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THE POSSIBLE SUNSHINE DURATION OVER THE COMPLEX TOPOGRAPHY OF PAKISTAN

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ABSTRACT

The concept of distributed model based on the Digital Elevation Model (DEM) data as input to a GIS system for simulation of possible sunshine duration (PSD) with a fine resolution of 90 by 90 meters over the complex topographic regions of Pakistan has been applied for the first time. The simulated results indicate that landforms are useful to produce the reliable spatial distribution of monthly and seasonal possible sunshine duration. The inner shielding impact of landforms is more dominant in winter than summer. The northern and western rugged territory of the country shows a robust inner shielding effect on the spatial distribution of PSD. However, the joint effect of landforms and latitude on the spatial distribution of PSD at a monthly and seasonal level is obvious that varies region-wise in Pakistan. A gradual decrease of PSD in winter occurs from south to north in the country, while in summer the central parts of the country obtain maximum PSD. The mountainous territory displays larger variation dependent on slope angle, height, and aspect orientation which is addressed by this paper. The slopes exposed to the sun have longer PSD while their opposite counterparts reflect shorter PSD. This study is an initiative for the scientific investigation in Pakistan with a subtropical location and complex topography in the situation with an ample amount of possible sunshine duration but an acute shortage of energy required for economic development

KEYWORDS: Possible sunshine duration (PSD), Digital Elevation Model (DEM), GIS, spatial distribution, rugged terrain, landforms impact

1. INTRODUCTION

The importance of renewable solar energy caught the attention of scientists in climate sciences owing to the unprecedented growing energy demands in domestic, agriculture, and industrial utilization. The spatial distribution of possible sunshine duration got a tremendous scope in the housing industry, agricultural practices, remote sensing, and hydrology, sustainable development in mountainous terrain, glacial studies, forestry, and climate change studies. Pakistan is a developing country with resources yet to be explored for economic development. Solar energy could be a cheap and environment-friendly renewable resource if harnessed properly. Being in the subtropical region Pakistan receives ample hours of sunshine during the four seasonal patterns of winter, spring, summer, and autumn. According to Kepler's Second Law, the total insolation received at the earth's surface stays almost constant. However, seasonal latitudinal and regional variation of insolation on the globe is of utmost significance. For example, 25% variation occurs in the solar energy availability received at the latitudes of 65^o owing to the seasonal obliqueness of solar radiation (Berger and Louter, 1991).

Various distributed models have been produced to quantify and map various aspects of solar radiation over the rugged terrain. Many of the researchers in the field of PSD estimation over the complex terrain suggested that the distributed models approach is one of the best available tools to effectively estimate the PSD distribution over the complex topography (e.g Dozier 1979, 1990; Bouquet 1984; Stefanovic, 1985; Li & Weng, 1988). Fu (1983, 1996) is considered one of the pioneers who simplified the calculation of sunset and sunrise times on the slope through his analytical formulation. The availability of DEM data with fine spatial resolution paved the way for the development of spatial models capable of mapping PSD in inaccessible vast rugged terrains. In this context, Zeng et al. (2003) present a model of PSD over the rugged terrain of China based on DEM with a spatial resolution of 1km×1km. Qiu et al. (2004, 2005) innovatively simulated astronomical solar radiation over the Yellow River Basin based on DEM and also developed a distributed model of extra-terrestrial solar radiation over the rugged terrain of China. These models provide a primary baseline for further scientific investigations in geospatial sciences.

The astronomical and geographical factors highly influence the PSD received at groud. The direct solar radiation reached the ground surface when the sun start shines above the horizon. By definition, PSD is considered as the maximum possible sunshine duration that can occur between sunrise and sunset times. Its spatial distribution is substantially affected by the local relief and configuration of landforms. The PSD refers to its astronomical analogy and geographic counterpart with no atmospheric impact taken into account and only terrain inner shielding is considered in its spatial distribution (Li, 1988). The terrain inner shielding impact on PSD always remains significant as it affects the net amount of PSD received at any particular point or locality (Li and Weng, 1988).

