The Role of SPOT Satellite Images in Mapping Air Pollution Caused by Cement Factories

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ABSTRACT

Environmental analysis and monitoring of pollution are important tasks in Egypt and all over the world. In this study, temporal SPOT satellite multispectral images were used for locating the horizontal dispersion of air pollution caused by a cement factory that was constructed near Assiut City in Egypt. Two different working conditions of the factory were analyzed. In the first one (1995), with average production rate 8341 Ton/day, the dust emission from the factory was not properly controlled, while in the second one (1998), with average production rate 10577 Ton/day, the factory applied optimum control on dust emission due to the constrains of the environmental lows which are taking place in Egypt nowadays. The techniques of image interpretation, unsupervised classification, and image thresholding were used. This approach allowed us to map the source of pollution and its aerial extent and to identify different degrees of contamination intensities under the different working conditions. This study proved that multispectral SPOT images can be used as a global tool for locating and monitoring air pollution phenomena caused by uncontrolled industrial pollution.

1. INTRODUCTION

The cement industry contributes to the economical growth, as an essential material for constructing different types of buildings. However, in spite of the economical importance of this industry, it can be considered as one of the biggest contaminators of the surrounding environment. The optimum technique for monitoring and modeling the behavior of the environment should be based on the use of best available sources of information.

This study investigates the role of SPOT satellite images for mapping air pollution caused by cement factories. Although the potential of using satellite data for mapping air pollution has been analyzed by some authors, the present study concentrate on the practicality of analyzing the spectral information of temporal SPOT multispectral images to detect and locate the air pollution around a cement factory under different working conditions. Two working conditions were analyzed, the first one (1995) with average production rate 8341 Ton/day where the dust emission from the factory was not properly controlled, while in the second one (1998) with average production rate 10577 Ton/day, the factory applied optimum control on dust emission due to the constrains of the environmental lows which are taking place in Egypt nowadays.

2. STUDY AREA AND DATA

The study area is located around a cement factory that was constructed in the west desert about 17 km to the west of the center of Assiut City (Egypt). A location map showing the relative position of the cement factory and the surrounding environment is given in Figure 1. This map is a part of topographic map, produced in 1991 by the Egyptian General Surveying Authority (EGSA). Two SPOT multispectral images with 20 m ground resolution were the main data source for this study. The SPOT images correspond to column 113 and row 296 of SPOT Grid Reference System (GRS). The first image was captured by SPOT-2 on 25 July 1995, and the second image was captured by SPOT-4 on 11 August 1998. SPOT-1, 2, 3 and 4 are equipped with High-Resolution Visible (HRV) sensor that recording three bands in the multispectral mode with 20 m ground resolution. Band 1 (the green band) covering the spectral band from 500 nm to 590 nm, band 2 (the red band) covering the spectral band from 610 nm to 680 nm , and band 3 (the near infra red band) covering the spectral band from 790 nm to 890 nm [Michele 1981 and SPOT Magazine No 28 (January 1998)].

Field measurements were carried out in order to determine the ground coordinates of the control points using Global Positioning System (GPS) with differential correction technique.

