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Performance Analysis of Different Threshold Determination Techniques for Change Vector Analysis

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Abstract :Change vector analysis as change detection technique is an effective tool for extracting and identifying land-cover change information from satellite imagery data. Threshold determination is one of most critical task in change vector analysis (CVA) which distinguishes "change" pixels and "no-change" pixels. Many threshold determination techniques for CVA such as empirical strategies, manual trial-and-error procedures or double-window flexible pace search (DFPS) semi-automatic, have been developed since last two decades. But the selection of appropriate threshold determination technique for specific study area is a very important and difficult process because overall accuracy of CVA depends upon threshold value. In this paper, different threshold determination techniques such as empirical strategies, manual trial-and-error procedures and DFPS, have been implemented to evaluate a method for CVA which could more effectively distinguishes the "change" pixels and "no-change" pixels on snow cover area. Experimental results confirm that a semiautomatic DFPS has greater potential than trail-and-error and empirical procedure to determine the specific threshold value for CVA technique that minimizes the overall change detection error probability and maximizes the overall accuracy.

Keywords: Change vector analysis (CVA), Threshold determination, Double-window flexible pace search (DFPS).

INTRODUCTION

The detection of environmental changes is one of the major applications of remote sensing. The change detection is a process of extracting "change" or "no-change" pixels from digital data acquired by satellite. The choice of the satellite sensor spectral bands depends on the specific type of change to be detected such as water, vegetation or snow cover. For change detection analysis of snow cover area, an analogous concept applied is the widely used change vector analysis (CVA) technique. The interest in change vector analysis as a change detection technique has increased in last decade (Malila, 1980; Merril and Jiajun, 1998; Johnson and Kasischke, 1998; Chen et al., 2003; Chen et al., 2011) because of its wider application.

The change vector analysis (CVA) method has already proved to be very effective tool in change dynamics of land-use/land-cover research (Brovolo and Bruzzone, 2007; Kontoes, 2008). The CVA characterizes the change in spectral space over different time instances in terms of magnitude and direction (Johnson and Kasischke, 1998; Brovolo and Bruzzone, 2007). The former CVA method (Malila, 1980) can be applied on single band only which latterly extended up to multiple bands (Nackaerts et al., 2005). The threshold determination performs central task in CVA to evaluate a specific threshold value. Many of the change detection methods require threshold value to separate "change" and "no-change" pixels (Fung and Ledrew, 1998). It is very important to calculate accurate threshold value otherwise results may be incorrect since overall accuracy of CVA depends upon threshold value.

Presently, threshold determination techniques for CVA based on use of empirical values (Allen and Kupfer, 2000), interactive trial-and-error procedures (Fung and Ledrew, 1998) and semi-automated approach (Chen et al., 2003). The trial-and-error method interactively adjusts the threshold value until it achieves satisfying results. On the other hand, empirical technique based on the estimation of threshold value by direct observation of image analyst and it must be noticed that the accuracy of empirical technique greatly varies with analyst skills. The double-window flexible pace search (DFPS) (Chen et al., 2003) technique iteratively select the threshold value until maximum accuracy is achieved. All threshold determination techniques are the most extensively applied to generate binary change image which defines the "change" and "no-change" information even though disadvantages are there in selecting a specific threshold value (Lu and Weng, 2004). In this paper, empirical strategies, trial-and-error procedures and semi-automatic DFPS, have been implemented as threshold determination techniques to evaluate a method for CVA which could more effectively distinguishes the "change" pixels and "no-change" pixels.

In order to assess the effectiveness of threshold determination techniques, all techniques were implemented on the same study area. CVA as change detection technique applied on multi-temporal data set which composed of multispectral band images. This paper is divided into six major sections. Following an introduction, description of study area and required preprocessing steps are described in section two. Third section involves a brief introduction to CVA as change detection method. All the threshold determination techniques are presented in the fourth section, followed by the results and discussion of previous studies on different threshold determination techniques for CVA in fifth section. At the end general conclusions are drawn.