More than half area of Pakistan is dominated by rugged terrain. Neither do we have such a dense network of observatories nor is it possible to work out PSD manually in the difficult northern and western rugged terrain of Pakistan. Therefore, this paper for the first time addresses the impact of landforms on the spatial distribution of PSD in Pakistan by making use of DEM input into ArcGIS. In this scenario, the simulated results validate that the DEM-based model can be successfully utilized through GIS platforms.

2. MATERIAL AND MEATHODS

Three astronomical factors are very important, position, direction, and altitude of the sun but exposure to the sunshine in rugged land is much dependent on the role of responding landforms through their inner shielding impact. In this context, a specific locality or point in the rugged terrain can face three different situations. First, the slopes can see the sun, second cannot see, and third is exposed partially to the sun. Therefore, these three situations are the combined effect of astronomical and ground topographical impact. Thus, the responding shielding influence of landforms on the PSD is varying along with the sun's position in the sky. Therefore, the daily PSD varies from place to place in rugged topography owing to the height of the slope, its orientation, and the hindrance induced by neighbouring terrain (Li, 1999). The slopes opposite to the sun’s exposure can’t see the sunrise (earlier) or sunset (later) than the horizontal flat surface (Weng et al. 1981; Qiu et al. 2005). It is imperative to mention that atmospheric and climatic impact on the sun shining is not considered in this model. The model is based on its mathematical construct of the distributed PSD model developed by Zeng et al. (2003) for the rugged terrain of China.

Presume that a specific point *P* on the ground surface is located at a certain latitude (φ) where the solar-hour-angle (▯▯▯) at sunrise and sunset times is measured in radians from the true solar noon time taken as a reference point which is considered positive (negative) towards the west (east). While the solar declination (▯) is considered positive (negative) towards the north (south) of the equator.

Practically, the PSD for a point *P* relies on the sun's elevation angle, azimuth, and inter-shielding impact of landforms. This is the basic element of the model that the point *P* will get exposure to the sun if the sun elevation angle (h_i) is bigger than the slope angle otherwise not. By using the day length (ΔT), the daily PSD can be calculated by the required corresponding sun hour angle Δ (in radians), now it becomes possible to split the interval between sunrise and sunset times for a horizontal plane. Consequently, the shielding impact (S_i) caused by landforms for the particular point *P* is dependent on the direction of Φ_i, sun elevation angle $h_{i,}$ and elevation of the terrain.

If the solar irradiance is at point *P*, and the (S_i) is shielding impact from elevations $S_i = 1$, otherwise $S_i = 0$ and shields point *P.* Practically, the terrain with variable elevations is depicted through DEM. If point *P* is the starting point and ΔL is the space step length, the stepwise screening of terrain elevations at point *P* is determined. The number of Calculations (*N*) is dependent on the screening radius *R*. Here *R* is 50 km, which can meet the demand of required calculations and the time step length (ΔT) of 10 minutes. By applying suitable, resample methods like the nearest neighbor interpolation, bilinear interpolation, and double cubic convolution interpolation (Zhang, 2000). The nearest neighbor interpolation resample was found highly efficient but with low precision and double cubic convolution interpolation was perceived with the highest precision but low efficiency. Keeping in view the *n* + 1-time interval the two adjacent times can take the form of one interval leading to *I* intervals. Now suppose that the screening coefficient (*gi*) for each of the intervals can be obtained as,

$$gi = \frac{1}{2}\ (S_i - 1 + S_i)$$

Conclusively, the PSD (in hours) on any of the solar days for the point *P* on rugged terrains can be given by

$$T = \frac{24}{2\pi}\left[\sum_{i=1}^{n-1} g_i \Delta\omega + g_n \bmod\left[\frac{2\omega_o}{\Delta\omega}\right]\right]$$

3. RESULTS AND DISCUSSION

First, DEM was constructed from 3arc second data obtained from SRTM. Initially, the PSD was calculated at a monthly level in the whole study domain by making use of DEM with a spatial resolution of 90m × 90m. The screening radius R was taken 50 km and the time step length ΔT equals 10 minutes. For the sake of precision double linear interpolation was carried out. The DEM input was simulated through the platform of ArcGIS. The simulated results in the rugged territory of the country reveal that the model parameterization has to lead to the calculation and computation with appropriate accuracy.

