Coastline extraction using high resolution WorldView-2 satellite imagery

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Abstract
The aim of this paper is to remark possibilities to use WorldView-2 imagery for coastline extraction. Applications are conducted on a Phlegrean area in the Campania Region (Italy): the considered range of coastline is particularly interesting because it shows two typologies of shoreline including reefs interspersed with segments of sandy beach. Two indices are used: Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). To enhance geometric resolution of the results pan-sharpening is applied so as to obtain maps with the same pixel dimensions of the panchromatic data. To solve the problem of thresholds determination that typically affects the classification, Maximum Likelihood method based on training sites is adopted to distinguish bare soil and sea water. Best results are given by NDWI and, comparing the resultant coastline with that obtained with visual interpretation of images, shifts of less than 1 m outcome from pan-sharpened data.

Keywords: WorldView-2 images, coastline, NDVI, NDWI.

Introduction
Recently, VHR (Very High Resolution) images, due to both reduced dimensions of pixel and also to the availability in different acquisition bands, have had major success in many application fields of remote sensing for objects identification and contouring. The launch of IKONOS in September 1999 and QuickBird in October 2001 gave birth to a new age; as a matter of fact, VHR satellites are able to capture images of the earth’s surface with a Ground Sample Distance (GSD) of 1 m and even less [Aguilar et al., 2013]. Recently cell size of 50 centimeters has been achieved for panchromatic data, such as in the cases of GeoEye-1 [GeoEye, 2013] and WorldView-2 [DigitalGlobe, 2013a].

The very small dimensions of pixels supply geometric accuracy for contouring objects while the availability of different layers of the same area, each concerning the reflectance in a specific spectral band, allows better identification of spectral signature and consequently a higher thematic accuracy. Several applications have been carried out in order to detect coastline from satellite images, but for automatic extraction it is necessary to consider their geometric resolution [Puissant et al., 2008]. If defined as the intersection of land and water...
Coastline extraction can be easily extracted from low and medium resolution satellite images only by using spectral information because of the different nature (and signature) of the two neighboring elements. In case of in-deep studies, coastline is very difficult to map because of its dynamic nature that yields different results as related inherent to the moment of acquisition: shoreline shifts may be observed along a day due to tidal fluctuations, being especially large for steep slope beaches located at macro-tidal areas [Aguilar et al., 2010]. On the other side differences are introduced in consideration of geomorphologic units: for sandy beaches and wetlands, the coastline is the vegetation limit; for soft rock cliffs, it is the foot of the hill-slope while for hard rock cliffs, the coastline is the top of the cliff [Puissant et al., 2008].

Coastline extraction is fundamental for many studies. IKONOS images, for instance, are used in coastal erosion studies [Basile et al., 2011]: by means of panchromatic data (geometric resolution: 1 m x 1 m) and multispectral data (geometric resolution: 4 m x 4 m) coastline can be identified with great accuracy [Guastaferro et al., 2011], but more accurate results can be achieved with WorldView-2 images because of their smaller pixel dimensions and higher number of bands [Baiocchi et al., 2012]. To reach this goal VHR images are usually pansharpened, orthorectified and managed in an object-oriented environment [Palazzo et al., 2012].

In this paper the attention was focused on the extraction of instantaneous coastline, as identified in the WorldView-2 imagery without considering tide. The shoreline identification was based on grouping all the pixels from the imagery into three contrasting classes: sea, land and vegetation. The groups were achieved using two indices, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). The attention was focused on the different spectral reflectance of water compared with that of rocks as well as sandy beaches. For these, because of the anthropized nature, the identification of vegetation tracks would be misleading, so the only separation between sea and sands was considered for coastline extraction. NDVI and NDWI have been used frequently for water body mapping, but the most part of their application concern medium and low resolution images. NDWI was introduced by McFeeters [1996] to difference land surface water and vegetation in Landsat TM images and modified by Xu [2006] that changed the combination of the bands. NDVI and NDWI are frequently used to map surface water body in Landsat TM and ETM+ images and adaptations of them for other sensor data are common in literature. CIWI (combined index of NDVI and NIR) was introduced by [Mo et al., 2007] for MODIS images. An integration of NDVI and NDWI was proposed by [Lu et al., 2011] for images acquired by HJ-1A and HJ-1B, China’s two small environment satellites with on-board CCD cameras that have four bands including blue, green, red, and near-infrared spectrum, a spatial resolution of 30 m and the spectral range of 0.43 µm – 0.9 µm.

