Evaluation of Fusion Techniques on Quickbird-2 Imagery in the region of Kassandra Peninsula, Chalkidiki, Greece

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Abstract: Fusion is utilized to produce images of enhanced spatial detail while preserving the spectral quality of the original MS image. This study compared 6 fusion techniques: Principal Components, Wavelet, Gram-Schmidt, modified Intensity-Hue-Saturation (IHS), High Pass Filter (HPF) and Hyperspherical Colour Space (HCS). They were applied to Quickbird-2 data, which was acquired over the area of Kassandra peninsula in Chalkidiki. The results were evaluated qualitatively with visual inspection and quantitatively with statistical analysis. All techniques were effective; the HPF and the HCS gave the best results, following modified IHS, Gram-Schmidt and PCA, while the Wavelet technique created distortion in the fused image.

1. Introduction

Fusion is a widely used procedure in remote sensing applications, because it facilitates extracting more information from satellite imagery. This is largely due to the complementary nature of many image datasets (Chavez et al., 1991).

Panchromatic images contain more spatial information, while multispectral ones contain more spectral information. Fusion combines spatial content from the former and spectral content from the latter into one fused image, which is better interpretable than the original images and thus more useful to various applications. Therefore many scientists have been involved so far with the development and implementation of different fusion techniques (Chavez et al., 1991; King & Wang, 2001; Siddiqui, Y. 2003; Han et al., 2008; Padwick et al., 2010 etc).

In this study 6 different fusion techniques, among them also some of the most recent ones (High Pass Filter and Hyperspherical Colour Space), were applied to a set of Quickbird-2 imagery, including rural, coastal and semi-urban areas, villages and to a large extent forest.

2. Study area

The study area is located in Chalkidiki, in Central Macedonia, Northern Greece. More specifically, it is situated in the broader region of the Kassandra peninsula. It includes the tourist town Pefkochori and the villages Paliouri and Agia Paraskevi. In Figure 1 the study area is pointed out and the corresponding multispectral image used is shown.

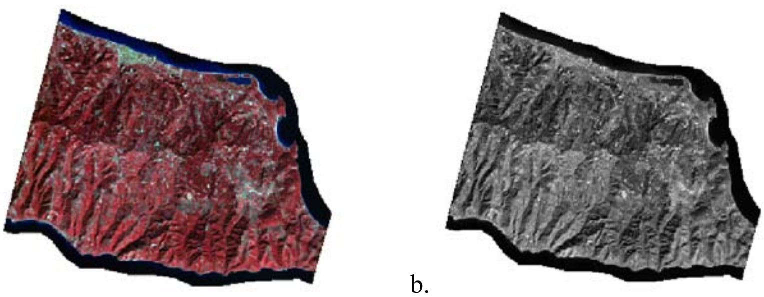
The area is characterized by the forest tree species of Aleppo pine (*Pinus halepensis*). The structure of the forest stands is of the same age due to fire. But there also exists irregular structure, having its origins to irregular loggings and grazing. Its climate is typical Mediterranean, consisting of mild winters and dry hot summers (Tsitsoni, 1991).

Figure 1. *The geographical location of the study area. Satellite imagery extent is marked and the multispectral Quickbird-2 image is presented above the arrow. The study area is a part of the Kassandra peninsula, the first peninsula of Chalkidiki.* *© Google Earth, Copyright 2015.*

3. Remote sensing data

3.1. Satellite imagery dataset

Two Quickbird-2 images, one multispectral with 2.4 m spatial resolution and one panchromatic with 0.6 m spatial resolution were used in this study (Figure 2). They



a. b.

Figure 2. *The Quickbird-2 dataset: a) the multispectral image of 2.4 m spatial resolution, RGB combination = Bands 4/3/2, b) the panchromatic image of 0.6 m spatial resolution.*

were captured on 17-01-2004 with an off nadir view angle of 10.6°. They were in UTM projection, zone 34, WGS84 ellipsoid and WGS84 geodetic datum.

