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Correction of spectral radiance of optical satellite image for mountainous terrain for studying land surface cover changes

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Abstract: Qualitative and quantitative results of high terrain elevation effect on spectral radiance of optical satellite image which affect the accuracy in retrieving of land surface cover changes is given. The paper includes two main parts: correction model of spectral radiance of satellite image affected by high terrain elevation and assessment of impacts and variation of land cover changes before and after correcting influence of high terrain elevation to the spectral radiance of the image. Study has been carried out with SPOT 5 in Hoa Binh mountain area of two periods: 2007 and 2010. Results showed that appropriate correction model is the Meyer's one. The impacts of correction spectral radiance to 7 classes of classified images fluctuate from 15% to 400%. The varying changes before and after correction of image radiation fluctuate over 7 classes from 5% to 100%.

Keywords: image radiation correction, correction models, slope and terrain aspect, image classification

1. Introduction

Optical satellite image radiance is influenced of changing terrain elevation. Its effect is easily to be recognizing on multi-spectral images such as SPOT, Landsat, etc, especially in the terrain with high elevation. The Illumination of terrain with high elevation differences will appear areas obscured by shadow that will affect on determining quantitatively object features on ground surface in image classification and in studying land surface cover changes. The method of image radiometric correction for decreasing minimum of high terrain elevation effect is a necessary task, especially in mountainous areas in supervision work of vegetation changes.

The image radiation correction methods based on the slope and terrain aspect (azimuth of slope direction) can be implemented by mathematical or empirical models (experience). The models are characterized by general lack of consideration of the components of diffuse light, and the light reflected from the surrounding area.

Teillet et al. (1982), in their study, describes four methods of correction methods such as Lambert-cosine, Minnaert, empirical-statistical, and C-correction method. Each method requires the need to specific criteria (Teillet et al, 1982), which show the weakness of the full parameterization with the adjustment of the model parameters, in order to be able to use on a large scale. From tradition of statistical methods it is very difficult to build an image radiation correction function for common application (Teillet, 1986). Teillet et al. (1982) proposed C-correction model based on the linear correlation between the experimental observation of image radiation and cosine of the incidence angle of sunlight. Although the coefficient C, calculated from the slope and aspect (or azimuth of slope direction) of the regression line and put on cosine-Lambert method, in order to compensate for the effects of light in the sky. C value can be very large for some images. However, the C correction method lacks the correct physical basis to explain (Gu et al, 1998).

Based on the simplified assumption of the interest surface is Lambert surface, the cosine (or cosine-Lambert) model has been applied in a number of studies. Kawata et al. (1988) found that it significantly reduces the effects of terrain using topographic data that has been smooth, but it has relatively high ground albedos while the incidence angle *i* is small. Angle i is defined as the angle between the direction of incidence of the sunlight ray and regional topographic surface normals. Also assuming Lambertian become very weak when the incidence angle of the sunrays falls below a threshold value.

Minnaert correction method (Smith et al, 1980) applied the principle of bi-direction reflection. In this modified method, the ideal measure represents the surface diffuse reflection, which is the Minnaert constant. Ekstrand (1996) found that the Minnaert constant change according to the cosine of the incidence angle *i*. As a result of a number of studies such as Colby (1995); Meyer et al. (1993), Ekstand (1996) Minnaert correction method is better than cosine method, but still lack to parameterization of radiation of light in the sky.

Comparative studies of Minnaert constant from remote sensing data for three different forest types have been carried out experimentally on a forest in mountainous Sangun area near Fukuoka, Japan (Murakami, T., 2002). Minnaert constants for each class is calculated by using the remote sensing data of the terrain with similar conditions (e.g., slope and aspect), and found that the difference significantly between the Minnaert constants were calculated. Data obtained from the Landsat 7 scene SPOT / HRV in 1997.

For forest canopy, statistical correlations appear between the image radiation values and topographic parameters such as the incidence angle *i* related to the normal of the surface topography (Soenen et al., 2005). Civco (1989) to determine the coefficient obtained from experimental testing by comparing the spectra response function of the sample having large number of pixels located on the northern and the southern slopes with the average spectrum responses for the deciduous forest type.

