Journal of Materials and Environmental Sciences
ISSN : 2028-2508
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University of Mohammed Premier
Oujda Morocco
JMES, 2017 Volume 8, Issue 5, Page 1690-1695

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Estimation of Atmospheric Water Vapor Using MODIS Data 1. (Case Study: Golestan Province of Iran)

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Received 20 Nov 2016,
Revised 10 Jan 2017,
Accepted 15 Jan 2017

Keywords

- Atmospheric Water Vapor,
- MODIS,
- band ratio method,
- Golestan province of Iran.

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Abstract

Atmospheric Water Vapor (AWV) is one of the important parameters in the hydrologic cycle, energy exchange between the surface and the atmosphere, modeling the flow of energy at the ground level and climate change. Thus, the estimation of AWV has a great importance in the hydrology and climate studies. In this paper, the band ratio method was used for estimating AWV content of Golestan province in Iran using Near InfraRed (NIR) Moderate Resolution Imaging Spectro radiometer (MODIS) data. For this purpose, the bands 17, 18 and 19 of MODIS as near-infrared bands and band 2 to remove the ground reflectivity were used. The results showed that the amount of AWV in the forests, range-land, agriculture, barren-land, residential and water bodies, were 3.104, 2.250, 3.791, 1.263, 2.731, 5.247 gr/cm^2 respectively. The lower atmospheric water vapor in the barren lands than other land-uses can be considered as lack of rainfall and high evaporation potential in these areas. The results also revealed that the use of remote sensing and band ratio method is an appropriate method to estimate AWV in a large area.

1. Introduction

Atmospheric water vapor is an important component of the atmosphere that have a significant impact on atmospheric thermodynamic and climatic processes [1] and an important parameter in the global hydrological cycle, global climate change, energy exchange between the earth and atmosphere and modeling the earth's energy flow [2-4]. Since atmospheric water vapor is one of the greenhouse gases components, 10% of global warming is created and Climate sensitivity to greenhouse gas increases has almost doubled, but there are doubts about this symptoms and effect [5]. There are several ways to estimate atmospheric water vapor content. Meteorological and direct method to estimate the amount of water vapor, including the use of radiometer observations and radiometric atmometer [6,7], the measurement of water vapor by scanning microwave Radiation Monitors [8] and in recent years the total precipitable water measurements by GPS [9-12] respectively. These methods are only based on a profile of the surface to be small scales. Synoptic Characteristics of weather stations and point measurements of radiosonde data has limited its
Applications [13,14]. Radiometric atmometer was also very expensive and in addition, does not provide the possibility of full coverage information of 24 hours a day [6]. Using of remote sensing is one of water vapor extraction techniques that are useful in regional and global scales. The total amount of atmospheric water vapor, is an essential factor in some special applications of remote sensing to estimate the land surface temperature, biosphere modeling using vegetation indices of remote sensing and atmospheric correction [15,16]. These methods have been developed in recent years to estimate atmospheric water vapor content [4]. Studies of the total atmospheric water vapor content extraction carried out using sensors such as ASTER, AVHRR and MODIS. There are two main methods to estimate the total atmospheric water vapor content using remote sensing data [17]. The first method is regression-based statistical relationships based on the brightness and temperature of the thermal remote sensing image pixels [18,19]. The second method is the direct use of radiative transfer equation to estimate the total atmospheric water vapor content. Radiative transfer equation is considered the brightness of remote sensing sensor as addition of terms, so the total atmospheric water vapor content is an implicit parameter in them. This method requires having the adequate information about land surface

temperature and surface reflectance / radiation [20,21]. According to the mentioned above, the objective of this study is to estimate total atmospheric water vapor content of Golestan Province using MODIS images and band ratio method.

2. Materials and Methods

2.1 The study area

The study area is located in northeast of Iran (Fig 1). It lies between latitudes 36° 30' to 38° 10' N and the longitudes 53° 50' to 56° 20' E and covers an area of approximately 21400 km^2. Altitude varies from about -40 to 3800 m a.s.l. The climate is temperate with the annual average temperature of 16.88°C and mean annual precipitation of 454 mm.

