PROSPECTIVE OF HIGH RESOLUTION WORLDVIEW-2 SATELLITE DATA FOR GEOSPATIAL SURFACE FACIES MAPPING OF AN ALPINE GLACIER

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ABSTRACT

Alpine glaciers are dynamic in nature; and are thus seen as sensitive indicators of climate change. The study of glaciers with respect to these changes must be carried out by first mapping the glacier surface facies. This study has attempted to map the available range of surface facies of an unnamed glacier from the Chandra Basin, in the Great Himalayan Range, Himachal Pradesh. The classification of these facies has been carried out using object-based and pixel-based approaches. Conventional glacier facies classification has usually utilized data acquired in the melt season. This study however has endeavored to map facies on data acquired during early winter. WorldView-2 high-resolution imagery has been used to develop customized spectral indices using the new bands in its multispectral range. Error matrices were utilized to assess the classification accuracies. The object-based approach has been found to have an overall accuracy of 88.33%. Two pixel-based classifiers were utilized, yielding overall accuracies of 81.67% and 78.33% respectively. The highest kappa statistics obtained for the object-based strategy is 0.86 and the pixel based classifiers delivered Kappa statistics of 0.78 and 0.74 respectively. The results clearly indicate that the object-based classification is superior to the pixel based classification methods.

1. INTRODUCTION

A glacier is a vast moving body of snow and its metamorphosed forms along with air, water and debris. Glaciers are sensitive indicators of climate change. These changes are monitored very carefully to assess their causes and impacts. Glacier facies are those zones of snow, characterized by a particular set of factors that relate to certain properties of snow surfaces, which enable their distinction. Mapping and assessment of these facies is essential as it directly relates to the accumulation and ablation. Given the concepts of gain and loss for a glacier, a "healthy" glacier is one that has a higher net gain. The difference between the net accumulation (gain) and the net ablation (loss) is the mass balance of a glacier. When calculated for the changes occurring in a whole year, it is the annual mass balance. The mapping of glacier facies serves as a "diagnostic tool" for the assessment of these changes. Glacier facies are a direct visual implication of the kind of changes that a glacier is experiencing. Mapping of glaciers and several glacier related features using various remote sensing (RS) sensors has been carried out previously (Mitkari et al., 2017; Paul et al., 2016; Bhardwaj et al., 2015; Fugazza et al., 2015; Jawak & Luis, 2013d). The performance of WV-2 for cryospheric applications has been examined in detail by previous studies (Jawak & Luis, 2013a; Jawak & Luis, 2013b; Jawak & Luis, 2011a; Jawak & Luis, 2011b). However, the potential of the WorldView-2 (WV-2) satellite for the purpose of glacier facies classification has not been fully exploited. The most relevant technical innovation of WV-2 lies in an improvement of its potential spectral performance since the number of bands that comprise its multi-spectral (MS) product has been increased to 8, instead of the four classic bands (Blue, Green, Red and Near Infrared) offered by all previous very high resolution (VHR) satellites (Aguilar et al., 2013). Table 1 shows the sensor characteristics of WV-2.

The most reliable approach for mapping glacier facies using RS imagery involves image classification. The overall objective of image classification procedures is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand & Kiefer, 1989). Classification is executed based on "pattern" recognition. This pattern is of various contexts. When this pattern refers to the set of radiance measurements obtained from each pixel, the pattern is known as "spectral pattern". When this pattern refers to the contextual characteristics, it can be called as "contextual pattern". Traditional pixel based supervised classification performs classification by utilizing training sites to provide a data set for comparison to the classifier. However, these methods may be suitable for classification of coarse to medium resolution satellite data (Khan et al., 2015; Shukla et al., 2009; Salomonson & Appel, 2004; Vikhamar & Solberg, 2003). Image pixels are not true geographical objects and pixel topology is limited. The pixel based image analysis uses high spectral information but low spatial information, which neglects texture, context and shape information. This technique when applied to VHR images results in high inaccuracies and data redundancy (Wei et al., 2005). The technique of object-oriented classification (OOC) has developed over the years to resolve the problems faced by traditional pixel based classification (PBC). Each object on the earth has a unique reflectance pattern as a function of wavelength. Meaningful objects are created with segmentation algorithms, which replicate the spectrally homogeneous land cover type and pixels having heterogeneous reflectance (Yadav et al., 2015). Thus, OOC classifies several pixels together (an object) representing a more “true to nature” geographic feature. This study utilizes WV-2 data in an object-oriented domain to classify glacier facies by devising customized spectral index ratios (SIRs) using the new bands in its MS range. The accuracy of the OOC method is then compared to that of the traditional PBC.