The months of January and July are simulated as representative monthly cases, and for seasonal representation, three months were evaluated together winter and summer each. Therefore, the spatial distribution of PSD in January, July, winter, and summer are given in Figures 2, 3, 4, and 5 which configures their sub-regional characteristics in terms of PSD variations in Pakistan. The PSD varies with the geographical extent from the south (north) to the north (south) as well as from east (west) to west (east) at the sub-regional level in the study locus. Based on results, Pakistan reflects a 'three-zone pattern' of distinct PSD, the southern zone, central zone, and the Himalayas, Karakoram, and Hindu Kush (HKH) zone. These zones encompass Pakistan from south to north. It is important to mention that, first, the geographical extent of each discrete zone varies in monthly and seasonal cases second the mountains and hills in each zone intrinsically influence the monthly and seasonal PSD and eventually disrupt the zonality of PSD within each zone. The consideration of distinct PSD zones provides methodical ground for discussion.

3.1. Possible sunshine distribution in January

In January, Sun is shining vertically in the tropics of the southern hemisphere and solar declination δ remains negative thus Pakistan lying in the northern subtropical region receives oblique solar radiation where the low sun angle results in less PSD and more inner shielding impact of landforms. Hence, January is the month with the lowest duration of sunshine in Pakistan like other subtropical regions of the northern hemisphere. Simultaneously, the difference can be made at the sub-regional level by the impact of landforms from the south (north) to the north (south) in the country. Referring to Figure 1, the southern parts of the country south of 29^{o} N latitude and north of 24^{o} N latitude receive sunshine hours in January between 131-313 hours. These areas are mainly comprised of the plains including the lower Indus plain, coastal plains, and most of the Balochistan Plateau south of 29^{o} N latitude excluding its mountainous territory with small enclosed basins. In this southern distinct PSD zone of the country, a rugged territory including Kirthar ranges, central Brahuvi ranges, and Makran hills receive PSD in January that varies between 224-297 hours. The piedmonts and slopes exposed to sunshine in central and southern Balochistan reflect a range of PSD from 274-331 and on the contrary northern and northwestern slopes have 204-273 PSD hours.

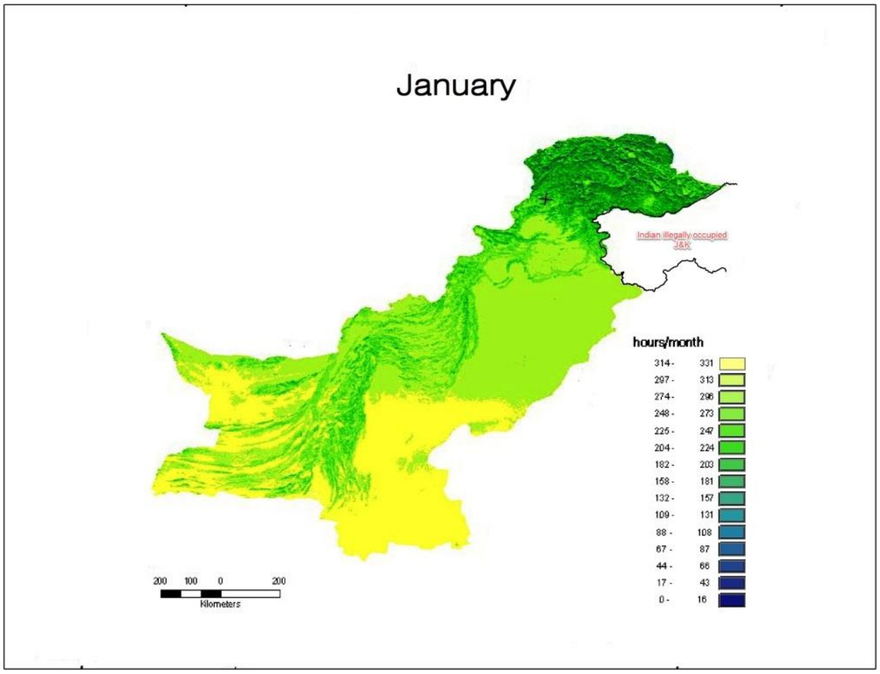

Figure 1: Spatial distribution of PSD in Pakistan during January (unit hours/month).

