Modeling Snow Cover Area and Predicting Its Changes in Haraz Catchment

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***Abstract*—Changes in climate and hydrological parameters have extensive effects on ecological, economic, and social systems. Amongst, snow reservoirs from mountainous watersheds are considered as important water resources which supply significant amount of usable water for human. In addition, sow covered area has significant role in earth energy balance. The purpose of the present research is investigation and monitoring snow covered area of Haraz catchment and predicting this parameter changes in future. Therefore, MODIS measuring instrument was used in 2000-2013 and snow area map was extracted. Results showed reduction in snow covered area in all studying months except April and it had significant increase in April. In the next step, changes in snow covered area were predicted using ARIMA time series model then model performance was evaluated using error measurement criterions. Obtained results from prediction of snow covered area shows that snow covered area will decrease in future (2015-2025) than its basic period (2000-2013) and 20% increase in snow cover area is seen in April. Comparing to changes in basic period, January and February will be months with the highest changes.**

Keywords— Snow Cover Area, MODIS, Times series model, ARIMA.

I. INTRODUCTION

By supplying 75 percent of the world's fresh water, snow reservoirs in the mountains play an important role in the hydrological cycles and are one of the essential components of climate system [1]. Hydrological, ecological and climatic importance of snow cover area (SCA) is because of its performance in energy storage, high reflectivity, insulating properties of the ground surface, significant heat capacity, and water storage and its release during the melting seasons [2, 3]. Runoff resulted from snow melting due to the dilatory role is categorized among the main sources of aquifers' charging and in some cases due to the simultaneity with spring rainfall is the origin of destructive floods with the flow volume more than the capacity of rivers [4]. Moreover, in preventing soil erosion and its protection, the snow cover area is an effective factor [5]. Since mid-twentieth century, the expanse of snow cover in Northern Hemisphere has decreased by about 10% [6]. There are many different factors that affect snow cover and make it to be melt that some of them are as follows: reducing in snowfall, increasing rainfall rate than snow, air temperature, the exchange of long wave radiations of accumulated snow with the surroundings, the final heat of vaporization resulted from distillation, the exchange of land heat, and so on [6, 7]. If the study and evaluation of snow cover changes would be carried out with respect to the spatial and temporal dimensions, it would be led to a more accurate conclusion. In terms of spatial changes of snow cover, it should be said that the effect of hot weather differs for different altitudinal belts, which changes in the environment conditions causes the spatial sequence of snow expanse in the mountain to be changed and be appeared at different altitudinal levels. In addition to these mountainous areas, seasonal trends and melting time of snow is a key factor for understanding of the dynamics of river flow at highland areas, hillsides and downstream [8]. Situating of Iran in arid and semi-arid belt of the world, and also the snowy highlands in the vicinity of dry lands in Iran, make it necessary to monitor past changes in the basins of the snowy mountain and predict the future changes.

In recent years, one of the methods to predict the climatic and hydrological parameters which have attracted the attention of researchers is the modeling of time-series [9]. A time-series apply for a set of observations with the recorded values of a parameter that are classified in terms of time (or any other dimension). The aim of a time-series analysis is to determine the legitimacy and recognition of its behavior to predict in the future [10]. Indeed, the performance of this method is based on past behavior of that series and understanding of random changes in it [11]. The analysis of a time-series requires comprehensive and integrated information about the studied variables. So we need alternative and continuous values for prediction and modeling of snow cover area. Achieving the information related to snow in the highlands is only possible through continuous imaging with the help of remote sensing technology because the observed information of the ground snow is little and usually is limited to areas with low altitude and achieving to it at one time through ground methods is difficult and costly [7]. After four decades, remote sensing technology has provided a resource for main information needed to monitor the changes in the cryosphere [6]. Remote sensing has many unique advantages such as simultaneous images at several different wavelengths, repeating images, vast coverage, and possibility of using from computer techniques to interpret the information [12].

