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Detection and Extraction of Linear Structures in Satellite Images by Line Segmentation of Watersheds: Application to The Extraction of The Road Network of The City Of Douala

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Abstract:

This article presents a method for detecting and extracting linear structures based on mathematical morphology in satellite images. The mathematical morphology allows to provide the tools (erosion, expansion, opening and closing) appreciable in segmentation especially in segmentation by line of water partitions because it allows to take into account the notions of shape and size. This as well as the extraction of linear structures will be developed by segmentation by line of water divisions and as the road and hydrographic networks consist of the same texture or similar pixels, this technique will be followed by the thresholding technique. The segmentation by line of the water divisions is a technique which has already proved its worth, especially for the delimitation of regions in a satellite image. The thresholding technique is generally used when it is necessary to identify similar pixels with the same radiometric values. It is therefore a question of creating partitions in the image while identifying similar pixels in order to detect and extract linear structures in the satellite images type Synthetic aperture radar and satellite images for earth observation. From the combination of these two techniques, road networks and hydrographic networks appear clearly from the choice of a threshold specific to each satellite image. Our results show that they are satisfactory; we were able to detect the road network of the city of Douala, this is in agreement with those presented by the detection method by processing neighborhoo**ds.**

Keywords **—mathematical morphology, line segmentation of water partitions, thresholding, linear structures**

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I. INTRODUCTION

Since then, several works have been carried out with radar images on Cameroon, in the case of the cities of Douala (Timothéekombe et al, 2005) [1] and the city of Yaoundé (Tonye et al, 2000) [2] in view to extract the road network. In practice, in an urban environment, the different entities are delimited by detection of the contours (TimothéeKombe et al, 2005) [1]. The latter are highlighted thanks to a low threshold higher than the radiometric level of the water and an upper threshold lower than that of the shiny points (roofs) which makes it possible to isolate the water which leads in most cases to a binarization of the image. The object of this study is to propose an approach for producing maps using mathematical morphology.

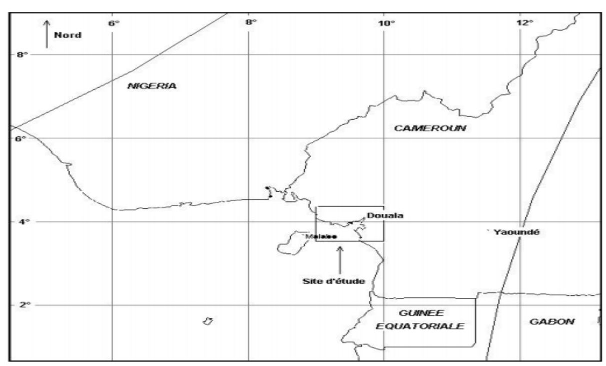
Many methods have been developed to solve the problem of detecting road networks from satellite and aerialprocesses to extract the linear networks in the satellite and aerial images although she obtained very satisfactory results, this method presents some on detections and omissions given the automatic character of the method.Other methods have also been proposed, such as that of (TimothéeKombe et al, 2005) [1]. The method of detecting the Douala city network from a synthetic aperture radar image in their case is by neighborhood processing. But the problem of discontinuity and false detection are still present. To deal with these problems of discontinuity and false detection, we have therefore developed a detection method for the road network of the city of Douala based on mathematical morphology: segmentation by line of water divisions which will be followed by thresholding. Detecting line arrays in satellite images therefore amounts to looking for elements comprising the same texture, that is to say elements having similar pixels or the same luminance value.The texture is conceived here as a continuous and repeated zone in which the change of character is not detectable, it is developed by the first-order statistical method which is likened to the histogram because studies the relations between a pixel and its neighborhood (JanvierFotsing et al, 2009) [5]. The determination of the shape was made possible through the use of morphological transformations which are: erosion, expansion, opening, closing. Thus, segmentation by water divide line therefore responds to this problem of similar pixels because the objective is to create partitions in the image by identifying similar pixels from a well-defined threshold.

