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Influence of Terrain Attributes on the Number of Snow-Covered Days Over Karoon River Basin, Iran

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Abstract

Objectives: The purpose of this study is to find the relationships of snow-covered days (SCDs) with topographic variables such as elevation, slope and aspect by using MODIS data. **Methods/Statistical Analysis:** MODIS data were used from 1 January 2003 to 31 December 2015. Due to cloud contamination in the daily data of MODIS snow products, it is not reasonable to use the data without any processing aimed at reducing cloud blockage. To reduce cloud cover effect, the daily data of MOD10A1 and MYD10A1 were combined and a three day filtering technique was applied to further reduce cloud cover effect. **Findings:** 1) The relationship of SCDs with elevation is not necessarily a linear relation; 2) The slope value of 22° is the critical slope in the Basin above which the snow accumulation decreases; and 3) The most SCDs are on the N and NE facing slopes and the least SCDs are on the SW facing slopes. **Application/Improvements:** The study showed that the slopes steeper than 22 degree are not suitable for snow accumulation. So in a country like Iran that is 3 degree Celsius warmer than the globe and snowfall frequency is dramatically low and this may be considered as a new restriction to accumulation of snow in high altitudes of the country.

Keywords: Aspect, Elevation, Karoon River Basin, Slope, Snow-Covered Days

1. Introduction

Having snow is of great importance in high mountainous areas as these regions provide downstream population with fresh water. Snow cover plays an important role in the water budget of arid watersheds in many mountainous regions in the world. In more than half of the mountainous regions, seasonal snow glaciers have a supportive role for downstream water resources[1]. Therefore, accurate monitoring of snow cover areas and having fundamental information regarding snow cover, SCDs, accumulation and ablation of snow is notably important. Traditionally snow data were available from ground station data[2]. Analysis of snow cover based on ground station data can't provide very helpful data as the stations are very sporadic and limited due to harsh environmental weather conditions and terrain accessibility. Therefore, remote sensing that provides continuous and high resolution data can serve as an alternative to overcome the problem. Remote sensing is also becoming a powerful tool in climatological studies[3]. Many researchers have applied remote sensing snow data to investigate snow characteristics over different regions, for instance, the spatial and temporal change of snow cover over TP region have been studied recently[4]. The findings show that majority of the studied region has indicated a decreasing tendency for SCDs. The investigation of the spatial and temporal variations of snow cover in Loess Plateau located in China shows that the snow cover areas and SCDs have no significant trend[5]. In some of the other studies the relationship of

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snow covers and SCDs have been examined with terrain variables[6-8].

The aim of this study is to explore the effects of terrain variables such as elevation, slope and aspect on the spatial distribution of SCDs in the Karoon river basin, based on a new developed snow data set derived from the daily time series of terra (MOD10A1) and Aqua (MYD10A1). This basin is regarded as one of the most important one in Iran as many large rivers of Iran originate from it and the largest reservoirs of the country have been constructed here to supply water need for agricultural, industrial and domestic uses. The total population of downstream region of the Basin is nearly 4 million people which are heavily dependent on the rivers in the Basin.

2. Study Area

The Karoon River Basin is located at the south-west of the country with a total area of 67,000 km^2 and has a complex mountainous terrain. The terrain is high in north and east but low in the south. The climate of this region is highly affected by terrain feature and the elevation ranges from 0 near the Persian Gulf to 4290 meter at the top of Zagrous mountains (Figure 1). The largest rivers of Iran originate from the snow cover areas of Zagros Mountains that are located in this Basin.

3. Data and Methods

In this investigation, MOD10A1 and MYD10A1 products provided by the National Snow and Ice Data Center (NSIDC) were selected to conduct this study. The spatial

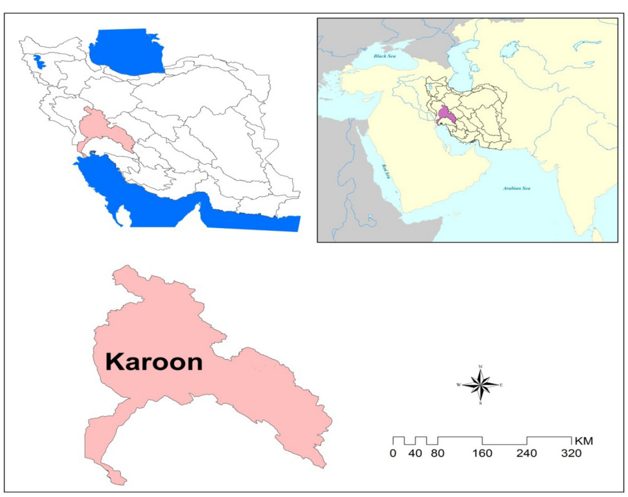

Figure 1. General location of Karoon river basin.

