ANALYSIS OF SATELLITE IMAGE APPLIED TO ARCHAEOLOGICAL RESEARCH IN NORTH-WEST INDIA : DELIMITATION OF LINEAR NETWORKS

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ABSTRACT

The study comes within an archaelogical research in an area between the Ghagghar valley and the northern piedmont of the Arawalli Hills in northwestern India (Indo - French Archaeological Mission : A.S.I./CNRS).

We use the satellite imagery to find traces of ancient irrigation system, which is an evidence of historic and protohistoric human occupation. We apply ourselves to recognize automatically all sorts of lineaments found on the images. In the field, these shapes correspond to natural or artificial linear networks : streams, paleo-courses of rivers, drainage traces, sand features, roads, tracks, railways, canals (ancient and modern).

We use the quantitative analysis of images : texture analysis and especially mathematical morphology. Our work involves developping recurrent morphological transformation procedures which aim at extracting the predefined objects according to their shape and their size.

We present examples to explain the whole process which is applied to satellite images. We show different results of enhancement of various types of networks on MSS Landsat data. The final delimitation of the main networks is obtained from processings of Spot images.

1. OBJECTIVES

This study fits into an archaeological research concerning the plain west of Delhi, between Yamuna and Sutlej, Arawallis and the piedmont of Himalaya (the Siwaliks), in the subarid part of north western India, on borders of Rajasthan, Haryana and Punjab. A small part of this area has been selected to be intensely surveyed (fig.7).

We try to find the linear continuity of ancient irrigation systems belonging to different periods (medieval to protohistoric periods). Nowadays, these canals are often pointed out in the field by linear sand features.

We also want to study the ancient drainage pattern : we search for paleo-courses of rivers, drainage traces which don't clearly appear in the field.

The final aim of this dual research is to explain the links between past landscape modifications, especially drainage pattern modifications and the presence in the study area of many archaeological remnants, like sites (Late Medieval to Early Harappan/4500 yrs BP), traces of ancient irrigation canals (FRANCFORT, 1985)

1. Presented at the Ninth Asian Conference on Remote Sensing, at Hotel Ambassador, Bangkok, Thailand, November 23-29 1988.

We use remote sensing data in order to obtain informations about the spatial extension of the networks. The aim of this work is to detect automatically natural or artificial linear networks on multiband Spot images (resolution 20 m).

We also want to *extract* these objects, that is to say that they have to be restored on uniform background.[2]

The methods commonly used to recognize predefined objects from satellite imagery are based on their spectral characteristics but don´t take into account their spatial structure. As we are looking at lineaments, we have considered morphological indicators as more pertinent than spectral ones.

We principally use the methods of mathematical morphology which are suited to automatic analysis and interpretation of shapes of objects on an image. Our work consists in developping morphological transformations with the aim of extracting the objects according to their shape and their size. Unlike classic photointerpretation, such process is automated and can be reproduced from images of geographically similar area in order to reach the same kind of objective.

We present here various examples on test images to explain the method developped to achieve recognition and extraction of all sorts of lineaments. The classification and the selection of archaeological networks will be the topic of a future work.

2. OBJECTS ON THE GROUND AND OBJECTS ON THE IMAGES

The study area has a semi-arid climate. Rainfalls occur during July and August and range from 300 to 500 mm. The area consists in a flat to undulating plain partly covered with sand dunes and drained by a few saisonal streams. Vegetation is fairly dense in the depressions and very scattered on the sand dunes. Because of the lack of water, irrigation is achieved by wells, canals or tanks. Therefore, the landscape has been wholly modified in Haryana for about thirty years by the setting up of an important artificial irrigation system. Consequently, fields have been leveled, ancient canals have often been re-used and thus altered.

At the present time, we have no pertinent criterion on which to differentiate the various kinds of archaeological networks on the images. Especially, the ground clues used to find out ancient canals (linear sand features) are not sufficient to recognize them on Spot images. On an image, we can differenciate roads from steams, or canals from cart-tracks, but we cannot distinguish natural sand features from ancient canals. A more elaborate information about their size, shape, and neighbourhood, would allow to formulate recognition criterions on the image. That is why we have attempted an extraction of all sorts of lineaments visible on the images.