In this context potential and limits of NDVI as well as NDWI for shoreline extraction from VHR images such as WorldView-2 are investigated considering applications on the Phlegrean area in the Campania Region (Italy). The attention is focused on the possibility to enhance geometric accuracy of results using pan-sharpened data, so to extract coastline from images with cell size of 50 cm rather than 2 m. The paper is organized as follows. In Section 2 the main characteristics of used WorldView-2 imagery and methodological aspects are resumed, distinguishing pre-elaboration actions (geometric correction and pan-sharpening) and NDVI as well as NDWI applications. In section 3 results are compared and discussed. Section 4 ends the paper with the generalization of the results.
Data and Methods

WorldView-2 imagery

WorldView-2 satellite has a sun-synchronous orbit at 770 km with an inclination of 97.2° and was launched on October 8, 2009 from Vandenberg Air Force Base in California. WorldView-2 has a revisit time of 1.1 days at 1 m GSD or less and of 3.7 days at 20° off-nadir or less (0.52 m GSD). Main characteristics of this satellite are reported in Table 1.

Table 1 - Datasheet WorldView-2 satellite.

| Parameter                     | Value                                                                 |
|-------------------------------|----------------------------------------------------------------------|
| Launch date                   | 8 October 2009                                                       |
| Orbit altitude                | 770 km                                                               |
| Orbit type                    | Sun-synchronous (10:30 am-descending orbit)                          |
| Inclination orbit             | 97.2°                                                                |
| Orbital period                | 100 min                                                              |
| Swath (nadir)                 | 16.4 km                                                              |
| Acquisition mode              | Synchronous                                                          |
| Revisitation period           | 1.1 days (GSD 1 m)                                                   |
| Revisitation period (nadir)   | 14 days                                                              |

On board of satellite WorldView-2 two types of sensors are available (both with a swath width of 16.4 km at nadir) and respectively give multispectral images with pixel dimensions 1.84 m × 1.84 m at nadir and panchromatic (Pan) images 0.46 m × 0.46 m at nadir. The first type offers spectral resolution better than the second; the second offers spatial resolution better than the first. Radiometric resolution for both is 11 bits with a range of brightness values (BVs) from 0 to 2047. WorldView-2 images are distributed with resolution of 0.50 m (Pan) and 2.0 m (multispectral) [DigitalGlobe, 2013a]. Main characteristics of these images are reported in Table 2. The Relative Spectral Radiance Response of the sensors is reported in Figure 1. According to its manufacturer, WorldView-2 images offer great potential because of their higher geometric resolutions and number of bands: when looking at land classes, WorldView-2 is expected to deliver an increase of up to 30% in the classification accuracy compared with traditional Visible to Near InfraRed (VNIR) imagery overall; specifically, the ability to classify roads was shown to improve from around 55% to over 80%; the classification of water bodies is expected to improve from 85-90% with traditional data to between 95-98% with WorldView-2 [DigitalGlobe, 2010]. On the benefits that the additional Coastal, Yellow, Red-Edge and NIR-2 bands can provide, several studies are available in literature. In one of them WorldView-2 was compared with QuickBird-2-simulated imagery regarding their potential for object-based urban land cover classification: two datasets were created, one with all (eight) WorldView-2 bands and another one with only the four bands also available in the QuickBird-2 sensor; in 10 out of 16 classifications, higher Kappa values were achieved when features related to the additional bands of the WorldView-2 sensor were also considered; in most cases, classifications carried out with the 8-band-related features gave less complex and more efficient models than those given only with QuickBird-2 band-related features [Novack et al., 2011].
Figure 1 - The Relative Spectral Radiance Response of the WorldView-2 panchromatic and multispectral sensors.

Table 2 - Characteristics of WorldView-2 images.

| Bands   | Spectral Range (µm) | Spatial Resolution (m) | Dynamic Range (bits) |
|---------|---------------------|------------------------|----------------------|
| Coastal | 0.400 - 0.450       |                        |                      |
| Blue    | 0.450 - 0.510       |                        |                      |
| Green   | 0.510 - 0.580       | 1.84                   | 11                   |
| Yellow  | 0.585 - 0.625       |                        |                      |
| Red     | 0.630 - 0.690       |                        |                      |
| Red-Edge| 0.705 - 0.745       |                        |                      |
| NIR1    | 0.770 - 0.895       |                        |                      |
| NIR2    | 0.860 - 0.940       |                        |                      |
| PAN     | 0.450 - 0.800       | 0.46                   |                      |

