Relationship Between Spectral Response and Changes of Water Level: La Purísima Dam, Guanajuato, Mexico

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Relationship Between Spectral Response and Changes of Water Level: La Purísima Dam, Guanajuato, Mexico

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Abstract

La Purisima Dam is a water body located south of Guanajuato City (Mexico) and it provides water to irrigate 4,500 hectares for Irapuato and Guanajuato municipalities. At this moment there aren't studies about the relationship between the fluctuation of the water level and the physical and/or chemical characteristics of water. For this reason, the aim of this work is to establish relationships between the spectral responses linked to water level variation. To meet the goal, Landsat TM5 images were used in six different dates ranging from 1986 to 2009. The methodology included techniques such as radiometric corrections, segmentation image and spectral signature analysis for 3 points on a transect North-South. The results indicate that La Purisima Dam has a surface variation from 7.32 km^2 in 2005 to 3.02 km^2 in 2000 (reduction to 58%). The spectral responses for point 2 (midpoint) show a strong contrast between the visible and infrared regions for 2005, while the signature obtained for 2000 is flatter, showing less contrast between both regions of spectrum. The point 1 (north edge) shows a characteristic response of vegetation with high water content for 2000. This result is consistent with the variation of water level, since this year has the lowest level in the past 23 years. The spectral signatures for the point 3 (south edge) have a similar behavior to point 2. Future works include a project to acquire a field spectroradiometer and the chemical water analysis, to better understand the spectral and chemical behavior of water bodies.

Introduction

Several types of information about the Earth's surface can be derived from the absorption and emission features found in a Spectral Signature (Decker et al., 1992; Bogrekci and Lee, 2005; Chang et al., 2009). Based on the analysis of spectral signatures (figure 1), we can get information on certain characteristics like the amount of chlorophyll, the plant structure and the amount of water in the plant. It is also possible to obtain other information about the surface as the type of rock, vegetation or soil (Sahai et al., 1981; Price, 1994; Krezhova et al., 2007; Gangale and Prata, 2010). Several studies have shown that this information can quickly, efficiently and illustratively be used to prove and monitor the occurring chemical or physical changes in the water bodies (Decker et al., 1992; Doxaran et al., 2002; Fan et al., 2009; Marhaba et al., 2009). So, the extraction of spectral information from satellite images constitutes an important optical database that will aid in the understanding of inland waters as La Purisima Dam located in Guanajuato (Mexico). At this moment there aren't studies about this thematic for La Purisima Dam and for that reason, the goal of this study is to show the connection between the spectral characteristics of water and its level fluctuations. For this work we have used the Landsat TM5, since they are readily available and various studies have shown the effectiveness of these images in the extraction of spectral signatures.

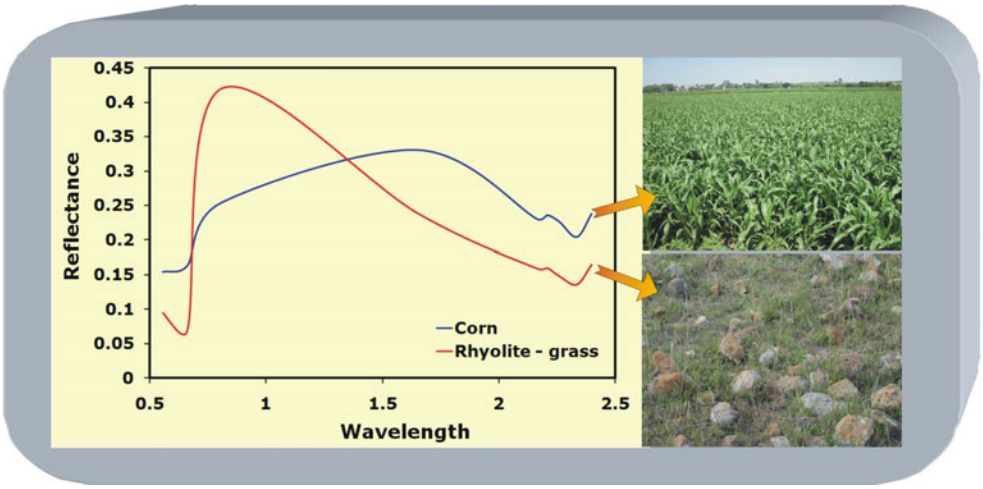

Figure 1. Reflectivity curves of a cornfield and rhyolite outcrop. Both surfaces form a part of Guanajuato's landscape.