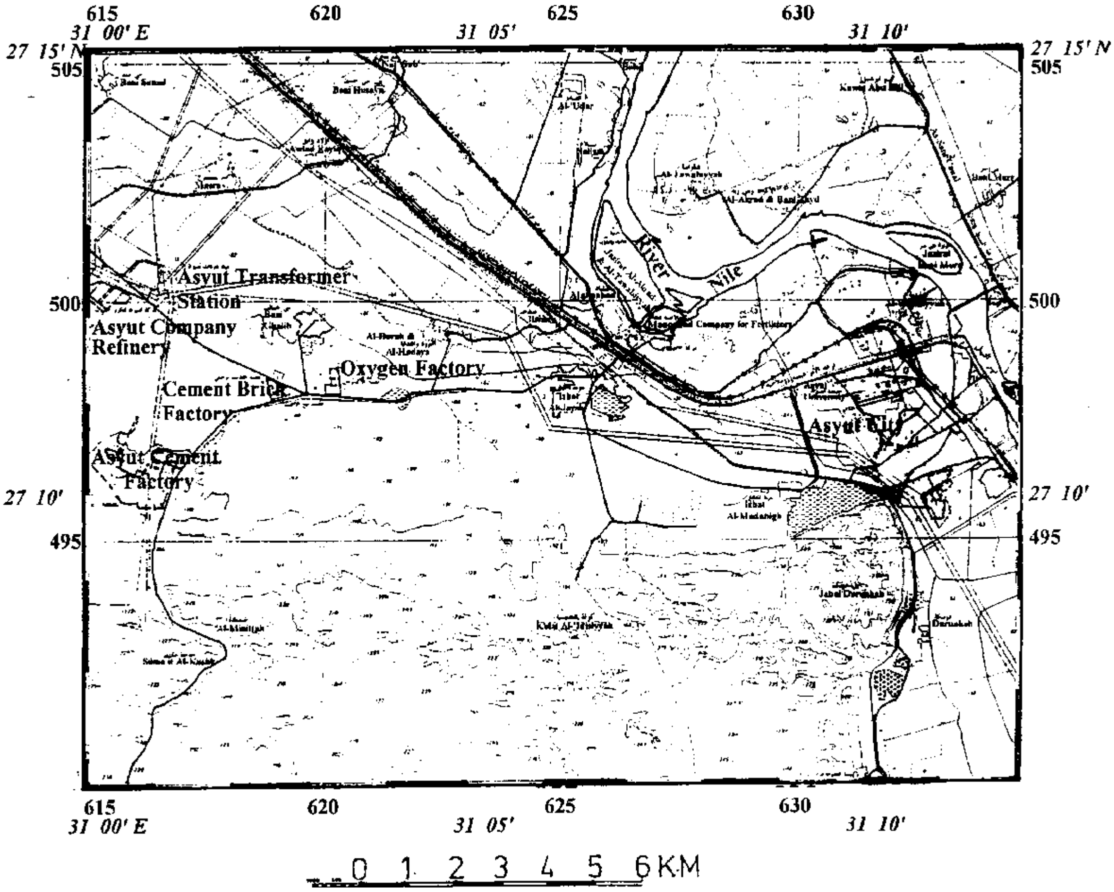


Figure 1- Location map showing the relative position of the cement factory and the surrounding environment

3. METHODOLOGY

A combination of image interpretation, unsupervised classification and image thresholding, techniques incorporation with ground measurements were applied in order to analyze the information contents of SPOT images. The images were analyzed at its original spectral condition and the process did not include radiometric correction, such as haze correction. This can avoid distortion of the information contents of the original image. IDRISI, grid-based geographic information and image processing, software was used as an image processing tool in this study.
The process and analysis of each of SPOT images consisted of three steps. Firstly, the images were geometrically corrected. Secondly, a composite image was constructed and examined visually then unsupervised classification was carried out. Thirdly, the data of the green band which is the most sensitive band for such pollution was examined and analyzed. Then the obtained results were presented in form of maps and charts. These steps can be briefly explained as follows:

STEP 1: Geometric correction of SPOT images is essential for carrying out quantitative analysis. The bands of each image were rectified to the Universal Transverse Mercator (UTM) coordinate system using a second order polynomial transformation. The measurement of the ground coordinates of the control points was carried out in the field by applying Differential Global Positioning System (DGPS). The residual Root Mean Square (RMS) error was 18 m (0.9 pixel). Each of the three bands was individually geometrically corrected using the same set of control points. The resampling process of each band was carried out using nearest neighbor method (in order to avoid any smoothing to the original image data). A square window of 458 km^2, corresponding to a part of the map shown in Figure 1, was extracted from the geometrically corrected image. The area represented by this window of the image contain several types of land cover as shown in the classified images given in plates 1 and 2 for 1995 image and 1998 image respectively. This window of the image was used for visual analyzing of image data and used for adjusting the histograms of the green bands of the images (details are given later). For further analysis a smaller portion of each image (corresponding to 12 km x 17 km on the ground), that cover the cement factory and the surrounding area (which is possibly infected by air pollution) was processed. These image portions are shown as classified images in plates 3 and 4 for 1995 image and 1998 image respectively.