Radiation reflected from surrounding terrain is very difficult to model even. Sandmeier used approximation method to estimate the radiation reflected and Proy proposed a sophisticated and accurate model to calculate the single reflected radiation from the surrounding terrain (Proy et al, 1989). In recent time the use of hyperspectral images for studying complicated terrain is one of the goals of remote sensing researchers (Lenot et al, 2009).

Results of the above studies have confirmed:

– The image quality after topographic effect correction is higher than before not correction; especially in the area obscured by the high difference of terrain.
– The use of images topographically corrected will be in high-grade reliability on image classification than using image uncorrected due to high elevation differences.

The paper previously shows the correction models of image radiance, based on estimated CV (coefficient of variation) index for selecting an appropriate model. Continuously, the paper gives results that are related image classification work and assessment of changes for each case before and after using the correction model of high terrain elevation. The results confirm a need to correct spectral radiance of optical satellite image due to high terrain elevation effect in change study, especially in forestry field.

2. Technology solutions

2.1. Correction models

In the terrain with high elevation, incident rays from the sun to topographic elements are different. Figure 1 introduces an incidence angle i between the incident ray and the normal of topographic surface element N and solar zenith angle sz. In this case, the angle i is a function of the angle sz, a solar azimuth A_S, a slope angle α of each topographic element (pixel) and a solar azimuth of each topographic pixel A_T, meaning $i = f(sz, A_S, \alpha, A_T)$. The value of $cosi$ is denoted IL and estimated as follows:

$$\cos i = \text{IL} = \cos sz.\cos\alpha + \sin sz.\sin\alpha.\cos(A_T - A_S)$$

Four correction models of spectral radiance affected by high terrain elevation that are considered by researches, which are given as below:

Cosine correction model: $\text{Rn} = \text{R}.(\cos(sz)/\text{IL}),\ \text{IL} = \cos i$ (M1)

Minnaert correction model: $\text{Rn} = \text{R}.(\cos(sz)/\text{IL})^k$; k is a coefficient (M2)

Teillet correction model: $\text{Rn} = \text{R}.[(\cos(sz) + \text{C})/(\text{IL} + \text{C})]$; with $\text{C} = \text{b/m}$ (M3)

Meyer correction model: $\text{Rn} = \text{R} - m.\text{IL} - b + \text{R}_{mean}$ (M4)

Where: Rn – spectral radiance image after correction; R – spectral radiance before correction; R_{mean} – expectation of R; *m* and *b* are parameters of the linear regression line between R and IL.

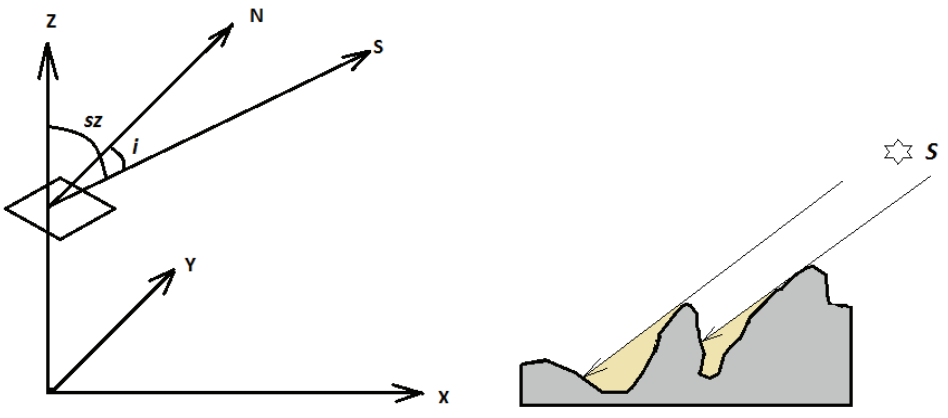


Fig. 1. Incident angle *i* of inclined terrain (left) and hidden shadow due to high terrain elevation (right)

A technical process for correction of high terrain elevation effect to spectral radiance of optical satellite image is presented in the Figure 2.