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2. The resulting binary images provide available inputs to carry out later quantitative analysis on the networks spatial distribution characteristics and to estimate their distance from archaeological sites.

On the test image [3], we can find different sorts of linear networks (fig.11 and 12) :

- artificial networks : present irrigation canals, metalled or unmetalled roads, cart-tracks, parallel networks (road/canal or cart-track/canal).
- natural networks : dried drainage traces still undated.

Recognition and extraction of these objects from a classification of their spectral signature is not pertinent here for different reasons :

- these methods don't lead to the differenciation of objects having nearly the same spectral signature but some different shape such as a canal and a river.
- The different sorts of networks have no specific and stable spectral signature : in the study area, many present linear networks (communication, or canals) are tree-lined (*Acacia arabica* and *Prosopis specigera*). The networks spectral answer can be mixed with the tree-vegetation spectral signature. A road and a canal may have the same spectral signature. A road will not have the same radiometry if it is tree-lined or not or according to its covering.
- At last, some lineaments are less wide as the size of one pixel (20 m). We cannot talk about spectral signature, they are only visible because their shape make a break in an homogeneous environment.

Hence we apply ourselves to recognize on a Spot image all sorts of linear networks regardless of their content (water, asphalt, sand, bare soil), we want to enhance and then extract rectilinear shapes (present artificial networks) and more or less curved linear shapes (ancient artificial networks, natural networks) whatever their direction, their width, their length, their neighbourhood and their spectral signature.

3. IMAGE PROCESSING : PRINCIPLES AND RESULTS

3.1. Basic morphological transformations

We use concepts and tools of the quantitative analysis of images, especially *mathematical morphology*. The application of this method to complex remotely sensed images is quite recent. The aim of mathematical morphology consists in analysing objects on the image as geometrical sets (SERRA,1982).[4]

One of the basic methods of mathematical morpholgy consists in transforming the objects under analysis with another predefined object called *structuring element*. This is a perfectly definite simple geometrical shape, to which we refer to analyze some shapes on an image. We use here an hexagon and a segment. These structuring elements are characterized by their size (hexagon radius, segment length). The choice of some or other kind of structuring element depends on the kind of information we want to find.

We don't present here in detail mathematical properties of the morphological transformations, but we give simple and illustrated

3. Spot scene 203-292, 22 May 1986

4. On binary images, these sets are defined as patterns on a background (isolated pixels or connected sets of pixels). On grey tones functions, the sets are defined as the umbrae of the grey tone function defined on a set of pixels.

principles of the elementary transformations that we have used : binary *erosion* and *dilation*, grey tones *dilation* and *erosion*, and *closing*.

In binary images, sets are identified by pixels of value 1. The background is composed by the pixels having the value 0.

- The *dilation* Y of a set X with respect to the structuring element B, noted $X \oplus B$, is defined by the equation :

$$Y = \{ X : B_x \cap X \neq 0 \}$$

where x are the centers of the structuring element B_x. The physical effects of the *dilation* are an increasing of the set surface with connecting of the disjointed parts and smoothing of the edges (fig.1).

- The *erosion* Y of a set X with respect to the structuring element B, noted $X \ominus B$ is defined by the function :

$$Y = \{ X : B_x \subset X \}$$

The physical effects of the binary *erosion* are a reduction of the set surface and equally a smoothing of the edges (fig.2).

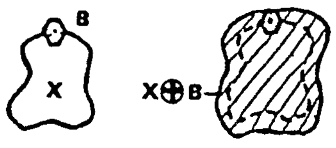

fig.1.Binary *dilation*

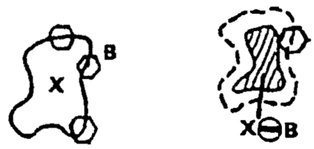

fig.2.Binary *erosion*

The grey tones function (GTF). We can say that an image with grey tones values is equivalent to a relief map with peaks and valleys. In other words, an image is totally defined by the brightness b(x,y), of each pixel (x,y) just like a relief map is defined by the height at each point. The analysis of a grey tones image can be performed by studying the function b(x,y).