resolution of these products is 500 m and the projection is an equal area sinusoidal grid[9]. The time range for the selected MOD10A1 and MYD10A1 snow data products extends from 1 January 2003 to 31 December 2015. MODIS tiles of h22v05 and h22v06 cover the entire Basin therefore were selected in this study. Only the pixels that were present within the boundary of the Basin were extracted. The data are in HDF format and special codes have been assigned for different types of ground objects (e.g., 25 for no snow cover, 37 for lakes, 50 for clouds, 100 for lake ice, and 200 for snow). The biggest problem to analyze snow cover in remote sensing data is cloud contamination that complicates snow detection. To overcome this problem some techniques have been suggested by many researchers. In this study two common methods were applied to reduce cloud contamination. The first approach merges the MOD10A1 and MYD10A1 snow cover products. In this method, if a pixel is cloud covered in MOD10A1 but snow covered in MYD10A1 that pixel will be considered as a snowy pixel. As the Band 6 on Aqua MODIS is non-functional, MYD10A1 products (Aqua) present less accurate snow maps in comparison to Terra; MOD10A1[10,11]. Therefore, the based product is Terra (MOD10A1). The combination of two sensors has been carried out in various studies[12-14]. The second method is based on the temporal combination of three successive days in the combined data set. If a pixel is cloud covered, the prior day and the next day are checked and if they are both snow-covered that pixel will be considered as a snowy code. This new data set will be referred to MOYD hereafter. Based on this data set (MOYD), we tried to explore role of topographic features on the number of snow covered days (SCDs) in the Basin.

3.1 Digital Elevation Model Data

Digital elevation model (Dem) for the tile numbers of h22v05 and h22v06 was obtained from (ftp://landsc1.nascom.nasa.gov/outgoing/c6_dem/sin_500m/). This digital elevation model was exactly consistent with snow data both on spatial resolution and projection system. In the elevation model, slope and aspect data were also available in 500 m resolution.

3.2 Station Data

In this study daily snow depth data for 9 stations operated by IRIMO (Islamic Republic of Iran Meteorological Organization) were obtained from 1 January 2003 to 31

December 2012. The stations are mainly located at low elevations from nearly 1500 to 2550 meter above sea level (Figure 2). The snow depth data of less than 1cm were excluded from the analysis. The snow depth data were used to analyze the accuracy of MOYD data to detect snow.

3.3 Accuracy Assessment of MODIS

The results of accuracy assessment of MODIS under clear sky for each of the snow depth classification have been depicted in Figure 3. As can be seen the accuracy increases as the snow depth increases. Even in clear sky conditions MODIS has problem to accurately detect thin snow covers. The important point to note here is that the snow depths are reported from the stations at 6:00 a.m. but the satellite pass time is several hours later. This inconsistency of time can lead to the thin snow depth to be melted before the collection of data is done by satellite. Therefore, part of MODIS failure to accurately detect thin snow cover may be attributed to this time difference. We also calculated the effectiveness of MOYD data set in minimizing cloud cover effects. The results have been depicted in Figure 4. As can be seen from Figure 4, detection rate decreases when clear and cloudy conditions altogether are taken into account. Percentage frequency distribution of snow depth data has been depicted in Figure 5. As can be seen the frequency of shallow snow is very considerable. So it can be inferred that the Basin does not receive much snow. The accuracy assessment of MODIS has been carried out in various geographical territories[15-17].

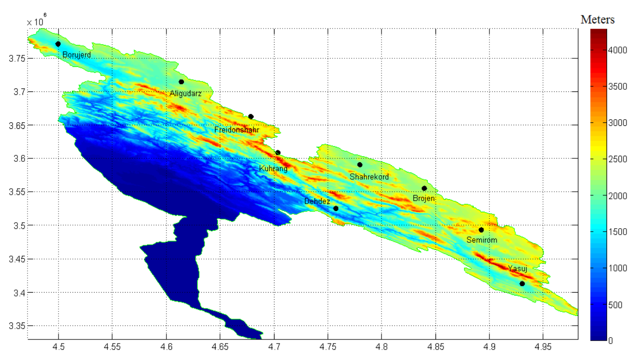

Figure 2. Digital elevation model of the Basin in sinusoidal projection system.