For estimating image quality corrected by particular models presented as above, the CV (coefficient of variation) index has been used, that is in following formulae

$$CV = \frac{\sigma}{\mu}$$

Where: σ – the standard deviation and μ – image mean.

Digital Elevation Model (DEM) is not only used to image geometrical rectifying but also applied to its radiometric correcting. One of the important steeps of topographically correcting image radiation is related with creating the slope and aspect (azimuth of slope direction) products of terrain. The accuracy of DEM affected on qualities of image geometrical rectifying and its radiometric correcting (Nichol and Hang, 2008). The intermediate data of the slope and terrain aspect can be extracted from Digital Elevation Model (DEM) based on ArGIS.

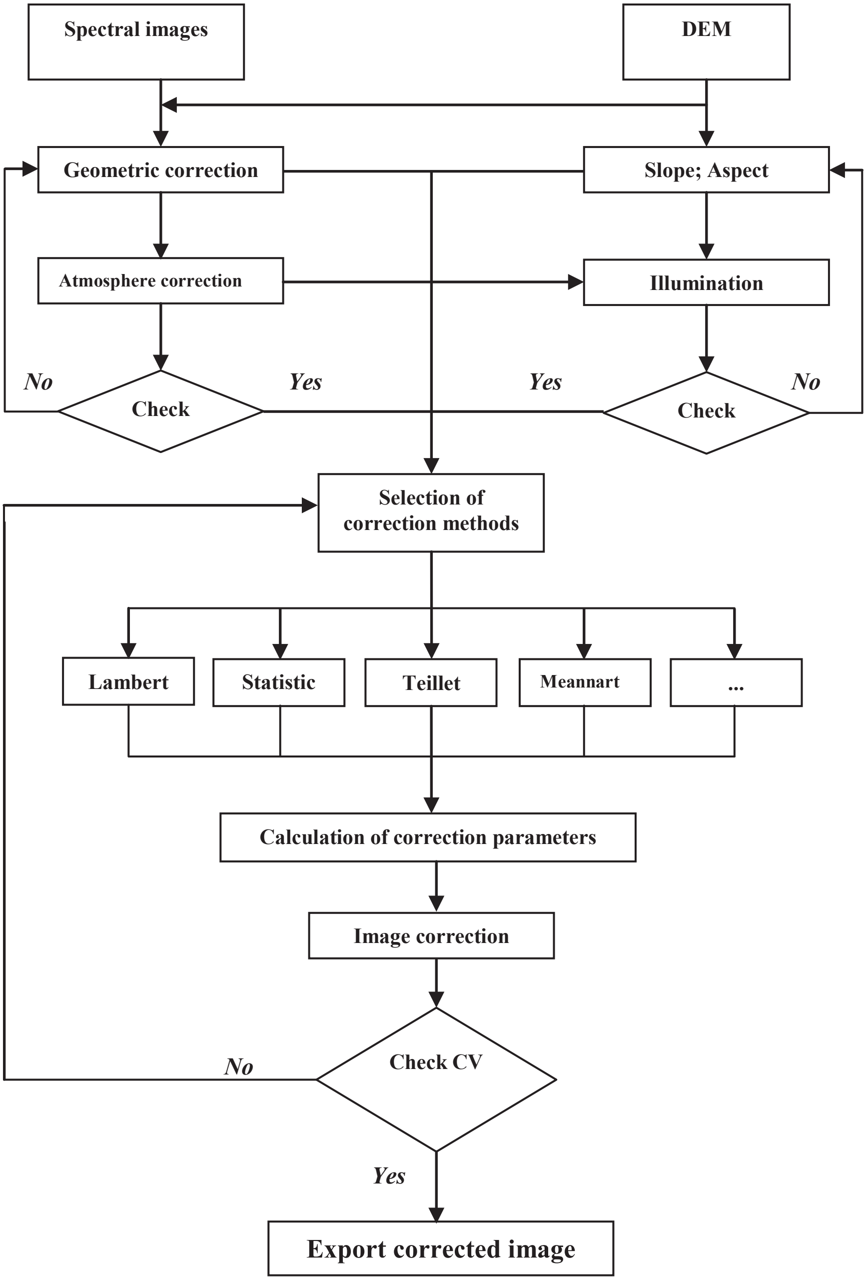


Fig. 2. A technological process for correcting image spectral radiance for mountainous terrain