In this article we bring our contribution to the resolution of the problems of discontinuity of omissions and over detections during the detection of road networks by proposing a method based on mathematical morphology. The segmentation by line of the water divisions followed by an arbitrary choice of the threshold specific to each image shows us satisfactory results. This is how we will first talk about binarization by thresholding, then the notion of filtering, then we will also present the different morphological transformations, then the segmentation by lines of the water divisions. We will end with the presentation of some results accompanied by a comparative study with other methods of extracting linear structures, in this case the treatment by neighborhood developed by (TimothéeKombe et al, 2005) [1] and the treatment by punctual marked processes developed by (carolinelacoste, 2004) [4].

II. DATA USED AND STUDY SITE

We used a portion of the SAR image of the European Remote Sensing Satellite (ERS 1) acquired in 1994 in C-band, 5.3GHz frequency with VV polarization and 12.5m x 12.5m spatial resolution. But also other images of the National Center for Space Studies (NCSS) and an image PS-MS LANDSAT.

The various treatments were carried out with the MATLAB software.



(Source: European Space Agency)

III. METHODOLOGY

3.1. Filtering

To improve the visual quality of the image, the effects of noise (parasites) must be eliminated by subjecting it to a treatment called filtering. Filtering involves modifying the frequency distribution of signal components to the given specifications. The linear system used is called a digital filter.The filters we used are low pass filters of Gaussian and medium (average) type.

(a) The medium (average) filter

The medium (average) filter is based on information redundancy. The new value of a pixel is calculated by the means of averaging the values over a neighborhood. This linear operation can be seen as the discrete convolution of the image by a mask.

$$I'(i,j) = \sum_{(m,n)\in \upsilon} h(m,n) I(i-m, j-n) \quad ,(1)$$

$$\sum_{(m,n)\in \upsilon} h(m,n) = 1 \quad ,$$

Where I is the intensity of the original image, I' is the intensity of the filtered image, υ is the neighborhood used and h is the convolution mask.

b) The Gaussian filter

The Gaussian filter provides better smoothing and noise reduction than the average filter. The Gaussian function is defined by

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{(x^2+y^2)}{2\sigma^2}} \quad (2)$$

c) The Sobel filter

To calculate the gradient of each image we used the Sobel filter. This indicates the direction of the largest variation from light to dark, as well as the rate of change in that direction. The operator uses convolution matrices. The matrix (usually of size 3-3) undergoes a convolution with the image to calculate approximations of horizontal and vertical derivatives.

Let$\boldsymbol{A}$ the source image $\boldsymbol{G_x and G_y}$ be two images which at each point contain approximations of the horizontal and vertical derivative of each point, respectively.These images are calculated as follows:

$$G_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} * A et G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * A (3)$$

At each point, approximations of the horizontal and vertical gradients can be combined as follows to obtain an approximation of the gradient standard:

$$G = \sqrt{{G_x}^2 + {G_y}^2} (4)$$

3.2. Binarization by threshold.

The first strategy is to binarize the image by threshold and to keep pixels whose intensity is above the threshold. Pixels of values within a given range of the histogram are therefore grouped together within the same class. The threshold is generally defined by the user by considering the characteristics of the image and ensuring that objects of interest (roads and river systems) are taken into account.

This binarization strategy has the advantage of being simple and quick to implement. One can directly decide whether a pixel belongs to the background or object. However, choosing the threshold is a delicate thing. Parts of objects of interest can be assigned to the background of the image if the pixels have an intensity slightly below the fixed threshold. Moreover, this choice is generally not automatic. It is left to the user who empirically determines it. Since the threshold can vary from image to image (depending on the type of sensor, the area studied, the amount of sunlight...) the user must examine each new image before proceeding with the threshold, which is naturally time-consuming. It is also possible to perform automatic thresholding (using well-known techniques such as (Ridler and Calvard, 1978) [6] or (Otsu, 1979) [7]). However, even if the process becomes more generalized, the resulting binary image has the same defects as with manual thresholding. This method of binarization is in fact a global method. It assumes that only two spectral classes are represented in the image, and that objects can be identified by a single spectral signature. As the road and river networks are almost dark the radiometric values are between 0 and 1. So with each image we have determined the detection threshold of the linear structures as well as the road network of the city of Douala. The different thresholds found are 0.495 for the detection of the road network of the city of Agadir (Figure 10), 0.475 for the hydrographic network (Figure 9) and 0.51 for the road network of Douala (Figure 12).