PRE-PROCESSING OF STUDY AREA

The study area is a part of western Himalaya (India) acquired by MODIS (Moderate Resolution Imaging Spectroradiometer) sensor satellite, lies between latitude of 32.20 degree to 32.65 degree north and longitude of 76.90 degree to 77.21 degree east. Two MODIS multi-temporal images (6th of November, 2010 and 8th of February, 2011) have been used in this work (Fig.1). In MODIS imagery preprocessing (Mishra et al., 2009), all imageries were geometrically corrected with respect to Digital Elevation Model (DEM) using 25 Ground Control Points (GCPs) to relocate pixel values of image dataset in a common geographic coordinate system. This process displays the images with the correct scaling and orientation when viewed in conjunction with other GIS data, such as a DEM. A first order polynomial transformation has been used to maintain the Root Mean Square Error (RMSE) less than one (Mather 2004). The RMSE represents a measure of the accuracy of GCPs points in the dataset. The Nearest Neighbor (NN) method has been selected for resampling the satellite imagery. In NN, each incorporated pixel allocated to the value of the nearest distance point in the input imagery. It occupies less space and fast to compute the process. This step reduces arbitrary and residual distortion which results a 'map-coordinated' dataset. The MODIS reflectance R_λ image under lambertain assumption computed using Equation 1 (Song et al., 2001; Pandya et al., 2002):

$$R_\lambda = \frac{\pi(L_{sat\lambda} - L_p)d^2}{(E_0 \cos\theta_z + E_d)} \quad (1)$$

E_0 and $L_{sat\lambda}$ represents the exo-atmospheric spectral irradiance and sensor radiance of MODIS, respectively (Mishra et al., 2009). θ_z is the solar zenith angle and calculated for each pixel (Kasten, 1962), d is the earth – sun distance in astronomical units (Van der Meer, 1996), E_d is

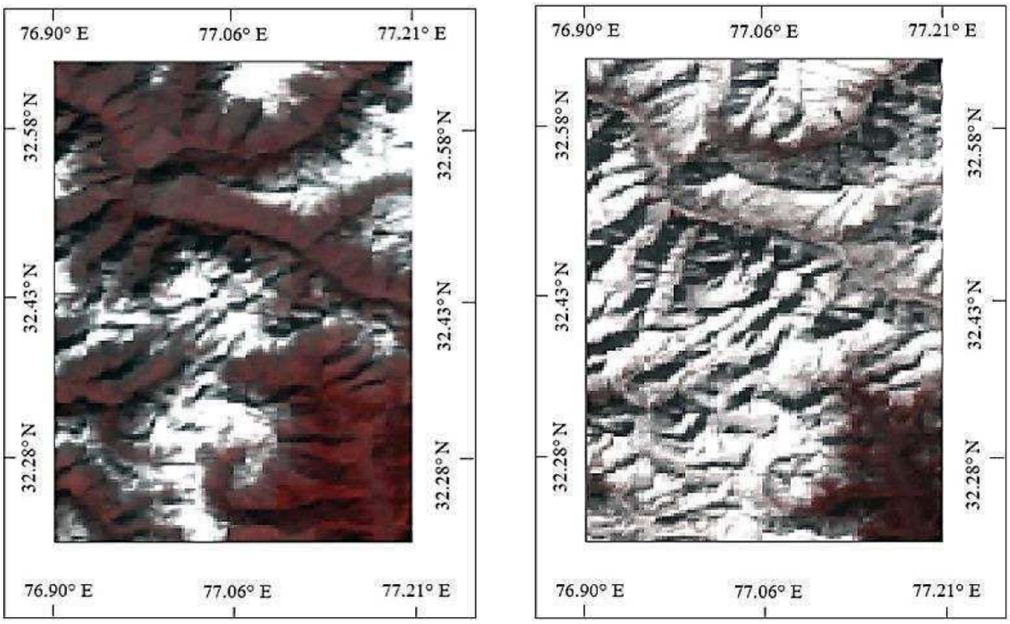

Fig.1. MODIS sensor satellite data imagery of study area. (a) 06th November 2010 and (b) 08th February 2011.

the downwelling diffused radiation and assumed zero (Chavez, 1989). L_p is the path radiance (Chavez, 1989; Chavez, 1996).