2.2. Image classification and assessment of changes

Aim to prove a need of correction of spectral radiance of optical satellite image for mountainous terrain (Hale and Rock, 2003; Wu et al., 2004); the study content uses an unsupervised classification method ISODATA. There are 4 images taking classification:

- An image before and after correction of high terrain elevation of period 2007: M0(2007) and M4(2007).
- An image before and after correction of high terrain elevation of period 2010: M0(2010) and M4(2010).
- Assessment of changes consists of 2 major contents:
- Assessment impacts of correction of high terrain elevation to image classification results of periods 2007, 2010 and to changes in the classes.
- Assessment of varying class changes before and after correction of high terrain elevation.

3. Experiment

3.1. An experimental area

The experimental area is located in a mountain region belonged to Tan Lac district, Hoa Binh province, which is about latitude 20°30'–20°45' North, longitude 105°30'–105°45' East and it is far away from Ha Noi around 73km. The topographic area is a high mountain, split complex, large steep and toward NW-SE direction. The high mountain (in the North East) has average high from 600-700 m, the largest high point is 1189 m, and the average steep is 30-35°.

3.2. Data

Digital elevation model (DEM)

DEM of the experimental area is built by topographic maps 1:25 000 with its accuracy is 3m (equally 1/3 high of basic contours of the topographic map 1:25 000). DEM has a magnitude value pixel 20m that is re-divided sample of 10m resolution for matching the spatial resolution of multispectral satellite image SPOT5.

Satellite image data

Satellite image used was SPOT 5 of Hoa Binh province. Its parameters of both periods 2007 and 2010 are showed in the Table 1.

Table 1. SPOT 5 parameters in 2007 and 2010

No	Atribute	Parameter	
1	Image ID	269-309	269-309
2	Acquisition time	2010-11-02 03:30:44.1	2007-11-05 03:44:43
3	Sensor	HRG 2	HRG 2
4	Processing level	1A	1A
5	Channels number	4	4
6	Orientation angle	12.°307103	17.°760773
7	Incidence angle R	17.°930865	20.°198991
8	Sun elevation angle	50.°776214	51.°353703
9	Solar azimuth angle	151.°966534	157.°508498
10	Spatial resolution of 3 multispectral channels	10 m	

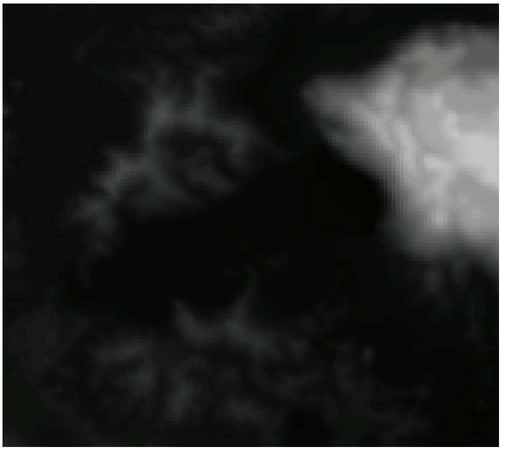
3.3. Image radiometric correction

The products of intermediate products such as slope image, aspect and illumination image IL became created from DEM, based on ArGIS are represented in the Figure 3.