The study area

La Purisima Dam is located 6 km south of Guanajuato City (Mexico) between 20°52° and 20°54' of Nord latitude and 101°15' and 101°18' of West longitude (figure 2). The daDue to flooding in the city of Irapuato, Guanajuato, and to control flood water from the city of Guanajuato, the dam "La Purisima" was begun in November 1976 and was completed in August 1979 and it began operations in 1980 (Cano-Rodríguez, et al., 2004). La Purisima Dam is the biggest body of water near of the Guanajuato City. It is about 4.5 kilometers long and a little more than 2 kilometers wide and it provides water to irrigate 4,500 hectares for Irapuato and Guanajuato municipalities. The altitude of the area varies between 1800 an 1960 m. La Purisima Dam is located in a zone of dry semi-warm climate with summer rains, with an average annual temperature ranging between 18° and 20°C. In May, the warmest month, is recorded temperatures between 23° and 24°C. In January, the coldest month, temperatures varie from 15° to 16°C. Average annual rainfall is 553 mm (Gobierno Estatal de Guanajuato, 2005).

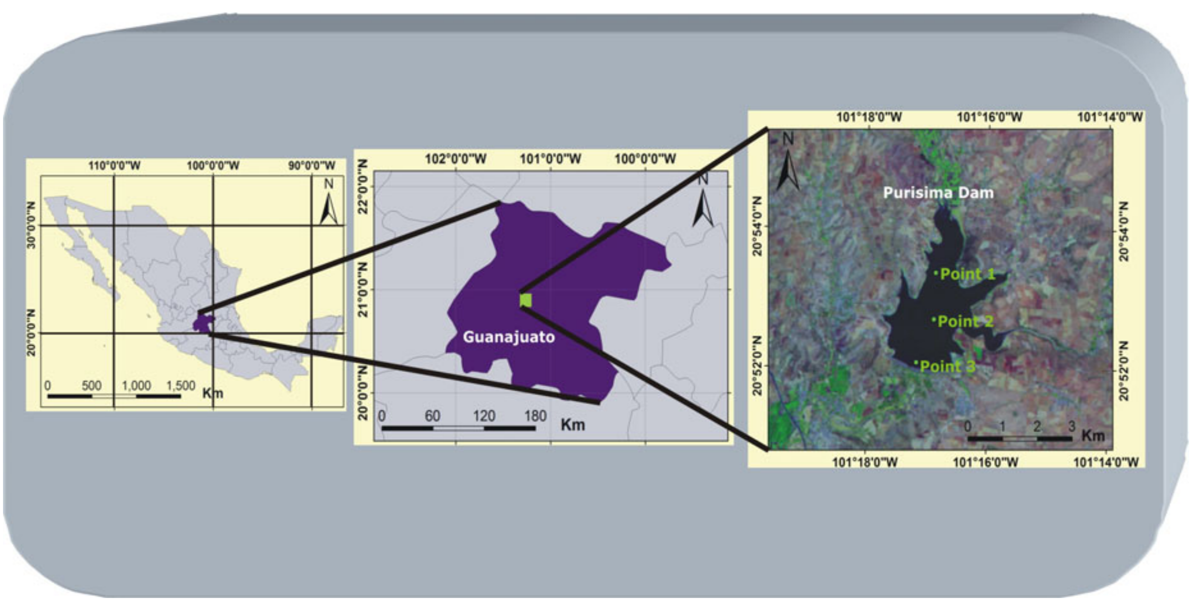

Figure 2. The zone of study is located at south of Guanajuato City in the Central part of Mexico.

Methodology

This research was conducted using six Landsat scenes (path 028 and row 045) of April for the years 1986, 1990, 1995, 2000, 2005 and 2009. These images were processed with ENVI 4.5 and the features extracted by remote sensing were integrated in ArcGIS 9.2 (figure 3).