3.2. DEM (Digital Elevation Model)

The DEM used in this study was supplied by the Greek National Cadastre and Mapping Agency. Separate files in .adf format were provided, that were mosaicked into one file in the ArcGIS 10 environment (Figure 3). The coordinate system of the DEM was the Hellenic Positioning System (HEPOS). The HEPOS was designed and implemented by the Greek National Cadastre and Mapping Agency (Greek National Cadastre and Mapping Agency, 2009).

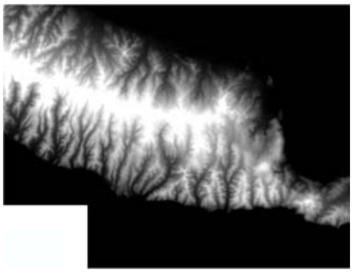


Figure 3. *The DEM (after mosaicking of the separate files).*

4. Preprocessing

4.1. DEM Preprocessing

For the transition from the HEPOS coordinate system to the GGRS87 (Greek Geodetic Reference System or else EGSA87) coordinate system, the affine transformation was utilized (Patias, 1991). The points selected for the transformation were located at the corners of the DEM image (6 points). The EGSA87 coordinates used in the transformation were calculated with the 'HEPOS Transformation Tool' software, which was developed by the Greek National Cadastre and Mapping Agency (KTIMATOLOGIO S.A.) in collaboration with AUTH (URL 1). This software is freely available from May of 2009 (Gianniou, 2010). The total RMS (Root Mean Square) error of the transformation was 0.01 m.

4.2. Quickbird-2 Orthorectification

Image orthorectification is an essential preprocessing step, especially when information extraction is intended, because through this procedure errors due to terrain, sensor geometry and satellite orientation are corrected (Patias, 1991; Tsakiri, 2002). For the orthorectification of the Quickbird-2 imagery, the DEM supplied by the Greek National Cadastre and Mapping Agency was used (after its transformation in the EGSA87 coordinate system). The horizontal coordinates of the control and check points used in the orthorectification were acquired from the webpage of the KTIMATOLOGIO S.A. through the Orthophotos Viewing Service (URL 2). Their vertical coordinates were acquired from the DEM (Figure 3). 20 control points and 10 check points were utilized, which were distributed throughout the image. For the multispectral image the Root Mean Square Error (RMSE) was 0.60 m for the control points and 0.56 m for the check points, while for the panchromatic image the RMSE was 0.35 m for the control points and 0.36 m for the check points. After the orthorectification, the Quickbird-2 images were in GGRS87 (or else EGSA87) coordinate system.

5. Fusion Techniques

In this section the fusion techniques applied in the present study are presented and analyzed.

Principal Component Analysis (PCA): The PCA fusion technique uses the PCA transformation on the multispectral image. The panchromatic image is then scaled to the same data range as the first PCA band of the multispectral image and substitutes this band (PCA-1). Then, an inverse PCA transformation is applied in order to produce the fused image (Chavez et al., 1991; Welch &Ehlers, 1987).

Wavelet: The algorithm embedded in ERDAS Imagine 2013 software was implemented. This algorithm is a modification of the work of King &Wang (2001) with extensive input from Lemeshewsky (1999; 2002). The image processing with wavelets is similar to the Fourier analysis. The panchromatic image is decomposed to a high-pass component, containing the spatial detail, and a low-pass image component, containing the spectral information. The Fourier transformation uses long continuous waves as the basis, while the wavelet transformation uses short and discrete wavelets instead. These components are used to create new images of lower spatial resolution through a wavelet decomposition process iteratively, until the spatial resolution of e.g. 2.4 m (in the current study). Then, the 2.4 m low-pass component is replaced by the 2.4 m multispectral image. A reverse wavelet decomposition process follows, during which the high-pass components from the forward decomposition procedure are utilized, in order to gain the high spatial information of the panchromatic image and the spectral of the MS image (ERDAS, 2013).