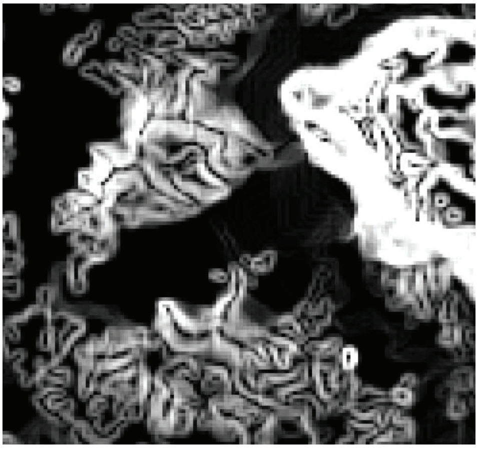
Next, the process of topographically correction, basing on four models M1, M2, M3, and M4 as presented in the paragraph 2.1 has been run on ENVI software. The Table 2 shows assessment results of CV index for 4 introduced correction models in the section 2.1. The result of Table 4 shows: the M4 model has the smallest CV (better qualification image), which is selected the appropriate model for study image classification and assessment of land cover changes. Visually, qualification image after correction of radiation image because of high terrain elevation based on the M4 model compared to the original image M0 of both periods 2007 and 2010 are showed in Figure 4.

Table 2. The CV index of four correction models of spectral radiance image

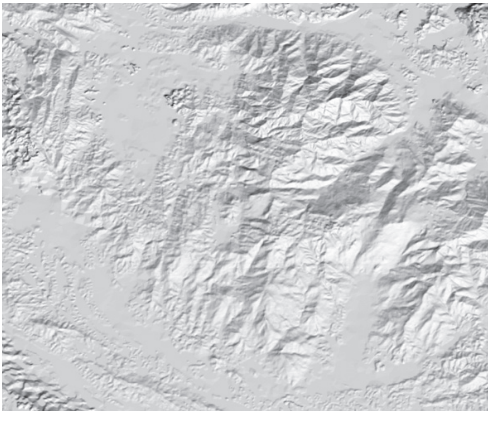
	Coefficient of variation CV (%) of the original image and corrected image 2007					Coefficient of variation CV (%) of the original image and corrected mage 2010				
Correction model	M0	M1	M2	M3	M4	M0	M1	M2	M3	M4
XS1	22.61	23.21	21.15	21.04	22.12	17.39	18.94	17.28	16.60	16.78
XS2	37.01	37.14	36.11	36.33	28.84	22.48	23.39	21.83	22.19	18.06
XS3	25.25	28.24	24.67	24.82	20.81	13.15	16.73	12.88	12.95	11.04
Average	28.3	29.5	27.3	27.4	23.9	17.7	19.7	17.3	17.3	15.3