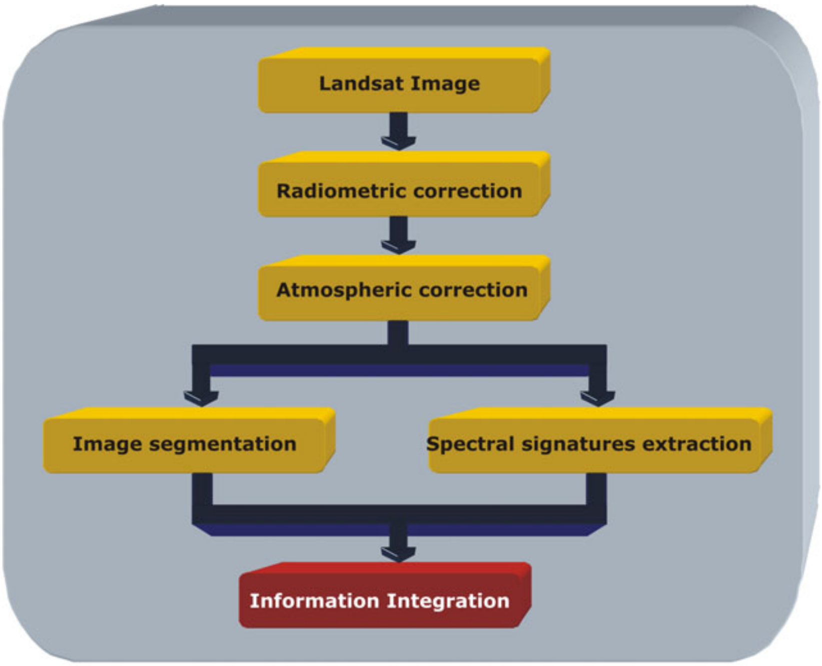

Figure 3. Methodology used for the delineation of body water of "La Purisima Dam" and the analysis of spectral signatures of water.

Radiometric and atmospheric corrections were made in order to improve image quality by reducing atmospheric effects of absorption by atmospheric gases and the atmospheric scattering processes as suggested by Kaufman (1987); Vicente-Serrano et al., (2008) and Hadjimitsis et al., (2009). In this study, we first applied radiometric correction which involved converting digital number (DN) into radiance. Coefficients provided by Chander and Markham (2003) were used to correct Landsat TM images (Ec. 1). The resultant radiance was used in order to produce an image atmospherically corrected using the method of image-based suggested by Chávez (1996) (Ec.2). The data of transmittance used were those proposed by Gilabert et al (1994) (Ec. 2).

$$L\lambda = \left(\frac{LMAX\lambda - LMIN\lambda}{Qcalmax} \right) Qcal + LMIN\lambda \qquad \textbf{Ec. 1}$$

Where:

Ll =	spectral radiance at the sensor's aperture in W/(m^2 sr mm)
Qcal =	quantized calibrated pixel value in DN's
Qcalmin =	minimum quantized calibrated pixel value (DN) corresponding to LMINl
Qcalmax =	maximum quantized calibrated pixel value (DN) corresponding to LMAXl
LMINl =	spectral radiance that is scaled to Qcalmin in W/(m^2 sr mm)
LMAXl =	spectral radiance that is scaled to Qcalmax in W/(m^2 sr mm)

$$\rho_k = D\pi(L_\lambda - L_{a,k}) / E_{sun} * \cos\theta * \tau_{k,i}$$ **Ec. 2**

Where:

ρ_k =	reflectivity
D =	earth-Sun distance
L_k =	spectral radiance at the sensor's aperture in $W/(m^2\ sr\ mm)$
$L_{a,k}$ =	scattered atmospheric radiance onto the band k $W/(m^2\ sr\ mm)$
E_{sun} =	solar irradiance on the target $W/(m^2\ sr\ mm)$
θ =	zenital angle
$\tau_{k,i}$ =	atmospheric transmittance 0.70 (TM1), 0.78 (TM2); 0.85 (TM3), 0.91 (TM4), 0.95 (TM5) and 0.97 (TM7) (Gilbert et al., 1994)