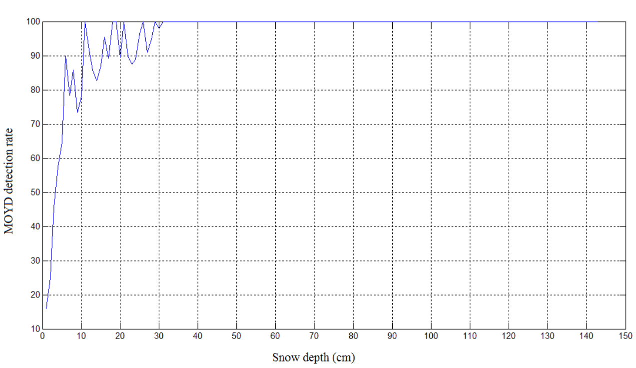

Figure 3. MOYD detection rate under clear sky.

4. Discussion

4.1 SCDs and Elevation

The relationship between elevation and SCDs for the seasons of winter, spring and fall shows that with the increase in elevation the number of SCDs increase as well. The highest correlation between elevation and SCDs can be seen in winter. The highest number of SCDs is seen in winter. For instance in this season at the elevation of 2000 m, average number of SCDs is 14 days in the Basin but in fall in this elevation the number of SCDs is only 4 days. However in spring the SCDs is near zero. The important point that is particularly noteworthy is that the relationship between elevation and SCDs is not necessarily a linear

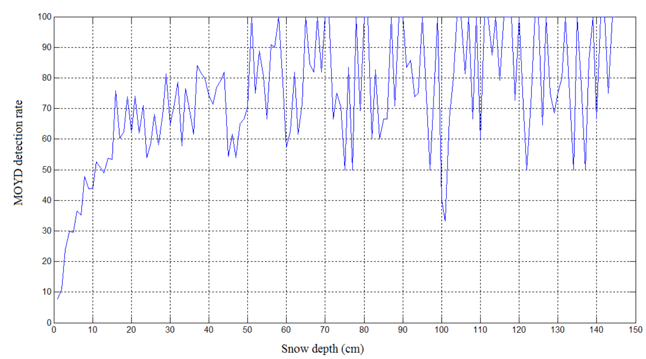

Figure 4. MOYD detection rate under clear and cloudy conditions.

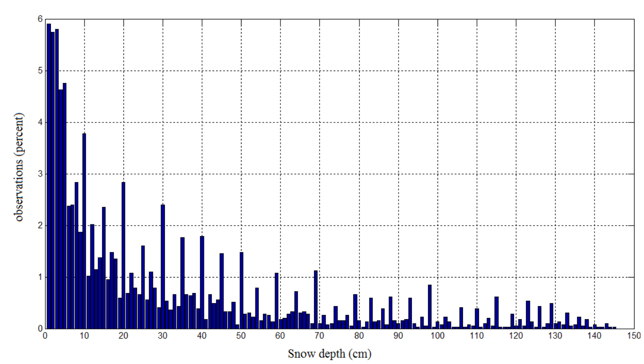

Figure 5. Percentage frequency distribution of snow depth data.

relation. In the higher elevations of the Basin a scattered pattern may be seen (Figure 6) and in some cases the SCDs decrease as elevation increases. To understand why SCDs show a scattered pattern in higher elevations, from the lowest point to the highest elevation at the intervals of 1 meter, we calculated the number of pixels that are located in each of the elevation intervals, (Figure 7). The calculations indicate that approximately from the elevation of 3000 m to the higher elevations the frequency of pixels decreases. One of the reasons that might have caused the SCDs to portray a scattered pattern in higher elevation is that the mean of the SCDs in these elevations have been derived from fewer data points in comparison to the lower elevations. For instance the mean of SCDs for the elevation of 2727 m has been derived from 102 data points whereas there is only one data point for the elevation of 4002 m. To make it more clear, we calculated the number of points that fall in the elevation range from 2000 to 3000 and from 3000 to 4290 m at the intervals of 1 meter. As seen in (Figure 8) the number of pixels in the elevation range of 2000 to 3000 is considerably higher than the pixels falling in the elevation range from 3000 to 4290 m (Figure 9). At the very high elevations of the Basin, there is just one or even no data point. Another reason that can be attributed to the occurrence of scattered pattern of SCDs in higher elevations is the increase of slope at the elevations above 3000 m. The steeper the slope, the less persistence of snow covers on the slope. The mean of slope has been displayed for each of the elevation groups at 1 meter interval in (Figure 10). To further investigate the relationship, we calculated R^2 of SCDs