Modified Intensity-Hue-Saturation (modIHS): This tool provides an implementation of a modification of the traditional IHS method for fusing multispectral and panchromatic images proposed in (Siddiqui, 2003). In traditional approaches only 3 bands can be processed at a time, as a result of using the RGB to IHS transformation. In this modified approach, more than 3 bands can be merged by running two passes of the algorithm and merging the selected bands to the output image. Generally, it works best when there is a significant overlap of the wavelengths between the multispectral bands and the panchromatic band (ERDAS, 2013).

Gram-Schmidt: The Gram-Schmidt fusion algorithm uses the spectral response function of a given sensor to estimate what the panchromatic data looks like. In the ENVI software, the Gram-Schmidt fusion is performed by simulating a panchromatic band from the multispectral bands. Then, a Gram-Schmidt transformation is performed on the simulated panchromatic band and the multispectral bands, where the simulated panchromatic band is used as the first band. Then the panchromatic band is swapped with the first Gram-Schmidt band. At last, the inverse Gram-Schmidt transformation is utilized to form the final fused image (ENVI, 2007).

High Pass Filter (HPF): For the High Pass Filter (HPF) fusion the algorithm by Ute Gangkofner of Geoville, Inc. and Derrold Holcomb of ERDAS, Inc. was utilized. It involves a convolution using a High Pass Filter (HPF) on the high resolution data, reducing the lower frequency spectral information of the high spatial resolution image (Han et al., 2008). The multispectral image is resampled to the pixel size of the high resolution image using a bilinear algorithm. Then the filtered image and the MS image are added to produce one image, combining the spatial information of the PAN image with the multispectral information of the MS image (ERDAS, 2013).

Hyperspherical Colour Space (HCS): The HCS algorithm that is presented in (Padwick et al., 2010) and is embedded in ERDAS Imagine 2013 software was implemented in this study. It was developed for the 8-band data of the Worldview-2, but it performs with all multispectral data with 3 or more bands. The image data is transformed from the native colour space to the hyperspherical colour space. This transformation between the native colour space and the hyperspherical colour space follows the standard definition of transformation between n-dimensional Cartesian space and n-dimensional hyperspherical space (ERDAS, 2013; Padwick et al., 2010).

6. Evaluation-Results-Discussion

The results were evaluated both qualitatively and quantitatively. For the former evaluation, visual comparison was applied in RGB combinations of 3/2/1 bands (natural colour) and 4/3/2 bands (colour infrared) (Figures 4-6).

For the quality assessment of the fused image, some quantitative measures have to be examined (Wald et al., 1997), thus statistical analysis was carried out to control how much identical the both images are (MS and fused).

Prior to the statistical evaluation, the necessary radiometric balance was attained between the compared images (MS and fused ones) through histogram matching. Also, the proper spatial degradation of the fused images to the spatial resolution of the MS image was carried out (Wald et al., 1997; Tsakiri et al., 2002).

The statistical measures: (a) correlation coefficient, (b) mean and (c) variance for the MS image before and after fusion and (d) standard deviation of the difference image (MS image - fused image) were used in the statistical evaluation.

The correlation coefficient expresses the closeness between two images. It ranges from +1 (best performance) to -1. It was calculated between the bands of the fused images and the bands of the original MS image. The correlation coefficient between the bands of the same image was also calculated for the MS and the fused bands. It is important that the MS image maintains the internal balance of the correlation coefficient values between its bands after fusion, so that its spectral content is more close to the original image (Stournara, 2005). Thus the correlation coefficient between the bands of the same image prior to and after fusion was examined.

The mean of the MS and the fused image should be identically 0. The relative mean difference to the original MS mean was examined. The difference in variance between the MS and the fused image (MS image – fused image) expresses the amount of information that is gained or lost through the fusion process and should be identically 0. The relative difference of the variance to the original MS image was utilized. The standard deviation generally expresses the error at pixel level. The identical value is 0 (Tsakiri et al., 2002; Karathanassi et al., 2007).