- The *dilation* of a function f with respect to the structuring element B is the function $f \oplus B$ whose value at point x is the highest value reached by f inside the structuring element B centered on point (x,f(x)). The physical effects of the *dilation* are the widening of the peaks and the narrowing of the valleys (fig.3). On figures 8 and 9, we have represented respectively the standard deviation filter on a Landsat MSS 6 image, and the morphological *dilation* of the previous one. This sequence of transformation enhance two types of networks, the river in red on figure 9 and the canal in blue (fig.9).

- The *erosion* of the function f with respect to the structuring element B is the function $f \ominus B$ whose value at point x is the smallest value reached by f inside the structuring element B centered on point (x,f(x)). The physical effects of this transformation are a widening of the valleys and a narrowing of the peaks (fig.4).

- The *closing* f^B is the composition of two transformations, a *dilation* followed by an *erosion*. The *closing* has no effect on the peaks and merely fills up the valleys (fig.5).

- The *top-hat* transformation is a morphological filtering which extract peaks or valleys (fig.6) :

$$\text{Top-hat } (f) = f^B - f$$

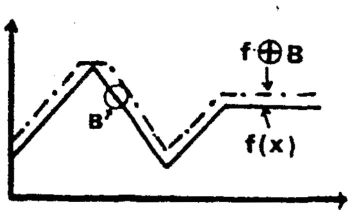

fig.3.*Dilation* of the GTF

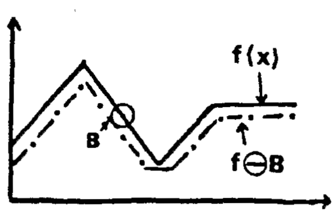

fig.4.*Erosion* of the GTF

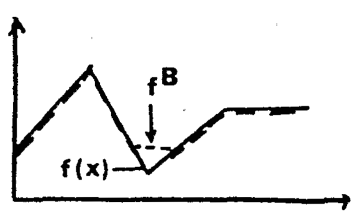

fig.5.*Closing* of the GTF

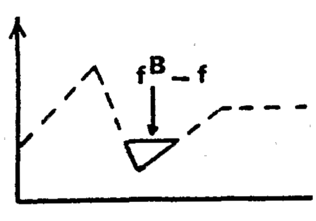

fig.6.*Top-hat* transformation

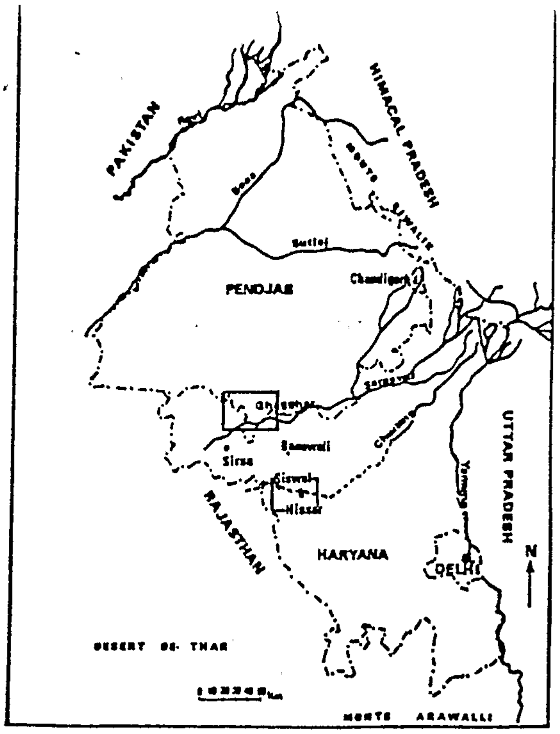

fig.7 Location of the study area in NW India

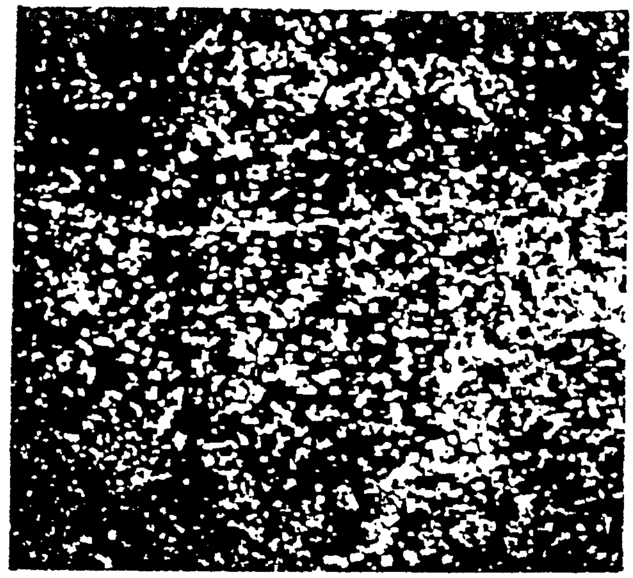
fig.8. A : Standard deviation filter on Landsat MSS 6 image

