COMPARATIVE ANALYSIS OF LANDSAT-5 AND LANDSAT-7 DATA FOR LAND COVER CLASSIFICATION, QUALITATIVE EVALUATION OF IMAGE FUSION PRODUCTS AND INVESTIGATION OF THERMAL CHARACTERISTICS OF INDUSTRIAL DISCHARGE SOURCES

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ABSTRACT

The Western European Union Satellite Centre (WEUSC) recently commenced participation in the evaluation of the continuity of data from the LANDSAT programme. A study area has been selected in the province of Extremadura, Western Spain, which comprises a variety of land cover categories and geological formations. In addition the Almaraz power generating facilities were included in the study area. Using image acquisition from LANDSAT-5 and 7 and near simultaneous acquisition of SPOT panchromatic images for several dates, a series of comparisons designed to evaluate qualitative and quantitative aspects of the two multi-spectral data sets is undertaken. Image fusion products utilising panchromatic data with a smaller pixel size (SPOT panchromatic 10 m pixels and LANDSAT-7 Band 8 15 m pixels) and multi-spectral data (LANDSAT-5 Thematic Mapper (TM) and LANDSAT-7 Enhanced Thematic Mapper Plus (ETM+)) with coarser pixels are investigated to evaluate their use as image interpretation products. The consistency between results made using supervised classification approach to LANDSAT-5 and LANDSAT-7 are presented. Comparison with existing geological and land cover maps is made to assess the results of the image classification/interpretation. The utility of the thermal infrared band of the TM and ETM+ - with special attention to the improvements implemented on the last one - is investigated using as objective the temperature in the reservoir immediately adjacent to the Almaraz power generating facility.

1 INTRODUCTION

1.1 Study Objectives

The main objectives of this study were a comparative analysis of LANDSAT-5 and LANDSAT-7 for land cover classification and image fusion products and monitoring of industrial sources using thermal infrared data in the area of the Almaraz power plant, Extremadura, Spain. The following goals were considered: (1) Study of the area surrounding the power plant with emphasis on the land cover and the structural-geology. The simultaneous acquisition by the ETM+ of the pan and multi-spectral channels was expected to improve (considering the characteristics of the TM on LANDSAT-5) the interpretation and understanding of the land cover and geological settings of the area. (2) Analysis of power plant activity with particular emphasis on the possible exploitation of the redesigned thermal band provided by the ETM+. The improved spatial resolution (from 120 to 60 m) was designed to provide significant benefits to the analysis of surface processes and thermal activities (e.g. power generating plants). (3) Comparison of image fusion and classification techniques developed to achieve goals (1)-(2) using two sets of images: LANDSAT-7 (multi-spectral plus panchromatic band) and LANDSAT-5 plus SPOT PAN. The aim of this comparison was to estimate the difference between the results obtained in the two cases, i.e. one representing the new RS market state and the other a comparable situation before the launch of LANDSAT-7.

For goals 1 and 2, feature analysis and extraction played a fundamental role in the interpretation processes required to achieve the proposed goals. The resolution and (multi-)spectral information are key factors in remotely sensed images interpretation. The contribution of fused products (e.g. a higher resolution panchromatic image merged with a lower resolution multi-spectral image) in broadening the discriminative capabilities may be summarized as follows: spatial characteristics of objects such as shape and texture are usually better highlighted in panchromatic images whilst spectral characteristics can often be characterized by behaviour in the near-infrared region of the spectrum. The fused products maintain the characteristics of the higher resolution panchromatic scene, thus offering a better match with larger scale georeferenced information. The simultaneous acquisition of panchromatic and multi-spectral data by LANDSAT-7 reduces greatly the geometric processing required to perform resolution merges within a single scene. Before its launch TM products had to be merged with higher resolution panchromatic products acquired by other sensors. For these reasons the comparison to evaluate the performances of the new ETM+ was planned with a LANDSAT-5 TM together with a SPOT PAN.