STEP 2: In this step major emphasis was made on the accurate identification and delineation of the contaminated area based on the information contents of the composite images. The unsupervised classification was carried out to illustrate the possibility of automatic discrimination of the polluted areas.
The composite images were constructed and displayed in pseudo natural color, where band 2 was assigned to red, band 3 was assigned to green and band 1 was assigned to blue. Visual interpretation was carried out to give an indication of number of classes that can be discriminated on the image and possibility of distinguishing the source of pollution and the contaminated places. Several tests were carried out in order to choose the optimum number of classes in the classified image. It found that 10 classes give reasonable results. The unsupervised classification was carried out for the purpose of automatic discrimination of the polluted area in the images and to identify different intensities of pollution. The classes that result from unsupervised classification are spectral classes. Accordingly, the identification of such spectral classes will not be initially known, because they based only on the natural groupings in the image values. In this study, the classified images were compared with maps and information from the field visits to determine the information classes. The resulting classified images by this technique are given in plates 1 and 2 for 1995 image and 1998 image respectively.

The results of visual interpretation of the composite and classified images can be summarized as follows:
a- The pollution source is clearly identified and the contaminated area is clearly distinguished in the processed images.

b- There is clear difference between the identified polluted area as they identified from the two images, where the size of the identified polluted area from 1995 image is larger than that identified from 1998 image.

c- Taking into account the wind direction at the time of imaging (which is the average wind direction in the study area, almost from North to South) the dispersion and the aerial extent of pollution as identified from the two images take, in its general shape, the Gaussian Plume model [Durucan (1995)].

d- The ten classes of the unsupervised classified images can be interpreted as follows:

i- Desert mixed with scattered contaminated areas	vi- Reclaimed areas
ii- Desert	vii- Contaminated areas (I)
iii- Cultivated land (I)	viii- Contaminated areas (II)
iv- Cultivated land (II)	ix- Water bodies
v- Built-up areas	x- Irrigated fields

e- As given above, different intensities of pollution can be identified and delineated. Accordingly, a smaller window of the images was considered for further analysis (12 km by 17 km as defined in step 1 above). Unsupervised classification was carried out in order to classify this window into ten classes as shown in plates 3 and 4 for 1995 image and 1998 image respectively. These classes can be identified as, three classes of contaminated areas with different degrees of contamination intensities, four classes as different types of desert areas, one class as built-up areas and one class as cultivated (reclaimed) land.

STEP 3: In this step major emphasis was made on the accurate identification and delineation of the contaminated area based on the information contents of the green band of SPOT images, where maximum information about air pollution can be extracted from the green band [Farrag (1997) and Nicolas Sifakis (1992)]. The green band of each of the two images was processed separately and the obtained results were compared. The processing includes histogram adjustment of band images and then applying stretching and slicing to the images of these bands.

a- Histogram adjustment of image bands
In order to be able to compare the reflectancy of temporal images, the DNs corresponding to common features were examined. For the purpose of linking the results of this study with previous research work which was carried out by the author, the reflectancy of the green band in SPOT mage of the same area that captured by SPOT-1 on 23 July 1992 was used as a reference for this purpose [Farrag (1997)]. As mentioned above, the window of the image which represent a square area on the ground of 458 km^2 contains several types of land cover, such as urban areas (cities and villages), cultivated land, water bodies (river Nile and canals), reclaimed desert areas, desert areas, paved roads, etc. Some of these land covers does not suffer from major changes during the period between 1992 to 1998, such as water bodies,

desert areas and paved roads. Such common types of land cover were used to compare the reflectancy (DNs) in the green band of 1995 image and 1998 image compared with their reflectancy in the same band of 1992 image. Then the green band of images of 1995 and 1998 was shifted by certain value to be comparable with the reflectancy in the same band of image 1992. It is found that the green band of 1995 image need to be shifted by +5 while the green band of 1998 image need to be shifted by +30. The histograms of the adjusted green bands are given in Figure 2. One can realize that there is some similarity between the histograms (especially with respect to the pixels that represented by small DNs). The little shift can be due to difference in crop's age because the image of 1992 and the image of 1995 were captured on June while the image of 1998 was captured on August.