II. Background

The rainfall trend in West of India predicted and analyzed using ARIMA model in Narayanan et al (2013) study. The results illustrate a satisfactory performance for ARIMA model [11]. Valipour et al (2013) predicted the input flow to the reservoir of Dez Dam using ARIMA model. By comparing artificial neural networks and ARIMA model, they also concluded that ARIMA model had less error in the prediction [13]. In another study, Dedíue et al (2014) used remote sensing methods and reflective images of MOD09 and the product of snow cover of MOD10 sensors MODIS, and prepared the snow cover maps of a ten-year period (2000-2010) for two different study area where are located in Central Asia and Europe. Their results showed that reducing in the snow cover area at the highlands of central Europe (1500 meters) and in Central Asia at higher altitudes (3000 meters) has further been observed [8]. Khadka et al (2014) using multi parameters regression method and using the relationship between temperature and precipitation and snow cover area in the past and future, predicted the snow cover area. The results of this prediction is indicative of sensitivity and intense changes in snow cover area in winter and spring rather than other seasons [1]. Veisipour et al (2010) analyzed and predicted the trend of the precipitation and temperature in Kermanshah using ARIMA time-series model. Their results showed that in the future the maximum temperature will increase and the precipitation will have a decreasing trend [14]. Vafakhah et al (2011) compared the snow cover area derived from MODIS and NOAA satellite images in Taleghan watershed. The results of this study showed that the estimation error of snow cover area of NOAA images is 57.97% than the MODIS sensor [15]. Ebrahimi (2011) in a research with using MODIS snow cover in a ten years period (2001-2010) determined the areas where are covered with snow in Iran. The results of this study showed that in snow in some months has increased and decreased in others [16].

According to the background, despite the importance of the prediction of changes in snow cover area in the watersheds, very limited studies have been done in this field. It has been tried in this research to answer the following two questions: How was the temporal and spatial changes in snow cover area in Haraz watershed during the years of 2000-2013? How will be the trend of these changes in the future? For this purpose, first with using MODIS sensor images the snow maps of these zones have been prepared and snow cover area were extracted from them and were used as input data for ARIMA time-series model to predict the snow cover area in the future.

III. Study Area

Haraz catchment is located in $51^\circ 56'$ to $52^\circ 36'$ of the east longitude and $35^\circ 45'$ to $36^\circ 22'$ of the north latitude. This basin is located in the southern region of Mazandaran Province and in term of the political division is a part of Amol County. The catchment area is 231,400 hectares. The minimum altitude of the basin is about 700 m and the maximum altitude is 5610 meters. All rivers of the basin will end in River Haraz. Main rivers of the basin includes rivers Aachen sar, Shirkolarverd, Namarestagh. Important mountains of the basin are Mount Damavand, the highest area in the catchment area. The climate of the catchment based on Ambrish method ranges from semi-humid at slopes to semi-arid at mountains. The minimum precipitation occurred in the months of August and September and the maximum precipitation occurred in February and March. The coldest month is January and the warmest month is July [17].

IV. Materials and Methods

First, the snow maps were prepared in order to predict the changes in snow cover area in the Haraz watershed. The used satellite data were including the images of MOD09 and MOD10A2 of sensor MODIS of TERRA satellite. This data has the spatial resolution of 500 meters per day. The timeframe of the selected images is from January 2000 to December 2013. Spectral, spatial and temporal resolution of MODIS sensor has made it be one of the best optical sensors for the study of snow and separating of snow from some phenomena such as clouds that have similar spectral behavior like snow [12]. The initial images from MODIS satellite have sinusoidal coordinates system. In this research through MODIS conversion tool (MCTK), which was added to ENVI software, coordinates system of these images with using the nearest neighbor method was converted to UTM. The format of output files also was changed from HDF to geotif. Hitherto, various methods have been used to measure snow cover area through remote sensing which some of these methods are as follows: supervised and unsupervised classification [18], spectrum hybrid analysis [19], normal differential index of Landsat satellite and MODIS [20], and the linear models of snow cover reflection [21]. The algorithm of snow map of MODIS, known as Snow Map Algorithm, is a base decision type algorithm using group tests of thresholds. In this algorithm, the normalized difference snow index (NDSI) is used. NDSI is used as a criterion for separating snow from the ground surface and segregating of snow from clouds. The snow has high reflectance in the visible wavelength region and has a strong absorption in short wavelength infrared. This feature is used to differentiate snow from other surfaces. For calculation of NDSI, the reflection of band 4 with wavelength of 0.545 to 0.565 μm in the visible spectral range is used, and band 6 with wavelength of 1.628 to 1.652 μm in the range of infrared spectral in the MODIS images is used. This index is defined by Equation (1) [22]:

$$NDSI = \frac{Band\,4 - Band\,6}{Band\,4 + Band\,6}$$

According to the Snow Map algorithm, if the reflection rate of band 2 is more than 11 percent, we can accept the results of NDSI index. Also the reflection of 10% in the band 4 is known as low limit of the segregation of plant cover from snow. The feature of reflection in band 4 helps for separating snow from water that has similar NDSI values. Snow pixels in the forest areas with the help of normalized difference index of plant cover can be identified. This means that even if a pixel has a NDSI less than 0.4, if its NDVI is approximately equal to 0.1, that pixel classifies as snow [23]. Finally, the prepared snow map has binary format and follows Boolean logic that in this model, the entire image is classified into two zones of snow and without snow width. In the next step, areas of the snowy zones were calculated as monthly averages. Then ARIMA time-series model was used to predict the changes in snow cover area.

Time-series models are as follows: the Stochastic Auto Regressive model, Moving Average model, Auto Regressive Moving Average model that combines the two previous models and Auto Regressive Integrated Moving Average (ARIMA) model. One of the important methods to determine the best model for a time-series is the investigation of Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) changes in different time delays [24]. In this study, first ACF and PACF graphs were plotted and ARIMA model was determined as the best statistical model for the analysis of time-series of snow cover area. Since the static process should be established for the use of time-series model, Box and Jenkinks in 1994, presented ARIMA model for non-static conditions. Static condition can be briefly defined as the fixed average, variance and other statistical parameters. ARIMA model that can be used for simulating, producing the information, and predicting, is a parametric linear stochastic model. For modeling time-series, ARIMA model is shown as ARIMA(p,d,q)(P,D,Q)ω and defined as follows [13]:

$$\left(1-\Phi_1 B^{\omega}-\ldots-\Phi_p B^{P\omega}\right)\left(1-\varphi_1 B-\ldots-\varphi_p B^{P}\right)\left(1-B^{\omega}\right)^{D}\left(1-\mathrm{B}\right)^{d} Z_t$$
$$=\left(1-\Theta_1 B^{\omega}-\ldots-\Theta_Q B^{Q\omega}\right)\left(1-\theta_1 B-\ldots-\theta_q B^{q}\right)\varepsilon_t$$

In the above equation, ω is the frequency period, auto regressive orders, differencing and seasonal moving average of P, D and Q and non-seasonal of p, d and q. B is the backward operator, Zt the parameter value at time t, θ moving average non-seasonal model, φ non-seasonal auto regressive parameter, Θ seasonal moving average model, Φ seasonal auto regressive parameter and εt is random variable. The first step in modeling a time-series is plotting the data chart in terms of time. Non-static at variance, being seasonal or not, and identifying outlier data can be identified by the chart of time-series. To analyze the time-series, investigation of the adherence of the data from normal distribution is essential. Next step is the determination of non-randomness of the data. One of the methods to determine these characteristics is sequence test. Next step is the determination of the number of ARIMA model parameters that is done by plotting the charts of ACF and PACF [25]. Checking auto correlation functions and partial auto correlation functions shows the necessity of the presence of auto regressive and seasonal moving average components in modeling. q order is determined from ACF graphs and p order is determined from PACF graphs. d is also the order of differencing. Making series differential means the removal of the process. Mann-Kendall test [26 and 27], can be used to assess the necessity of differencing. If the null hypothesis, based on that there is no trend in the studied time-series, is not rejected, non-seasonal differencing is not necessary. Among several fitted models based on ACF and PACF, the most appropriate model can be detected using Akaike Information Criterion (AIC). Among the different models, the model is more appropriate that has less AIC. The last step is the goodness test of fitting the selected model and the fitness of the model should be checked. One of these methods is the analysis of the remains. By plotting the charts of ACF and PACF, if these charts do not show a certain trend and do not exceed their limits, is indicative of the independence and static of the remains [25].

For evaluating the performance of Model performance indicators, mean absolute error (MAE) and root mean square error (RMSE) are used. Coefficient of determination is a dimensionless measure of which the best value is one. The model mean error and root mean square error represent the model error rate of which the best value is equal to zero [28].

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n}\left|X_i - Y_i\right|}{n}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{n=1}^{n}\left(X_i - Y_i\right)^2}{n}}$$

In the above equations X_i and Y_i are i-th observation and simulated data by the model, respectively. x_μ and y_μ are the average of all data of X_i and Y_i in the study population and n is the number of all samples to be tested.