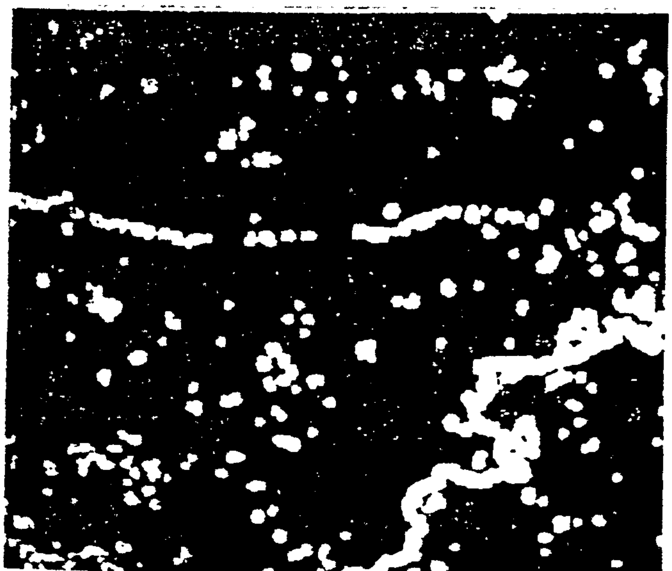
fig.9. B : *Dilation* on A

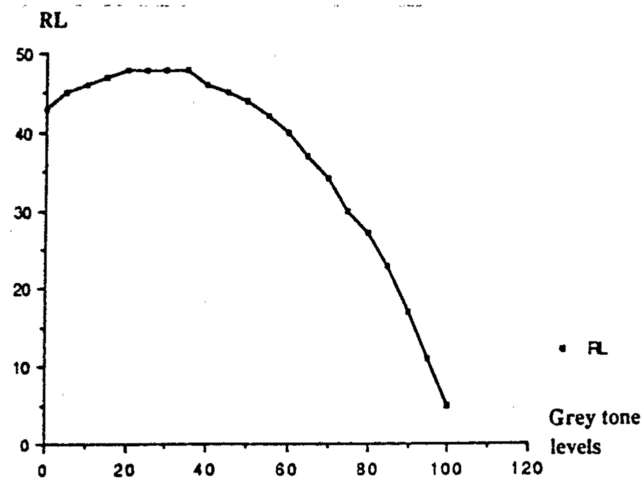

fig.10. Variation of ratio R_L


fig.11. Zone extracted from Spot Scene 203-292, 2 May 1986 (first Karhunen-Loeve

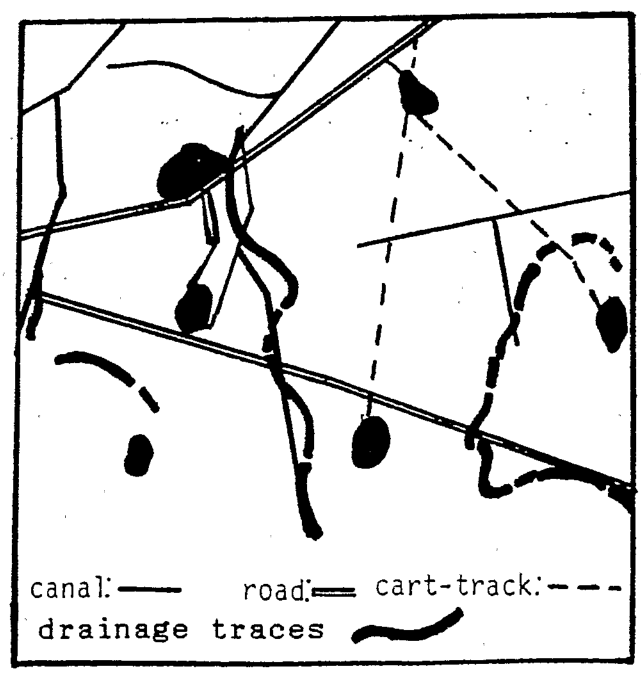

fig.12. Different types of linear networks

3.2. Sequence of enhancement procedures

As basic image for morphological analysis, we have chosen the *first Karhunen-Loeve component* which is more contrasting than the three original spectral bands and thence on which networks are more clearly visible (fig.11).

We extract from Spot scene a 256 pixels x 256 pixels image[5]. We can see on the first Karhunen-Loeve component image (fig.11, 13) that the linear features are characterized by lower values of the function (darker regions of the image). In order to filter the linear features, we use an anisotropic and convex structuring element, that is the *segment*. Therefore the filtering has to be done in all the directions : we process a sequence of *closing* by three segments having the directions of the lattice (0°, 60°, 120°) and three segments having the three complementary directions (30°, 90°, 150°).

In order to enhance the linear dark lineaments, we use a *top-hat* transformation. On resulting images (fig.14, 15, 16) we can see lineaments and other isolated group of pixels.

3.3. Thresholding

The problem of the thresholding has been solved in the following way : we want to select the threshold delimiting the greater number of lineaments in proportion with the total area of the corresponding binary image.

For each possible threshold, that is to say for all the grey tones g, we have evaluated the ratio R_L between the number of linear configurations occuring on the binary image and the total area :

$$R_L(g) = \frac{N_L(g)}{A(g)}$$

$N_L(g)$: number of linear configurations for the threshold g
$A(g)$: area of the set obtained by threshold g

The idea is to select the threshold G that maximize $R_L(g)$. The linear configuration has been estimated by peculiar digital configuations inside the elementary hexagon, for each of the twelve directions. For example, we assimilate a horizontal linear configuration (0°) to the following digital ones :