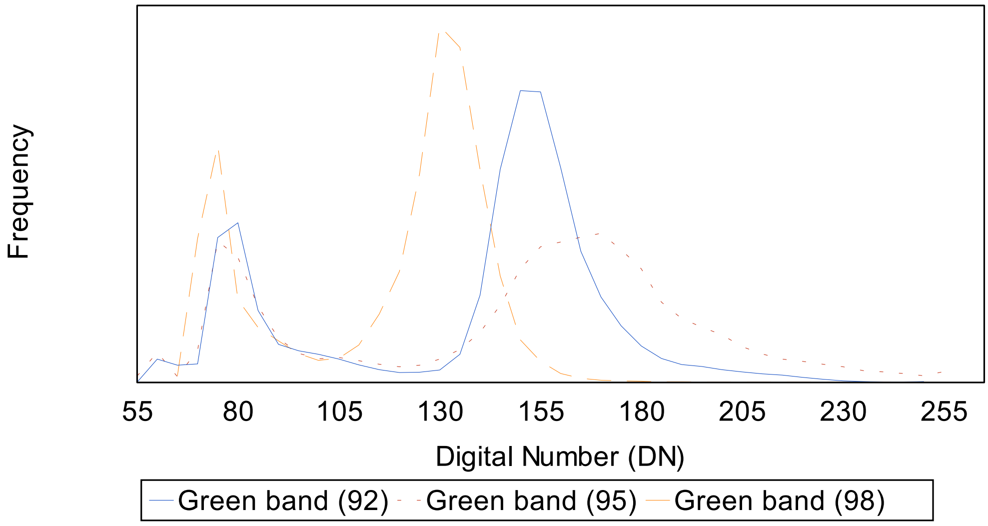


Figure 2. Histograms of green bands after adjustment of DNs

b- Stretching and slicing image bands to a number of levels

The process of stretching and slicing image bans to a number of levels was carried out on a smaller portion of the image that corresponding to 12 km x 17 km on the ground as identified in step 1 above. The process of linear stretching involves identification of two brightness values (DNs) as minimum and maximum values in the resulting stretched image. These minimum and maximum values represent the limits of the feature of interest (the polluted area in our case). Then the image data between the two limits was sliced to a number of levels, to be interpreted as pollution levels.

As a result of examining the image of each band, it found that, the polluted pixels are located at the extreme end of the green and the red bands (have high digital numbers) and near the end at the near infra red band. Also these pixels are highly separable from the surrounding pixels in all bands [Farrag (1997)]. As mentioned above, the analyzing of information contents of the green band of SPOT images is emphasized, in this study. After several tests on the green band of 1992 image it has been found that the minimum brightness value of the threshold to extract the polluted pixels has been defined to be 155 [Farrag (1997)]. The same value can be used for stretching the green bands of 1995 image and of 1998 image, because the DNs of these image bands were adjusted to be comparable with those of the green band of 1992 image. All pixels with spectral response above that threshold (within the specified window) are corresponding to polluted areas, while, all pixels with a spectral response below that threshold are corresponding to other classes.

Reasonable results were obtained by selecting six levels in the stretched green band of the two images. The resulting images of streatched green band of 1995 image and 1998 image are given in Plates 5 and 6 respectively.

The six classes of the stretched green bands can be identified as:

- One class of zero brightness corresponds to the background (uncontaminated area).
- Four classes of brightness variations corresponding to polluted areas, with different degrees of intensities.
- One class of brightness corresponding to the open pit mine (to the west of the factory) and some places within the factory. This class is identified as high contaminated areas.

