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Regional and Monthly Assessment of Extraterrestrial Solar Radiations in Pakistan

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Abstract

The monthly extraterrestrial solar radiations (ESR) have been simulated separately for all the months of the year. The subtropical location and distribution of mountains and their height determine the spatial distribution and amount of ESR in Pakistan. The mountains, piedmonts, enclosed valleys and plains show distinct diversity of ESR values. The assessment acknowledged that countries like Pakistan with ever increasing demand of energy receive sufficient amount of ESR that could be linked with solar irradiance where development of solar energy has great potential. The simulation was done with the help of ArcGIS based on distributed modeling.

Keywords

Pakistan, Extraterrestrial Solar Radiation, Monthly, Spatial Distribution, GIS

1. Introduction

Pakistan needs to explore and annex chief available sources of energy for agriculture and urbanization. It seems very difficult to measure the slopes and other topographic information in the field manually for a large area where we lack database of solar radiation, hence distributed models could be reasonable tool to map the extraterrestrial solar radiation (ESR) over rugged terrain. The DEM has been used very efficiently for modeling in the GIS platform in climate and hydrological and other sciences [1]-[3]. Distributed solar radiation models proved to be successfully implied in various scientific avenues including environmental studies, meteorology and climatology [4]-[6]. The differences in landforms height, aspect and orientation of slope play key role in the spatial variation of solar radiation at ground [7]. Various studies have addressed the interaction between solar radiation and rugged complex terrain e.g. [8]-[11]. Since 1980s, spatial modeling got tremendous scope in geosciences [12]. The simulation of solar irradiance as well as possible sunshine duration (PSD) over difficult terrains paved

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the way for estimation of ESR over the rugged territories [13] like Pakistan. Hence, such studies not only provide geospatial database but also provide visualization of geographical accessibility to the resources in difficult terrains. To make the solar energy as a future energy source, it is pivotal to have reliable assessment of solar energy required in diversified topography at small scales [14]. In this paper, an effort has been made to assess ESR in Pakistan at monthly scale and local level with the help of distributed model.

2. Methodology

The simulated results are mapped based on digital elevation model (DEM) processed in ArcGIS. The DEM data was retrieved from Shuttle Radar Topography Mission (SRTM) [15]. The sun declination angle and slope in rugged terrain are essential factors to determine the amount of ESR on a particular point or grid. The atmospheric attenuation has not been considered. For more, technical detail read [14]. Some high northward slopes are not exposed to sun shining while there are slopes and plains which never hide from solar exposure until the sun sets. Thus, the landscape contributes by direction, height and steepness (angle) of the slope, while latitudinal extent is the factor which explains the angle of incident flux of solar radiation in different 12 months of the year. The response of the plains and slopes is different in case of ESR, particularly at the sun rise and sun set timings. This makes difference in daily and monthly quantity of ESR received over the plains and slopes. The results are based on the simulated model shown in **Figure 1**, while physical map has been given with the detail of landforms and national territories in **Figure 2** for the easy inculcation of results.

The observed ESR in diversified lands are based on the following principles

$$W_o\alpha\beta=\frac{T}{2\pi}\left(\frac{1}{2}\right)^2 I_o\left\{u\sin\delta\left[\sum_{i=1}^{m}\left(w_{ssl}-_{wsrl}\right)\right]+v\cos\delta\left[\sum_{i=1}^{m}\left(\sin w_{ssl}-\sin w_{srl}\right)\right]u\sin\delta\left[\sum_{i=1}^{m}\left(w_{ssl}-_{wsrl}\right)\right]\right.$$
$$\left.+v\cos\delta\left[\sum_{i=1}^{m}\left(\sin w_{ssl}-\sin w_{srl}\right)\right]-w\cos\delta\left[\sum_{i=1}^{m}\left(\sin w_{ssl}-\sin w_{srl}\right)\right]\right\}$$

where $W_o\,\alpha\,\beta$ is the daily quantity of ESR on the grid,

I_o represents solar constant,

δ denotes the solar declination angle,

u, v and w representing geographical/topographical factors:

$$u=\sin\varphi\cos\alpha-\cos\varphi\sin\alpha\cos\beta$$
$$v=\sin\varphi\sin\alpha\cos\beta+\cos\varphi\cos\alpha$$
$$w=\sin\alpha\sin\beta$$

w_{srl} denotes sunrise hour angle,

w_{ssl} represents sunset hour angle.