In order to achieve the proposed goals, the comparison process had been split in two parts: (1) Qualitative analysis: the two sets of original and fused images were compared in terms of subjective interpretation / extraction of information. Single feature analysis (e.g. single anthropic feature, landscape element, etc.) and geological interpretation were used as examples to estimate the improvements/benefits to be derived from using LANDSAT-7. (2) Quantitative analysis: the two sets of original and fused images were compared according to their performance in classifying land cover classes. A land cover map produced by the Spanish Ministry of Environment was used to define training sample and ground truths for the classification process. Additionally in the frame of the quantitative analysis, particular attention was paid to the thermal bands of the TM and ETM+ sensors to evaluate the plant activities, mainly focusing on its discharge into the neighbouring reservoir.

1.2 Study Area

The area is covered by the series M7814 sheets 13-25, 14-25, 13-26, 14-26 (1:50,000) of the Spanish Military Cartographic Institute. It covers approximately 2100 Km^2 of the province of Extremadura, including the small towns of Almaraz, Navalmoral de la Mata, Lagartera and Valdeverdeja. The landscape is characterized on the N side of the Tajo river (cutting the area from E to W) mainly by crops, pasture / grassland and *dehesa* type cover classes. The S side is mainly characterised by woods covering mountainous formations (peaks about 800 m a.s.l.). Three reservoirs are present in the area. The Almaraz nuclear power plant is adjacent to the westernmost reservoir, *Embalse de Arrocampo-Almaraz*, close to the town of Almaraz. The two reactor domes are clearly visible on the eastern bank of the reservoir.

2 METHODS

2.1 Data Acquisition and Preparation

The imagery acquisition strategy followed certain priorities determined by the objectives of the study. For the LANDSAT-7 data the earliest available scene of 1999 (27 August) was acquired to meet the land cover classification objective. The aim was to capture as much as possible of the variation in vegetation vigour in order to differentiate between land cover categories characterised by different phenological curves (note that LANDSAT-7 data only became available in late summer). Once the LANDSAT-7 scene had been identified, the data search focused on the selection of a 1999 LANDSAT-5 scene acquired under the most similar conditions. In order to meet the objective of comparing image fusion products, a SPOT PAN scene with a low incidence angle and similar acquisition date was also ordered. Additional LANDSAT-5 and SPOT PAN scenes from similar dates in previous years were requested to serve as reference data. Due to the excellent weather conditions characterising the area, cloud cover did not represent an obstacle for the objectives.

The topographic maps were used to georeference the panchromatic band of LANDSAT-7. This was then used as unique reference to geometrically correct the remaining imagery. After geometric correction, all images were subset using a frame matching the bounding coordinates of the study area. The Spanish Ministry of Environment provided a digital land cover file of the study area with a full description of the cover classes (Ministerio de Medio Ambiente, 1998). Four geological maps (1:50,000) (corresponding to the layout of the topographic maps) produced by the Spanish Technological Geo-mining Institute were also acquired, scanned and georeferenced.

Various image processing techniques were applied to the data sets considering both the multi-spectral and panchromatic components. As the study is focused on a comparison of data sets, the same processing was susbsequently applied to each set of images (LANDSAT-7 and LANDSAT-5 + SPOT PAN). For the thermal analysis only the thermal band of each LANDSAT scene was considered.

2.2 Image Fusion

Image fusion is achieved by an initial stage of geometric registration between images and a subsequent manipulation, via a range of algorithms, of their DN values to produce new output images. The technique used in this study manipulates panchromatic and multi-spectral images with the goal of combining the advantages of smaller pixels within the panchromatic data and spectral information from the multi-spectral data. The assumption underlying this combination is that the level of spatial detail within the panchromatic data is higher than that within the multi-spectral data, whilst the discrimination between objects based on their reflectance characteristics is preserved in the output data.

The initial phase of geometric registration poses some difficulties for images acquired under different sensor-target geometry. As geometric distortions arising from terrain relief are dependent upon observation angle the precise registration of images acquired with different viewing angles requires the implementation of corrections for relief displacement. Consequently, the advent of the ETM+ sensor, which acquires panchromatic and multi-spectral data simultaneously (and thus with the same senor-target geometry), eliminates a significant amount of processing effort. Whilst a great deal of research has been undertaken to develop image fusion products a much smaller effort has been made to assess the value of the products within image analysis. Thus the present study focuses on the results from qualitative and quantitative comparisons of image fusion products as a tool for information extraction rather than on their production.