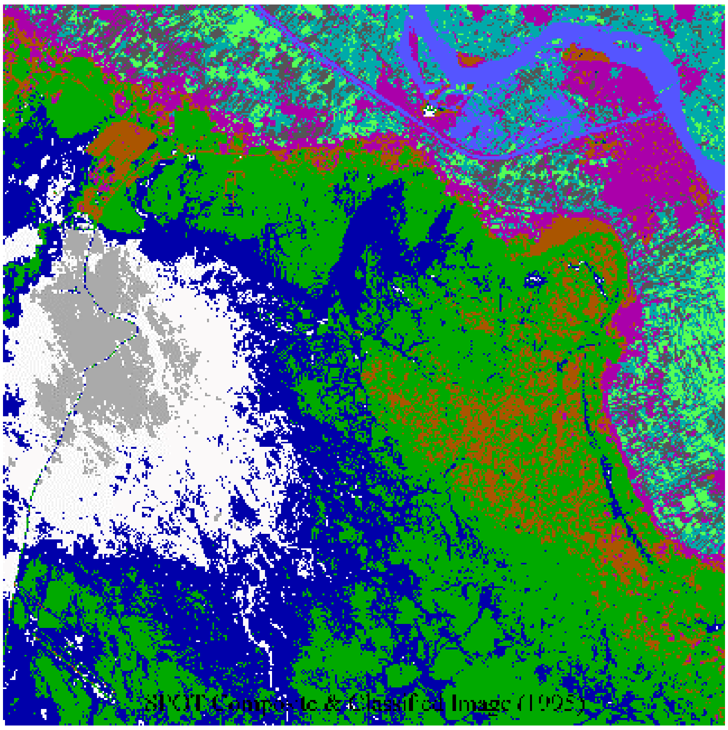


Plate 1 Window (458 square km) of 1995 image (unsopervised classified)

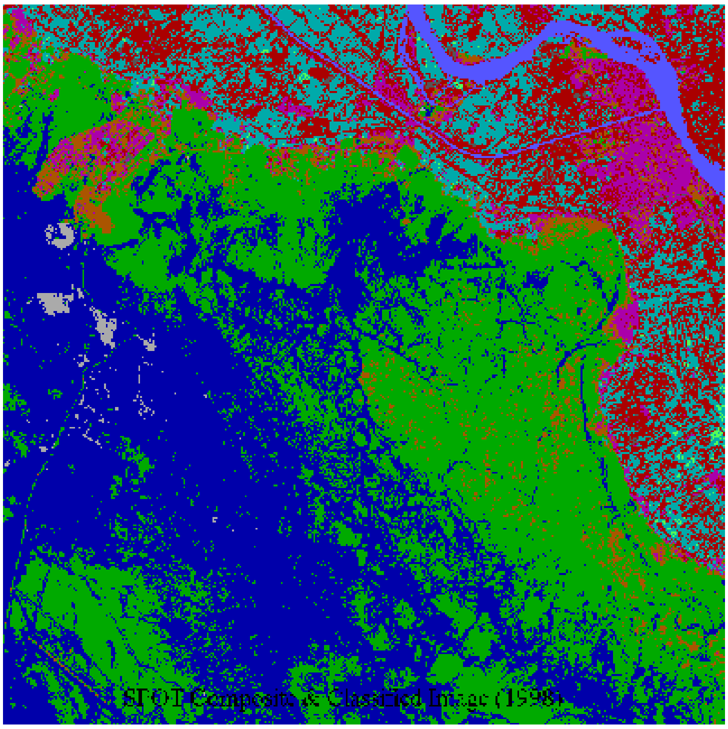
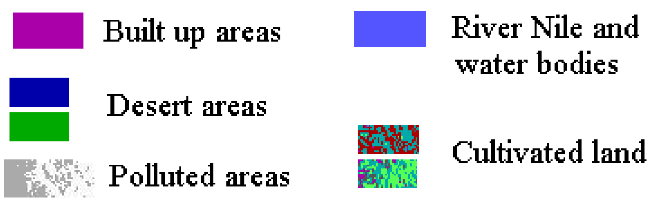


Plate 2 Window (458 square km) of 1998 image (unsopervised classified)



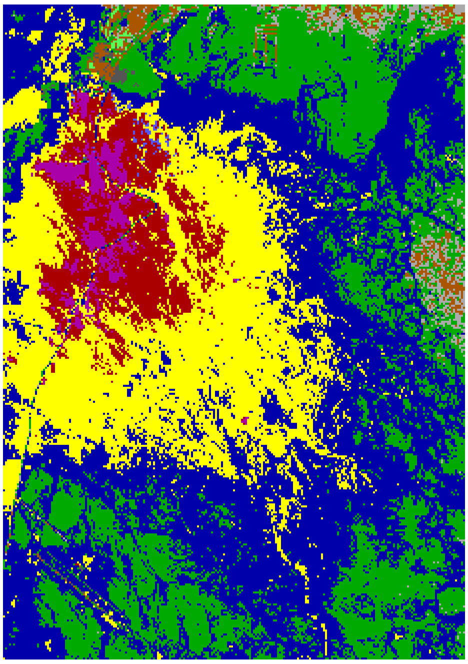


Plate 3 Window (12x17km) of 1995 image (unsopervised classified)