3. Results and Discussion

The amount of ESR is less in January, gradually increases with shift to February, March, April to May, and touches maximum level in June and July. After July, the decline in ESR starts gradually and reaches up to minimum in December and January.

January: The ESR in southern parts of the country was observed from 726 - 809 MJ/m$^{2.}$ The areas mostly stretch along the coastal areas of Balochistan and Sindh. Here from moving onward to the interior of the country from south to north, most obvious zones embracing 662 - 725 MJ/m^{2} are central Balochistan, Brahui and Kirthar Ranges, northern Sindh and southern Punjab. Most of the Punjab, Sulaiman ranges excluding their small enclosed valleys; Peshawar valley and surrounding acquire 484 - 661 MJ/m^2. Complex situation persists in northern rugged parts of Hindukush, Karakoram Himalayas (HKH). The southern high slopes obtain ESR that varies from 662 MJ/m^2 to 1257 MJ/m^2 while some slopes show ESR at low level from 0 - 148 MJ/m^2.

February: The ESR observed in southern parts are 810 - 938 MJ/m^2 but the rugged parts received less amount because of shadow impact. From here moving to the interior of the country a wide zone of 728 - 809 MJ/m^2 mostly embracing central Balochistan, most of Sindh and southern Punjab; but Brahui.

Kirthar and Sulaiman ranges are exceptions. Most of the Punjab, southern slopes of northern Sulaiman ranges, Peshawar valley and surrounding display 662 - 725 MJ/m^2. In HKH, variety of ESR amount has been detected

