A new method of drainage network extraction using SAR radar images: a case study of Djanet (Algeria)

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ABSTRACT
An oriented, connected, acyclic graph can be used to represent a hydraulic network. We can consider the network as a set of arcs and nodes. Our research work entails extracting a drainage network from satellite images by preprocessing the data to have features that will compute the minimum cost function. In this paper, we propose an approach to obtain a drainage network based on information theory and mathematical morphology. Our idea is to consider a drainage network as a set of segments crossed two by two in a node. The best network segments minimize the variance calculated in the directions of propagation, maximize the covered geodesic distance, and are most rectilinear. To get results, we have applied these treatments: filtering, segmentation, minimization of a cost function and mathematical morphology operators. Our proposed approach gives excellent results of high quality and quantity. However, there are still some problems in this study, especially the choice of an adaptive index of linearity that differentiates the drainage network from the surrounding environment. Existing methods use a DEM to extract drainage networks, because they indicate networks where water circulates (3D topography). By contrast, in this study, we use images from ERS-1/2 satellites in order to exploit radar waves, thanks to their penetrating capacity and sensitivity to the dielectric and geometric properties of the land. The temporal and spatial resolutions of the SAR images also allow a historical monitoring of hydraulic networks because of the continual availability of SAR data.

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1. Introduction
The development and management of water resources in arid zones require a study of drainage systems. Most of the drainage network extraction methods use Digital Elevation Models (DEMs). These models allow for the extraction and calculation of various drainage and terrain morphometric parameters [1–5]. We can cite some methods. One method has presented work to show that the Karmanasa river basin is less prone to flooding, less vulnerable to soil erosion and an excellent resource of surface water. Its aim was to use the water resources for sustainable development in the Karmanasa river basin area [6]. Another method, based on remote sensing data, has presented work to show that in 1972, the morphometry active channel covered 12% of the area in Ganga River valley, and that its aerial extent was still 8% in 2010 [7]. A further method has introduced a study to investigate the regional topography and drainage dynamics of the Khurar river in central India, along with the textural, mineralogical, and geochemical behaviour of the bed-load sediments. SRTM data carried out the morphometric analysis [8]. Another method again has proposed work to process depressions and flat areas using the principal drainage line as the known hydrology network [9]. Research work has also been presented to identify an unsupervised channel network in complex mountainous terrain [10]. Other work still has been used to improve the efficiency of drainage network extraction from large terrain datasets [11]. Again, another approach has extracted drainage networks using assimilated rainfall data [12]. Elsewhere, an approach has introduced use of a generalized contour based on the analysis of drainage structure; the extraction of the drainage system occurs directly from the contour based on the Delaunay triangulation model [13]. One method has proposed to extract river networks from satellite images [14]. Finally, we have identified a method to trace flow paths from headwaters to the river outlet and to calculate the reasonable stream threshold [15].

SAR radar images make it possible to determine the spatial distribution of the drainage patterns, thanks to the high sensitivity of radar waves to the topography, the roughness and humidity of the terrain surface [16–19], and SAR’s ability to penetrate arid zones [20]. Our proposed research work consists of extracting a drainage network located southwest of the Djanet region in Algeria, from SAR radar images created at
different dates, using data from the ERS1/2 satellites. The importance and unique contribution of our study is based on three arguments: (1) we used the ERS-1/2 images between 1992 and 2011 to study the drainage system and to detect any changes during this period of almost 18 years; (2) the chosen study area is characterized by an arid region where the extraction of a drainage network is difficult and complicated under these conditions; and (3) the radar waves are very sensitive to moisture and land topography. Our method can be assimilated to methods using DEMs to extract the drainage networks and it will be used to update a hydraulic map in the case of changes over time.

2. Study area

Figure 1 shows the study area of Djanet in Algeria, with latitudes boundaries of 24°16'58.82" and 24°24'30.30" North, and longitude boundaries of 8°49'13.35" and 8°54'11.10" East. Djanet is an oasis located in the southeast of the Algerian Sahara, 2,300 km from Algiers.
3. Data and method

3.1. Data

Figure 2 presents two tested images at different dates (1992 and 2011). Table 1 shows the data used from ERS-1/2 satellites, supplied by the ESA (European Space Agency), in PRI (Precision Image) mode. These images cover an area of $(100 \text{ km (range)} \times 102.5 \text{ km (azimuth)})$. The image acquisition was conducted by day, descending and in an azimuth direction downwards. The terrain is lit to the right in lateral view with an angle of incidence of $23^\circ$, in the band C, with a wavelength of $5.65 \text{ cm}$ and

![Image](image_url)

**Figure 2.** Original ERS-1/2 satellites images of Djanet: (a) image taken in 1992; (b) image taken in 2011; (c) and (d) location of the study area.
We applied an adaptive threshold to obtain the entire drainage network. To evaluate the results, we used the registration principle.