$$L_{a,k} = (a_{0,k} + a_{1,k}) * DNmin$$

Where: $a_{0,k}$; $a_{1,k}$ = Brescale ; Grescale
DNmin = Minimum Digital Number

The corrected images were used to obtain the spectral signatures for 3 points in a North-South transect on La Purisima Dam. The selected points should be kept on an area with water for all dates tested. In addition the spectral analysis, the values of reflectivity were correlated to the water surface to try to establish a trend. For this purpose, graphs were made for each band of the 6 Landsat images (different dates). Each graph was made with the values of reflectivity of 3 random points (figure 6). Similar correlations have been described in different studies to show that the analysis of spectral signatures can provide information about of water pollution degree, the amount of suspended solids and/or the presence of certain metals in the water (Doxaran et al., 2002; Phinn et al., 2008).

The segmentation image was used in order to extract the body of water. This technique uses a dynamic window-based gray-level applied to neighboring pixels. The algorithm used in ENVI 4.5 is based on similarity of pixel values and spatial connectivity (McCallister and Hung, 2003). The bands 4, 5 and 7 of each Landsat image was used for water body extraction, because in these bands is observed the absorptions peak in the presence of water. Moreover, these three bands were used to compare results in the delineation of water body, because Ryu et al (2002) have recorded changes in the delimitation of waterline connected to the bands used for the waterline extraction.

Results and Discussion

The results of this study can be summarized as follows. Firstly, it was compared the surfaces of water obtained by segmentation image with topographical information of INEGI (National Institute of Statistics and Geography) and internal field reports of the National Water Commision. This comparison reveals that the best delineation of the water body was obtained by the band 4 (NIR region) in the range of values of 0.04 and 0.06. The accuracy in the delimitation of the water body from the band 4 was higher compared with the results obtained from bands 5 and 7 (82.3% and 78.6% respectively). These results could be explained by remnant surface water on the mud, which can be more sensitively recorded by the SWIR region of Landsat TM. These results correspond in part to the observations made by Ryu et al (2002), who reported this problem with the waterline extraction for Gomso Bay in Korea. Based on the observation of water surface obtained for different dates, it is clear that the water surface in 2000 is the smallest (30.22 km^2) in respect of the water surface observed in other years. Similarly, it was recorded the water body for 2005 (73.19 km^2) as the largest. The maximum fluctuation in the surface of water is 42.97 km^2, i.e. there is a difference of 58% (figure 4). As noted, the years 2000 and 2005 show a significant variation in the surface of water. These are anomalous events which can be explained in terms of La Niña for 2000 and El Niño for 2005, and the rest of results are explained by the normal variation of rainfall recorded in the area.