CHANGE VECTOR ANALYSIS (CVA) AS CHANGE DETECTION TECHNIQUE

Change vector analysis (CVA) is a change detection tool that identifies changes in terms of magnitude and direction of satellite imagery acquired on different time instances (Malila, 1980; Brovolo and Bruzzone, 2007). Various features and potentials of CVA have been discussed in some case studies (Michalek et al., 1993; Lambin and Strahler, 1994a; Lambin and Strahler, 1994b; Sohl, 1999). In this paper, CVA as change detection technique implemented in order to identify the best suitable threshold determination technique among empirical, trail-and-error and DFPS techniques. The change vector magnitude imagery is calculated according to Euclidian distance in Equation 2 (Malila, 1980; Chen et al., 2003).

$$|\Delta C| = \sqrt{(x_1 - y_1)^2 + \cdots + (x_n - y_n)^2} \quad (2)$$

ΔC includes the change information between the two multi-temporal images acquired on time T_1 (6th of November, 2010) and time T_2 (8th of February, 2011) for a given pixel by $X = (x_1, x_2, ... x_n)^{T_1}$ and $Y = (y_1, y_2, ... y_n)^{T_2}$, respectively and n is the number of bands in satellite imagery. The change magnitude image has shown in Fig.2 which calculated from Equation 2.

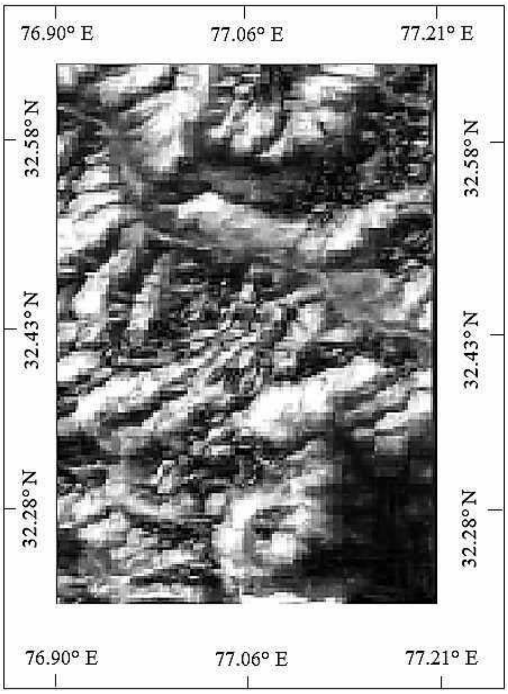

Fig.2. Change magnitude image

THRESHOLD DETERMINATION TECHNIQUES

The separation of "change" pixels and "no-change" pixels made by a specific threshold value. It performs the function of the direction of change (Malila, 1980). The selection of threshold value is most important task in change detection analysis because overall accuracy of change detection depends upon threshold value. Different threshold determination methods have been developed (Chen et al., 2003; Fung and Ledrew, 1998; Allen and Kupfer, 2000) but they required to be tested in the same study area. Hence different threshold determination techniques such as trial-and-error (Fung and Ledrew, 1998), empirical assumption (Allen and Kupfer, 2000) and DFPS (Chen et al., 2003) have been implemented on change magnitude image (Fig.2).

Trial-and-Error Technique

To calculate specific threshold value (T), the trial-and-error technique (Fung and Ledrew, 1998) requires two parameters the mean (M) and standard deviation (S) which can easily computed from change magnitude image of CVA (Fig.2). A variable parameter named as step size (N) which used to calculate maximum change information from change magnitude image. The trial-and-error procedure applied on change magnitude training sample according to Equation 3.

$$T = M + N \times S \quad (3)$$

At each step size, the obtained threshold value used to generate a binary image that separates "change" and "no-change" pixels. The selected suitable threshold value from the training sample applied on the entire change magnitude image to obtain binary image. In Fig.3, binary image generated through trial-and-error technique represents the "change" pixels in white color and "no-change" pixels in black color. This task identifies overall land cover change whose accuracy depends upon the threshold value.