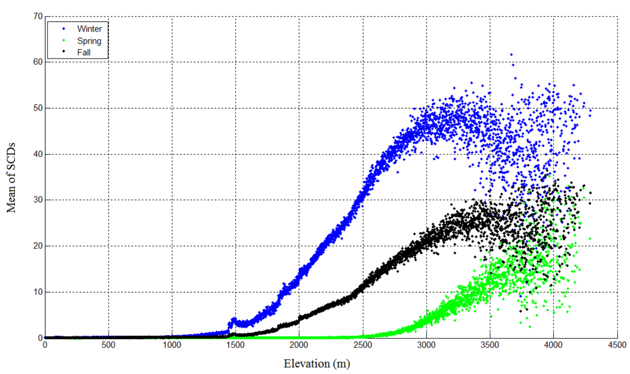

Figure 6. The relationship of seasonal SCDs and elevation.

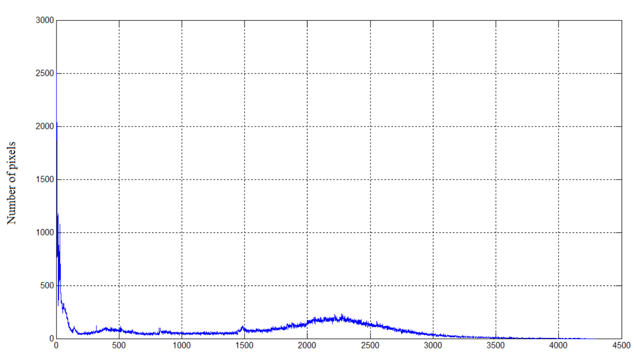

Figure 7. Number of data points (pixels) in each of the elevation intervals from 0 to 4290 m.

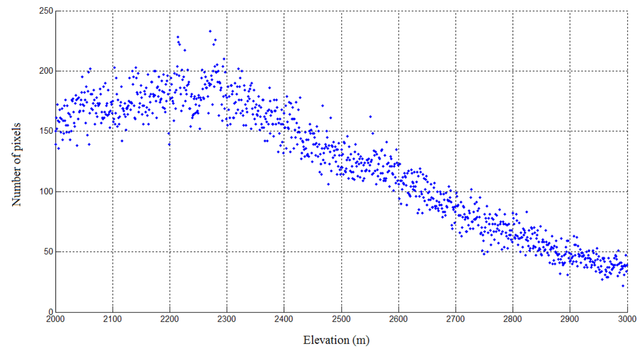

Figure 8. Number of pixels in each of the elevation intervals from 2000 to 3000 m.

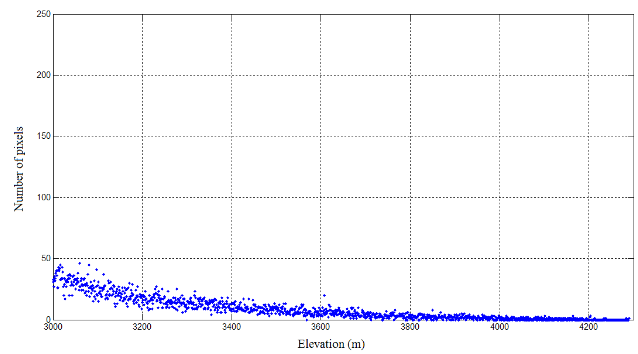

Figure 9. Number of pixels in each of the elevation intervals from 3000 to 4290 m.

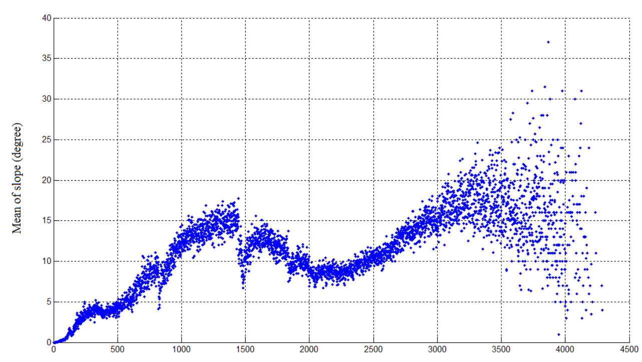

Figure 10. Mean of slope for each of the elevation groups.

with elevation. The analysis revealed that the greatest correlation is for winter and fall and lowest is for spring and summer respectively. (Table 1).