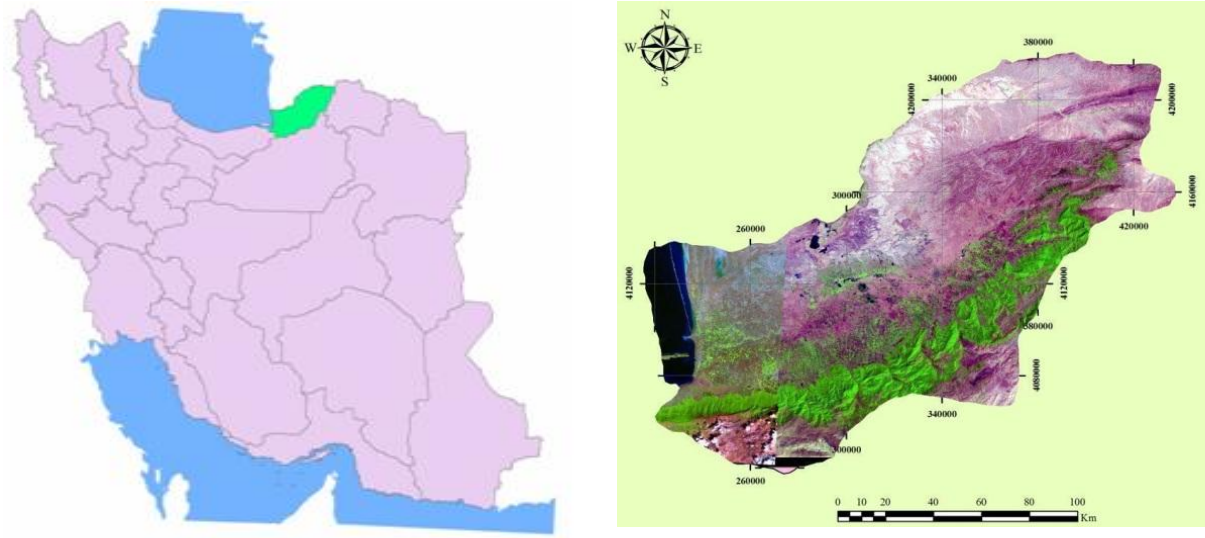

Figure 1: The location of Golestan province in Iran

2.2 Remote Sensing Data

To carry out this research, cloudless satellite images (Clear sky) were used. So after reviewing the available data, the 12 MODIS sensor images on Terra platform for July 2013 were prepared, that their details are shown in Table 1.

Table 1: MODIS sensor data that was used in this study

MOD021KM.A2013191.0700.005.2013191135444	MOD021KM.A2013193.0645.005.2013193140038
MOD021KM.A2013192.0740.005.2013192134807	MOD021KM.A2013194.0730.005.2013194140137
MOD021KM.A2013195.0635.005.2013195135317	MOD021KM.A2013196.0715.005.2013196135030
MOD021KM.A2013197.0620.005.2013197135231	MOD021KM.A2013198.0705.005.2013198135423
MOD021KM.A2013199.0745.005.2013203182014	MOD021KM.A2013200.0650.005.2013200141015
MOD021KM.A2013202.0640.005.2013202135415	MOD021KM.A2013205.0710.005.2013205135145

2.3 Methodology

Statistical regression method was used in this study that uses the band ratio of band 17, 18 and 19 MODIS sensor. Band 2 also was used to remove land cover reflectance that spectral properties of each band are shown in Table 2. This method formerly has been used and validated by Sobrino et al (2003) [22].

Table 2: Spectral characteristics of near-infrared bands of MODIS images that used for atmospheric water vapor extraction algorithms

Band number	(µm)Band center	(µm)Band width
2	0.865	0.04
17	0.905	0.03
18	0.936	0.01
19	0.940	0.05

Water vapor can estimated using the near-infrared band between 0/88 to 0/97 micrometers that in comparison with other insensitive bands to water vapor (0/04 ± 0/865) ,_Most major atmospheric absorption done by water vapor (Frouin et al., 1989). MODIS sensor data based algorithm was proposed by Sobrino et al (2003) to estimate the water vapor content. Bands 17, 18 and 19 are located in the range are sensitive to water vapor and band 2 is located in the range are insensitive to water vapor. The mentioned Algorithm is provided in equations 1 to 3, respectively.