V. Results and Discussion

Figure 1 shows the results of processing the images of MODIS satellite and applying Snow map algorithm to investigate the temporal and spatial changes in snow cover area in Haraz watershed. Using data of 30 m Landsat satellite as a ground accuracy map, the resolution of MODIS images were evaluated. To evaluate and compare the two above images, their synchronization is necessary. After assessment and evaluation of the two images, kappa coefficient obtained 0.7, which is indicative of the accuracy of MODIS image to determine the snow cover area in Haraz watershed. Due to the large number of Maps, only some snow zones on a monthly basis are shown in Figure 1.

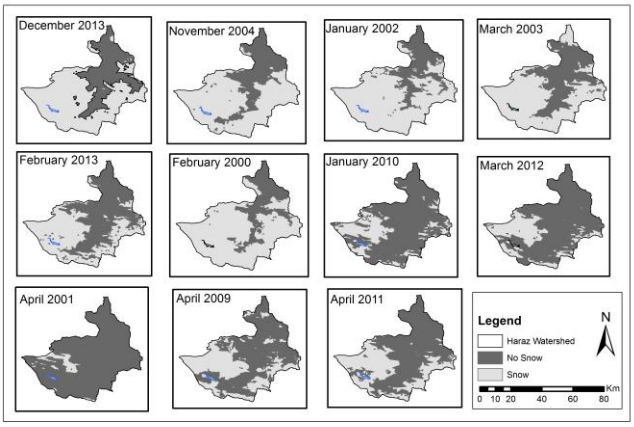

Fig. 1 Snow cover in the basin

Figure 2 shows the average annual snow cover in Haraz watershed. As it could be seen, snow cover area is without increasing or decreasing trend between the years of 2000 and 2013.

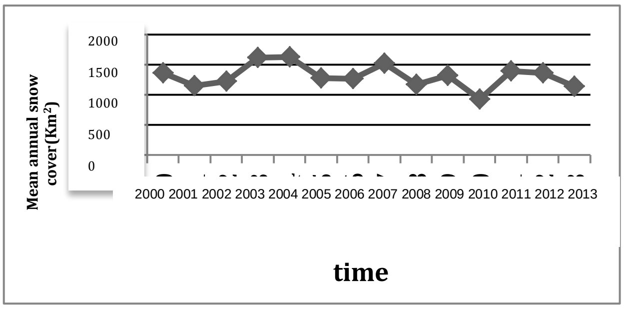

Fig. 2 The average annual snow cover in the catchment between 2000 and 2013

Table 1 shows the percentage of changes in snow cover area in the region as monthly between the years of 2000 and 2013. The results showed that snow cover area has decreased in all months except in April, when an increase of 36 percent in snow cover area was observed. Since the percentage of changes in months of June to October was so negligible, they are not showed in the table below.

Table 1.Percentage changes in snow cover in the catchment between 2000 and 2013

month	Jan	Feb	Mar	Apr	May	Nov	Dec
Percentage changes	-12.09	-19.58	-29.54	36	-15.22	-4	-3.65
Area (Km^2)	233.86	372.52	472.3	199.8	37.88	53	65.79

Figure 3 shows the monthly average of snow cover area in the watershed. As it can be seen, the greatest area of snow in the area is related to the months of December, January and February, and the lowest area was in the summer months when in these months the snow cover area is observed on Mount Damavand and snowy factor is almost zero below an altitude of 4000 meters.

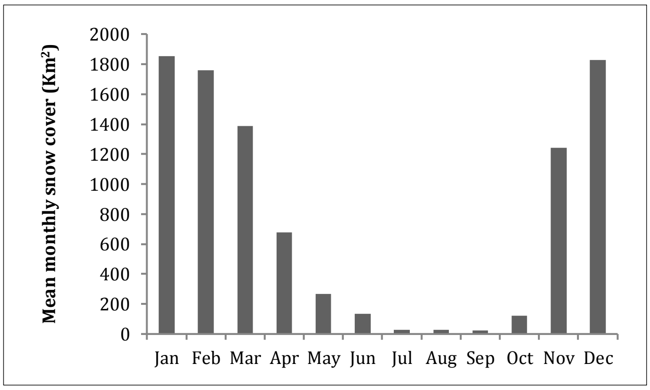

Fig. 3 Mean monthly snow cover between 2000 and 2013

As mentioned before, the first step in analysis of time-series is to check the normality and non-randomness of the data. The p-value was calculated zero from the sequence test, which represents the non-randomness of the series. The statistic of Mann-Kendall test is 0.27 and with respect to Figure 4, the null hypothesis based on that there is not significant trend in examined time-series at the level of five percent is not rejected and therefore differencing is not necessary. But in order to ensure from the removal of seasonal behavior in time-series, differencing is done once. This series is also static in terms of variance and conversions of variance stability are not needed.