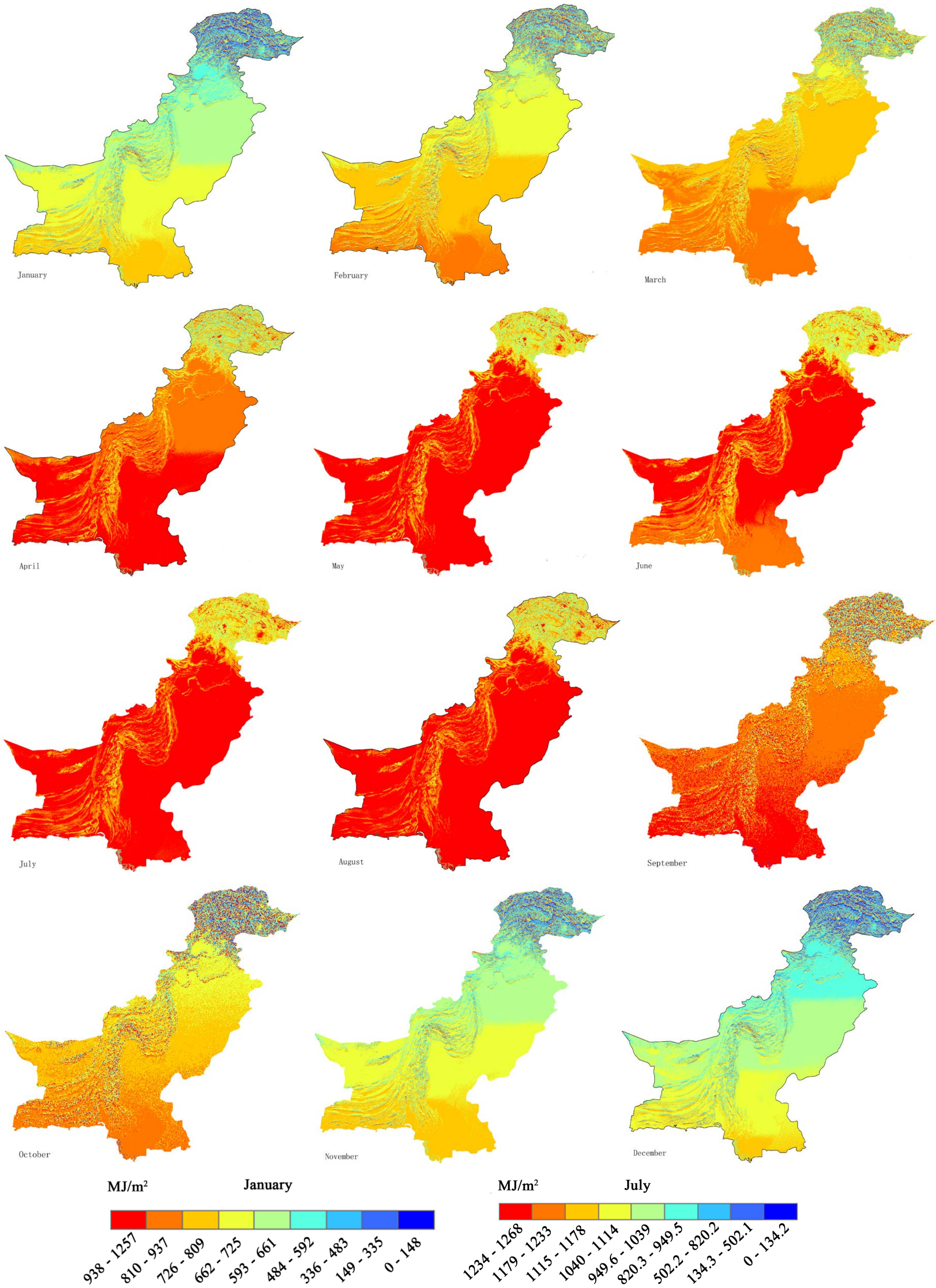

Figure 1. The Figure shows ESR for the twelve months of the year in Pakistan. The keys are shown for the January (minimum ESR) and July (maximum ESR) only, thus the key covers all the other months of the year also.

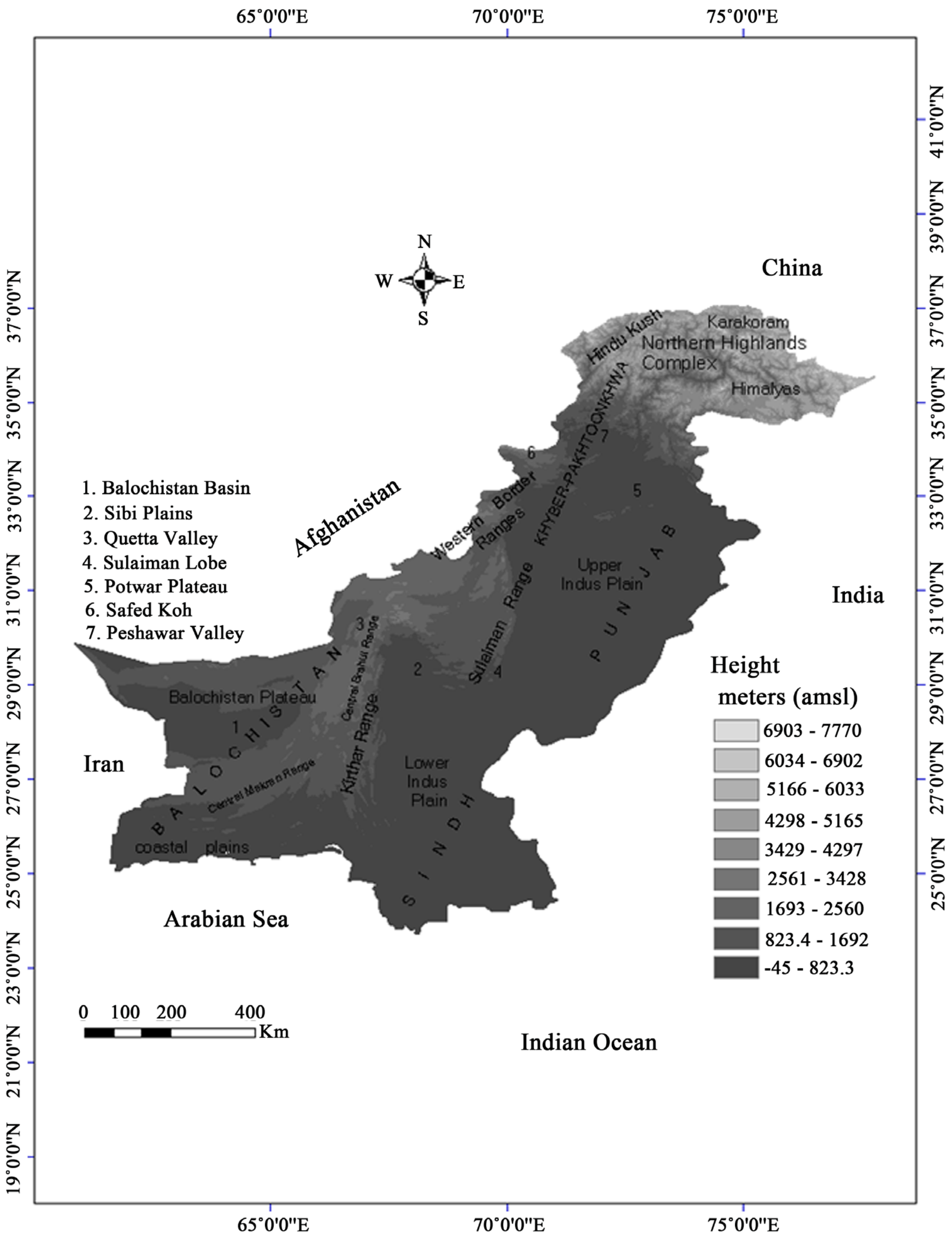

Figure 2. The Figure shows detail of landforms and localities in Pakistan.

due to lofty mountains and their slope aspects, therefore, this area configure 0 to maximum limit of ESR values.