Table 1. WorldView-2 spectral characteristics.

WV-2 Bands	Wavelength Range (µm)	Pixel Size (m)
PAN	0.45-0.80	0.5
Coastal	0.40-0.45	2
Blue	0.45-0.51	2
Green	0.51-0.58	2
Yellow	0.565-0.625	2
Red	0.63-0.69	2
Red Edge	0.705-0.745	2
NIR-1	0.770-0.895	2
NIR-2	0.86-1.04	2

2. STUDY AREA AND DATA

The glacier chosen for this study is an unnamed glacier (here on referred to as G2) in the Himalayas. G2 (Figure 1) resides in the upper Chandra basin, within the district of Lahaul & Spiti, in the state of Himachal Pradesh, India. This part of the Chandra basin is heavily glaciated. The glacier is located in the Great Himalayan range. The elevation range in this region is between 4800m to 6000m. Traditional facies mapping has been performed on images acquired during the end of the ablation season. This study has attempted to map glacier facies during early winter. Along with the acquired WV-2 image, an ASTER GDEM v2 (30m) was utilized. Table 2 displays the data used and the tasks employed for each.

Table 2. Data used and tasks performed.

Data Used		Date of Acquisition	Tasks
	Panchromatic	16 October 2014	To pan sharpen the multispectral image
	Multispectral	16 October 2014	• Delineation of glacier • Classification of facies • Generation of reference points for accuracy assessment
ASTER GDEM		16 January 2017	• 3-D view generation