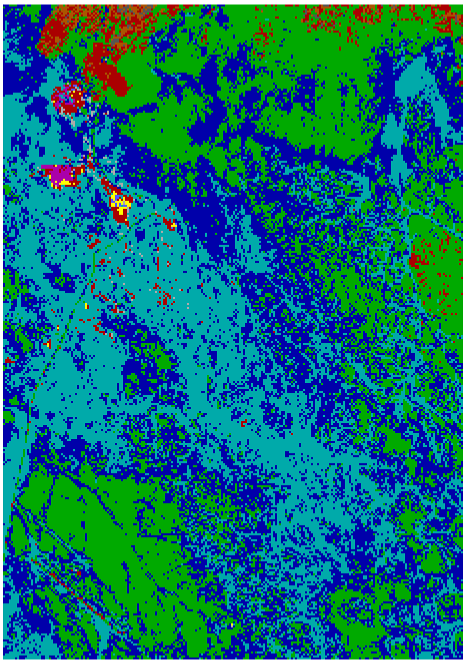


Plate 4 Window (12x17km) of 1998 image (unsopervised classified)

Polution levels (Plates 3 &4)

High density   Medimum density   Low density

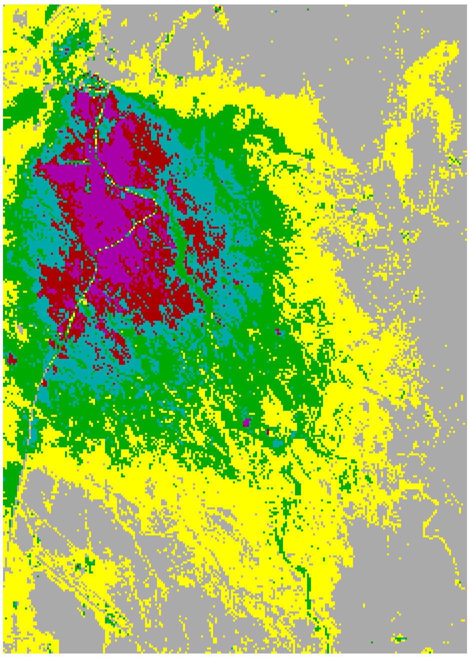


Plate 5 Streatched green band of 1995 image (corresponding to Plate 3)

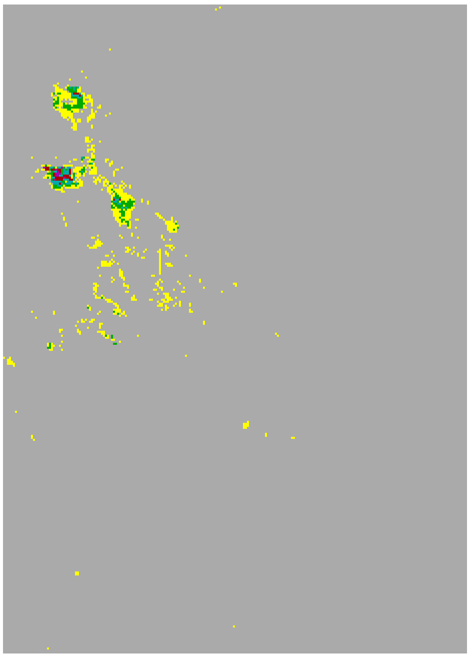


Plate 6 Streatched green band of 1998 image (corresponding to Plate 4)

Polution levels (Plates 5 &6)

High density   Medimum density   Low density

Back ground

4. QUANTITATIVE ANALYSIS OF RESULTS

In order to be able to obtain quantitative numerical results, the area on the ground corresponding to each pollution level was computed using the facilities available in the software. Also the maximum transport distance, from pollution source, of each of these levels was measured on the screen and given in the following tables. The data in these tables are corresponding to the sub image, which is corresponding to 12 km x 17 km on the ground. These data are represented graphically in Figure 3, where the cumulating of the extracted polluted area is represented (in square km) on the ordinate and pollution levels are represented on the abscissa. The identification of pollution levels (as low, medium and high) is suggested based on the location of the contamination with respect to the factory, where the closer places to the factory are expected to suffer from higher contamination.

