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Contribution of GIS to the morphometric characterization of Karcia watershed.

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The objective targeted here is, to establish the global portrait of physical environment of Karcia watershed. This is an essential step towards the control, protection and planning of its water resources. In that respect, emphasis is placed on geometrical, topographic and hydrographic characteristics, such information are necessary to predetermine watershed response to rainfall elements and characterize its flow. DEM of 30m of resolution was exploited due to its suitability for surface water flow modeling, while using the GIS approach. We have initially delimited watershed, generated DAM and hydrographic network. We have subsequently created the thematic maps and calculated physiographic indexes and parameters intervening in hydrological behavior. Results obtained are overall reliable, convincing and promising. Thus, Karcia watershed presents an elongated form: its length is 11 times greater than its width. It presents low relief, its topography decreases from NE and South towards the center. Maximum altitude equal to 50 m is located in upstream and minimum equal to 2m, in the downstream. More than 76% of topography has a slope less than 1.8% and the remainder varies between 1.8% and 7.2%. Karcia watershed is 3rd order stream and presents a poplar (or corridor) network type. It also presents a coarse drainage texture type and limited drainage density type. Interpretation of the results revealed that Karcia watershed is more adapted to infiltration than to runoff. These results provide interesting insights to watershed specialists for irrigation and flood protection projects.