March: Referred to ESR in March southern, central and northern distinct zones of ESR are obvious in the study locus. The southern parts of the country including Balochistan, Sindh with latitudinal extent of about 24˚N to 29˚N latitudes, the central zone is extending from about 29˚N to about 34˚N latitude embracing the areas of northwestern Balochistan, Punjab (excluding its southern parts), tribal areas, Khyberpakhtoonkhwa (KPK) except its northwestern parts. Northern zone is stretching predominantly over northern rugged parts of the country including HKH Mountains. Hence, southern, central and northern zones are predominantly dominated by 810 - 937 MJ/m^2, 728 - 809 MJ/m^2 and 0 - 1257 MJ/m^2 (about all ranges of ESR) respectively.

April: As the solar declination angle becomes high, the ESR amount is rising in Pakistan and the situation becomes different if compared with winter months. In April, the southern half of Pakistan is obviously dominated by ESR from 938 - 1257 MJ/m^2, at the same time central parts including most of Punjab, KPK and tribal areas configure 810 - 937 MJ/m^2. The rugged parts of southern and central Pakistan display variation between 662 MJ/m^2 to 1257 MJ/m^2. The HKH again has different levels of ESR, the southern slopes received 938 MJ/m^2 and above, while the other parts influenced by shadow impact have 338 MJ/m^2 and above. Some patches of 810 - 937 MJ/m^2 and 262 MJ/m^2 and above this limit can also be seen in this part.

May: After April, the major distinct three zones ESR pattern is almost disappeared. Moreover, about all Pakistan is covered by 1234 - 1268 MJ/m^2 except rugged parts. The rugged parts of Balochistan and Sindh mostly have 1115 - 1178 MJ/m^2. During this period in HKH, the patches of 938 - 1257 MJ/m^2 have obviously increased and areas acknowledged by 338 - 592 MJ/m^2 have decreased if compared with April.

June: As the declination angle of the sun in the sky increased consequently possible sunshine duration over Pakistan also increased thus amount of ESR also increased. The northern parts and some valleys were previously in shadow now come under the sunshine in June that increased substantially the amount of ESR in Pakistan. The maximum ESR belt has been shifted further north in the country. From the coastal plains up to Peshawar valley 1234 - 1288 MJ/m^2 prevails but the Brahui, Kirthar Sulaiman ranges have signatures of 1040 MJ/m^2 to 1233 MJ/m^2 due to their intershielding impact. The same is true for Safed Koh area in the southwest of Peshawar valley. The HKH region has shown progressive response and the observed amount of ESR was greater than May and July as well.

July: Based on results May, June and July are the months with highest values of ESR acknowledged by 1234 - 1288 MJ/m^2 in the plains and piedmonts. More or less, we have the same results as in June but the retreat of maximum ESR belt starts in July and onward. All the rugged parts almost indicate a wide range of ESR from 1040 MJ/m^2 to 1233 MJ/m^2; the same is true for HKH. Nevertheless, HKH makes little difference originated from the lofty nature of the mountains where southern slopes, northern slopes and valleys create substantial variation in the distribution of ESR that is why almost all the categories of ESR values as shown in the key can be located in HKH.

August: In HKH the screening impact of the mountains are more in August than June and July but at the south of Peshawar valley high values of ESR are still obvious. The plains and open valleys of the country receive 1234 - 1288 MJ/m^2. The other ranges like Safed Koh, Sulaiman, Kirthar and Brahui display ESR with values from 1040 MJ/m^2 to 1233 MJ/m^2.