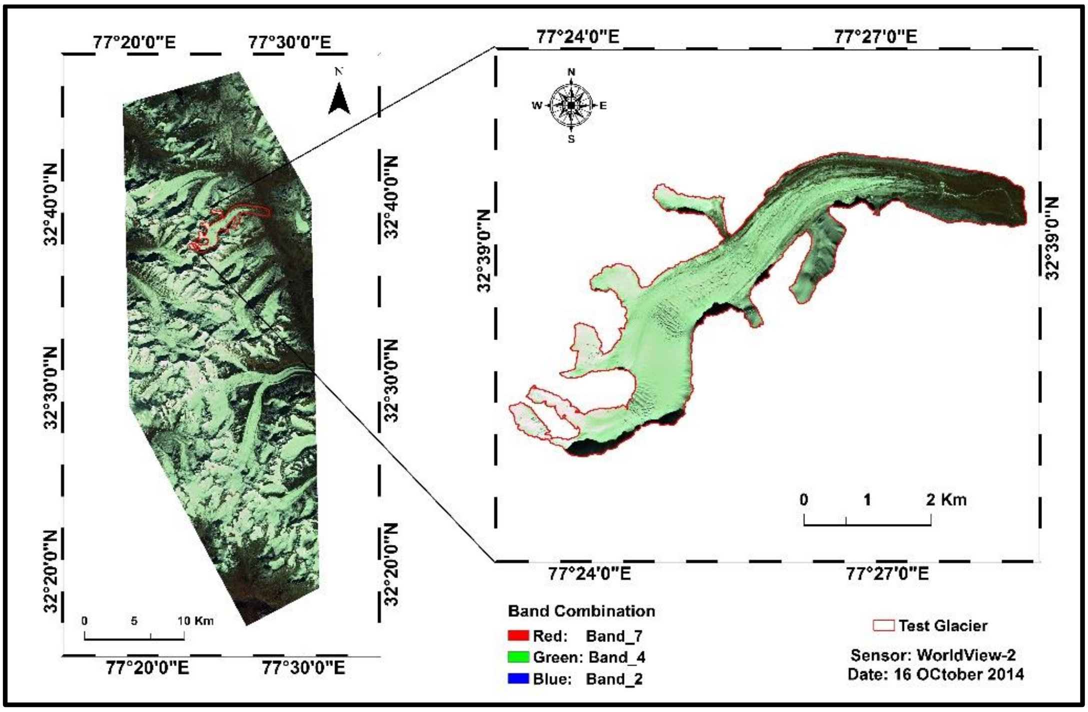

Figure 1. Location map of the study area.

3. METHODOLOGY

The protocol utilized for data processing consists of three major stages: (a) Preprocessing, (b) Classification and (c) Accuracy assessment. Figure 2 depicts the methodology executed in this study.

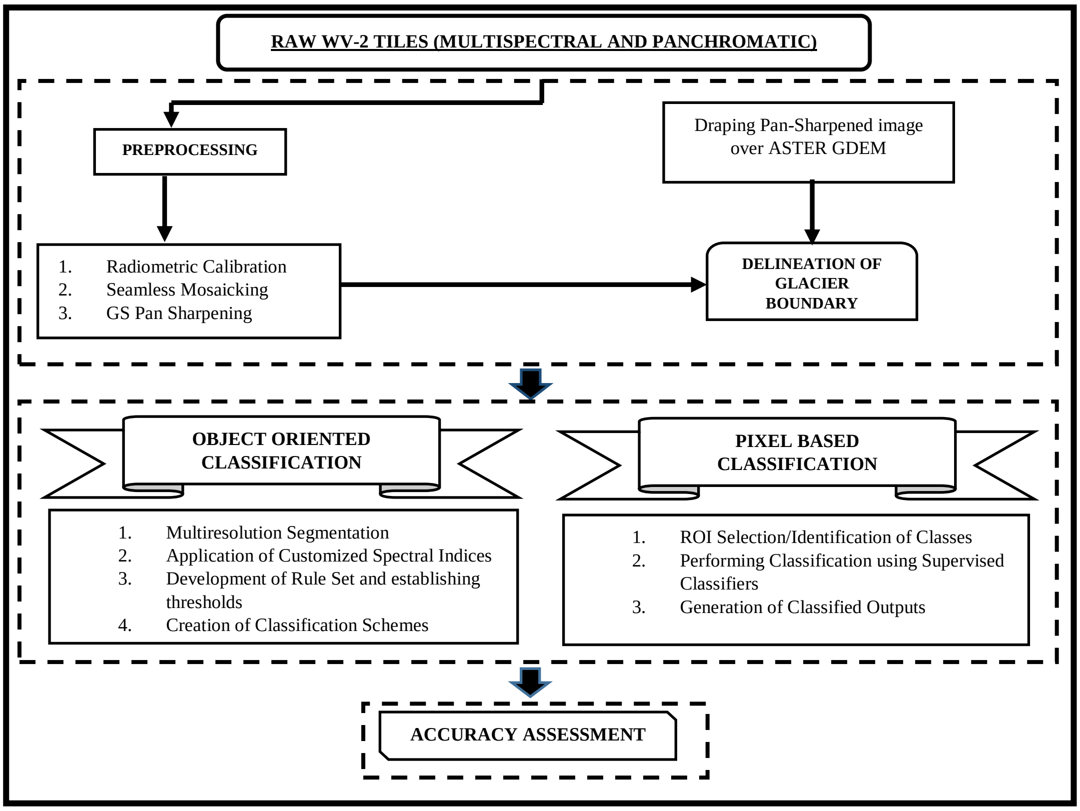

Figure 2. Methodology adopted for carrying out the present study.