The specific technique used for the generation of image fusion products in this study is referred to within the ERDAS™ software package as the Multiplicative Combination. This technique multiplies the values in the multi-spectral data by the values of the panchromatic data which results in an increase in the influence of the panchromatic data in the output values when compared with techniques based upon ratioing or principal components analysis. This results in a greater emphasis on the infrastructure components in the output image which enabled the qualitative comparison of image fusion products to be made at a range of scales.

2.3. Qualitative Analysis

The interpretation of LANDSAT TM and ETM+ images and image fusion products for qualitative comparison focused on two subject areas. First, the images were compared as tools for interpreting the geology of the study area. Second, the images were compared as tools for presenting maps at different scales. The specific interpretive approach for each comparative topic is described below. Inevitably the individual experience of the image interpreter plays an important role in the qualitative analysis. No attempt had been made to introduce measures of completeness or accuracy to the qualitative analysis by using a series of image analysts to perform the work.

Common to both topics was the use of colour composites from the image data sets. Colour composites may be used to display multi-spectral imagery directly from the DN values within each band and via manipulation of the original values. A commonly implemented manipulation produces natural colour composites via a transformation of values in the red, green and near infrared bands of the TM and ETM+ sensors. One advantage of the natural colour composite is that the imagery shows a familiar appearance to the user and as such is commonly used as a backdrop to thematic maps of land cover produced from multi-spectral images.

2.3.1. Geology

The availability of geological maps for the study area allowed a comparison to be made between the LANDSAT-5 and LANDSAT-7 imagery for identifying lithological and structural elements. This comparison is qualitative and is based upon the visual interpretation of the data sets as false colour composites and of the products of image fusion processing that was designed to take advantage of the higher resolution panchromatic data (LANDSAT ETM+ Band 8 and SPOT PAN images) and the spectral information content of the multi-spectral data. The appearance of the imagery indicates that the atmospheric conditions were different for the acquisition of LANDSAT TM and ETM+ data but the objective of the comparison between data sets was met without recourse to extensive processing.

Attention was focussed on the Ordovician-Silurian (500 - 395 m.a.) segment of the stratigraphic column which comprises a series of tightly folded slates, sandstones and quartzites that trend SE-NW and show a strong geo-botanical association in terms of the amount of cover associated with individual units that permits lithological discrimination within the multi-spectral data. This geo-botanical association allows a better discrimination between lithological units to be made in the multi-spectral data than with the panchromatic data even thought the latter have a smaller pixel size (10 m for the SPOT PAN and 15 m for the LANDSAT ETM+ Band 8 data). The intrusive rocks within the region comprising granites, grano-diorites and migmatities show a marked textural pattern that, combined with the cross-cutting nature of their stratigraphic boundaries, permits their identification in the multi-spectral data. In the remainder of the stratigraphic column the similarity of the units and the extensive agricultural land-use limit the detail of geological interpretation. In addition the drainage pattern development shows no association with underlying rocks and as such limited the use of one of the traditional means for separating lithological units. Panchromatic imagery from LANDSAT-7 and SPOT were also compared as tools for identifying the fault lines identified in the geological map base.

2.3.2. Feature Analysis and Scale Comparison

One of the major potential improvements provided by the ETM+ in comparison to the TM is the 15 m pixel size panchromatic band. One of the objectives of this study was to evaluate this benefit in terms of enhanced capabilities in subjective image interpretation by considering the range of operability in terms of resolution/scale. The former LANDSAT-5 + SPOT PAN image fusion product was chosen for comparison with the LANDSAT-7 multi-spectral + panchromatic image fusion product, as this product represents the most similar combination of data comparable to LANDSAT-7 before its launch.

A multi-scale approach/analysis was chosen to establish scale limits for the identification of given surface elements in the two image fusion products. It is important to mention that the SPOT PAN pixel size is 10 m which is an advantage for detecting small objects. Thus at larger scales it is inevitable that the image fusion product based upon SPOT data would be more suitable than the LANDSAT-7. The aim here was to establish the scale limit at which the results were comparable. This first result has a critical importance in the decision making process for selecting remotely sensed data for the solution of specific problems.