3.2.1. Mathematical evaluation and the algorithm of extraction. The aim is to calculate two vectors X (a binary vector for the exact location of the segment to extract in each couple of windows of the segmented image), and Y (a random vector of likelihood for this segment). The objective is to find a best path representing a network’s segment. For these two vectors, their values are: (1) in case of presence of the segment $X = 1$ and $Y \approx 1$; (2) in case of its absence, $X = 0$ and $Y \approx 0$. This is about minimizing a cost function $F$ that its parameters are $X$ and $Y$ (Formula 1):

$$F(X, Y) = \sum_{c \in G} X_c(p - Y_c)$$  \hspace{1cm} (1)

where: $c$ couple of windows, $G$ is a graph of network segments and $p$ is a value in $[0, 1]$.

The following steps constitute our proposed algorithm of extraction:

1. To choose a study area;
2. To enter the number of the drainage network’s segments;
3. For each segment:
   - To choose beginning and end pixels;
   - To extract homogeneous pixels [22];
   - To compute the best line for each couple of windows obtained after segmentation of the image composed by homogeneous pixels [22];
   - To obtain the segment that is defined by this function $H$ (Formula 2):

$$H(a, b) = \arg \min_{c} \left( F(X, Y) = \sum_{c \in G} X_c(p - Y_c) \right)$$  \hspace{1cm} (2)

where: $a$ is the starting pixel and $b$ is the arrival pixel;

4. Application of a union operator of mathematical morphology on each two extracted segments or on all segments after their extraction to obtain a drainage network;
5. To apply a threshold on the image (result of step (4)) to differentiate the drainage network from the surrounding environment;
6. To use the registration principle to evaluate results.

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**Table 1. Radar data.**

| No. | Date       | Time      | Satellite | Orbit | Track | Frame | Center Lat°/Lon° | Angle Incidence |
|-----|------------|-----------|-----------|-------|-------|-------|-----------------|----------------|
| 1   | Nov 14, 1992 | 09:56:50  | ERS-1     | 06966 | 308   | 3123  | 23.96/9.12      | 22.21°         |
| 2   | Jan 18, 2011 | 09:58:10  | ERS-2     | 82326 | 308   | 3120  | 24.30/9.21      | 22.74°         |

...a vertical polarization (VV). This representation of the terrain is important for the study, because we used the ERS-1/2 images between 1992 and 2011, which are in band-C, to study the drainage system for 18 years. Band-C detects target responses vertically [21]. It is very sensitive to moisture and to the topography, which allows us to use the same principles as DEM methods.
4. Results and discussion

We have tested our proposed method on two radar images of ERS-1/2 satellites at different dates 1992 and 2011 with $12.5 \times 12.5$ m$^2$ resolution, representing drainage networks of Djanet. Figure 4 shows the results.

The structure of the two networks is almost equivalent, in terms of the homogeneity of the drains identified and geographic precision, especially for long drains. But the vision of the network is less clear for small drains. However, an increased cost could result from the semi-automatic extraction of the drainage
network, because of parameters requiring some manual adjustments. This proposed model gives good results, but there are some difficulties, such as the choice of an adaptive index of linearity that differentiates the drainage network from the surrounding environment.

This work allows the drainage maps to be updated by improving information in the GIS database, because its principal aim is the study of the extension of drainage networks over long periods of time. It also shows its usefulness and efficiency in monitoring drainage systems. The results of the two images at different dates – 1992 and 2011 – are identical (Figure 4). Therefore, the studied drainage system did not register any change in this period of over 18 years. This is because of the arid characteristics of the study area. This area did not undergo any major climatic and geological phenomena in this precise period.

This method uses two-dimensional (2D) data differently from other methods using DEM (3D). It makes the extraction of the drainage system easier, faster, more precise, and less expensive, and it exploits the properties of radar waves. The temporal and spatial resolutions of the SAR radar images allow the hydraulic networks to be monitored over time, thanks to the penetration of SAR radar waves and their sensitivity to the dielectric and geometric properties of the terrain. They can detect old networks hidden under the sand and also possible changes because of the continual availability of SAR data, past, present and future. Our method gives satisfactory results. However, the proposed algorithm of extraction is more complex and difficult because of the choice of parameters in function of image resolution and its size especially.

5. Conclusion

The proposed approach in this research is highly coherent, and is computationally efficient. We have used two concepts (information theory and mathematical morphology), a cost function that integrates the geometric and radiometric characteristics of the pixels, and a set of selected crossing points. We have obtained competitive results using a complex region (Algeria Sahara-Djanet). Our approach adapts to SAR images by exploiting the properties of radar waves, their penetration capacity, and their sensitivity to the dielectric and geometric properties of the terrain. The work presented in this paper makes it possible to create a set of comparable network data, which is very important in studies of hydraulic network systems. The temporal and spatial resolutions of the SAR images allow hydraulic networks to be monitored over time, thanks to the availability
of data. For future work, we suggest processing larger datasets, as tools to minimise labour.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

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