In the central distinct PSD zone, north of 29^{o} N latitude and south of Peshawar valley the PSD range is from 131-297 hours in January with the little exception in the highest slopes of Zarghoon and Takatu mountains in Quetta region, Sulaiman ranges, and Safed Koh regions (Parachinar area). In the Safed Koh region, some PSD patches of about 224 hours have also been noticed. Most of the plains in this central part of the country obtain PSD between 274-313 hours.

The HKH zone, the northern lofty rugged terrain of the country north of Peshawar valley and northern Punjab, receives a minimum PSD that varies between the ranges of 16-298 hours in January. This is the most complicated region where PSD is affected by the robust inner shielding impact of landforms in winter, especially in January. The southward slope gets maximum PSD while northern aspects receive minimum duration. There are potential patches on northern aspects of HKH that see no sunrise round the year.

3.2. Possible sunshine distribution in July

In July (Figure 2) the southern distinct PSD zone south of 29^o N latitude and north of 24^o N latitude has an apparent difference in PSD can be seen between rugged and flat parts. The flat parts receive PSD from 400-418 hours. These areas are mainly comprised of the lower Indus plain, coastal plains both in Sindh and Balochistan, and most of Balochistan Plateau south of 29^{o}N latitude excluding its mountainous territory which does not fall in this category. In the same southern zone, a rugged territory including Makran hills, Kirthar ranges, and central Brahuvi ranges receives PSD in July that comes under the range of 308-400 hours. The southern and southwestern piedmonts in south Balochistan depict no obvious difference as was perceived in January because of little chance for mountains to cast a shadow on their respective piedmonts due to the high elevated sun angle in July. In the central distinct PSD zone, north of 29^o N latitude and south of the foot of HKH in the plains of central Pakistan, the PSD is greater than any other zone and varies between 308-418 hours in July with a lower limit of PSD in the mountains and high limit of PSD in the plains. The mountains including Zarghoon and Takatu, Sulaiman ranges and western border mountains, and the Safe Koh area receives less PSD about 334-418 average hours in July. Thus, the upper Indus plain and enclosed basins in central-western parts of Pakistan, mostly receive the larger PSD in July than any other part of the country. The upper Indus plain can be termed as the breadbasket of the country and ample sunshine supports agricultural production. The HKH distinct zone of PSD in northern lofty mountains receives comparatively minimum hours due to the high slopes and complexity of the terrain. The PSD range found in this zone is quite complicated. The two obvious ranges of PSD are from 334-400 hours and 370-104 hours. Some patches of highest PSD can be seen over the highest southward slopes with maximum exposure to the sun, on the contrary, some patches can be located with no sunshine on northward slopes in HKH despite the high elevated sun angle in July. Because the declination angle of the sun does not excel the slope angle.

3.3. Possible sunshine distribution in winter

In winter the results based on Figure 3 configure that the southern distinct zone of PSD in the country south of 30°N latitude receives more hours of PSD than the central distinct zone of PSD north of 30° N latitude up to Peshawar Valley (including Peshawar valley) and northern Punjab that extends up to the foot of HKH (about 34°.5' N). The least winter PSD is simulated in the HKH zone. In southern parts maximum, PSD from 862-973 hours is received in the plains, including lower parts of the upper Indus plain, the whole Sindh province, Sibi-Jacobabad plains, and flat parts of Balochistan Plateau. The southern PSD distinct zone in winter is more extensive than the southern PSD distinct zone in summer. The rugged parts in the southern zone of the country present an uneven situation, where the enclosed small valleys receive a range of PSD hours from 786-862, and owing to terrain-shielding, the PSD ranges from 316-694 over the mountains.