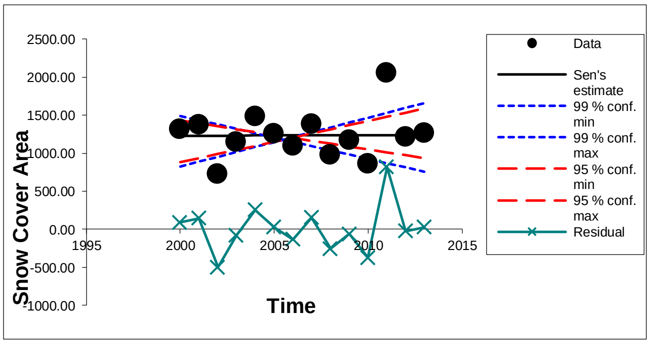

Fig. 4 No trend graph of snow time series by using Mann-Kendall

The result of the best fitted model is presented in Table 2. The best model is the one which has the lowest AIC among the fitted models and is used to predict the snow cover area. Then, using the criteria of error measurement including the coefficient of determination, absolute error mean and root mean square error, which are presented in Table 2, the performance of the model was evaluated. After selecting the superior model, the goodness test of the remains of fitted model to ensure from selecting the model, was plotted and the assumption of normality of the remains is approved.

Table 2. ARIMA model performance evaluation criteria

ARIMA	AIC	Criteria for Performance Evaluation Model	
		MAE	RMSE
(3,1,3)	2246.125	0.503	0.878

Based on the results shown in the above table, ARIMA (3,1,3) model has an appropriate performance for predicting data of snow cover area. The results of this prediction are presented in Figure 5. The lowest percentage of changes is observed in November and December and the greatest is observed in late winter and early spring.

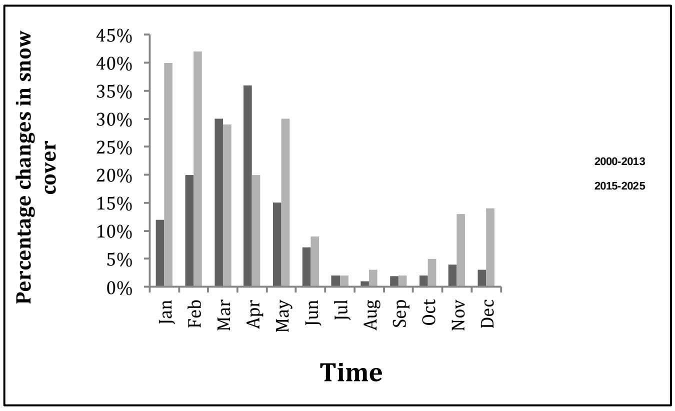

Fig. 5 Changes of snow cover in the study area

VI. Conclusion

The significance of climatic studies in Haraz watershed mainly due to the location of Mount Damavand and its proximity to metropolis of Tehran which puts it as backup of this metropolis, compared to other places is very important. Due to lack of meteorological stations and lack of proper distribution of them in highlands, the snow cover area is one of the most appropriate parameters to evaluate climatic and hydrological changes. Investigating the spatial changes of snow cover area, together with the temporal investigations would be resulted in a fairly comprehensive view of climatic changes in the region. Snow cover area due to its function in storage and releasing water, insulating the ground surface due to significant heat capacity, preventing from soil erosion and its protection, and generally because of its hydrological, ecological and climatic importance, is an important factor in climate studies. In this regard, the method of modeling time-series and consequently the use of appropriate satellite images as input data to this model, is one of the methods for predicting climatic and hydrological parameters which also has a significant efficiency about the snow cover area.

Snow survey results shows that in all studied months, except for the month of April, the snow cover area has decreased from 2000 to 2013 and a significant increase can be seen in April. The results of this study is in accordance with the results of Ebrahimi (2011), that was conducted to determine the changes of snow cover area in the whole country, so it confirms the results of the research. The results from the prediction of snow cover area also show that the snow cover area will be reduced in the future years as compared to the base period and only an increase of 20 percent in snow cover area is observed in April. Compared to the changes of base period, the months of January and February will have the most dramatic changes.

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