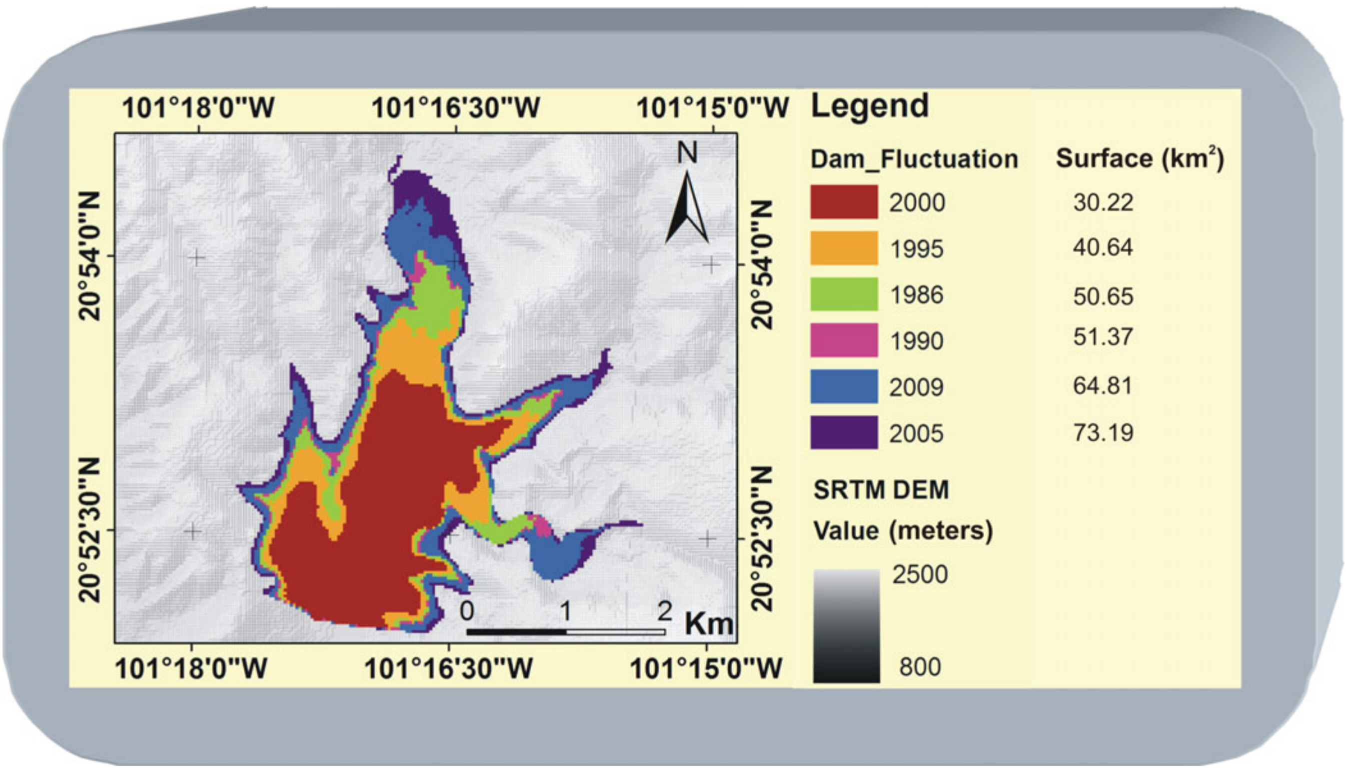

Figure 4. Fluctuations in the limits for the water body of La Purisima Dam

The spectral signature analysis shows that the main difference lies in the spectral behavior registered for the point 1 (northern limit of the dam) in 2000, which corresponds to vegetation signature (figure 5). This behavior could be due to the presence of incipient vegetation related to low water level. Similar observations have been addressed by Doxaran et al. (2002) and Phinn et al. (2008) who show the influence of sediments and vegetation in the spectral signature of the water. The graphs of spectral behavior show the highest reflectivity values for 2005, in opposition, 1990 proves to be the lowest ones. These spectral behaviors may indicate that 2005 was the period of the most turbid water, and 1990 was the cleanest one (figure 5).

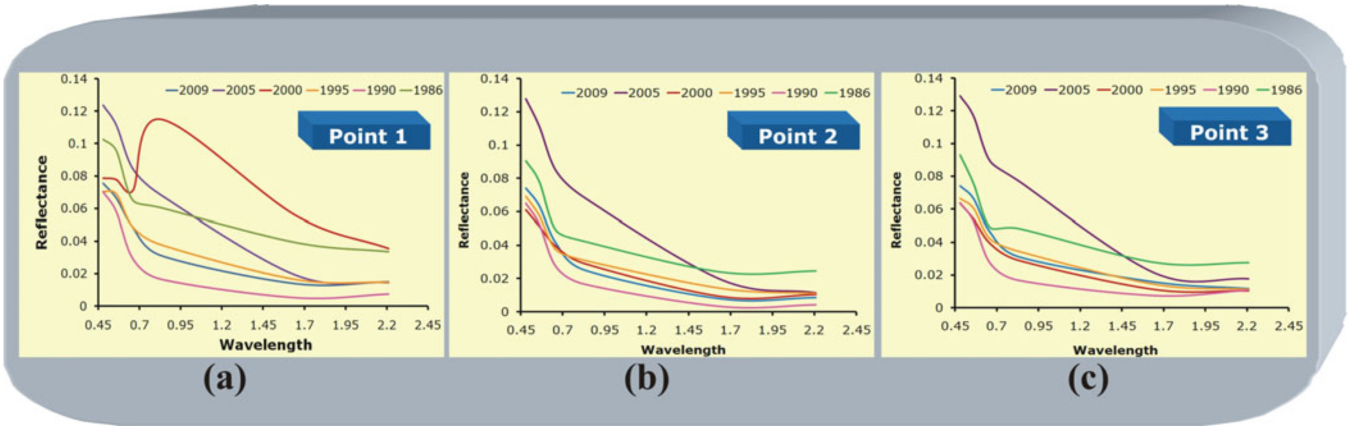

Figure 5. Spectral signatures obtained of 3 random points in a North-South trend on “La Purisima” dam