3.3. Mathematical morphology

The analysis of images by mathematical morphology dates back to the sixties. This theory was originally introduced in material science by J. Serra and G. Matheron [8] to analyze objects through their texture (J. Serra, 1982) [8]. Over the past two decades, it has undergone numerous developments, both theoretically and practically. Today, it covers a wide range of fields of application, particularly in robotics and industrial vision, medical imaging and multimedia (Soille, 2004) [9]. As seen by numerous published works, the mathematical morphology applied to a binary image, extracted from an RSO grey-level image of the ERS1 satellite, was recently used to automatically map the mangrove area of Cameroon's coastal region (Akono, 1996) [10]. In the same study, another RSO image of the ERS1 satellite was used for the extraction of the hydrographic network in the southern region of Cameroon, using mathematical morphology. In a more recent study (Tonye and al, 1999) [11], mathematical morphology was combined with texture analysis, for mapping the shoreline on Cameroon's Atlantic coast, using ERS1 and E-SAR data.

The various morphological operations were done using a structuring element B that has simple geometric shapes: round, square, hexagon, octagon, and line **(Figure 1).**

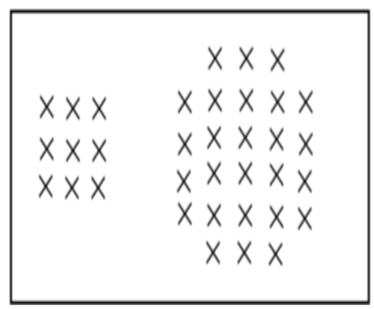


Figure 1: Square and hexagonal structuring elements

3.3.1. Principles

The analysis of an image by mathematical morphology consists in applying one or more morphological operators to this image by means of a predefined mask or geometric pattern (square, rectangle, circle, hexagonal...). The geometric pattern, called the structuring element **(Figure 1),** is moved into the image so that its center occupies all the positions of the space (p pixels). For each of these positions, the chosen operator is applied. The result is a transformed image in which X elements may have been eliminated, merged, thinned, **(Figure 2).**

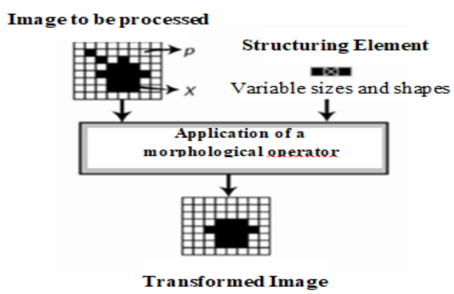


Figure 2: Principle of image analysis by mathematical morphology.

A distinction is made between the ensemble mathematical morphology, which deals with binary images, and the functional mathematical morphology that operates on images in grey levels. The first uses set theory. For each position in the centre of the structuring element, a set relationship (union, intersection) of the Structuring element with the elements of the image is checked. The result of the transformation is a new binary image composed of points that satisfy the relationship. For grey-level images, morphological transformations are generalized and applied to functions (and not sets) this time considering the values taken by pixels in the structuring element domain. Depending on the operator chosen, the maximum value of pixels in the centre of the structuring element (in case of flat dilation) or the minimum value (in case of flat erosion) will be assigned, for example.