Positive evaluation of WorldView-2 data was provided for other applications, such as biomass estimation, once again recognizing the relevance of the four additional bands and the higher spatial resolution, but identifying the main drawback of the sensor in the lack of a middle-infrared band [Eckert, 2012]. For this application a complete set of WorldView-2 imagery (panchromatic as well as multispectral data) acquired on 03/24/2012 and concerning the Phlegrean area (municipality of Pozzuoli, West of Naples), already radiometrically corrected and geo-referenced in UTM-WGS84, was used. The whole scene includes Cratere of Astroni, a natural reserve protected by the World Wildlife Fund (WWF) and situated on the western bound of the city of Naples between the ancient road Campana and the plain of Agnano [Maglione et al., 2013a]. The imagery contains a range of coastline that is formed by reefs interspersed with segments of sandy beach. The territorial framework of the considered area is reported in Figure 2.
Pre-elaboration: geometric correction

The WorldView-2 dataset was supplied by the vendors as *Ortho Ready Standard* product [DigitalGlobe, 2013b]: it was already projected to a plane using a map projection (UTM, *Universal Transverse of Mercator*) and datum (WGS84), projected to a constant base elevation (calculated on the average terrain height established for the area of interest). In other terms, the dataset was not ortho-rectified in the photogrammetric sense, so geo-location errors were present. To establish the planimetric accuracy of the whole scene, 30 *Check Points* (CPs) easily distinguished on the Pan image as well as on orthophotos of Campania Region at scale 1:2,000 (pixel dimensions: 20 cm x 20 cm) of the same area were considered: planimetric differences between rigorous cartographic and effective coordinates presented RMS = 37.53 m (Tab. 3). Of course, this positional accuracy is not acceptable considering the geometric resolution of the images and possible applications for in-deep studies.

| Table 3 - Residuals (in meters) obtained for Check Points before RPFs application. |
|---------------------------------------------------------------|
| Mean (m) | Min (m) | Max (m) | St. dev. (m) | RMS (m) |
| CPs: 30 | 29.149 | 1.497 | 87.992 | 23.632 | 37.525 |
To correct geometric distortions of WorldView-2 satellite imagery, *Rational Polynomial Functions* (RPFs) [Tao and Hu, 2000; Toutin et al., 2001] were used. However the imagery was supplied by the provider with *Rational Polynomial Coefficients* (RPCs) that were generated considering the position of the satellite at the time of data capture [Parcharidis et al., 2005]. For rectification was used the tool OrthoEngine of PCI Geomatics software, that permits the user to introduce *Ground Control Points* (GCPs) to improve coefficients calculation and generally good results are achieved with a small number (10-15) of points [Maglione et al., 2013b]. In this case, because of the variable morphology and in according with analogous situation for the same area [Maglione et al., 2014], a considerable level of accuracy were obtained without original RPCs using 130 GCPs (Fig. 3).

![Figure 3 - WorldView-2 pan image with 130 GCPs (red) and 30 CPs (green) for RPFs application.](image)

In Table 4 statistic values (maximum, minimum, mean, standard deviation, RMS) of the residual errors obtained for GCPs and CPs in XY direction are reported.

|        | Mean (m) | Min (m) | Max (m) | St. dev. (m) | RMS (m) |
|--------|----------|---------|---------|--------------|---------|
| GCPs: 130 | 0.585    | 0.085   | 0.974   | 0.206        | 0.620   |
| CPs: 30   | 1.193    | 0.816   | 1.569   | 0.200        | 1.210   |
Pan-sharpening application
Coastline extraction based on applications of NDVI or NDWI requires multispectral images that in the case of WorldView-2, likewise the other satellite dataset, are characterised by greater dimensions of pixels and smaller width of band than the panchromatic ones. In other terms, coastline can be extracted with resolution of 2 m rather than 0.5 m. However, to exceed this limit, geometric resolution of panchromatic data can be transferred to multispectral ones using pan-sharpening [Parente and Santamaria, 2014]. In this way more detailed images are derived and can be used for more accurate coastline detection. A large number of pan-sharpening methods are present in the literature of the last two decades: one of them named Zhang method [Zhang, 1999] and implemented in the software Focus by PCI Geomatics Enterprise was applied in this study because of its considerable level of performance (Fig. 4).

Figure 4 - Comparison among: panchromatic (0.5 m x 0.5 m) image (Pan), multispectral (2 m x 2 m) true color composition (RGB) and pan-sharpened (0.5 m x 0.5 m) true color composition (R’G’B’).
To establish the quality of results, in accordance with traditional approaches in literature for evaluation of pan-sharpening application [Parente and Santamaria, 2013], in addition to the Correlation Coefficients ($\rho$) between original and derived images also the Relative Dimensionless Global Error in Synthesis was considered. Introduced by [Wald, 2000], this index is better known as ERGAS, abbreviation of Erreur Relative Globale Adimensionnelle de Synthèse and is supplied by the following formula:

$$\text{ERGAS} = 100 \frac{h}{l} \sqrt{\frac{1}{K} \sum_{k=1}^{K} \left( \frac{\text{RMSE}(k)}{\mu(k)} \right)^2} \quad [1]$$

where,

- $h/l$ is the ratio between pixel sizes of Pan and original multispectral images;
- $\text{RMSE}(k)$ is the Root Mean Square Error of the k-th band;
- $\mu(k)$ is the mean of the k-th band.