September: The ESR has been substantially decreased in September as the sun migrates towards the south in the sky with respect to the location of Pakistan. The southern parts of the country receive ESR within the range of 1179 - 1288 MJ/m^2. Mountains have dominant patches of 1040 - 1178 MJ/m^2 while some slopes of high peaks ensure ESR with value of 502.2 - 1039 MJ/m^2, in addition the ESR on piedmonts exhibit 1179 - 1233 MJ/m^2. As we move on northwards, the interior Balochistan exhibits a blend of 1179 - 1233 MJ/m^2 and 1234 - 1288 MJ/m^2. In Quetta and the surroundings, the plains have 1179 - 1233 MJ/m^2 while mountains have 1115 - 1178 MJ/m^2 on their southern aspects on the contrary the northern slopes have 820.3 - 1049 MJ/m^2. The Indus plains are provided with uniform distribution of 1179-1233 MJ/m^2. Further north the Potwar Plateau, Peshawar valley and the surroundings have the ESR ranging from 1115 to 1233MJ/m^2 but the high landforms do not follow and have values from 820.3 to 1039 MJ/m^2. The HKH have a variety of values, the southern slopes have 1234 - 1268 MJ/m^2, while enclosed valleys have a wide range of ERS comprised of 134.3 to 1178 MJ/m^2. The values of 0 - 134.2 MJ/m^2 have been observed on the slopes having less or no exposure to the solar irradiance.

October: The values of 1115 - 1233 MJ/m^2 have been noticed in southern Balochistan and southern Sindh, in this part the rugged territories have 1234 - 1268 MJ/m^2, 134.3 - 945.5 MJ/m^2, and 1115 - 1233 MJ/m^2 on southern slopes, northern slopes and piedmonts respectively, furthermore the same is true for the rugged parts of northern Balochistan and northern Sindh. The plains of national central territories possess about 1115 - 1178 MJ/m^2. The values about 1040 - 1114 MJ/m^2 have been identified in the plains of northern Punjab, Potwar Plateau and Peshawar valley. The lofty HKH area demonstrates variability of ESR values including 0 - 134 MJ/m^2; 134 - 502 MJ/m^2; 502 - 820 MJ/m^2; 821 - 1039 MJ/m^2 and even small patches of highest ESR values can also be located.

November: The result shows that there is substantial decline of ESR values in the autumn months. Pakistan displays four major distinct zones in November, the southern zone having about 809 - 1100 MJ/m^2, as one proceeds northwards ESR obvious with values of about 662 - 809 MJ/m^2 prevails in most of the Balochistan, northern Sindh and southern Punjab. Mountains remain an exception here with small values. The third zone extends from about 30˚N latitude up to Peshawar valley where 484 - 725 MJ/m^2 are dominant but the rugged lands remain an exception with 336 - 592 MJ/m^2 mostly in Khyber valley and Waziristan Hills however, southern aspects remain as exceptions with high values. The HKH represents the fourth zone with least values at the bottom of the slopes and in the valleys but the high southward slopes gain substantial ESR approximately above 810 MJ/m^2.

December: If the plains of the national territories are examined, they display a latitudinal pattern starting from 809 MJ/m^2 in the south close to 24˚N latitude, by shift towards north a belt in Balochistan and Sindh shows 662 - 725 MJ/m^2 where Kirthar and Makran ranges stand excluded. Further shift northwards confirms a wide zone of 593 - 661 MJ/m^2 encompasses most of northern Balochistan, northwestern Sindh and southern half of the Punjab, while Brahui and Sulaiman Ranges show lower limit of ESR. The Potwar Plateau, tribal areas and Peshawar valley received 484 - 592 MJ/m^2 in December. The observations in HKH are the lowest where we have maximum intershielding impact of high mountains but some towering southern slopes still have ESR above 810 MJ/m^2.

4. Conclusion

The effort is based on the integration of estimated ESR simulated through DEM input into ArcGIS in order to elucidate the patterns and spatial distribution of ESR at monthly scale. The simulated results captured a blended effect of latitude and landforms that show discernible areas of varied ESR per unit area. The plains, mountainous areas, piedmonts and enclosed (open) valleys were found with different responses. In HKH, north of Peshawar valley the situation is quite complex due to towering mountains. The study could be effective for surface regional analysis of solar energy. The HKH nurture Indus River system therefore, the energy balance here based on solar irradiance is of great significance. The spatial distribution of ESR could be instrumental in the estimation of evapotranspiration and solar energy balance for agricultural practices. Based on observations, in ample areas of Pakistan, ESR was above the limit of 1200 MJ/m^2 especially in southern parts where we have encouraging prospects of solar energy development. Balochistan and Sindh (southern provinces of Pakistan) could be the best options for generation of electricity from solar energy near to Karachi, the industrial and commercial hub of Pakistan. Additionally, in northern areas, high southern slopes are also appropriate places where solar stations can be established in order to generate electricity.

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