Since we seek here to show the importance of mathematical morphology in detecting linear structures based solely on shape information, the method we propose uses only binary morphological operators. Indeed, the use of morphological operators in grey-levels also provides information about the texture of objects because it incorporates order statistics (minimum, maximum) calculated locally. This texture information may of course be relevant for the detection of linear structures, but its exploitation is not envisaged here. The rest of the presentation is therefore part of the binary mathematical morphology.

3.3.2. Fundamental Morphological Operators

The two elementary operators of mathematical morphology are erosion and dilation. They are represented $\boldsymbol{X \ominus B}$ **and** $\boldsymbol{X \oplus B}$ respectively where **X** corresponds to the binary image to be processed and **B** to the structuring element with which the image is browsed. These operators are defined by the following equations:

$$\ll X \ominus B \gg = \{t \in C, telque B_t \subseteq X\} \quad (5)$$

$$X \ominus B = E^B(X) \quad (6)$$

$$\ll X \oplus B \gg = \{t \in C, telque B_t \cap X = \emptyset\} \quad (7)$$

$$X \oplus B = D^B(X) \quad (8)$$

Erosion eliminates objects or parts of objects that are smaller than the structuring element (following the total inclusion relationship to be checked). Some connected objects can also be separated. On the other hand, dilation increases the size of objects, and merges some of them, when the distance between them is less than the size of the structuring element (non-empty intersection).

From these operators, a series of other operators are defined as complex combinations of erosions and dilations. Thus, the morphological opening, which aims at removing details smaller than the structuring element (without reducing the size of the other elements), corresponds to erosion followed by a dilation that is noted by the equation:

$$X \circ B = (X \ominus B) \oplus B \quad (9)$$

It can also be written

$$O^B(X) and O^B(X) = D^B(E^B(X)) \quad (10)$$

The dual operation, which corresponds to the morphological closure, is defined as a combination of dilation followed by erosion that is noted by the equation:

$$X \cdot B = (X \oplus B) \ominus B \quad (11)$$

It can also be written

$$C^B(X) and C^B(X) = E^B(D^B(X)) \quad (12)$$

It should be noted that the opening and closing are idempotent in other words; the result is invariant after successive transformations.

(Figure 3) illustrates the effect of the different morphological operators defined above (the original image being the image to be treated in **Figure 1).**

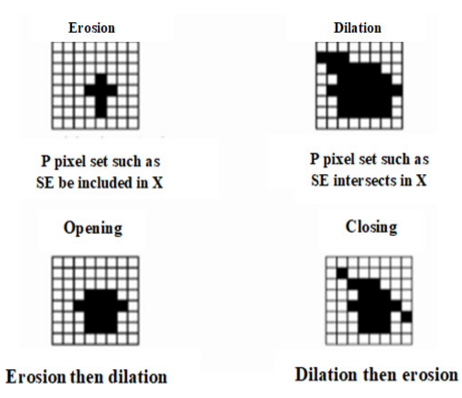


Figure 3: Basic Morphology Operations

3.4. Line segmentation of watersheds

Image segmentation in mathematical morphology is almost essentially based on a single transformation that is the water divide line. The other techniques based on thresholding, top hat, morphological decomposition, skeleton are used only in cases of pathology because of their complicity (C. Vachier and H.Talbot ,1994) [12] or for their extreme simplicity for which the line of watershed is in no way an optimal solution. This technique was developed in 1977 by Lantuejoul [13] and as a segmentation tool by S. Beucher [14] in 1989. But it is F .Meyer's work [15] on the notion of marker that has made it possible to make it a water dividing line.

It can therefore be said that in image processing, water-sharing line segmentation refers to a family of image segmentation methods derived from mathematical morphology that consider a grey-level image as a topographical relief, of which flood is simulated. The water division is therefore the line separating 2 watersheds (from this line, a drop of water can flow towards at least 2 distinct local minima.