3.1 Preprocessing

The preprocessing stage consisted of data calibration, mosaicking, pan sharpening, generation of 3D surface, digitization and extraction of study area. Data calibration (Jawak & Luis, 2014) is done to reduce or correct errors in the digital numbers of images. The process improves the interpretability and quality of remotely sensed data. This process requires a.) The conversion of raw DN values to at sensor spectral radiance, and b.) The conversion of at sensor radiance to at sensor or surface reflectance. The second step is also known as atmospheric correction. The method utilized for atmospheric correction in the present study is the FLAASH atmospheric correction tool (ENVI 5.3). The raw WV-2 data was obtained as 21 individual tiles. The calibrated tiles were then mosaicked together to produce the full image of the study area. Seamless mosaicking was carried out in ENVI 5.3 for this purpose. The raw tiles were already geometrically corrected to the projection system of UTM WGS 84 43N and the geographic coordinate system of GCS WGS 1984. Gram Schmidt (GS) Pan sharpening method (Laben & Brower, 2000) was utilized for this study, which is the most suitable for land cover classification (Jawak & Luis, 2013c). To facilitate greater accuracy in the delineation of the study glacier G2, the pan-sharpened image was draped on a 3- Dimensional surface model of the study area in ArcScene 10.3. The base height for this 3-D model was computed using an ASTER GDEM v2 (30m). This was continuously referred to during the delineation process. The delineated border was used to extract the study area from the rest of the image in ArcGIS10.3. The extracted test glacier was then subjected to the classification processes.

3.2 Classification

Two approaches were used to conduct the glacier surface classification; (1) object oriented classification; and (2) pixel based classification (PBC).

3.2.1 Object Oriented Classification

OOC was carried out in eCognition Developer 64. It involved several steps in its developmental procedure. They were multiresolution segmentation, application of customized spectral indices, development of rule sets and thresholds, generation of classification schemes and performing manual corrections. Multiresolution segmentation is an optimization procedure, which, for a given number of image objects, minimizes the average heterogeneity and maximizes their respective homogeneity (Definiens Developer, 2012). The segmentation was carried out using user-defined parameters that are image layer weights, scale parameter, shape/color, and compactness. The layer weights assigned are listed as follows; Coastal=2, Blue=1, Green=2, Yellow=1, Red=1, Red Edge=2, NIR1=4, NIR2=3. The properties of the objects to be generated through the segmentation process are dependent on the values assigned for scale parameter (200), shape (0.4) and compactness (0.8). The segmented image was then subjected to manual scrutiny to develop customized SIRs for facies classification. The bands used to devise the indices were chosen based on the spectral response pattern pertaining to the target spectra and a trial and error method was adopted to determine the best possible SIRs. Table 3 displays the indices developed.

Table 3. Customized SIRs devised for classification of facies.

Index no.	Mathematical expression
SIR1	$\frac{YELLOW}{\frac{NIR1+NIR2}{2}}$
SIR2	$\frac{RED\ EDGE}{\frac{NIR1+NIR2}{2}}$
SIR3	$\frac{BLUE}{\frac{NIR1+NIR2}{2}}$

Extraction of accurate facies using the SIRs (Table 3) necessitated the assignment of thresholds. Thus, it can be said that with respect to the SIR under consideration, these thresholds are a specification of the spectral characteristics of the facies. An advantage of the object-oriented domain is that along with the spectral even the contextual information is used to achieve precise classification schemes. The facies extracted using these techniques are wet snow, glacier ice, ice mixed debris, thick debris and crevasses. Shadowed areas in images of alpine glaciers occur due to sensor angle and solar azimuth. Shadowed areas in this image could not be extracted specifically as the spectral response pattern of the various shadows across the glacier vary both within themselves as well as among each other.