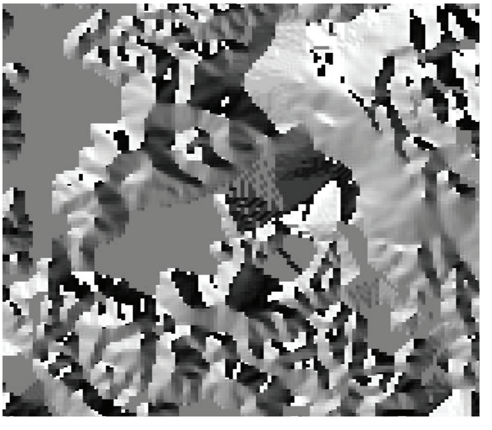
DEM of study terrain



Terrain slope



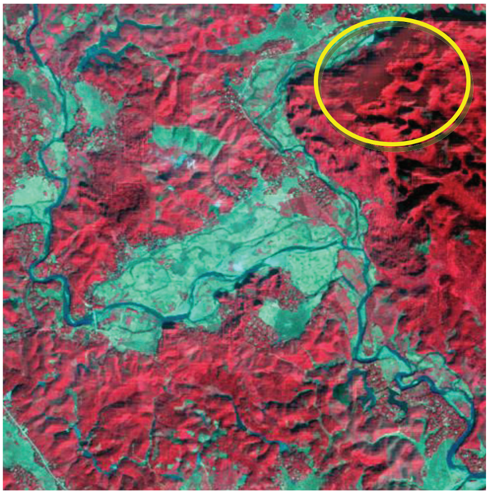
IL image



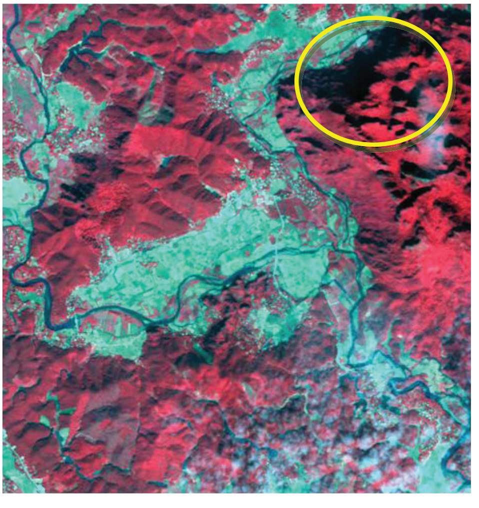
Terrain aspect

Fig. 3. DEM, products from DEM and image illumination

Original image (M0), 2007



Model 4 (M4), 2007



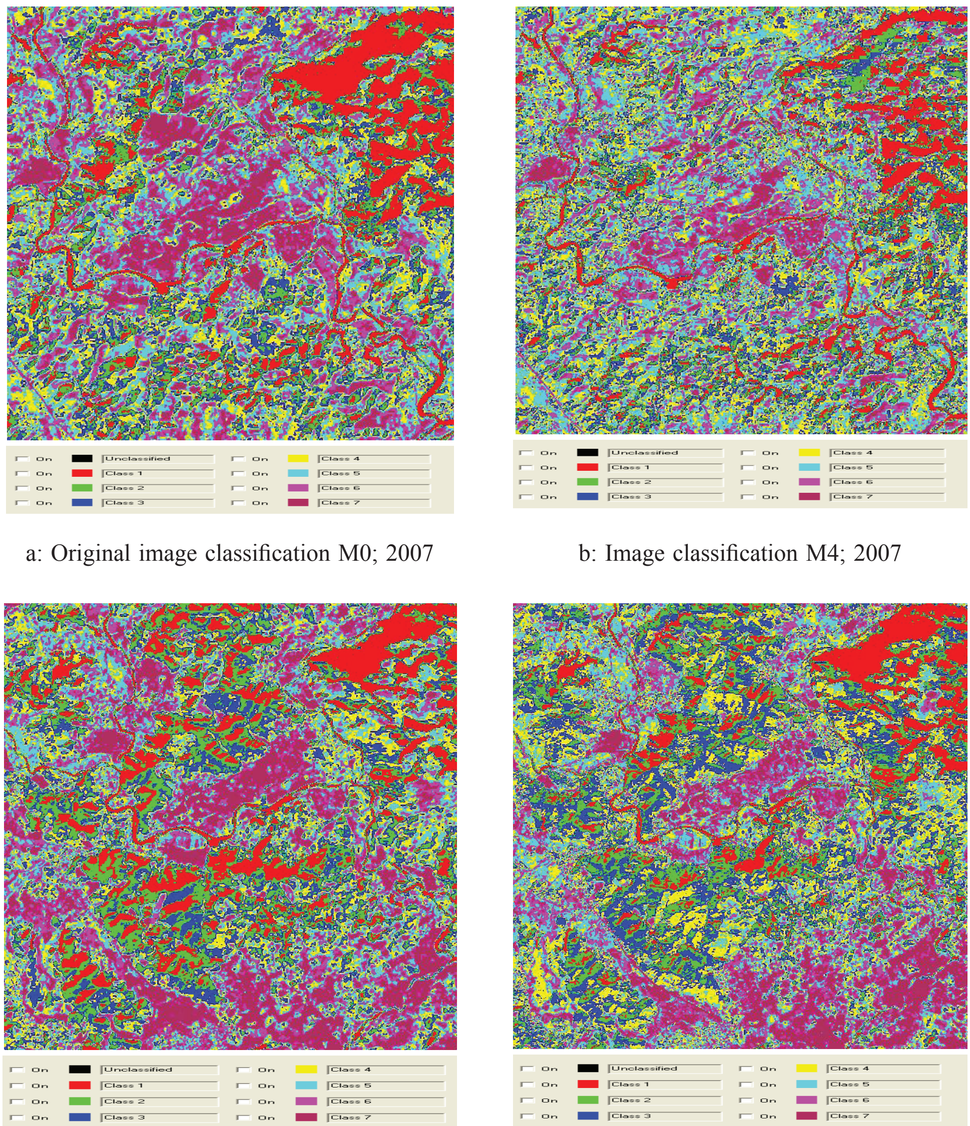
Original image (M0), 2010

Model 4 (M4), 2010

Fig. 4. Comparison of qualification image before (M0) and after (M4) correction

3.4. Image classification and assessment of land cover changes

For comparison, assessments of reflected spectral values of land surface cover before and after correction of high terrain elevation has been done. Images have been classified using ISODATA method of both images in both periods M0 (2010; 2007) and M4 (2010; 2007).



a: Original image classification M0; 2007

b: Image classification M4; 2007

c: Original image classification M0; 2010

d: Image classification M4; 2010

Fig. 5. Image classification before and after topographic correction

Classification results *before* correction of spectral radiance due to high terrain elevation (image M0) of periods 2010 and 2007 are presented in figures 5a; 5c and table 3. Classification results *after* correction of spectral radiance due to high terrain elevation (image M4) are showed in Figures 5b; 5d and Table 4.

Table 3. Assessment of changes before topographically correcting of original image M0

Original image M0 (2010)			Original image M0 (2007)		Changes
No	Pixel numbers (8242641)	Rate %	Pixel numbers (8242641)	Rate %	Rate %
Class 1	1076608	13.1	811634	9.8	3.3
Class 2	1035085	12.6	994978	12.1	0.5
Class 3	1327478	16.1	1570237	19.0	-2.9