3.4.1 Principle:

a. Immersion technique

- Every local minimum of the surface is drilled.
- The surface is flooded from local minima, with water rising at constant and uniform speed in watersheds.
- When the waters from 2 different minima meet, a dyke is built so that they do not mix.
- At the end of the immersion, all the dykes form the dividing line of the waters.

b. Algorithm:

- The first step is to generate the image of the gradient module, i.e. the ridges corresponding to the contours **(Figure 4).**

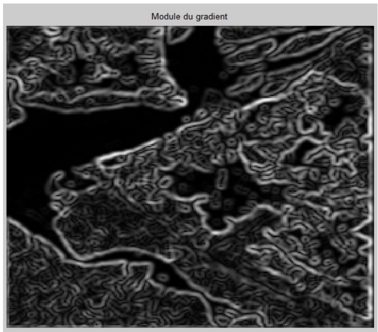


Figure 4: Gradient Module of the City of Douala

- An evaluation of the contour detection line of water-sharing is then carried out by detecting closed contours and over-segmentation illustrated **(Figure 5).**

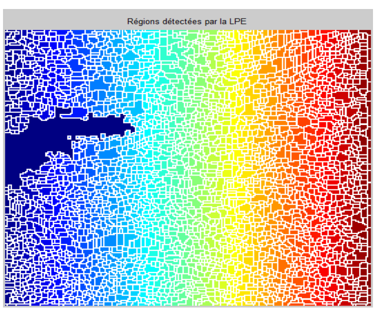


Figure 5; Region detected by watershed line

- The application of dilation and erosion is used to detect regional maxima in the image **(Figure 6**).

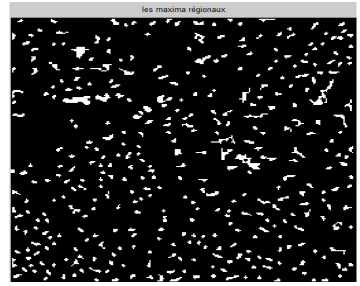


Figure 6: Regional maxima

- The regional maxima are then superimposed on the original image and the same dilation and erosion operations are repeated **(Figure 7).**

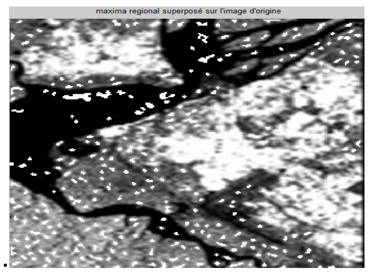


Figure 7: Regional Maxima superimposed on the original image

These different operations allow us to detect the regions in the image and is separated using lines called water-sharing lines. Our method is characterized by a sequence of steps, some of which are based on mathematical morphology. The different stages are illustrated in **(Figure 8**).

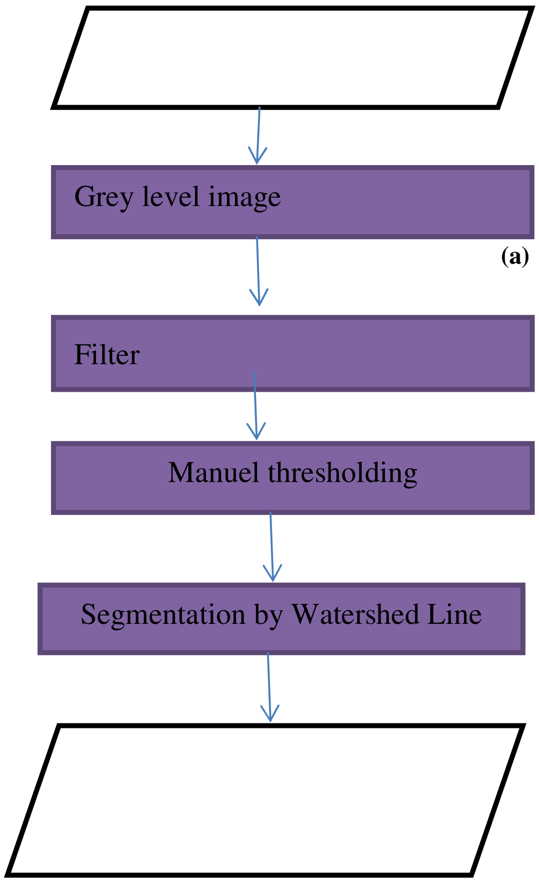
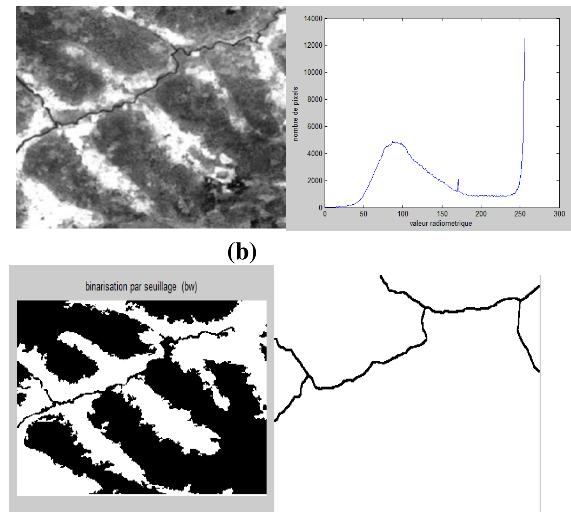