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1. Introduction

Worldwide water management has become one of the major concerns of scientists, managers and decision-makers at the highest levels of government. Its social, political and strategic stakes are major both in terms of disaster prevention and in terms of its indispensability [1]. Because of its rarity, in most countries of the world, water is a limiting factor in development and a source of social tension. This scarcity is apprehended in terms of water stress and resource irregularity, two factors which are likely to increase with climate change [2]. Concerns about its sustainability at international scale emerged in the 1970s, spreading slowly from developed to developing countries [3,4]. The first concerns about water have been related to pollution, but over the decades, several others have emerged, mainly due to inadequate access to water in many parts of the world, due to rarity, uneven distribution, poor quality, but also in terms of depletion of groundwater resources, impacts on ecosystems and the impacts of hydrometeorological phenomena [5]. The approaches used so far for water management and development have a strong sectoral orientation, meaning that each sector is managed separately, with limited coordination between them [5]. The results were to ignore the interactions between the different uses of water and the unintended social and environmental consequences of these sectoral water development projects. Moreover, governments insisted on increasing supply in relation to demand management, ignoring the fact that water is a finite resource [3,6]. In response to these sectoral approaches, Integrated Water Resources Management concept has emerged as a means of tackling water problems at different spatial scales, by seeking sustainable use of water resources [7]. This concept aims to promote the coordinated development and coordinated water management, land and related resources in order to maximize economic and social well-being in an equitable manner without compromising the sustainability of vital ecosystems [8]. Efficient assessment of water resources aims at a complete and integral vision of the state of water resources in a particular context (country, state, region or basin) and that deals with the quantity, quality and temporality of surface and groundwater, and their interaction with society [9]. It allows identifying main water resource problems and potential conflicts, their severity and social implications, risks and dangers such as floods and droughts [3]. Main constraint in the water resources management, reside in satisfaction of needs corresponding to the different uses. This constraint can be very complex when there are several actors [10, 11]. Efficient management of river basin water resources requires a thorough knowledge of hydrological processes involved and their particular time and space scales [12]. But, it must be recognized that a water resource and its uses constitute a complex system: a set of many variables linked by interactions. For African Sudano-Sahelian countries, the control of water resources is a crucial factor for the development of social, economic, agricultural and industrial activities [8]. Its rational exploitation must require knowledge of all water resources available in all forms, needs of different users and their mode of use [13]. Whether surface or subterranean, water resources must be integrated into a continental hydrology, decompartmentalizing traditional disciplines [14]. One of most important aspects in obtaining, managing and exploiting water resources are the river basin. Transformation of rainfall into flow passes through the river basin. This latter is defined as the region receiving precipitation and, following hydrological processes causing losses and delays, transports them to an outlet corresponding to the most downstream point of the hydrographic network through which all the runoff water drained by the Basin [15]. Runoff intensity and density in a river basin, distributed in space and time, can have a positive impact on the water reserves alimentation and a negative impact related to intense flooding and flow. [7] adds that Integrated water resources management is a systematic process for the sustainable development, allocation and monitoring of water resources, which promotes more coordinated management of land and water, the river basin and upstream and downstream interests. According to [3], Watersheds are the most appropriate spatial framework for water management. As they are the terrestrial forms that collect and concentrate water from precipitation, highly interdependent interrelationships are created between uses and users of water within, which depend on an interconnected system formed by surface water And groundwater, aquifer recharge areas, extraction points, hydraulic works, wastewater discharge points and others [7]. A particular interrelationship exists between upstream and downstream uses and users, in which downstream users are critically dependent on the quantity, quality and timing of remaining water from upstream uses [16].There is also a tight interrelationship and interdependence between water and the rest of natural resources such as soils, wildlife and vegetation. Changes in use of natural resources have implications on downstream water cycle [17]. Finally, watersheds constitute a special framework for interaction and interdependence between physical and biotic systems and the socio-economic system formed by inhabitants and other natural resources users such as industries [18]. In this context, one then understands easily the need to develop management and decision-making tools which allow bettering investing the natural hydrosystems functioning and the becoming of water in its environment [19]. User of these instruments can thus benefit from a better knowledge of the spatial and temporal distribution of the water flows and of the materials and compounds that it conveys at the watershed scale. These numerical tools, unavoidable, allow to integrate multi-source data, to extract the existing relationships between the elements of these systems and also to make analyzes being able to take account of very diverse constraints for an optimization of water the management [20]. This provides to actors the useful and scientifically valid information, involved in planning, management, policy- and decision-making processes, including public officials, planners and scientists, and the general public [3]. In addition to the climatic conditions governing the functioning of the watershed, its physical characteristics influence the volume (in terms of the balance sheet) and the temporal distribution of flows [21]. Physical characteristics include topography, geology, nature and occupation of the soil, but also the shape of the watershed, of which one well conceive that it influences the flow characteristics resulting from a given rain [22]. Hydrologists have thus been tempted to characterize this morphology by simple computable indices with the sole competition of topographic maps. According to [23], the physiographic characteristics of a watershed strongly influence its hydrological response, in particular the flow regime during periods of flood or low water. Traditional techniques used in the study of watershed physical complex, are based mainly on manual methods, whose results are generally incorrect [24]. With apparition of new tools such as GIS and remote sensing, it has become easy to determine the form parameters, relief and typology of a hydrographic network [9]. Use of these new techniques has thus allowed answering the requirements of surface water exploitation and prevention against the risks of flooding [25]. This work concerns Karcia watershed located in the region of Sedhiou in the South of Senegal. It is for us to evaluate its morphometric parameters to predict its response to rainy elements, and this, in order to characterize its flow. The availability of information on such parameters facilitates informed decision-making on watershed developments related to the rational management of surface waters that generates a large number of applications such as irrigation. For this, we relied on the performance of the GIS software, ArcGIS used in very varied applicative domains, in particular to answer the precise problem of definition of the hydrographic network and watersheds from a Digital Elevation Model. These new techniques allow giving numerical information characterizing the relief and basin morphometric [26].