Class 4	1492037	18.1	1918829	23.3	-5.2
Class 5	1383292	16.8	1628037	19.7	-2.9
Class 6	919516	11.2	818066	9.9	1.3
Class 7	1008625	12.2	500860	6.1	6.1

Table 4. Assessment of changes after topographic correction (according to model M4)

Model M4 (2010)			Model M4 (2007)		Changes
No	Pixel numbers (8242641)	Rate %	Pixel numbers (8242641)	Rate %	Rate %
Class 1	787815	9.6	407855	4.9	4.7
Class 2	1000201	12.1	985633	12.0	0.1
Class 3	1676610	20.3	2017470	24.5	-4.2
Class 4	1886631	22.9	2476348	30.0	-7.1
Class 5	1365730	16.6	1514685	18.4	-1.8
Class 6	707173	8.6	499227	6.0	2.6
Class 7	818481	9.9	341423	4.1	5.8

According to Table 3 and Table 4, Table 5 has been established for assessing the variation of change caused by topographic correction. Only in the class 7 is less changes; other classes are the greatest changes.

Table 5. Variation assessment caused by topographic correction

No	Changes after correction (Model M4)	Changes before correction (Model M0)	Varying changes before and after correction of spectral radiance	
(1)	(2) [%]	(3) [%]	(4)=(2)-(3) [%]	(5)=(4)/(3).100% [%]
Class 1	4.67	3.3	1.4	42
Class 2	0.1	0.5	- 0.34	-80
Class 3	-4.2	-2.9	-1.3	45
Class 4	-7.1	-5.2	-1.9	36
Class 5	-1.8	-2.9	1.1	-38
Class 6	2.6	1.3	1.3	100
Class 7	5.8	6.1	-0.3	-5

In order to assess the impact of correcting high terrain elevation effect to spectral radiance, we establish Table 6 and Table 7 of both periods 2007 and 2010. Fluctuations in the smallest value (%) belong to class 2 (0.1%); the largest value belongs to class 4 of period 2007 (table 6). In the period 2010 (table 7), fluctuations in the smallest value belong to class 5 (0.2%); the largest value belongs to class 4.