(Eq.1) $$G_{17} = \frac{L_{17}}{L_2},\ G_{18} = \frac{L_{18}}{L_2},\ G_{19} = \frac{L_{19}}{L_2},$$

(Eq.2) $$\begin{aligned} W_{17} &= a_1 + b_1 G_{17} + c_1 G_{17}^2 \\ W_{18} &= a_2 + b_2 G_{18} + c_2 G_{18}^2 \\ W_{19} &= a_3 + b_3 G_{19} + c_3 G_{97}^2 \end{aligned}$$

(Eq.3) $$WV = f_{17}W_{17} + f_{18}W_{18} + f_{19}W_{19}$$

Where: Lj Radiance of band j MODIS sensor and fj is the weight of each band. Coefficient a1 ... a3, b1 ... b3 and c1 ... c3 factors are derived from regression. WV is water vapor content. Although the bands sensitivity to atmospheric water vapor greatly reduced in dry or wet conditions due to the saturation [22].

Table 3: Band ratio method Coefficients by using three bands 17, 18 and 19

Coefficient	a_1	b_1	c_1	a_2	b_2	c_2	a_3	b_3	c_3
Amount	26.314	54.434-	28.449	5.012	23.017-	27.884	9.446	26.887-	19.914

Fj weight values in the above equation, based on the sensitivity to water vapor transmission in band j changed according to the equation 4:

(Eq.4) $$f_j = \frac{|\Delta\tau_j|}{\sum|\Delta\tau_j|}$$

Where: Δτj differences between the maximum and minimum possible transfer of water vapor content. In this study, the water vapor content was considered between 0.092 and 5.4. Portability was calculated using MODTRAN 4.5. Then f_i values were determined in three different band combination (bands of 17, 18 and 19) and just combine the two bands 18 and 19. In Tables 4 and 5, the results of all weights are presented. As can be seen in the tables, Band 18 has a more participation in estimating water vapor based on the used algorithm.

Table 4: The weights of water vapor estimation based on bands 17, 18 and 19

	Full range (0.092 to 5.4) gr/cm^3	Dry (0 to 2) gr/cm^3	Wet (2 to 5.5) gr/cm^3
f 17	0.141	0.1	0.31
f 18	0.444	0.6	0.25
f 19	0.415	0.3	0.44

Table 5: The weights of water vapor estimation based on bands 18 and 19

	Full range (0.092 to 5.4) gr/cm^3	Dry (0 to 2) gr/cm^3	Wet (2 to 5.5) gr/cm^3
f 18	0.517	0.67	0.36
f 19	0.483	0.33	0.64

3. Results

Distribution of atmospheric water vapor content (Figure 2) and the mean value of water vapor have been shown (Table 6). As indicated, the maximum amount of atmospheric water vapor is in water bodies and the lowest amount is in barren lands. Figure 6 shows that ignoring the water bodies, the total atmospheric water vapor

content in areas with more vegetation is higher than other areas and by reducing the amount of vegetation coverage, the amount of water vapor is reduced.
The maximum amount of atmospheric water vapor is 6.45 gr/cm^2 and the minimum amount is 0 gr/cm^2 in 2013. Atmospheric water vapor in the northern, central and western regions of study area is higher that other regions. The lowest amount was observed in the barren lands of southern regions of Golestan province. The maximum atmospheric water vapor was observed in water bodies and agricultural land (5.247 and 3.791 gr/cm^2) and minimum amount in barren land (1.263 gr/cm^2).