Figure 8: Steps in the method of detecting linear structures.

IV. RESULTS

Our images were submitted to our algorithm which we implemented with MATLAB. We obtained satisfactory results but much remains to be done on the choice of the best threshold and the best structuring element.

Figure 9 shows an **image SPOT XS2 source: (Caroline Lacoste, 2004)[4]** representing ahydrographic network, after reconstruction by threshold and by application of the EPS we were able to extract the network(**Figure 9d)** at threshold **0.475.**

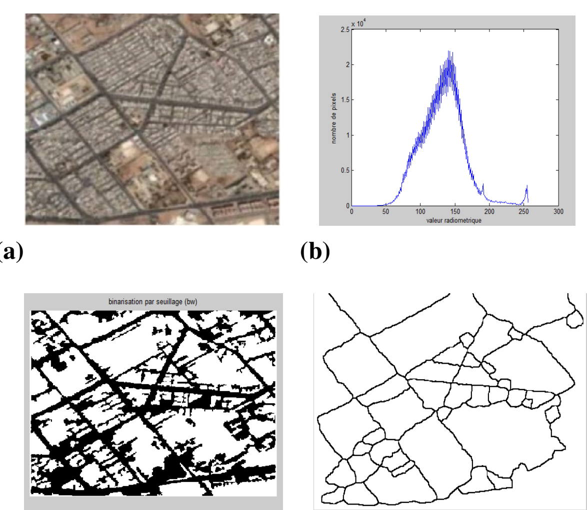


(a) **(b)**

(c) **(d)**

Figure 9: (a) Original image, (b) Histogram, (c) Threshold image, (d) linear network

Figure 10a shows an**image PS-MS Landsat ETM - presenting the city of Agadir (Morocco) source :(Soufiane IDBRAIM, 2009) [16].**We obtain the road network extracted **(Figure 10d)** at threshold **0.495.**

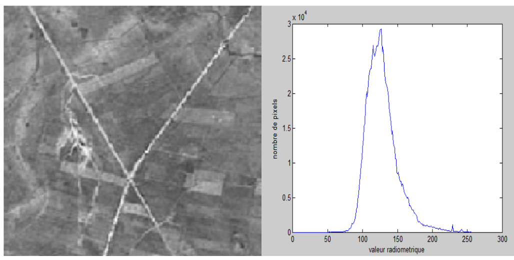


(a) **(b)**

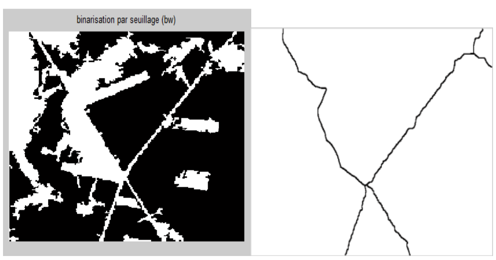
(c) **(d)**

Figure 10: (a) Original image, (b) Histogram, (c) Threshold image, (d) linear network