4.2 SCDs and Slope

To assess the relationship between slope and SCDs, we calculated mean of SCDs from the lowest slope (1°) to the highest slope (54°) at the interval of 1°. Figure 11 shows this relationship. As seen in this figure the slope with value of 22° is the critical slope value in the Basin, and the slopes that are steeper than this value are not suitable for the accumulation of snow.

4.3 SCDs and Aspect

The south facing slopes are warmer in comparison to the other slopes as they receive more energy. On the other hand, north facing slopes are colder because of less insolation. Aspect can have important effects on the distribution of snow[18-19]. Snow on the south facing slopes is shallower in comparison to the snow on the north facing slopes[20]. To examine the role of aspect value on the distribution of SCDs, we calculated the mean number of SCDs on each of the aspect values from 1° to 360° at 1° intervals. The findings revealed that aspect has a notable effect on the distribution of snow in the Basin. As can be seen from Figure 12, the north and north-east facing slopes have the most number of SCDs on average and are more suitable for the accumulation of snow. The lowest number of SCDs was found to be on south-west slopes.

Table 1. Seasonal relationship between SCDs and elevation in the Basin

Season	SCDs mean	R^2 (SCDs versus elevation)	P-Value	Equation
Winter	19.9	0.92	0	SCDs= 0.0153*elevation–11.06
Spring	3.3	0.74	0	SCDs= 0.0038*elevation–4.36
Summer	0.01	0.51	0.00	SCDs= 4.4e–06*elevation-0.002
Fall	9.5	0.92	0	SCDs = 0.0082*elevation–7.06

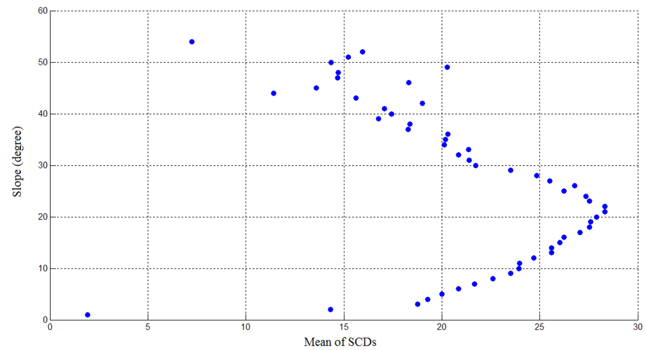

Figure 11. Relationships of SCDs mean and slope.

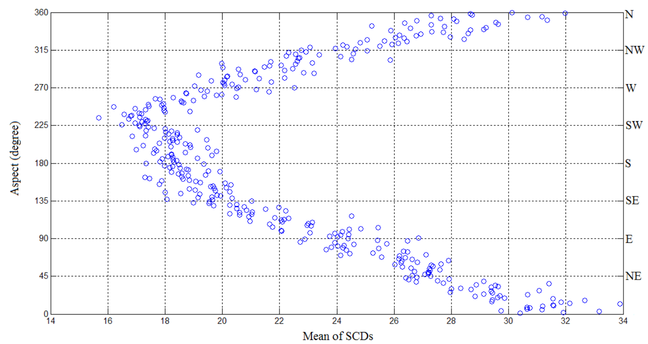

Figure 12. Relationships of SCDs mean and aspect values.

5. Conclusion

In this investigation the relationship of SCDs with topographic variables (elevation, slope and aspect) was explored over Karoon river basin which is located in the south-west of Iran. A new snow cover data set was derived from the daily time series of both Terra (MOD10A1) and Aqua (MYD10A1) products based on two common cloud removal methods. The time extent of this study covers from 1 January 2003 to 31 December 2015. The main findings of this study can be summarized as follows:

- The relationship of SCDs with elevation is not necessarily linear, and in very high elevation areas of the Basin it shows a scattered pattern and in some cases the SCDs decrease as elevation increases. This characteristic may be due to the notable decrease in the number of pixels falling in high elevation groups and occurrence of steeper slopes in these elevations.
- The slope value of 22° is the critical slope in the Basin above which the snow accumulation decreases.
- The maximum SCDs are on the N and NE facing slopes and the least SCDs are on the SW facing slopes.

The findings determined from the present investigation demonstrated the heterogeneous distribution of snow in terms of the different terrain variables that will be highly insightful to the glaciologists and climatologists. Further, such information would also facilitate the government in locating proper tourism facility sites in the snow covered slopes.

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