The comparison utilised several viewing scales chosen *a priori* for the LANDSAT-7 and LANDSAT-5 + SPOT products. Focusing on given elements a set of three scales was chosen and a comparison was then performed using as a metric the possibility of clearly identifying elements belonging to two groups of objects: (1) anthropic features; (2) natural landscape features.

2.4 Quantitative Analysis

The approach developed to make a quantitative comparison of the image data sets provides a more objective means for their evaluation. The quantitative analysis addressed two topics. First, a comparison of the performance of the data sets for land cover classification and second, an analysis of the data from band 6 of the TM and ETM+ sensors which measure the emitted radiation from the earth's surface in the thermal region of the electromagnetic spectrum.

2.4.1 Land Cover Classification

The multi-spectral imagery was classified on the basis of the spectral pattern present within the data for each pixel. The present study focused on a supervised classification process comprising three steps: (1) Representative training samples were identified based on their spectral reflectance and emittance properties and a numerical description of the spectral attributes of each land cover type was developed. (2) Each pixel in the image data set was categorized into the land cover class it most closely resembles using the Maximum Likelihood algorithm. (3) Assessment of the accuracy of the classified data via the calculation of standard statistics derived from a confusion matrix (Congalton, 1991).

Training samples were designed with the aid of the land cover map provided by the Spanish Ministry of Environment. Before running the classification algorithm visual inspection of each data set verified that the training samples homogeneously matched the same land cover classes. The adaptation of a single set of training samples to each pair of multispectral / panchromatic images would have probably increased the final accuracy of each classification but would have rendered the comparison among them meaningless. For the same reason the ground truth plots used for the accuracy assessment were the same for all classifications.

The optimisation of the LANDSAT TM and ETM+ bandwidths to allow discrimination of vegetation allowed a data reduction strategy to be implemented by comparing the proportion of the overall variation of the data represented by each band. The results of the classification were filtered using a smoothing filter in order to eliminate the "salt and pepper" appearance that results from the assignment of isolated pixels to a different land cover category within largely homogenous areas. The confusion matrix approach was used to estimate the accuracy of each classification and to compare the results of the different classifications. The overall classification accuracy is the average of the individual class accuracy (Mather, 1989). In order to assess the reliability of the accuracy assessments for each classification a *K coefficient* was calculated.

2.4.2 Thermal Analysis

The potential of using LANDSAT TM thermal data to derive temperature and distribution of thermal discharges in water bodies has previously been demonstrated (e.g. Gibbons and Wukelic, 1989). Importantly it has also been concluded that because of the large pixels of the thermal band of the TM sensor (120 m x 120 m) thermal plumes originating from industrial sources cannot be mapped in sufficient detail near discharge outlets. The 60 m x 60 m pixel size of the ETM+ thermal band potentially increases the analytical capabilities for the study of industrial discharge sources and other thermal phenomena. One of the pre-established goals of the present study was to compare the performances of the two sensors using the reservoir close to the power plant of Almaraz, which receives cooling effluents from the plant, as a test area. ETM+ and TM band 6 imagery were transformed to estimates of ground temperature and then compared. The conversion is achieved via a straightforward manipulation of the DN values in band 6 of the TM and ETM sensors using the calibration data supplied by the provider. Transformation of band 6 to surface temperature (EOSAT, 1986) was realized according to:

$$SR = band6 \cdot C1 + C2 \quad (1)$$

$$T = \frac{K2}{\log(K1/SR + 1)} - 273.15 \quad (2)$$

where:
SR Spectral Radiance (milliwatts per square centimetre per steradian per micrometer)
T Effective at-satellite temperatures in Celsius
C1 Conversion parameter for DN to radiance conversion
C2 Conversion parameter for DN to radiance conversion
K1 Calibration constant for offset of detectors in Band 6 of TM and ETM+ sensors
K2 Calibration constant for gain of detectors in Band 6 of TM and ETM+ sensors

The estimates of surface temperature may be refined to measurements of absolute surface temperature by using meteorological data. Atmospheric effects on remotely sensed data can be accounted for by calculating a corrected radiance and using the black body inversion formula to determine a correct temperature. Meteorological data had been requested for the study area to correct the results obtained but they have not been made available at the time of analysis. The inability to calculate absolute surface temperatures determined that the thermal infrared data were compared on the basis of temperature variation over the course of the three data acquisitions. Thus the variability of reservoir surface temperatures adjacent to the industrial facility was compared with that observed within the *Embalse de Valdecañas* reservoir located to the SE of the Almaraz power plant.