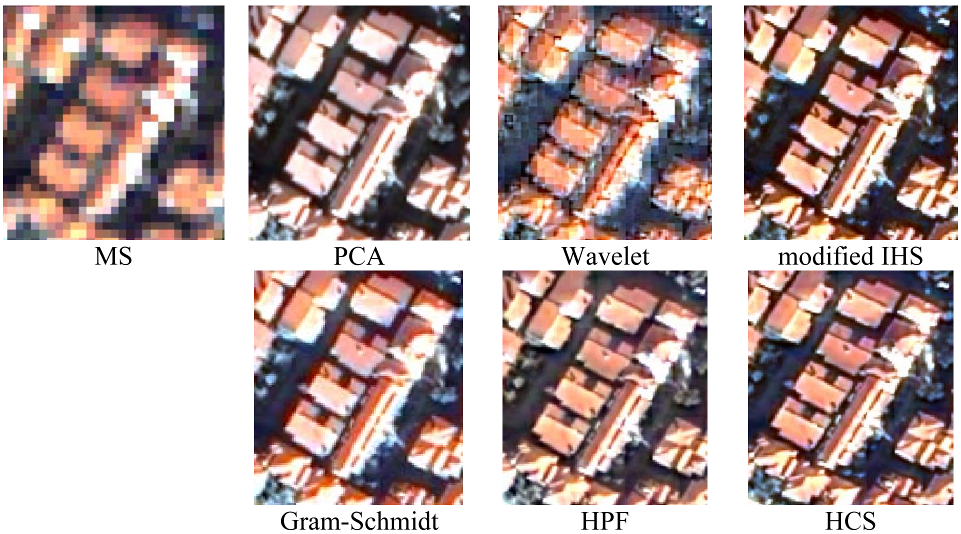


Figure 4. *Results from the 6 fusion techniques applied. A subset of the image depicting a semi-urban region is displayed in natural colour (RGB: 3, red / 2, green / 1, blue).*

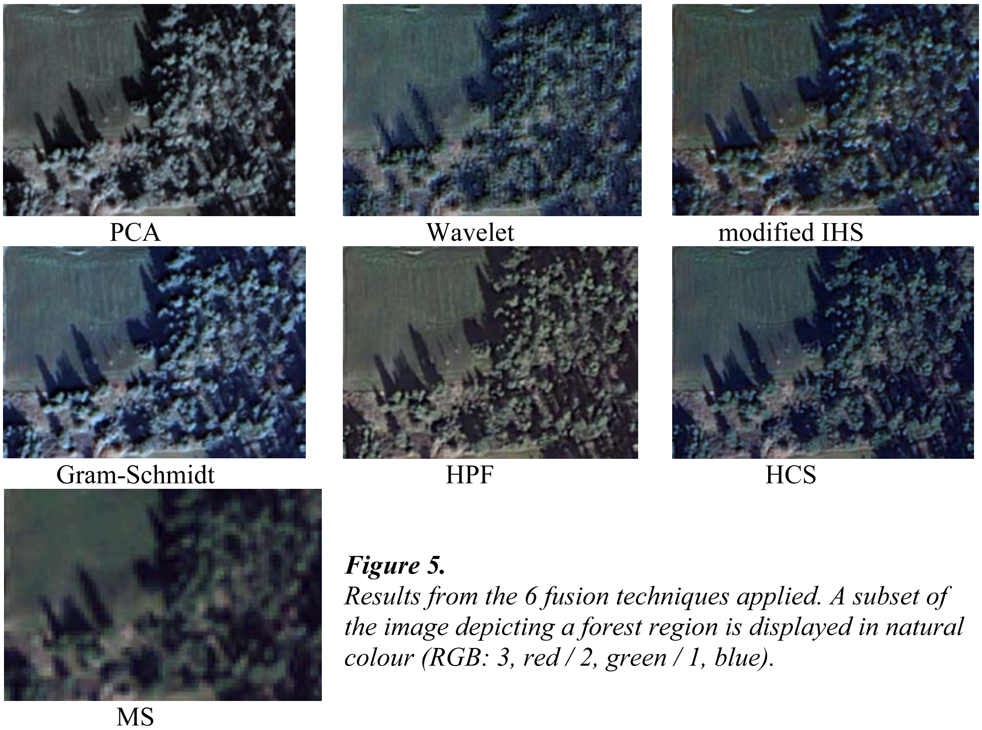


Figure 5.
Results from the 6 fusion techniques applied. A subset of the image depicting a forest region is displayed in natural colour (RGB: 3, red / 2, green / 1, blue).