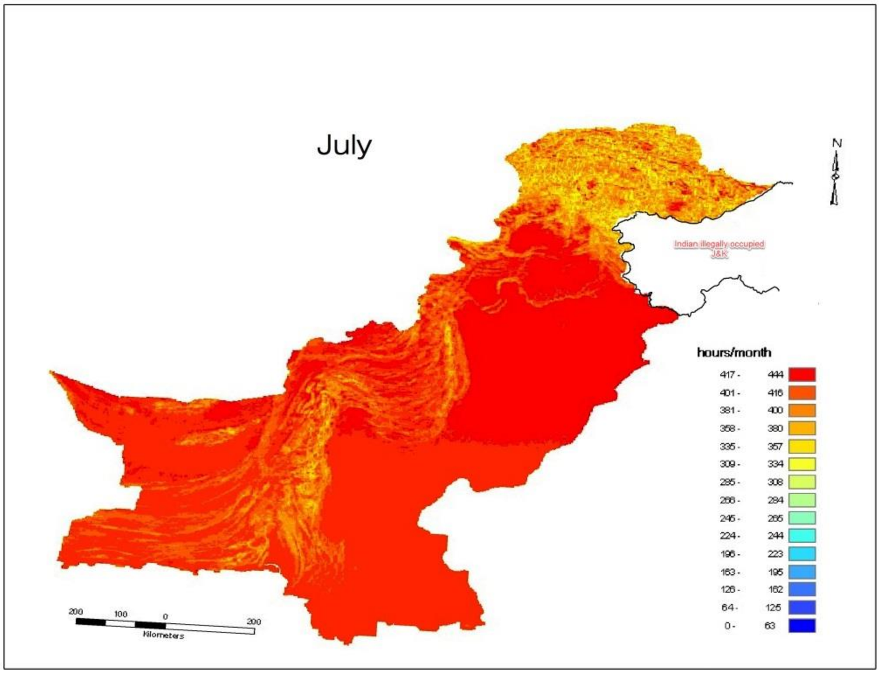

Figure 2: Spatial distribution of possible sunshine duration in Pakistan during July (unit hours/month).

In central parts of the country, including Potwar Plateau receives a range of 591-696 PSD in winter. The rugged portion in central parts of the country is mostly comprised of Sulaiman ranges and Safed Koh areas in tribal areas, Cherat hills and Salt ranges obtain the PSD range between 316-473 hours. The range of PSD lies between 473-145 hours in the northern parts of the country comprised of HKH which stands as a distinct spatial zone with minimum winter PSD in northern Pakistan. Possibly, there are areas in the northern aspects of the mountains which don't see sunrise throughout winter. Few patches in HKH reflect a range of 473-696 PSD hours either southward slopes or areas where most of the valleys are wide enough and get sufficient exposure to the sun.

3.4 Possible sunshine distribution in summer

The summer (Figure 4) shows a shrunken southern distinct PSD zone and extensive central distinct PSD zone than winter (Figure 3). In summer, the area of maximum PSD is not the southern zone but the central PSD zone located about north of 28^{o} N latitude. Therefore, in summer, the central zone of PSD receives maximum hours, followed by a southern zone of PSD south of 28^{o} N latitude which is opposite to the situation found in winter. As usual, a short period of PSD is figured out in the HKH zone except for those southward facing slopes which get maximum exposure to the sun shining in summer.

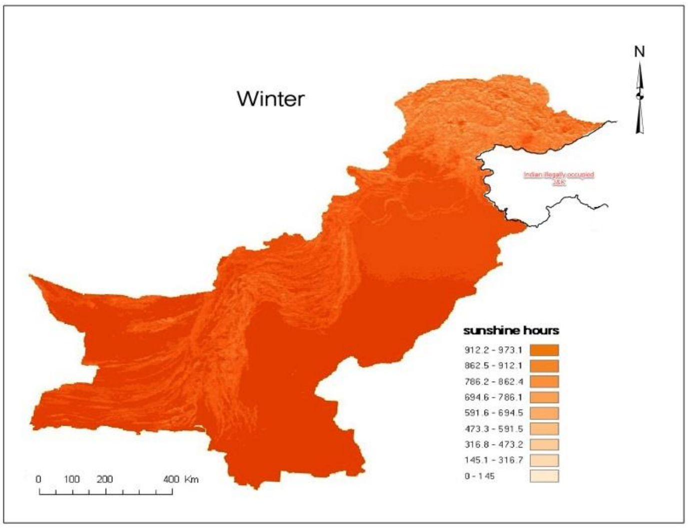

Figure 3: Spatial distribution of possible sunshine duration in Pakistan during the winter season (unit: hours/season).