To overcome this problem, shadowed areas were digitized in ArcMap 10.3. The original image with the shadowed areas was used in eCognition for facies classification. This caused overestimation of certain facies in the shadowed region. Masking of the shadowed areas would result in errors when calculating the areas of facies of the output generated from eCognition. Therefore, using the Erase tool in ArcMap 10.3 shadowed areas were erased from each of the individual facies to obtain shape files having no overestimation in the shadowed region.

3.2.2 Pixel Based Classification

The PBC technique adopted here is the supervised classification technique. The steps to classify facies using this technique consisted of selection of regions of interest (ROIs), application of supervised classifiers and generation of outputs. The selection of ROIs was based on the spectral characteristics of the target region. Supervised classification on the study area was carried out using the TERCAT (Terrain Categorization) workflow tool provided by ENVI 5.3. This tool is found under the SPEAR (Spectral Processing Exploitation and Analysis Resource) Automated Workflow Tools. The characteristic benefit of using TERCAT is that it allows for generating multiple classification algorithm outputs in one single go. The two classification algorithms utilized in this study are the Mahalanobis Distance (MH) and Maximum Likelihood (MXL) classifiers.

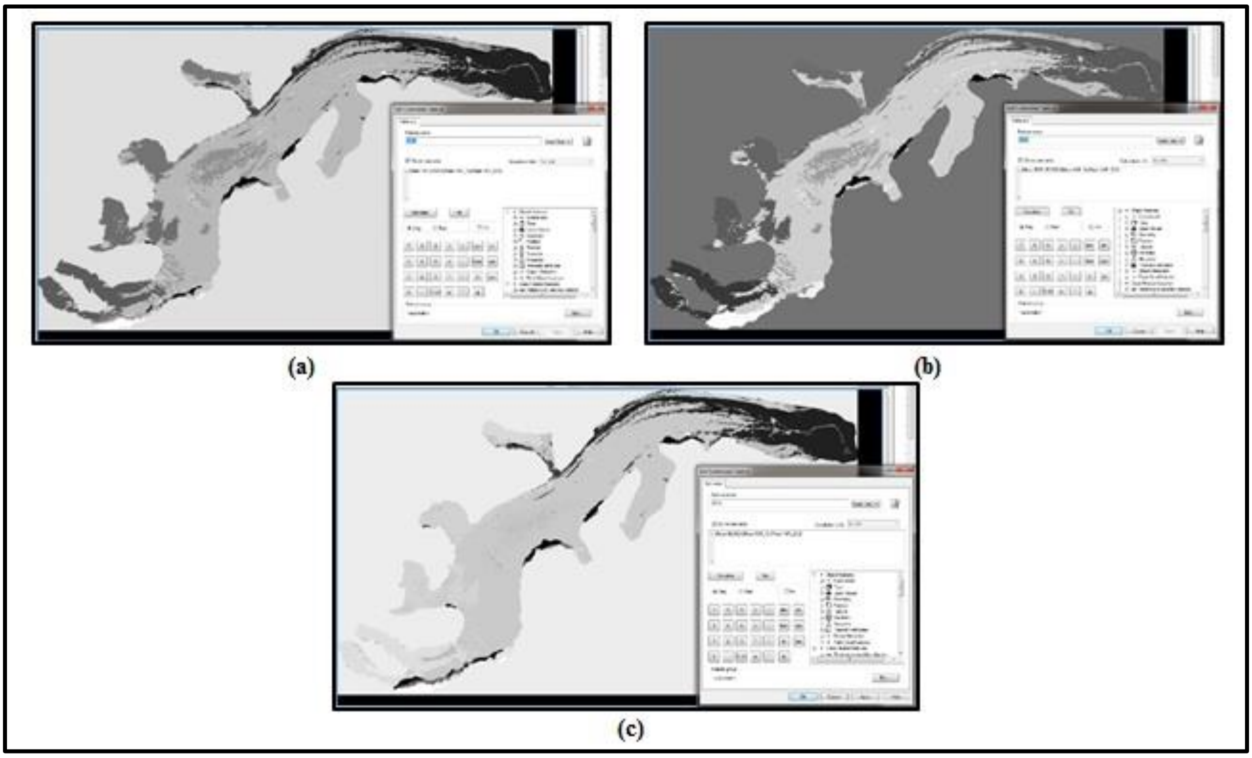

Figure 3. (a) The product of SIR1, (b) The product of SIR2, and (c) The product of SIR3

3.3 Accuracy Assessment

A total of 60 random points were equally distributed through six classes using visual scrutiny on the pansharpened imagery. Error matrices were utilized to assess the classification accuracy of the OOC and PBC techniques. Error matrices compare on a category by category by basis, the relationship between known reference data (ground truth) and the corresponding results of an automated classification (Lillesand & Kiefer, 1989). The measures used to determine accuracy are (i) error of commission, (ii) error of omission, (iii) producer's accuracy, (iv) user's accuracy, (v) overall accuracy, and (v) kappa statistics (κ).

4. RESULTS AND DISCUSSION

The results of the classification techniques are given in Figure 4. Table 4 describes the values attained for each measure of accuracy by all three classification schemes. The OOC achieved the highest overall accuracy of 88.33% and κ=0.86. Following it was the PBC. Among the pixel-based classifiers, the MH achieved the highest overall accuracy of 81.67% (κ=0.78). The MXL recorded an overall accuracy of 78.33% (κ=0.74).

Table 4. Measures of accuracy for each classification scheme

Measure of accuracy	OOC	MH	MXL
Error of Commission	11.67%	11.67%	21.67%
Error of Omission	8.73%	16.59%	19.96%
Producer's Accuracy	91.27%	88.17%	78.85%
User's Accuracy	88.33%	81.67%	80%