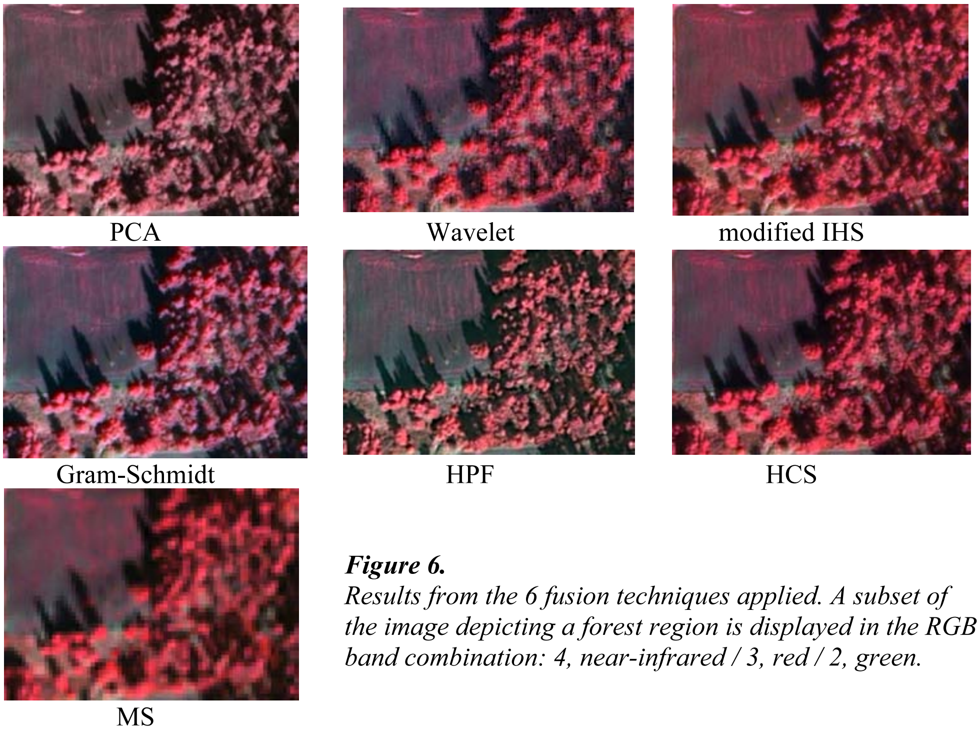


Figure 6.
Results from the 6 fusion techniques applied. A subset of the image depicting a forest region is displayed in the RGB band combination: 4, near-infrared / 3, red / 2, green.

In the 3/2/1 RGB combination of the PCA image (Figure 4), the colours of the roofs seem to be lighter than the original colours. The Wavelet image preserves well the original colours of the roofs, but presents distortion, while the rest of the fused images are better. The colours of the roofs in the Gram-Schmidt image seem to be a little more intense than the original ones. The colours of the roofs in the HCS image seem to be a little better than those of the HPF. But the HPF image is better in the colour of the trees· it is more green.

In the 3/2/1 RGB combination (Figure 5) the HPF method preserved better the green colour of the MS image. The PCA image presented fainter colours for the vegetated area compared to the original colours of the MS image. The Wavelet method created distortion in the fused image, which was more blur in the forested region than in the rest vegetated area of the image. The Gram-Schmidt image presented somewhat lighter colours than the MS image. The modified IHS and the HCS methods presented good results with colours close to the original ones, but turning in a mixed blue-green colour at some pixels, this fact being more intense in the modified IHS fused image.