Empirical Technique

The empirical technique for threshold determination based on predictively selecting the threshold value by direct observation of image analyst (Allen and Kupfer, 2000). Empirical technique is straightforward to compute and can be easily applied over large area. The only problem associated with this method is that its overall accuracy depends on analyst experience and varies from person to person. In this paper, training sample has been taken which covered all types of "change" exists in study area. When a

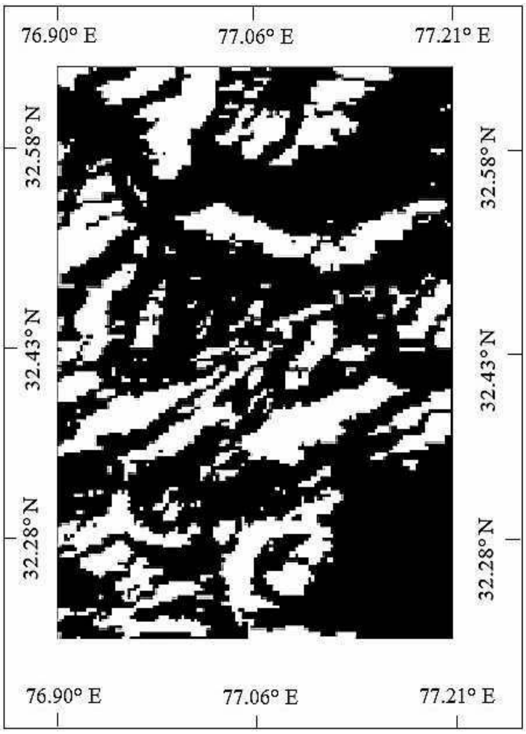

Fig.3. Binary image generated with Trial-and-Error technique

particular threshold value achieved, then it applied on entire change magnitude image to generate binary image. In Fig.4, binary image generated empirically represents the "change" pixels in white color and "no-change" pixels in black color.

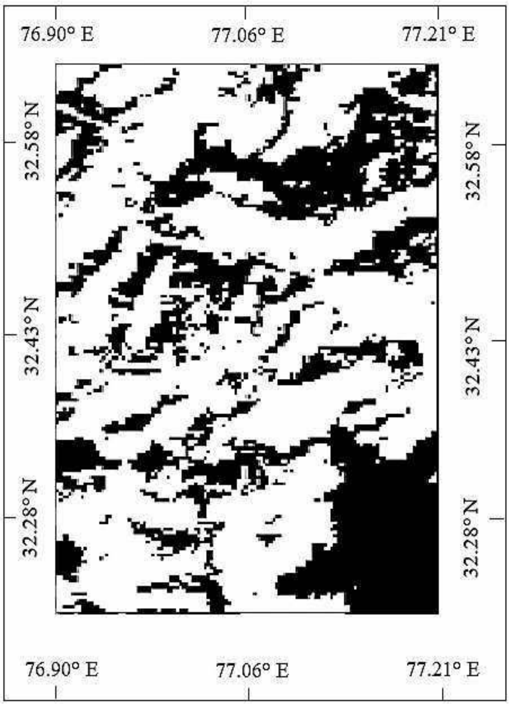

Fig.4. Binary image generated with Empirical technique

Double-window Flexible Pace Search (DFPS) Technique

The two methods discussed involves manual selection of threshold value. A semiautomatic method, called double-window flexible pace search (DFPS) proposed in (Chen et al., 2003) based on selecting a threshold from training samples which contains all possible kind of changes. The training samples must be covered for all type of changes and include only change type information. In this technique, inner and outer boundary is computed through training sample (Fig.5a). The inner boundary (Fig.5b) represents an area of interest to find the change information and outer boundary (Fig.5c) used to prevent the threshold from being too low.