No	Identification	Results from 1995 image		Results from 1998 image	
		Area (m^2)	Dispersion (m)	Area (m^2)	Dispersion (m)
1	Desert	139526400	-	202024400	-
2	Low contamination *	47455200	11381	223600	5247
3	Medium contamination *	13277600	6579	1414000	4414
4	High contamination *	3740800	4589	338000	1684
	Σ *	64473600		1975600	

Table 1. Results of analyzing the data of the unsupervised classified image windows, plates 3 &4

Class No.	Identification	Results from 1995 image		Results from 1998 image	
		Area (m^2)	Dispersion (m)	Area (m^2)	Dispersion (m)
1	Desert	53329200	-	202802000	-
2	Low contam. *	75561200	15431	734400	6420
3	Medium contam.(I) *	38034400	12569	232000	3115
4	Medium ontam.(II) *	19698400	6512	140000	2245
5	High contam. (I) *	10546400	5760	66000	2017
6	High contam. (II) *	6830400	4521	25600	2000
	Σ *	150670800		1198000	

Table 2. Results of analyzing the data of the stretched green band, plates 5 &6

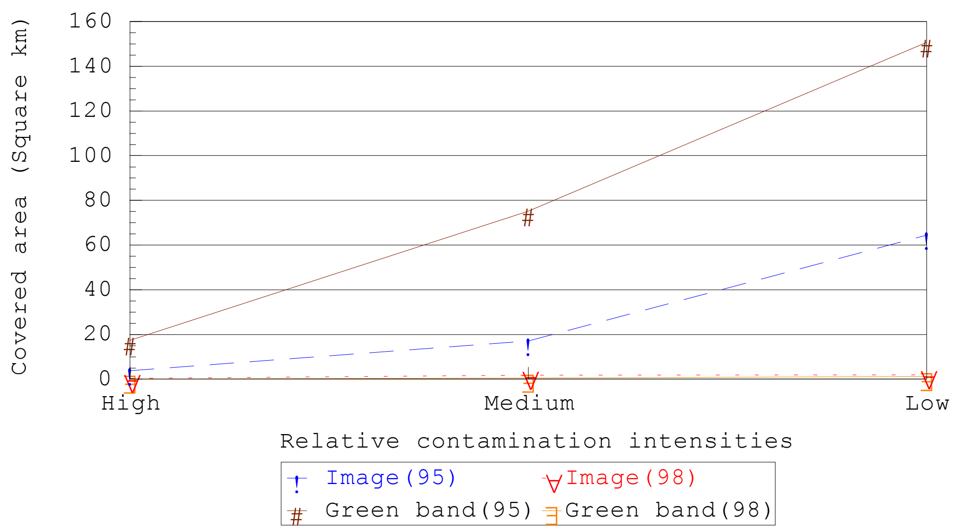


Figure 3. Graphical representation of the detected polluted areas

5. CONCLUSION

The digital analysis of satellite images proved to be a valuable tool for accurate detection of environmental pollution caused by cement factories. This study proved that the digital analysis of high spatial and spectral resolution SPOT multispectral images, with computer-aided visual approach, is an applicable tool for accurate locating and monitoring such air pollution phenomena. The working condition of factories can be monitored as varieties of pollution intensities under different working conditions were distinguished. Unsupervised classification and simple thresholding of the green band were found suitable for this purpose. The detected dispersion of air pollution of cement factories can be described in its general form by Gaussian Plume model, where the dispersion was mainly in the average wind direction.
According to the obtained results one can conclude that, SPOT satellite multispectral image proved to be one of the most important tools for global environmental monitoring at the resolution of pixel level (20 m).

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