Overall Accuracy	88.33%	81.67%	78.33%
Kappa Statistics	0.86	0.78	0.74

The overall trend of classification accuracies is thus, given as OOC>MH>MXL. The OOC achieved an excellent producer's accuracy of 91.27%, while the MH and MXL classifiers were able to attain only 88.17 and 78.85% respectively. The performance of the customized SIRs (Table 3) was outstanding. SIR1 (Figure 3a) resulted in a very precise mapping of crevasses. SIR2 (Figure 3b) was used in combination with SIR1 to extract glacier ice, while it was used singularly in the extraction of wet snow. SIR3 (Figure 3c) was able to distinguish between ice mixed debris and thick debris. The MH method clearly had overestimated the amount of shadowed area. Interestingly, both the MH and MXL methods classified nearly a similar amount of wet snow. Crevasses were most overestimated by the MXL classifier. Given these findings, it is clear that among the classification techniques assessed here, the classification performed by the object-oriented method proved to be the best. The use of contextual information enables the induction of human analytical skills into the classification procedure. This tremendously improves the accuracy of classification. Pixels are not practical representations of real world features. This issue does not delimit the OOC method as it classifies pixel segments rather than individual pixels.

5. CONCLUSION

This study brings a novel approach to classification of glacier surface facies by using the new bands (MS) available courtesy of WV-2. A comparative assessment of the applicability of OOC and PBC for accurate mapping of glacier facies is carried out here. Radiometric calibration was crucial to carry out this study, as segmentation as well as selection of ROIs were dependent on the spectral response of the facies. Pansharpening was needed, as delineation of the glacier boundary had to be performed accurately. The 3-Dimsensional surface generated using the ASTER GDEM v2 (30m) was used to understand the terrain and adjust the delineation process to avoid errors. The development of customized SIRs (Table 3) to map glacier facies of the study area was a huge success. Each of the SIRs proved worthy in the classification process. A characteristic feature of this study is that crevasses were exceptionally distinguishable using SIR1. Ice mixed debris and thick debris were exclusively extracted using SIR3. These SIRs must however be tested further to determine if they are transferable. Traditional SIRs used to extract information from snow and ice areas (Arora et al., 2011) involve the use of SWIR bands. A significant achievement of this study is that it successfully mapped facies without the use of SWIR bands. The manual corrections applied for shadowed areas was crucial, as without it large overestimations would have occurred. This same fault was found in the PBC results.