In the 4/3/2 RGB combination (Figure 6) the colours of the vegetation in the modified IHS, the HCS and the Wavelet images seem to be more close to the original

Table 1. *The correlation coefficient values between the bands of the same image (for the original MS image and all the fused images). The first column (underlined values) is displayed in the diagram of Figure 7.*

Fusion Techniques	Bands		1	2	3	4	Bands	1	2	3	4
		MS					**MS**				
	1	**MS**	1.00				**MS**	1.00			
	2		0.95	1.00				0.95	1.00		
	3		0.88	0.95	1.00			0.88	0.95	1.00	
	4		0.42	0.58	0.60	1.00		0.42	0.58	0.60	1.00
		PCA					**Wavelet**				
	1	**PCA**	1.00				**Wavelet**	1.00			
	2		0.98	1.00				0.95	1.00		
	3		0.95	0.98	1.00			0.86	0.95	1.00	
	4		0.77	0.82	0.78	1.00		0.39	0.57	0.58	1.00
		modified IHS					**Gram-Schmidt**				
	1	**mod IHS**	1.00				**Gram-Schmidt**	1.00			
	2		0.93	1.00				0.96	1.00		
	3		0.83	0.94	1.00			0.88	0.96	1.00	
	4		0.50	0.67	0.65	1.00		0.61	0.65	0.55	1.00
		HPF					**HCS**				
	1	**HPF**	1.00				**HCS**	1.00			
	2		0.97	1.00				0.95	1.00		
	3		0.91	0.96	1.00			0.87	0.95	1.00	
	4		0.49	0.63	0.63	1.00		0.44	0.60	0.60	1.00

ones (MS image). The disadvantage of the Wavelet method is that it presents distortion. Then follow the Gram-Schmidt, the HPF and the PCA images. The HPF image has apparently very good texture· the trees are well distinguished.

The correlation coefficient values between the bands of the same image showed that the HCS image is more close to the original MS image (Table 1 and Figure 7). This means that the HCS image preserves better the internal balance between its bands. Figure 7 shows the values of the correlation coefficient between the 1st band and the 4 bands of every image.

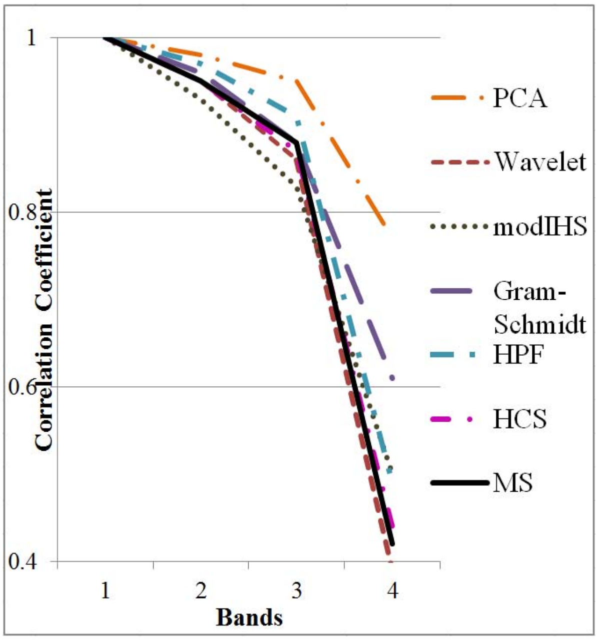


Figure 7.
The internal relationship of the MS image bands before and after fusion. The diagram shows the correlation coefficient values between the 1st band and the 4 bands of the same image (MS and all the fused images, PCA, Wavelet, modified IHS etc). It depicts part of the results shown in Table 1 (underlined values). As it can be seen, the one closest to the original MS image is the HCS fused image.

The values of the correlation coefficient (Table 2) were higher for the Wavelet, the HCS and the HPF methods, with the Wavelet method being the best. The PCA, the modified IHS and the Gram-Schmidt methods were almost equal, with the 1st band presenting the worst results.