2. Materials and methods

2.1. Study area and data

Karcia is a locality of the middle Casamance, located in the department of Sedhiou, region of Sedhiou, district of Diendé, commune of Diannah Malary and rural community of Diannah Ba. It is located between latitude 12 ° 49 'N and longitude 15 ° 10' W. This village is limited to the north by the Sadiala forest, to the south by the Casamance River, to the east by the region of Kolda and to the west by the CR of Diannah Bah (Fig.1).Its river basin covers an area of 107 km^2 at its outlet. According to the municipal authorities, Karcia has more than 1,000 inhabitants in 80 households. It polarizes many villages and its strategic geographical position (on the RN), makes it a magnet for the surrounding populations and for political, cultural and sporting events of all kinds. Its climate is of Sudano-Guinean type, hot and humid marked by the alternation of a rainy season from May to October and a dry season from November to April [27]. Rainfall is fairly satisfactory but irregular with peaks of more than 1300 mm. Temperatures range from 19 ° C to 35 ° C during rainy season and from 16 ° C to 40 ° C during dry season. March, April and May are the hottest months and December, January and February the coldest. The dry season is marked by the predominance of the continental trade wind (or harmattan) and the rainy season is dominated by monsoon flows. Air humidity in the area is about 15% and the wind speed is about 10 km / h. The relief is constituted of plateaus characterized by tropical ferruginous soils more or less leached which are adapted to rainfed crops (cereals groundnuts and cotton) and lowlands (valleys) characterized by hydromorphic soils ,with a high content of silt which are suitable for rice growing ,arboriculture and horticulture or market gardening. Vegetation cover is mainly influenced by rainfall, anthropogenic activities and the nature of soils. The plant formations are characterized by a predominance of the savannah wooded or sported and herbaceous. The area is relatively rich in fruit trees (mango, orange, lemon, banana, cashew etc.).Forest bordering the village constitutes not only a reserve of fertile land, but also a source of wood fuels timber handicrafts and services picking products medicinal plants and grazing but also a refuge of a fairly varied wildlife [28]. Hydrographic network is mainly constituted of the Casamance River whose water has become mild due to the construction of the Diopcounda dams in the west and Sare Mory in the east. In addition to the river, Karcia houses perennial pools and temporary pools which generally dry up in the dry season. This potential allows the village to develop throughout the year fishing, raising and other activities of rent. The village, located on a lowlands area, benefits from the presence of a flush and having a very high productivity for the wells and / or boreholes. Despite some constraints, the long-term needs in population nutrition and irrigation do not seem to be under threat. On the human level, Karcia is composed of Mandingoes in majority, Peulhs and Manjacques, all Muslims. Karcia strongly retains a rural aspect, especially in the habitat which remains of traditional type. The concessions are largely built in benches overhung with a wooden frame of roniers and a roof made of straw or zinc. The concessions are very large and without fences. The constructions are carried out without necessarily respecting the standards of urbanism and construction. Finally, it should be noted that agriculture, despite its many potentialities is slow to realize its full potential and to bring the economy in a sustainable and efficient way. Problems related to the form of production, the flow of production, the under-equipment of producers ,their lack of training , the dilapidatedness of available agricultural equipment, the resurgence of bush fires and the drying up of the water points, the rapid rural exodus would all be constraints which considerably slow down the development of agriculture [29]. Several basic data respecting the recognized validity criteria can be collected from the specialized structures for a good knowledge of the basin, its main characteristics, resources and problems. For this study, we have chosen the DEM which is a very adequate basic data for the modeling of surface water flow. This DEM was acquired on the USGS site with a resolution of 30m for more sharpness and precision. The use of this model facilitated the calculation of different parameters for each mesh: mean altitude, direction of drainage, average slope, etc. The knowledge of such parameters is an important step towards protecting and planning the waters of a hydrosystem.