Table 6. Impact assessment of topographically correcting to image classification of 2007

Original image M0 (2007)			Image M4 (2007)		Value changes of classes (%)
No	Pixel number (8242641)	Rate %	Pixel number (8242641)	Rate %	Rate %
Class 1	811634	9.8	407855	4.9	4.9
Class 2	994978	12.1	985633	12.0	0.1
Class 3	1570237	19.0	2017470	24.5	-5.5
Class 4	1918829	23.3	2476348	30.0	-6.7
Class 5	1628037	19.7	1514685	18.4	1.3
Class 6	818066	9.9	499227	6.0	3.9
Class 7	500860	6.1	341423	4.1	2.0

Table 7. Impact assessment of topographically correcting to image classification of 2010

Original image M0 (2010)			Image M4 (2010)		Value changes of classes (%)
No	Pixel number (8242641)	Rate %	Pixel number (8242641)	Rate %	Rate %
Class 1	1076608	13.1	787815	9.6	3.5
Class 2	1035085	12.6	1000201	12.1	0.5
Class 3	1327478	16.1	1676610	20.3	-4.2
Class 4	1492037	18.1	1886631	22.9	-4.7
Class 5	1383292	16.8	1365730	16.6	0.2
Class 6	919516	11.2	707173	8.6	2.6
Class 7	1008625	12.2	818481	9.9	2.3

Synthesizing Table 6 and 7, Table 8 has been done for integrating assessment of high terrain elevation impact on changing classes (according to % of column 5). The result in table 8 shows: Impacts of rectifying high terrain elevation is strong to class 2 (400%), class 5 (85%) and the smallness only in class 7 (15%).

Table 8. Impact assessment of topographically correcting image to changes of classes

No	Changes of classes (%), 2010	Changes of classes (%), 2007	Varying changes due to impact of topographically correcting	
(1)	(2) [%]	(3) [%]	(4)=(2)-(3) [%]	(5)=(4)/(3).100% [%]
Class 1	3.5	4.9	-1.4	-28
Class 2	0.5	0.1	0.4	400
Class 3	-4.2	-5.5	1.3	-24
Class 4	-4.7	-6.7	2.0	-30
Class 5	0.2	1.3	-1.1	-85
Class 6	2.6	3.9	-1.3	-33
Class 7	2.3	2.0	0.3	15

4. Conclusion

The experimental result of the image SPOT 5 shows:

– The Meyer model (M4) is the appropriate model to correct spectral radiance due to high terrain elevation of the mountain area. Image quality after correction with the model 4 increases 15%.
– Impact of correcting spectral radiance due to high terrain elevation of 7 classes is extremely different; fluctuation is from 15% do 400% (see table 8).
– Varying changes in 7 classes before and after correcting spectral radiance by the model Meyer fluctuate 5% to 100% (table 5).

By visually (figure 3) and statistically (statistical table), we realize the need to correct spectral radiance of optical satellite images due to high terrain elevation effect for image classification and investigation of land surface cover changes. The conclusion is appropriate to research applications done by other authors.

In the study above, there are two related problems as normalization of multi-temporal satellite images and corrections of sensor calibration and atmospheric correction were ignored. If continuous correction of spectral radiance according to both problems noted above, the image quality will be more father improved. Therefore, reliability, accuracy of image classification and also assessment of land cover changes could be improved. These will be contents of continuous researches.

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Radiometryczna korekcja satelitarnego obrazu optycznego dla terenów górzystych w badaniach zmian pokrycia terenu

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Streszczenie

W artykule został przedstawiony wpływ różnicy wysokości terenu na spektralne właściwości optycznego obrazu satelitarnego, pod kątem badania zmian pokrycia terenu. Praca zawiera dwie główne części: korekcję radiometryczną obrazu satelitarnego na terenach wysokogórskich oraz ocenę skutków i zmienności pokrycia terenu przed i po korekcji wpływu wysokości terenu na odbicie spektralne obrazu. Badanie zostało przeprowadzone w obszarach górskich Hoa Binh na podstawie analizy obrazów SPOT5 z lat 2007 i 2010. Wyniki wykazały, że odpowiednim modelem korekcji dla badanego terenu jest model Meyer'a. Wpływ korekcji radiometrycznej wynik klasyfikacji pokrycia terenu (wydzielono 7 klas) waha się od 15% do 400%. Zmiany pokrycia terenu przed i po korekcji wpływu wysokości terenu na odbicie spektralne wahają się od 5% do 100%.