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   0 0          0 0
  1  1  1     1  1  1
   0 0          1 1
```

The variation of the resulting ratio R_L calculated on a grey tone image is shown on figure 10. We can see that there are very little possible threshold (four in this case). We choose here the value : g=25.

3.4. Linear networks extraction sequence

The three binary images corresponding to the threshold of the *top-hat* images in the three complementary directions (30°, 90°, 150°) are reproducted on figures 14 to 16. The main lineaments are restored, but together with them, non linear spots are present all over the image.

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5. The original square lattice has been converted to an hexagonal one in order to utilize a symetric structuring element, that is the hexagone.

fig.13. C : First Karhunen-Loeve component

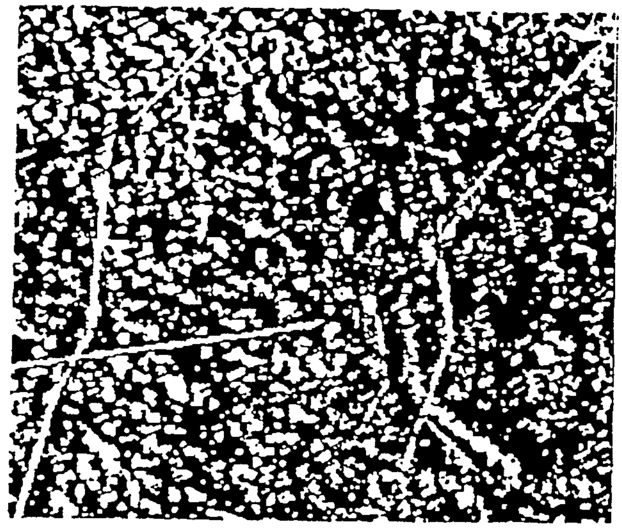

fig.14. D : *Top-hat* on C (30°)

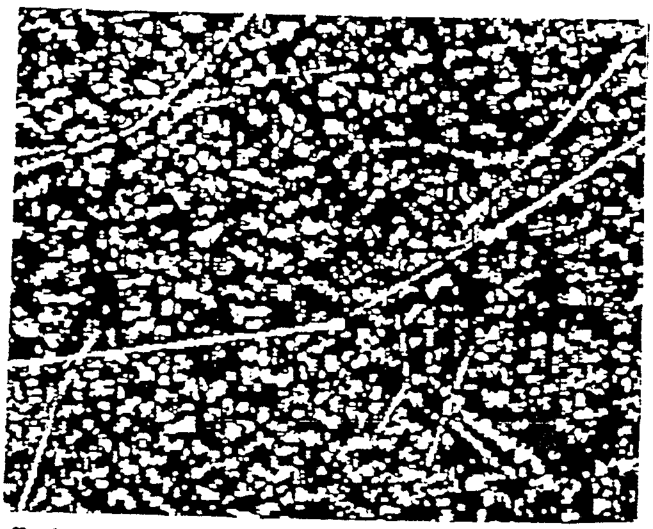

fig15. E : *Top-hat* on C (90°)

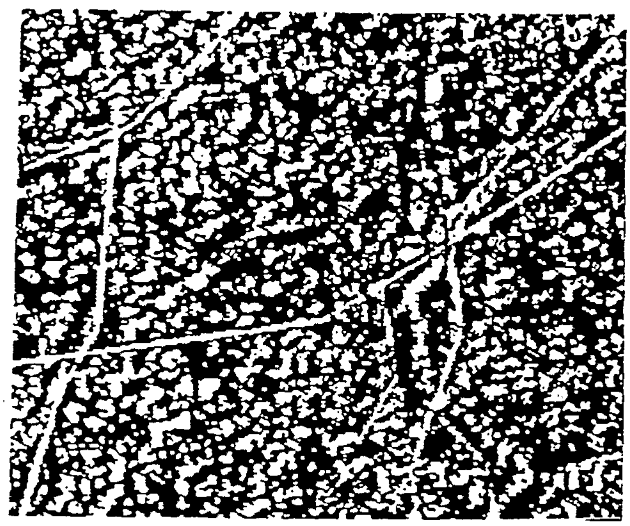

fig.16. F : *Top-hat* on C (150°)

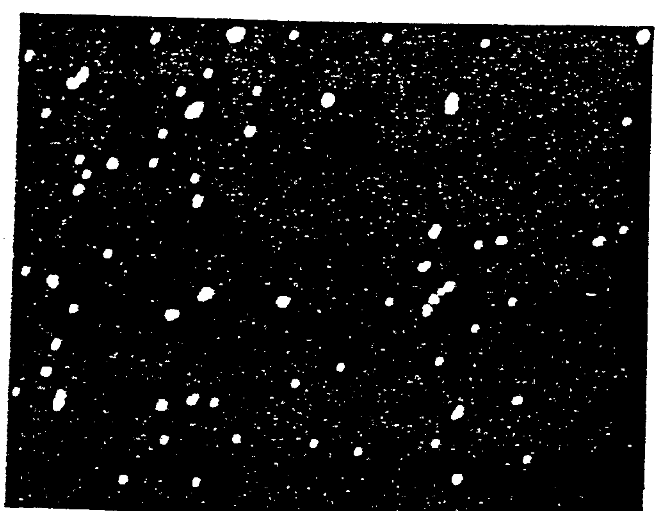

fig.17. G : Binary *erosion* on F

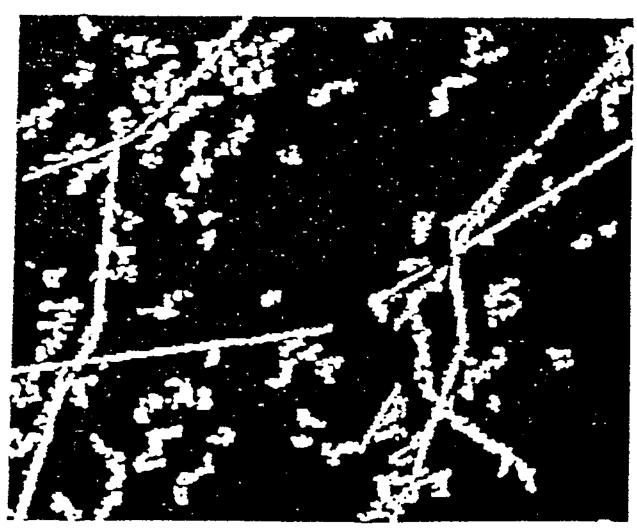

fig.18. H : Reconstructed components

With the method of *reconstruction* of connected components, we have tried to obtain an image containing only the set of connected lineaments on an uniform background.

This method consists in applying the following algorithm to binary image assimilated to a single set X_0 and where B is a convex structuring element :

$X_1 = X_0 \ominus B$

$X_2 = (X_1 \oplus B) \cap X_0$

$X_n = (X_{n-1} \oplus B) \cap X_0$

The first transformation (the *erosion* ; fig.17) eliminates all the isolated components smaller than the structuring element. Therefore, the resulting background is more uniform. The connected components that have not been eliminated previously are reconstructed thanks to the successive *dilations*. They are not delated over their initial size thanks to the intersection with the initial set X_0. So are reconstructed the original connected components bigger than the structuring element.