Figure 11a is a SPOT image provided by the National Center for Space Studies (CNES) **(Caroline Lacoste and CNES)**, it is a road network, we get the road network extracted **(Figure11d)** at threshold **0.5294.**



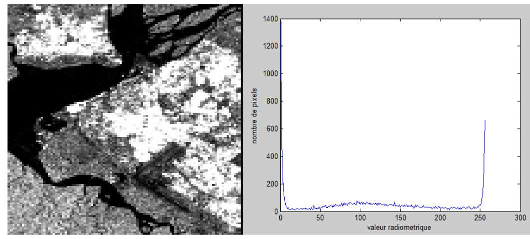
(a) **(b)**



(c) **(d)**

Figure 11: (a) Original image, (b) Histogram, (c) Threshold image, (d) linear network

We worked on a portion of the city of Douala **(Figure 12a)**. After several treatments on this portion of the image, we have by application of the segmentation of the watershed of the waters obtained some roads in Douala extracted at the threshold of **0.51 (Figure 12d).**



(a) **(b)**

(c) **(d)**

Figure 12: (a) Original image, (b) Histogram, (c) Linear image, (d) linear network.

V. Comparative study

We have compared our results with those presenting the main axes of Douala provided by the National Mapping Institute located in Yaoundé **(Figure 13).** We obtained some over-detections and omissions. We have similarities and we have gotten the following results.

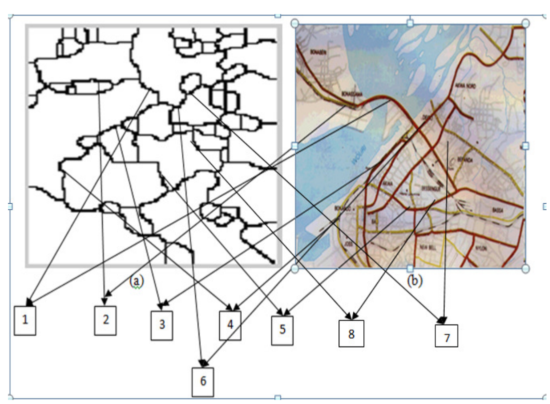
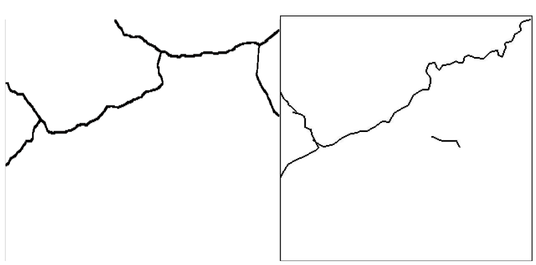


Figure 13: Road network extracted at the 0.51 threshold per line of shares in comparison with the main roads of the city of Douala.

1. Represents the bridge over the river Wouri
2. Represents entry and exit routes from and to Bonaberi
3. Represents the roundabout road -Bonanjo via the port
4. Represents the main road to Bonanjo
5. Represents the boulevard of the United Nations
6. Represents the north Akwa roundabout road
7. Represents the road from Deido to Bassa
8. Represents the North-South urban boulevard

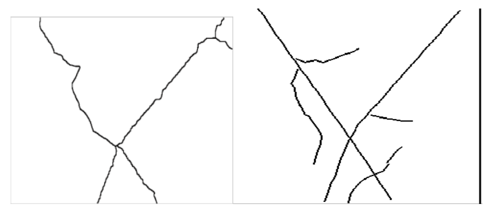
A comparison was also made between the networks extracted by other methods in this case the extraction of road networks by processing neighborhoods (Timothy Kombe and al, 2005) [1] and by marked point processes (Caroline Lacoste,2004)[4] with those extracted by water dividing lines .



