saifullah is a district in the northwestern Balochistan province. Table 4 shows Insolation of QilaSaifullah. Qilla Saifullah is about 135 km south of Quetta. The neighboring Districts

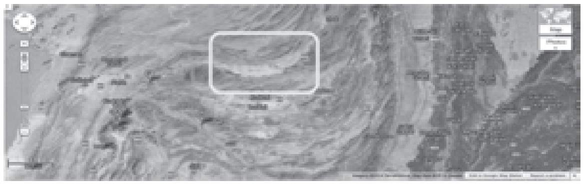

Figure 7: Site near to Qila Saifullah (source Google Earth)

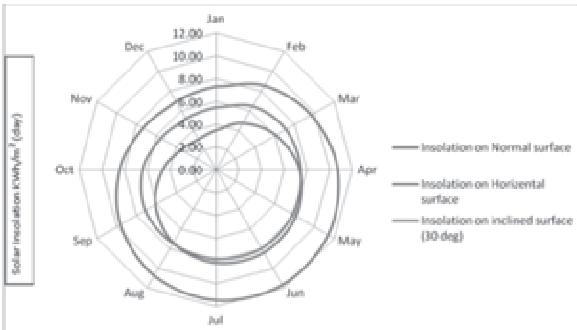

Figure 8: Normal and Direct Solar Radiation Qila SaifUllah (January-December)

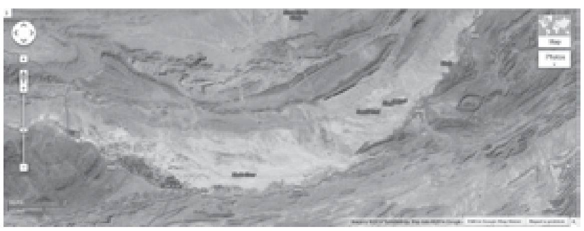

Figure 9: Magnified image of selected location (Source Google Earth)

Are Zhob, Loralai, Pishin. It shares a border with the neighboring Country Afghanistan. N-50 (D.I.Khan - Zhob- Kuchlack) highway also passes in this district and zhob river also flows in it.

Latitude : 30.7013000

Longitude : 68.3599300

Elevation above sea level: 1560m

Radar graph showing Normal and Direct solar radiation was developed for the whole year (month 1 to month 12), as shown in figure 9. Figure 9 shows normal and direct solar radiation in kWh/m2.

DISCUSSION AND CONCLUSION

Of all the calculated radiation values the radiation of QilaSaifullah is the highest and hence it is selected as the most suitable site for Pakistan. This is shown as an encircled location in Figure 8. There is a large barren land near QilaSaifullahat alatitude of 31 degrees and elevation from sea level of 1600m.The solar farm should not be developed at a distance less than 500 m from urban areas so it is suggested that in the QilaSaifullah district this farm should be planed near Aror. In this way the barren land will be utilized. There are nearby electricity grid stations shown by a dot in Figure 8, due to which transmission losses will be low. It is barren land of low price.

Pakistan is no doubt having energy crisis, the solar option seems a good one. This study has identified some potential sites for the installation of utility solar farms, although the exact location cannot be established but it indicates the suitable districts. When installing a solar farm it should be kept in mind that the quality of the terrain is good because slopped land, excessively rocky or sandy terrain increases the cost of installation. No known archeology on the land, no shading from large trees and excessive dust is bad.

Limitations of this study are that it does not take into account the practical, real data about sunshine, relative humidity, clouds cover and temperature because data collection is a costly affair. The method used in this research gives an estimate. Due to the uncertainly of data available from satellite maps[9,10,11,12]. Further study is needed to take care of the limitations of this study.

Recommendations

The Social benefit of Solar farm is that its construction and maintenance can create some job opportunities and also promote the development of industries relating to solar energy. The construction of the solar photovoltaic farm can speed up the development of new power projects in Pakistan to ensure a steady supply of power for Pakistan's economic growth.

Future research, in order to identify the potential sites the application of combining analytic hierarchy process with Geographical information system in Pakistan is recommended.

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