In DFPS, semi-automatic process performed by the success rate criteria (Chen et al., 2003). Success rate (S_r) identifies best optimal threshold value for CVA change magnitude imagery according to Equation 4.

$$S_r = \frac{(I_c - O_c)}{I_t}\% \tag{4}$$

In Equation 4, I_c represents number of change pixels detected inside an inner training window, O_c is number of change pixels detected on outer training window and I_c is total number of pixels in inner training window. The inner and outer training windows derived from training sample. Success rate calculated iteratively based on given parameters according to Equation 4. The search range of DFPS can be set from highest to lowest value of change magnitude with pace difference from maximum to minimum value (Table 1). When highest success rate has achieved, the iteration equation stopped and final threshold value

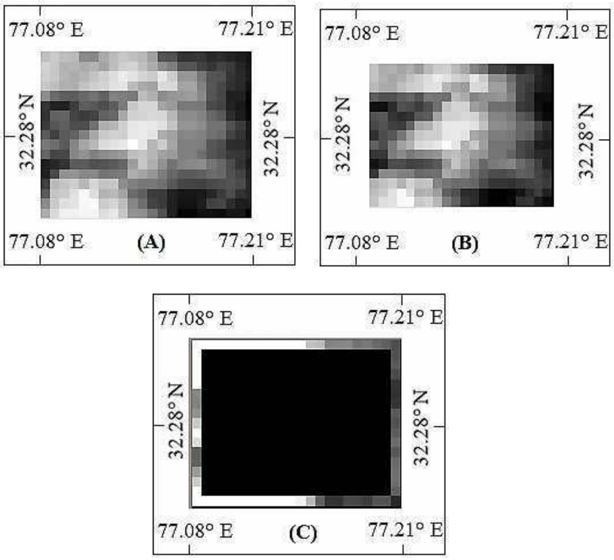

Fig.5. Training sample form change magnitude image (a) Sample, (b) Inner boundary of sample, (c) Outer boundary of sample

Table 1 Success rate results for DFPS threshold determination technique

Range = 140 - 20 Pace = 20		Range = 60 - 20 Pace =10		Range = 40 - 20 Pace = 5		Range = 35 - 25 Pace = 2-3		Range = 30 – 25 Pace = 1	
Threshold Value	Success Rate (%)	Threshold Value	Success Rate (%)	Threshold Value	Success Rate (%)	Threshold Value	Success Rate (%)	Threshold Value	Success Rate (%)
140	0.6	60	58.3	40	77.0	35	78.6	30	79.3
120	12.0	50	68.3	35	78.6	32	79.0	**29**	**80.3**
100	25.3	40	77.0	**30**	**79.3**	30	79.3	28	79.6
80	40.0	**30**	**79.3**	25	79.0	**28**	**79.6**	27	79.6
60	58.0	20	77.6	20	77.6	25	79.0	26	79.0
40	77.0							25	79.0
20	**77.6**								

corresponding to maximum success rate applied on to entire change magnitude image to generate binary image. In Fig.6, DFPS generated binary image represents the "change" pixels in white color and "no-change" pixels in black colour.

RESULTS AND DISCUSSION

In this paper, we focused on different threshold determination techniques for change detection analysis. Accuracy assessment of each threshold determination technique is an essential part of decision making process. In order to assess the accuracy of all techniques, binary output of each technique compared with reference image to generate the error matrix that shows the overall accuracy, kappa coefficient and commission error.

