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Spatio-temporal assessment of dust risk maps for solar energy systems using proxy data

Yassine Charabi [a,*], Adel Gastli [b]

[a] Department of Geography, College of Arts & Social Sciences, Sultan Qaboos University, P.O. Box 42, Al-Koodh, Muscat, Oman
[b] Department of Electrical and Computer Engineering, College of Engineering, Sultan Qaboos University, Muscat, Oman

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ABSTRACT

This paper presents a new approach for spatio-temporal assessment of dust risk map for solar energy systems in arid area using proxy open source data. The approach considers the recent NASA satellite data from the Multi-angle Imaging Spectro-Radiometer (MISR) which provides significant information about dust emission, transport, concentration and property evolution, through Aerosol Optical Depth (AOD). The analysis was conducted on Oman as a case study. The dust risk maps were developed based on the spatio-temporal evolution of MISR AOD in blue band (446 nm). These maps showed significant variations of AOD over the year. The summer season presents the highest risk of dust contamination because of the favorable regional weather synoptic conditions for the dispersion of mineral dust and creation of haze conditions. The annual average map of AOD was also developed and compared to the dust emission sources (desert sand locations), and the annual average maps of wind direction and air temperature at 100 m and 2 m above the ground, respectively. These maps show a good correlation between dust emission sources, wind and temperature profiles, and high atmospheric dust concentration captured by AOD. Finally, the impact of dust constraint on solar energy resource assessment and systems siting was investigated for Oman. It was found that a considerable reduction (64%) of the highly suitable land is obtained after consideration of dust concentration constraint.

1. Introduction

The most favorable solar belt is lying between latitudes 15° and 35° North and South equator, embraces arid regions that are naturally endowed with the most favorable conditions for solar energy applications. These arid regions are characterized by having the greatest amount of solar radiation, more than 90% of which comes as direct radiation because of the limited cloud coverage and rainfall (less than 200 mm per year). Likewise, there is regularly over 3000 h of sunshine per year. For this reason they can count on solar radiation as a steadfast source of energy that can be readily exploited for a multitude of purposes.

Beyond the availability of solar energy in abundance in these arid regions, the harness of solar radiation faces critical environmental risk mainly related to mineral dust deposition which can reduce considerably the revenue of any solar energy systems. The contamination of the solar collectors of any solar energy systems by dust deposition, leads to degradation of their optical properties with corresponding losses of efficiency and resulting in negative economic impact. The movement of a mineral dust particle, according to specific size and speed, is an efficient erodible agent that can affect the optical proprieties of any solar energy system which will require frequent cleaning using generally fresh water. Because of the general scarcity of fresh water in desert and semi-desert zones, this commodity should not be stressed or wasted for cleaning [1].

The general problems of collector surface maintenance have been reviewed in [2,3]. The optical effects of small particles of various sizes have been discussed in [4,5] and in a number of other papers. Typical sizes of particles in the atmosphere have been discussed in [6] and systematic measurements of the deposition velocities and fluxes of particulate contamination on the output of photovoltaic cells and performance of evacuated tube collectors, have been studied in [7,8] respectively. A computerized microscope system, for studying the physics of dust particles which adhere to various kinds of surfaces such as those of solar collectors have been developed in [1]. Dust accumulation on glass plates with different tilt angles have been studied and the transmittance of the plates under different climatic conditions have been measured in Mina,

* Corresponding author.
E-mail addresses: yassine@squ.edu.om (Y. Charabi), gastli@squ.edu.om (A. Gastli).

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Egypt over a period of one month [9]. The degradation in solar transmittance during this period was found to depend on the tilt angle of the glass plates with maximum and minimum values obtained when the plate is in horizontal and vertical positions, respectively. Measurements of dust accumulation on tilted glass plate located in Kuwait was found to reduce the transmittance of the plate by an amount ranging from 64% to 17% for tilt angles ranging from 0 to 60°, respectively after 38 days of exposure to dusty environment [10,11]. The influence of dust deposition on the evacuated tube collector field on the operating performance of the solar desalination plant at Abu Dhabi, UAE was presented in [12]. It was found that dust deposition and its effect on plant performance depend strongly on the season of the year and, hence, the frequency of jet cleaning should be adjusted accordingly. For example, for a transmittance decrease from an initial value of 0.98 (clean glass condition) to a low value of 0.6, corresponding to a very dusty glass condition, production drops from 100% to 40% of the clean collector production level. The effect of dust on the transparent cover of solar collectors was studied in [13]. An experimental set up was developed involving 100 glass samples with different tilt and azimuth angles. The preliminary results indicated that the reduction in glass normal transmittance depends strongly on the dust deposition density in conjunction with plate tilt angle, as well as on the orientation of the surface with respect to the dominant wind direction.

According to the existing published work, the impact of the dust deposition on solar energy systems was approached through in-situ experimental studies. Those investigations pointed out that the effect is site-dependent and differs largely from region to region and thus makes it difficult to generalize the impact of dust deposition on solar energy systems performance in a qualitative and quantitative manner. Proxy data, mainly derived from satellite imagery, could be a good alternative to assess the long spatio-temporal evolution of mineral dust, to determine their physical properties and to define the trend, the profile and the pattern of concentration locally. Aerosol satellite database can yield a consistent picture of the site exposure to mineral dust which allows the estimation of the periodicity of cleaning requirements along the year based on site profile and evaluation of the cost and the capacity factor. Most of site assessment for solar energy applications does not take into consideration the dust effect because of its measurement complexity. The recent NASA satellite data from The Multi-angle Imaging Spectro-Radiometer (MISR) provide significant information about dust emission, transport, concentration and property evolution, through radiative signatures.

The present study characterizes the degree of contamination by mineral dust and tracks the exposure to dust constraint at local scale using proxy data mainly from open sources. In this study, Oman is selected as a reference area for this investigations due to the high solar energy potential and substantial amount of dust generated locally from Sahara desert [14–16]. This paper is structured as follows. Section 2 details the data sets available from proxy data sources and their main features; section 3 presents the geography of the study area; section 4 discusses the main results

Fig. 1. Location of the Rub' al Khali or Empty Quarter sand desert.