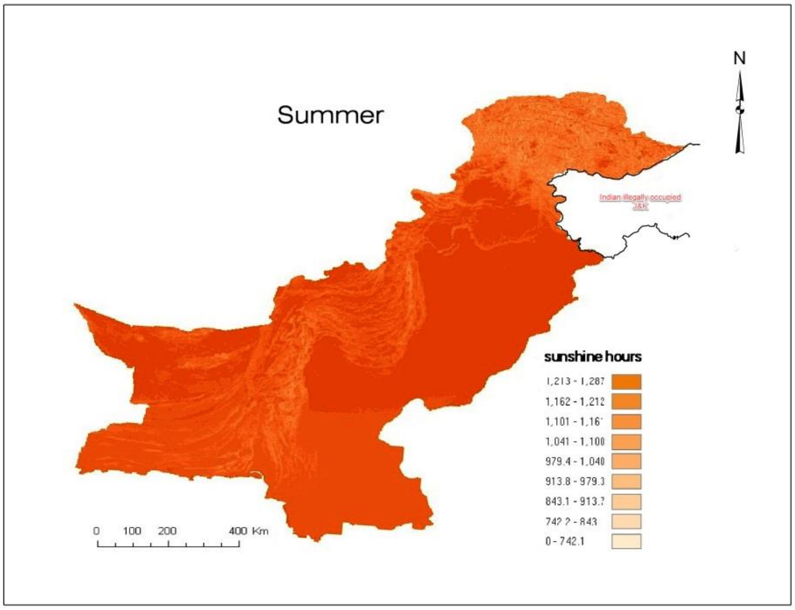

Figure 4: Spatial distribution of possible sunshine in Pakistan during summer season (unit: hours/season).

A wide range has been achieved in the central distinct PSD zone of the country in summer with lower and upper limits marked by 742 hours and 1287 hours respectively. The rugged portion in the central zone mostly embraces Sulaiman ranges, Safed Koh (Parachinar area) in tribal areas, Cherat hills, and Salt ranges demonstrating the PSD range between 1100-742 hours. The range of PSD in the HKH zone is 1100-742 hours in summer. The HKH has minimum PSD hours in the summer because of the inner shielding impact of lofty mountains nevertheless the impact is not as robust as in winter because of the high elevated sun angle in the sky. Some southward slopes show long PSD from 1212-1287 hours. Few patches in HKH exhibit a range of PSD above 1100 hours; these are the localities where most of the valleys are wide enough and get sufficient exposure to the sun in summer.

4. CONCLUSION

By making use of DEM with 90m×90m resolution in the GIS platform the monthly and seasonal PSD are depicted. PSD in January and July are simulated as monthly representative cases while three months together were simulated for winter (DJF) and summer (JJA) each as seasonal cases. The simulated results reveal that the model parameterization has escorted calculation and computation with appropriate accuracy. The results are quite compatible to explain that the landform inner shielding impact is more in winter than summer and answer how the zonal symmetry of PSD is deeply disrupted by the rugged terrain in Pakistan. We obtained three main distinct zones of PSD in the country from south to north (north to south) dependent on latitudinal and landform inner shielding impact, a southern, central, and HKH zone, each zone exhibits PSD variation at the sub-regional level. In the rugged terrains, the trend of mountains, aspects, height, and slope angle are the factors that shape the spatial distribution of PSD from month to month, season to season, and region to region within the study domain. This study could be a new avenue for the scientific investigation in the densely populated agriculture-based subtropical country with ample amount of sun shining but face an acute shortage of energy for its economic development.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to the privacy policy of the Pakistan Meteorological Department.

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