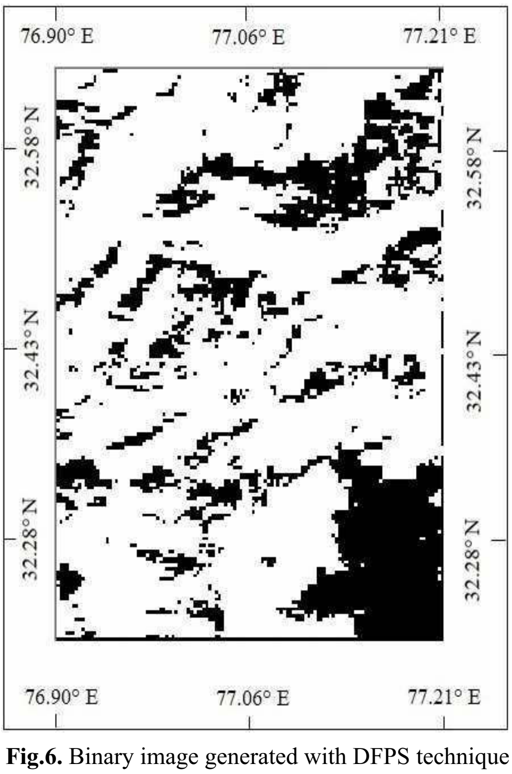

Fig.6. Binary image generated with DFPS technique

First technique, trial-and-error procedure based on simple threshold function. The manual selection of training sample which covers all types of change, has required to select a threshold value. An initial value of step size (N) is essential to set up by image analyst's and it increase until it reaches the maximum of the mean (M). The manual selections of step size (N) and training sample effect the accuracy assessment of trial-and-error threshold determination technique and increase the probability of suppressing some of the information up to a certain extent. As far as time consumption is concerned, this technique generally needs a long trial time (Bruzzone and Prieto, 2000; Chen et al., 2003; Singh, 1984; Stauffer M. L. and Mckinney, 1978). From the experiment results (Table 2), a kappa coefficient of 0.6000 is evaluated and overall accuracy of 80% achieved and commission error varied from 12% to 24.13%.

The empirical technique is one of the straightforward technique to quantify "change" and "no-change' pixels based on empirical value (Allen and Kupfer, 2000). The empirical value greatly varies according to analyst's skills (Chen et al., 2003) which effects the commission error, kappa coefficient and accuracy assessment. In case of more than two input spectral bands, threshold determination procedures become much more complex (Nackaerts et al., 2005). This technique has the advantage of being simple in implementation. Experiment results shown in Table 2 gives a kappa coefficient of 0.6689 and overall accuracy of 84% achieved and commission error varied from 7.14% to 27.27%.

The double-window flexible pace search (DFPS) technique has a level headed capability of determining the threshold value automatically with certain degree of skill of image analyst's (Chen et al., 2003; Chen et al., 2011; Sharma et al., 2013). Experiment results (Table 2) showa a kappa coefficient of 0.8000 and overall accuracy of 90% achieved and commission error varied from 8% to 12% only with this technique. The commission error increased by decreasing the threshold value and can be controlled efficiently through the double-window technique. Another

Table 2 Error matrices for assessing the threshold determination techniques: Trial & Error, Empirical and DFPS

Techniques	Classified data (Pixels)	Reference data (Pixels) *Change*	*No-change*	*Row total*	*Commission Error (%)*
Trial and Error	*Change*	18	7	25	*28%*
	No-change	3	22	25	*12%*
	Row total	21	29	50	
	Commission Error (%)	*14.28%*	*24.13%*		
	Overall accuracy = 80%, Kappa coefficient = 0.6000				
Empirical	*Change*	16	2	18	*11.11%*
	No-change	6	26	32	*18.75%*
	Row total	22	28	50	
	Commission Error (%)	*27.27%*	*7.14%*		
	Overall accuracy = 84%, Kappa coefficient = 0.6689				
DFPS	*Change*	22	3	25	*12%*
	No-change	2	23	25	*8%*
	Row total	24	26	50	
	Commission Error (%)	*8.3%*	*11.5%*		
	Overall accuracy = 90%, Kappa coefficient = 0.8000				

advantage of this method is improvement in search efficiency through flexible and varied search pace. It inferred that DFPS technique plays a vital role in change vector analysis to detect the snow cover changes of western Himalaya. It also evident that accuracy of manual techniques such as trial-and-error and empirical, are easy to compute but highly depends on skill of the image analyst which leads to low accuracy, low kappa coefficient and high error probability.

CONCLUSION

In this paper, it has been concluded that double-window flexible pace search (DFPS) threshold determination technique exhibits a good potential to identify land cover changes as compared to other threshold determination techniques such as trial-and-error, empirical procedure. The DFPS achieved overall accuracy of 90% (Kappa coefficient 0.80) whereas other techniques achieved less than 85% accuracy on the same study area and commission error has significantly improve in DFPS technique as compared to other techniques. So the DFPS as semiautomatic threshold determination has effectively overcome limits of manually threshold determination techniques.

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