3 RESULTS

3.1. Qualitative Analysis

3.1.1 Geology

Comparison of the individual LANDSAT scenes from the TM and ETM+ sensors and the products of image fusion between panchromatic data and multi-spectral data shows that the lithological boundaries within folded sequences of Ordovician-Silurian age rocks and those between intrusive rocks and adjacent alluvial deposits are more readily distinguished within the multi-spectral data than within the image fusion products.

The fused products created via the image fusion of SPOT Panchromatic data and LANDSAT TM data are unsuitable for the assessment of textural indicators in areas where significant mis-registration of the data sets occurs. As this mis-registration coincides with areas of moderate relief characteristic of the intrusive segment of the stratigraphic column, the image fusion product created by the processing of LANDSAT ETM+ panchromatic and multi-spectral data is superior to that created from LANDSAT and SPOT data for the purpose of discriminating intrusive rocks. Furthermore the incorporation of the panchromatic data and the multi-spectral data results in a reduction of the geo-botanical association of lithologies within the sedimentary sequence.

The LANDSAT ETM+ and SPOT panchromatic data contained evidence of linear features that might be interpreted as fault lines within the major sedimentary sequences. This identification was enhanced by use of the multi-spectral data due to the previously mentioned geo-botanical associations. Within the recent alluvial units the correspondence between fault identification in the geological maps and the imagery was zero. This is partly because many of the faults occur in areas of agricultural development and partly due to the pixel size of the imagery. Traditionally field mapping in areas adjacent to river courses identifies fault lines by small displacements within the sequence of alluvial terraces adjacent to the rivers. Evidently in the case of the rivers studied here these features are too small to be identified within the imagery.

3.1.2. Feature Analysis and Scale Comparison

A multi-scale approach/analysis was chosen to establish scale limits for the identification of given surface elements in the LANDSAT-7 and LANDSAT-5 + SPOT products. A set of three scales (1:50,000, 1:35,000 and 1:20,000) was chosen and a comparison was then performed analysing the possibility of clearly identifying elements belonging to two main groups of objects: (1-10) built-up anthropic features and (11-16) natural landscape features. They represent a heterogeneous set of objects with a degree of identification likelihood varying with the scale. They are:

1 - highway
2 - hard surface road
3 - loose/light surface road
4 - paths
5 - railroad
6 - bridges
7 - viaducts
8 - built-up areas
9 - isolated building (housing)
10 - isolated building (industrial)
11 - orchards
12 - crops
13 - pasture and grassland
14 - scattered trees/bushes
15 - woods (low density)
16 - woods (high density)

The scale selection derives from a simple decision process: at the scale of 1:50,000 the two products are very similar providing excellent performances while at 1:20,000 the pixel effect begins to degrade the outline of different features and the resolution of the LANDSAT-7 product becomes insufficient to detect the features. The 1:35,000 scale represents an intermediate situation.

As this part of the comparison is the most subjective, the possible error has been minimized by choosing readily identifiable features in order to reduce the possibility of getting different evaluations due to subjective interpretation which becomes more common as complex elements are introduced. Additionally, the possibility of discriminating between forest cover types, etc. was not considered a priority because this issue was addressed in the multi-spectral classification part of this study. The simplification of feature classes was also adopted to avoid case specific results both in terms of scale and location/environment. The recognition likelihood - for each of the 16 classes and 3 scales - was rated using three possible levels: (1) low; (2) medium; (3) high. It has to be considered that (a) the results represent an average of the overall situation and (b) no other intermediate/heterogeneous possibilities were taken into account. For example different elements of a feature class may not be consistently identifiable all over the area but when detected cannot be confused with other feature classes. Alternatively, there may be class objects that most of the time are readily detectable but are difficult to assign to a feature class because of some overlap between similar classes. Apart from the role of subjectivity in such estimations, it was considered impossible to field check, in a reasonable time, all possible occurrences. The topographic maps were therefore used as a reference. Considering the 16 possible elements listed previously, the results are presented, according to the 3 previously chosen scales, in the following table (note that only the 1999 LANDSAT-5 + SPOT merge and the LANDSAT-7 ETM+ image fusion products were considered in this comparison):