Because in the ideal case $\text{ERGAS} = 0$, the small value of ERGAS means good quality images.

The values of correlation coefficients and ERGAS are reported in Table 5 and show good results for this application of pan-sharpening.

|     | MS1 | MS2 | MS3 | MS4 | MS5 | MS6 | MS7 |
|-----|-----|-----|-----|-----|-----|-----|-----|
| $\rho$ (%) | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 |
| ERGAS |     |     |     |     |     |     | 3.867 |

**NDVI and NDWI application**

The indices used for this case study, NDVI and NDWI, adapted for the WorldView-2 [Wolf, 2010], are given by the formulas:

$$\text{NDVI} = \frac{\text{NIR}_2 - \text{Red}}{\text{NIR}_2 + \text{Red}} \quad [2]$$
NDWI = \frac{\text{Coastal} - \text{NIR}^2}{\text{Coastal} + \text{NIR}^2} \quad [3]

They were applied to both multispectral images of the initial dataset as well as pan-sharpened ones.

NDVI, although defined to estimate the density and the state of vegetation, allows to distinguish even 2 other classes, namely water and bare soil. The theoretical values of this index are between -1 and 1: as it is easy to deduce taking into account the spectral signatures, vegetation is characterized by high values (usually greater than 0.2), the water presents rather low values (usually less than -0.2) and the soil is placed in the middle position of the interval. NDWI also presents a range of variability between -1 and 1: considering the spectral signatures of the same 3 main categories, the sequence is reversed, with the water characterized by high values.

To determine the thresholds of separation, using the visual analysis of the RGB true color composition based on respectively original and pan-sharpened images, three types of training sites in relation to the reference classes (water, soil, vegetation) were identified. Applying the criterion of Maximum Likelihood the threshold values for both indices as well as for both different geometric resolutions were calculated.

Results and discussion
Using ArcGIS 10.1 (ESRI), coastlines were automatically extracted from NDVI and NDWI reclassified images (Fig. 5 and 6) and smoothing with PAEK (Polynomial Approximation with Exponential Kernel) algorithm [Bodansky et al., 2002] was applied to them to improve the results and render the poly-lines aspects closer to the reality.

Each coastline was compared with the corresponding obtained by visual analysis of RGB true color compositions and directly vectorised. Particularly two coastlines were manually achieved, the first considering the primary images (Fig. 7), the other the pan-sharpened ones (Fig. 8). The non-perfect overlap between the analogous and commensurate vector lines generated polygons which total area was considered as an indicator of the accuracy of the result. In particular, it is adopted an index already present in literature [Guastaferro et al., 2011] and given by the formula:

\[ I = \frac{S}{L} \quad [4] \]

where
S is the total area of the polygons and L is the length of the coastline taken as reference (manually vectorised one).
Figure 5 - Particular of NDVI and NDWI applications on coastal zone with original multispectral images.

Figure 6 - Particular of NDVI and NDWI applications on coastal zone with pan-sharpened images.
Figure 7 - Particular of coastline obtained from original multispectral images by: manually vectorising, NDVI and NDWI.
The values found for this index in the four different situations (generated by NDVI and NDWI with initial and derived images) are reported in Table 6. As evidenced also by visual
comparison in Figures 7 and 8, NDWI application supplied better results. Pan-sharpening permitted to enhance geometric resolution of results and to reduce to less than 1 m the mean value of shifts between the automatically extracted coastline and the manually vectorised one.

**Conclusions**

The WorldView-2 images provide detailed information in terms of both geometric and spectral resolutions, so they are powerful for a variety of applications, such as the identification of the coastline. Application of pan-sharpening permits to conduct multispectral images to the higher spatial resolution of the panchromatic one. Both NDVI and NDWI permit to easily delineate the coastline, guaranteeing accuracies compatible with studies on a large scale, especially in the case of pan-sharpened images. Maximum Likelihood Method permits to easily identify thresholds to distinguish the reference classes. NDWI, considering the extreme bands Coastal and NIR2 that remark differences between water and soil, produces better results than NDVI.

**Table 6 - The values of the I index.**

|                      | I (m) |
|----------------------|-------|
| NDVI - original images | 2.497 |
| NDWI - original images | 1.386 |
| NDVI - pan-sharpened images | 1.338 |
| NDWI - pan-sharpened images | 0.955 |

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