The results for the relative mean were almost equal, except for the 4th band of the Gram-Schmidt image, which was worse. In the criterion of the relative variance, the HPF image was better than all, as it showed the lowest values in all bands (Table 3). The results for the standard deviation of the difference image were better for the Wavelet method as it had significantly lower value in the 4th band compared to the other fused images. Second one was the HCS image. The modified IHS image and the Gram-Schmidt image were also good, with the modified IHS presenting lower values.

Table 2. *The correlation coefficient values between the bands of the original MS image and the fused images.*

			Multispectral (MS)			
		Bands	**1**	**2**	**3**	**4**
Fusion Techniques	**PCA (Principal Components Analysis)**	**1**	**0.86**	0.90	0.88	0.67
		2	0.85	**0.93**	0.92	0.73
		3	0.84	0.93	**0.96**	0.68
		4	0.50	0.67	0.69	**0.97**
	Wavelet	**1**	**0.95**	0.91	0.84	0.41
		2	0.93	**0.98**	0.94	0.58
		3	0.87	0.94	**0.99**	0.59
		4	0.41	0.58	0.59	**1.00**
	modified IHS (modIHS)	**1**	**0.85**	0.84	0.79	0.45
		2	0.89	**0.95**	0.92	0.62
		3	0.85	0.93	**0.98**	0.61
		4	0.43	0.60	0.62	**0.98**
	Gram-Schmidt	**1**	**0.82**	0.84	0.80	0.62
		2	0.89	**0.93**	0.90	0.67
		3	0.91	0.94	**0.96**	0.58
		4	0.45	0.54	0.48	**0.97**
	High Pass Filter (HPF)	**1**	**0.95**	0.93	0.86	0.46
		2	0.91	**0.96**	0.92	0.60
		3	0.85	0.92	**0.96**	0.60
		4	0.41	0.57	0.59	**0.97**
	Hyperspherical Color Space (HCS)	**1**	**0.93**	0.90	0.84	0.43
		2	0.93	**0.98**	0.94	0.59
		3	0.87	0.94	**0.99**	0.59
		4	0.41	0.58	0.59	**0.99**

7. Conclusions

In this study 6 fusion techniques were compared. The results were satisfactory, as the fused images preserved well the spatial and the spectral information of the original images. Based on the optical and the statistical evaluation results, the HPF, the HCS, the modified IHS and the Gram-Schmidt methods were better. The HPF image preserved better the green colour of the vegetation, while in the statistical evaluation the HCS image was better. The Gram-Schmidt and the modified IHS were also very remarkable.

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Table 3. *Other statistic results for the fused images.*
* *Difference (dif.) image of the fused image from the multispectral image.*

Fusion Technique	Bands	Relative Mean	Relative Variance	Standard deviation of the dif. * image
PCA	**1**	0.03	0.20	7.534
	2	0.02	0.12	10.707
	3	0.04	0.10	8.278
	4	0.02	0.08	17.976
Wavelet	**1**	0.02	0.30	4.901
	2	0.03	0.12	6.497
	3	0.05	0.07	5.579
	4	0.02	0.08	8.932
modIHS	**1**	0.02	0.37	7.209
	2	0.03	0.14	9.309
	3	0.05	0.06	6.294
	4	0.02	0.08	15.964
Gram-Schmidt	**1**	0.02	0.31	7.942
	2	0.03	0.17	10.822
	3	0.05	0.09	7.790
	4	-0.14	0.36	16.031
HPF	**1**	0.02	0.16	4.600
	2	0.02	0.14	8.542
	3	0.05	0.15	8.926
	4	0.02	0.15	19.814
HCS	**1**	0.02	0.38	5.631
	2	0.02	0.18	7.238
	3	0.06	0.07	5.839
	4	0.02	0.06	12.132

References

Chavez, P.S., Sides, S.C., and Anderson, J.A., 1991. *Comparison of Three Different Methods to Merge Multiresolution and Multispectral Data: Landsat TM and SPOT Panchromatic.* Photogrammetric Engineering & Remote Sensing, 57 (3): 295-303.