Features->	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	avg.
1:50,000 ETM+	3	1	1	2	2	2	1	3	1	2	1	3	2	1	1	2	1.75
1:35,000 ETM+	3	2	1	2	2	3	2	3	1	2	2	3	2	1	2	3	2.13
1:20,000 ETM+	3	3	2	3	2	3	3	3	2	2	2	3	3	2	3	3	2.63
1:50,000 TM+SPOT	3	1	1	2	2	3	2	3	1	2	1	3	2	2	1	2	1.94
1:35,000 TM+SPOT	3	3	2	2	2	3	3	3	2	3	2	3	3	3	2	3	2.63
1:20,000 TM+SPOT	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Taking into account the limited consistency of these results due to the subjectivity issue, some general conclusions could be drawn by considering any introduced error to be homogeneously distributed. The incorporation of SPOT panchromatic data clearly leads to a better definition of objects, a difference with LANDSAT-7 that becomes more perceptible at larger scales. In a scale to scale comparison the LANDSAT-5 + SPOT product is never poorer than the LANDSAT-7 image fusion product. Further comparative studies could be defined according to different interpretation purposes. Figure 1 shows an example of LANDSAT-7 Band 8 and SPOT PAN over the area of Almaraz.

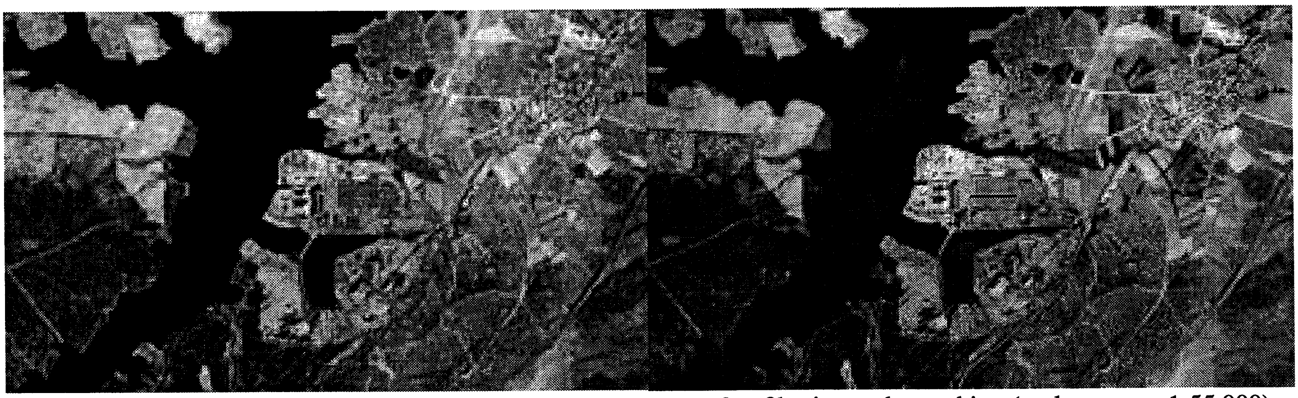

Figure 1. Example of LANDSAT-7 Band 8 (left) and SPOT PAN after filtering and stretching (scale approx. 1:55,000)

3.2. Quantitative Analysis

3.2.1. Land Cover Classification

The results of the correlation analysis led to the selection of Channels 3, 4 and 5 for both original and merged products for the classification processing. The selection of these bands was based upon the proportion of the overall variance of the data set they represent which is a consequence of their sensitivity to the reflectance spectrum minima and maxima for vegetation. Thus the correlation matrices indicate that these three bands show the least degree of correlation and thereby encompass the majority of the variance within the data sets.