(a) **(b)**

Figure14: (a) hydrographic network extracted by segmentation by watershed, (b) hydrographic network extracted by marked ad hoc processes.

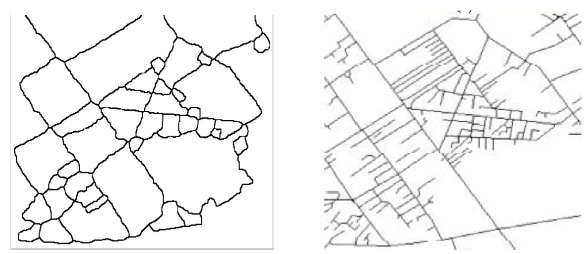
We observed an almost identical hydrographic network with some over-detections.



(a) **(b)**

Figure 15: (a) road network extracted by segmentation by watershed, (b) road network extracted by marked point processes.

We observed an almost identical road network with a few omissions.



(a) **(b)**

Figure 16: (a) road network of the city of Agadir extracted by segmentation by watershed,

(b) The thematic map of the road network of the city of Agadir.

Similarly, we observed a road network almost identical to that of the thematic map with some omissions.

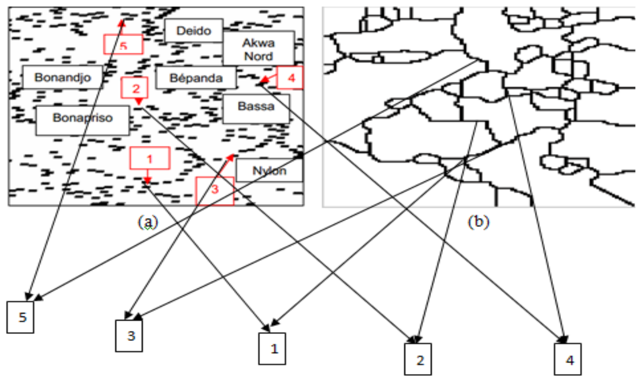


Figure 17: (a) road network of the city of Douala extracted by treatment by neighborhood, (b) road network of the city of Douala extracted by segmentation by watershed.

1. **Motorway or National N°3**
2. **United Nations Boulevard**
3. **North-South Urban Boulevard**
4. **Deido-Bassa Road**
5. **Bridge over river Wouri**

The problem with the extraction of road networks by the neighborhood treatment proposed by [TimothéeKombe] is that this method only highlighted a discontinuous road network instead of a continuous road network. By segmentation by watershed, however, we obtain on the a continuous network of road networks of the city of Douala.

VI. Conclusion

The object of this study was based on the detection of linear structures by segmentation of the watershed lines on satellite images. We used synthetic aperture radar images, as well as images from satellites for observation of the earth. Our method was based mainly on mathematical morphology and a technique based on the arbitrary choice of the detection threshold so the values are between 0 and 1. We obtained satisfactory results. For each of the images, the results were presented with very few omissions and on detection, but the problem of discontinuity was solved especially with regard to the city of Douala. The main interest of the proposed method lies in the fact that, in addition to the fact that we have the results which approach the reality on the ground, but it requires a multiprocessing series for the realization of the maps representing the sought structures (networks hydrographic, road networks).Regarding the city of Douala, the detection and extraction of the network was not total, we were able to extract some roads such as the entrance and exit road of Bonaberi, the main road of Bonanjo, the Deido roundabout road. inAkwa North the United Nations boulevard, the bridge over the Wouri, the Deido boulevard in Bassa and the Urbain North –South boulevard. We compared the results to those obtained by (TimothéeKombe et al, 2005,) [1] and we observed an improvement. One prospect would then be to find a method of extracting hydrographic and road networks that comes close to human vision. Finally, another approach would like us to be able to use this method of extracting linear structures to detect the road and hydrographic networks of the various towns in Cameroon, thereby finally making our contribution to regional planning. But also to detect other linear structures such as pipelines in order to prevent certain defects such as corrosion.

VII. Reference.

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