ENVI, 2007. *ENVI 4.4 On-Line User's Guide*. Research Systems, Inc.

ERDAS, 2013. *ERDAS 2013 On-Line Field Guide*. Intergraph Corporation, USA.

Gianniou, M., 2010. *Network Techniques of HEPOS-Transformation between HTRS07 and GGRS87 (Greek Geodetic Reference System87 or else EGSA87).* Presentation of Technical Chamber of Greece-Regional Section of Central Macedonia in "I cycle short term Terminals: National Cadastre", Thessaloniki, Greece.

Greek National Cadastre and Mapping Agency, 2009. *General information on HEPOS.* http://www.hepos.gr/ (March 2015)

Karathanassi, V., Kolokousis, P., Ioannidou, S., 2007. *A comparison study on fusion meth-*

ods using evaluation indicators. International Journal of Remote Sensing, Vol. 28 (10): 2309-2341.

King, R. and Wang, J., 2001. *A Wavelet Based Algorithm for Pan Sharpening Landsat 7 Imagery.* Proceedings of the Geoscience and Remote Sensing Symposium, IGARSS, Vol. 2, pp. 849-851.

Lemeshewsky, G.P., 1999. *Multispectral multisensor image fusion using wavelet transforms*. In: S. K. Park and R. Juday (Editors), Visual Image Processing VIII, Proceedings SPIE, Vol. 3716, pp. 214-222.

Lemeshewsky, G.P., 2002. *Multispectral Image sharpening Using a Shift-Invariant Wavelet Transform and Adaptive Processing of Multiresolution Edges.* In: Z. Rahman and R.A. Schowengerdt (Editors), Visual Information Processing XI, Proceedings SPIE, Vol. 4736, pp. 189-200.

Padwick, C., Deskevich, M., Pacific, F., and Smallwood, S., 2010. *WorldView-2 Pan-Sharpening.* Paper presented at 2010 Conference of American Society for Photogrammetry and Remote Sensing (ASPRS), San Diego, California.

Patias, P., 1991. *Introduction to Photogrammetry*. Ziti Publications Co., Thessaloniki, Greece, (in Greek), 346 pp.

Siddiqui, Y., 2003. *The Modified IHS Method for Fusing Satellite Imagery.* Proceedings of the ASPRS 2003 Annual Conference, Anchorage, Alaska.

Stournara, P., 2005. *The mapupdate procedure of topographic maps of 1:5000 scale of the Army Geographic Service with a synthetic (pansharpened) image of very high spatial resolution of Quickbird satellite*. Bachelor Dissertation, Aristotle University of Thessaloniki, (in Greek), 120 pp.

Tsakiri-Strati, M., 2004. *Remote Sensing-Academic Lectures*. AUTH Publishing Service, (in Greek), 180 pp.

Tsakiri-Strati, M., Papadopoulou, M. and Georgoula, O., 2002. *Fusion of XS SPOT4 and PAN SPOT2 images and assessment of the spectral quality of the products.* Scientific Journal of the Technical Chamber of Greece, Section A, 22 (3): 9-22.

Tsitsoni, T., 1991. *Stand structure and conditions determining natural regeneration after fire in the Allepo pine forests of Kassandra peninsula (Chalkidiki, Greece).* Ph.D. Dissertation, Aristotle University of Thessaloniki, (in Greek), 144 pp.

Wald, L., Ranchin, Th., Mangolini M., 1997. *Fusion of Satellite Images of Different Spatial Resolutions: Assessing the Quality of Resulting Images.* Photogrammetric Engineering & Remote Sensing, 63 (6): 691-699.

Welch, R., and Ehlers, W., 1987. *Merging Multiresolution SPOT HRV and Landsat TM Data.* Photogrammetric Engineering & Remote Sensing, 53 (3): 301-303.

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URL 1: http://www.hepos.gr, Retrieved 5-2015

URL 2: http://gis.ktimanet.gr/wms/ktbasemap/default.aspx, Retrieved 5-2015