Representative training samples were selected and a numerical description of the spectral attributes of each land cover type identified from the land cover category map of the Spanish Ministry of the Environment were developed. These samples are then used by the maximum likelihood classification algorithm during the comparison of spectral signatures of all pixels as a tool to derive the probability of category membership and assignment of each pixel to a unique class. The overall results are presented - from best to worst - in the following table:

	LANDSAT-7	LANDSAT-7 (+ band 8)	LANDSAT-5 (97)	LANDSAT-5 (99)	LANDSAT-5 (97) SPOT pan (97)	LANDSAT-5 (99) SPOT pan (99)
Overall accuracy	84.46%	82.12%	79.52%	74.98%	74.27%	74.09%
Overall K stat.	0.8221	0.7957	0.7659	0.7147	0.708	0.7057

It is essential to be aware that these results may incorporate a given degree of error due to the fact that it is impossible *a priori* to establish and prove that the training samples were definitely designed to equally/statistically identify - with the same degree of likelihood - the same categories in the different data sets. Assuming however that an error had been introduced in a homogeneous way the results indicated that the classifications obtained by processing the LANDSAT-7 (both pure and merged) reached the best overall accuracy especially when comparing the scores of the merged products.

3.2.2 Thermal Analysis

The pre-established goal of comparing the performances of the TM and ETM+ in mapping absolute ground temperature could not be achieved at the time of writing this document, due to the difficulty in obtaining meteorological data. However the presence in the reservoir of a warmer discharge at the level of the plant is evident. The temperature gradients indicate that the industrial discharge follows a counter clockwise path. The circulation is guided by a series of barriers within the reservoir that are identifiable in the SPOT imagery.

Analysis of the variability of temperature within the reservoir adjacent to the power plant and the variability of the *Embalse de Valdecañas* to the SE shows that the mean temperatures of the reservoir adjacent to the power station vary to a much greater degree than those observed in the *Embalse de Valdecañas* (see Figure 2). This conclusion drawn from the relative temperature measurements indicates clearly that changes in industrial activity can be monitored readily with LANDSAT TM and ETM+ data. However a much greater challenge not met by the present study is to link quantitatively the changes in water surface temperature with precise measures of power generation.

4 CONCLUSIONS

The results obtained indicate that the continuity between the LANDSAT TM sensor and the ETM+ sensor is very good. The two sensors provide completely compatible data sets for the purposes of monitoring of land cover processes, geological mapping and surface temperature measurements. The results of supervised classification of the TM and ETM+ images are compatible with the land cover maps produced by the Spanish Ministry of the Environment and as such provide a possible source for land cover map updating. Further corroboration with ground surveys would enhance the quality of the land cover maps.

The creation of image fusion products derived from the panchromatic and multispectral data from the ETM+ sensor is greatly simplified in comparison to the creation of similar products from LANDSAT multi-spectral images and SPOT panchromatic images due to the simultaneous acquisition of both categories of data. LANDSAT-7 image fusion products provide a means to produce maps at a scale of 1: 50,000 and 1: 30,000 without any loss of detail when compared with similar image fusion products produced from LANDSAT and SPOT imagery. However, the cost of producing maps at these scales is greatly reduced due to the wider coverage of the LANDSAT swath and the process of image acquisition is greatly simplified when a single data source is used.

Variability in relative surface temperatures within reservoirs adjacent to industrial discharge sources indicates that detection of industrial activity is possible with LANDSAT TM and ETM+ data. Absolute calibration of the data and correlation between changes in absolute surface temperature and levels of industrial activity would evaluate improvements provided by the ETM+ data with respect to TM data.

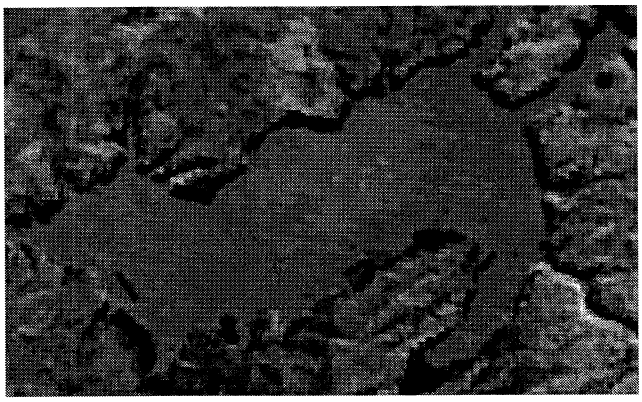

Figure 2. Temperature variability in the reserovoirs *Embalse de Arrocampo-Almaraz* (above) and *Embalse de Valdecañas* (scale approx. 1:140,000)

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