This algorithm stops automatically when the set X_n is equal to the set X_{n-1}. In the case of the reconstruction, one demonstrate the existence of an integer N from which the transformation ($\oplus$ B $\cap$ X_0) becomes idempotent[6]:

$$\forall\ n >= N \quad X_{n+1} = X_n$$

The reconstructed components depend only on the size of B. Here, we have chosen an hexagonal structuring element of size 2.

In order to catch the greater amount of lineaments provided by the previous *top-hat* transformations, we have processed the reconstruction algorithm on each of the six images. We have then processed the Union of the sets reconstructed from the top-hat transformations in the lattice directions. We have done the same for the complementary directions (fig.18).

Finally, we produce an image containing the main lineaments visible on the original image and some other spots having a sublinear shape. Some of the thinner lineaments that were perceptible on the original image and on *top-hat* images have disappeared. It will be necessary to imagine another kind of algorithm to delimite them.

4. CONCLUSION

Appropriate morphological transformations lead to an enhancement of some features of the image such as lineaments. They also make possible the extraction of the main networks. Some thin lineaments corresponding to artificial irrigation canals or to small paths, visible in the field are no more visible on Spot images and not restored with image processing. On the contrary, the lineaments corresponding to ancient natural drainage traces which are not perceptible in the field are appreciably enhanced and extracted thanks to image processing.

Adapted image processing can be further worked out in order to extract thin traces of ancient networks. The more accurate criterions of recognition and automatic extraction of lineaments of archaeological interest have to be elaborated by a field survey and algorithmic developpements in image processing.

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