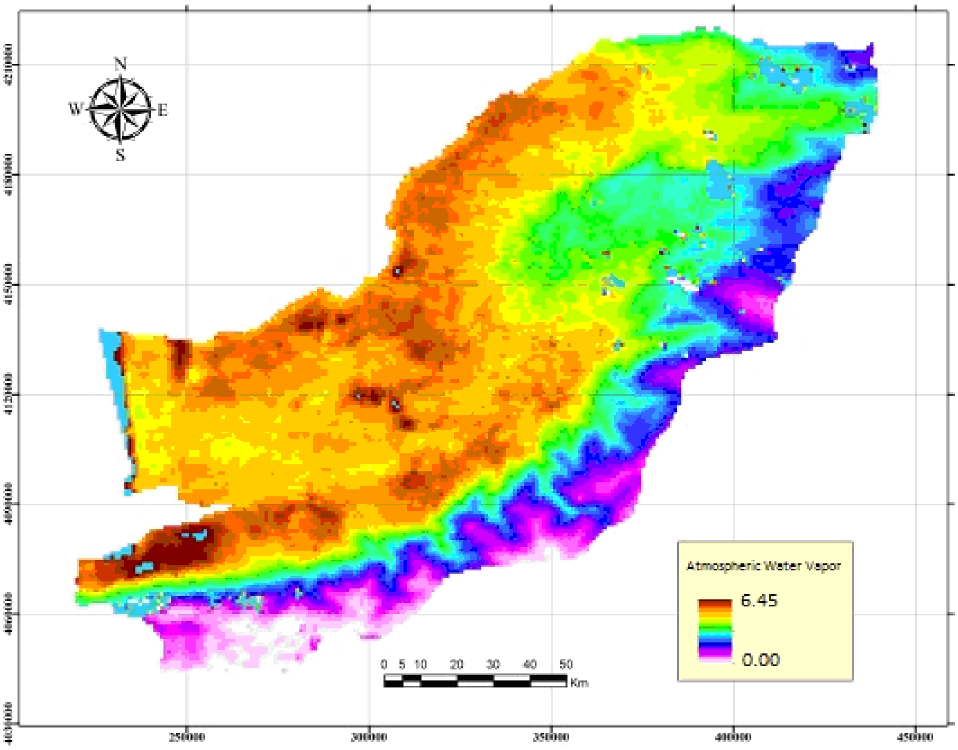

Figure 2: Spatial distribution of atmospheric water vapor of Golestan province, Iran in July 2013

Table6: atmospheric water vapor content in main land-uses of Golestan province in July 2013

Land-use	Atmospheric water vapor (gr/cm^2)			
	Minimum	maximum	Mean	standard deviation
water body	2.471	6.453	5.247	0.183
residential	0.070	3.814	2.731	0.061
Range-land	0.718	3.109	2.250	0.321
forest	1.015	4.085	3.104	0.132
barren-land	0.000	1.762	1.263	0.189
agriculture	1.283	4.681	3.791	0.408

4. Discussion

The results showed that the amount of water vapor can be extracted using the band ratio of MODIS sensor images. The results of validation using ground-based data and MODTRAN simulation by some researchers [22, 23] showed 0.06 to 0.17 gr/cm^2 for a standard deviation of this method. They also reported that the amount of bias to this method is 0.1gr/cm^2. Some studies [24] also demonstrated an immutable property of this method and considered error ratio of this method approximately was 9%. In using this method to estimate water vapor, we should bear in mind that in wet weather conditions if we remove the band 17, the accuracy of this model will reduce. This is probably due to the saturation of band 18 in wet conditions [24].
Because of the great distance between weather stations (approximately 60 km), the only method to extraction of atmospheric water vapor in areas without weather stations, is using interpolation. Water vapor extraction accuracy through interpolation is almost 25% with standard error 0.93 gr/kg [25], that this shows the benefits, accuracy and utility of band ratio method to estimate the appropriate polynomial coefficients and atmospheric water vapor extraction [25].

In this study total atmospheric water vapor content in Golestan province was extracted. The maximum amount of atmospheric water vapor was in the water bodies and the minimum amount was in barren lands. The total atmospheric water vapor content in areas with more vegetation higher than other areas and by reducing the amount of vegetation coverage, the amount of water vapor is reduced. The low amount of water vapor in barren land than other land-uses, probably due to the lack of rainfall and high evaporation potential in these areas [26]. Therefore, it should be noted that atmospheric water vapor extraction by this method is reliable and can be used in other studies. But due to the absence of actual measurements, validation was not performed and the results just show a distribution of water vapor in the study area. In this regard, some researchers [14] believed that because ground stations are use point measurements to estimate water vapor, So intrinsically are different with remote sensing measurements. Synoptically characteristics and spatial distribution of synoptic stations restricted their use to validate the results of remote sensing assessments. Comparison the estimations of various remote sensing sensors is the most appropriate validation techniques that provides a temporal variations of water vapor and in recent years has been considered. Due to inaccessibility to actual measurements some researchers [26] also did not validate the results of extracting water vapor. They believed that using this algorithm can provide an appropriate method for estimating water vapor using remote sensing techniques.

Analysis of the extracted water vapor content also can be show the reliability of water vapor estimation by this method. However, they believed that to appropriate validation of extracted water vapor further studies should be done on radiosonde observations; because further validation is necessary to increase the accuracy and quality of research [26].

Also it should be noted that because in this study we used 1 kilometer resolution pixels of MODIS sensors, the results cannot be compared with ground data's, because accuracy in meteorological purposes for selected ground stations not as a single pixel.

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