Future attempts may utilize advanced classifiers and development of more indices to increase the accuracy of the classification results. The results of this study prove that new sensors and new bands open new pathways for the addition of novel methods to the archive of facies extraction techniques.

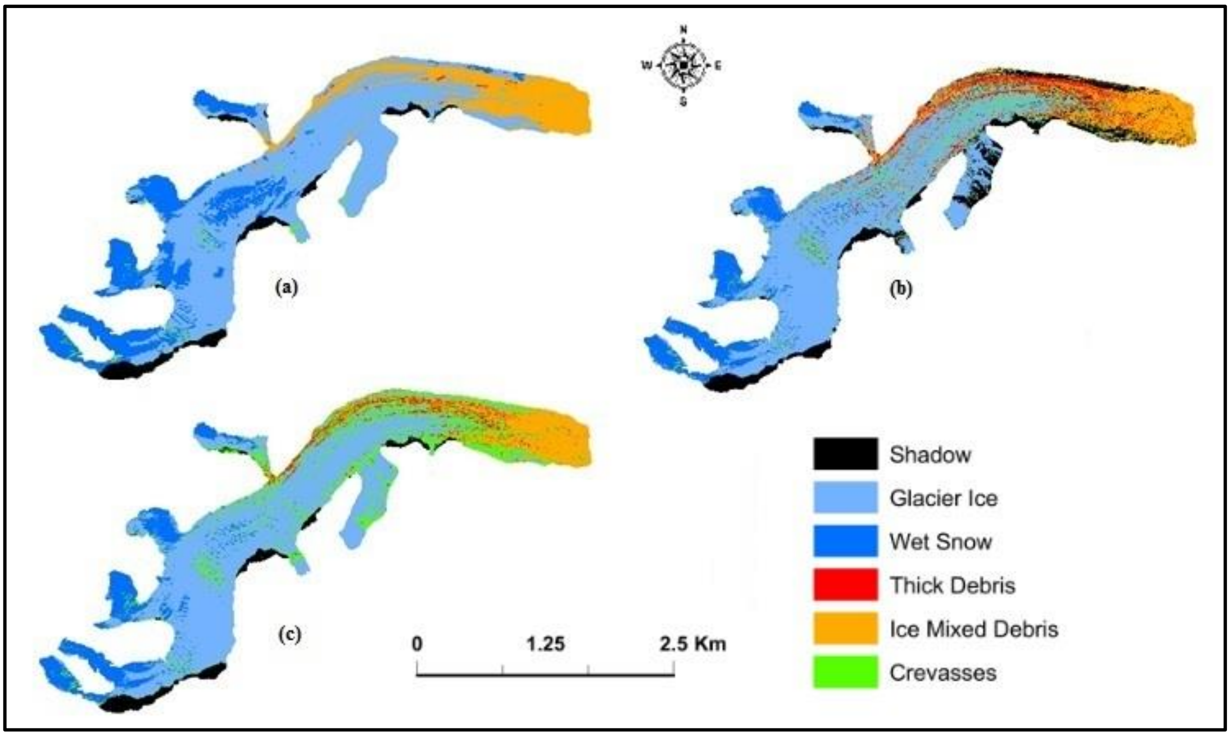

Figure 4. (a) Facies classification using OOC method, (b) Facies classification using MH method, (c) Facies classification using MXL method.

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