The graphs of correlation between surface and reflectance not show a clear trend. However, the graphs show a better correlation in the visible region (Band 1) compared with the NIR and SWIR regions (Bands 4 and 7; figure 6). The results indicate that the surface not clearly contributes to the variation of the reflectivity; it depends rather on the presence or absence of sediments and vegetation in the water as it has been discussed in other studies (Doxaran et al., 2002; Krezhova et al., 2007; Fan et al., 2009; Gangale et al., 2010).

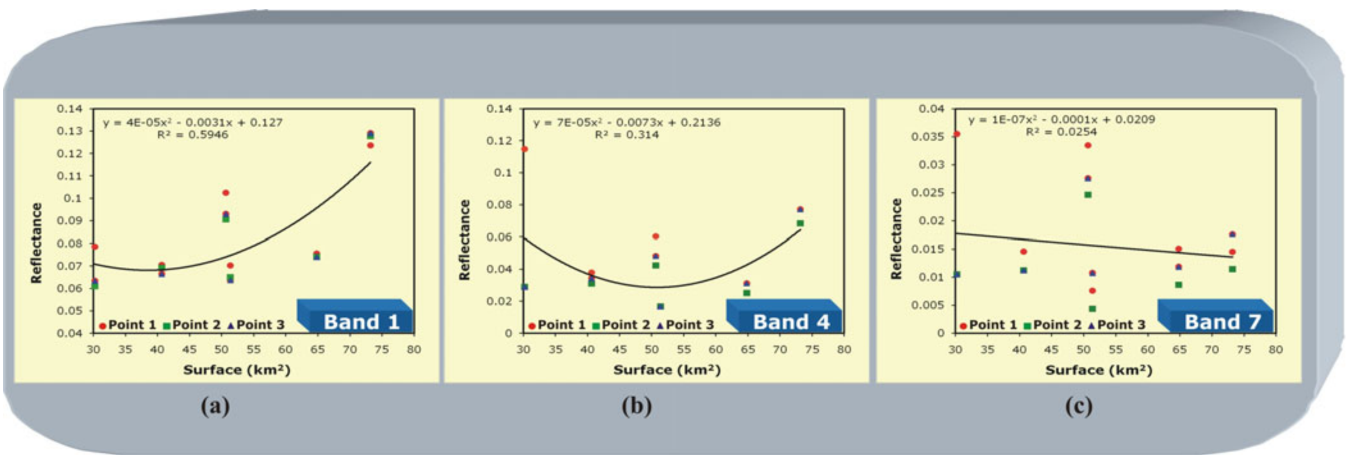

Figure 6. Surface-reflectance correlation graphs for the 3 random points. This figure shows the reflectance data for the bands 1 (VIS), 4 (NIR) and 7 (SWIR) of the 6 Landsat scenes.

Conclusions

This study addressed the possibility of establishing a relationship between the spectral behavior of water and its waterline fluctuation in La Purisma Dam (Guanajuato, Mexico). The results of the processing and analysis of six Landsat images indicated that the best delineation of water body is achieved using the range of values between 0.04 and 0.06 of the band 4 (NIR). The largest water body detected in this study corresponds to the year 2005. The spectral signatures analysis indicates that this year was also the most turbid water period. La Purisima Dam shows a maximum fluctuation in surface water of 58% between 2000 and 2005. This significant variation in the water surface is due to La Niña and El Niño and the rest of surface variations correspond to the normal precipitation periods in the zone.

There isn't clear correlation between water surface and its spectral behavior; it depends rather on the presence or absence of sediments and vegetation in the water.

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