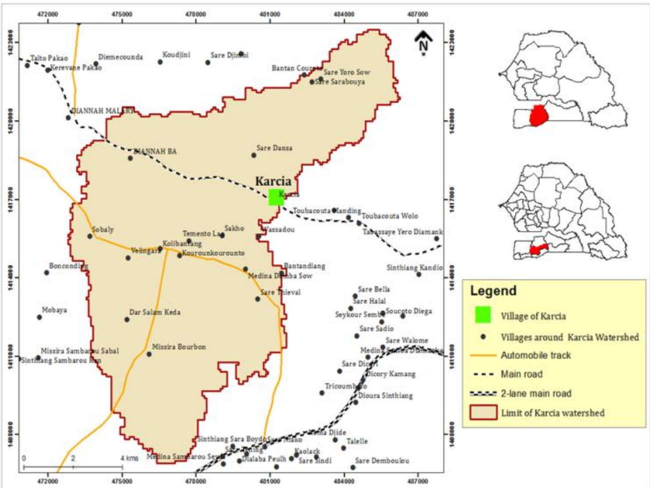

Fig.1: Location of study area

2.2. Study problematic

The importance of water as a vital resource and development factor is globally recognized, the protection of this resource is a necessity of the first order. The idea that the availability of information on morphological parameters favors informed decision-making has long been accepted by all those interested in watershed management. The Middle Casamance is a zone confronted with the problems of the runoff and the runoff of the rivers which are lost in the nature and the problems of water accumulation in an optimal way, in the zones with strong depressions. With the decrease of annual rainfall in the area, a large number of applications require management of water resources, such as irrigated perimeter management, flood control and flooding during occasional heavy rains, the installation of dams hills to combat drought, the study of unstable slopes, the study of erosion, etc. These concerns are major issues for the population both in terms of disaster prevention and in terms of the indispensability of water. One of the most important aspects in obtaining, managing and exploiting water resources is the drainage network of watersheds. The intensity and density of flows in a watershed distributed in space and time generally have a positive impact on the supply of water reserves and a negative impact on floods and intense flows. Morphometric analysis is an important step for the prioritization of watersheds. To do this, a set of important quantitative parameters are used in understanding the dynamism of a river and its watershed. This characterization is an essential step in the realization of an integrated water management project in an agricultural environment, because it allows to establish accurate diagnoses and to propose appropriate solutions. A good knowledge of the basin, its main characteristics, its resources and its problems is essential to start the planning of such a project.

However, the classical techniques used so far in the study of the physical complex of a watershed in this area and going in this direction are based essentially on manual methods, which do not allow reaching the levels of precision and reliability and therefore jeopardize the planning process for the improvements to be made. Traditionally, the identification of watershed boundaries is based either on the interpretation of a topographic map or on the stereographic observation of aerial photographs. In both cases, the possibilities of making reading errors are not negligible. Since other attributes are derived from the catchment delineation, it is generally desirable to minimize the possibility of error at this stage. In this context, the work we present here is part of a methodological approach to the processing of satellite images that will make it possible to draw up the characteristics of this basin in order to better know and effectively use its water cycle for planning purposes. , development and conservation. However, in this zone, a large part of the drainage network has been more or less altered by human action (irrigation or drainage reaches and upstream river bed digging to accelerate drainage), thus modifying several important parameters, such as, for example, drainage density. In addition, landscape description and physiography remained largely qualitative. Drainage systems and their BVs were described as young, mature, old, poorly drained or well drained, with no specific information on how, how much and why. In the particular case of the Karcia catchment which is the subject of this study, no quantitative information on the morphological parameters to characterize the physical environment and their influence on the surface flow and the drainage network (which is one of the most important in obtaining, managing and exploiting water resources), is not available at this date. In order to make the best possible analysis of an RD, it is imperative that it best represents its natural development, with the least possible anthropogenic modifications. With the advent of new tools such as GIS, it has become easy to determine the shape, relief and typology of a river system. The use of such powerful tools from a numerical model of high resolution terrain, are very necessary and useful in the context of this study to meet the requirements of rational exploitation of surface water for an application the irrigation. Such a study would also make it possible to control the risk of erosion and possibly floods and floods in the study basin.

2.3. Morphmetric characteristics

Morphmetric characteristics calculation aims to condense the evolution of the altitude inside the watershed [30]. The response of the watershed to a precipitation solicitation is influenced by various morphological characteristics such as the basin size (its surface), its shape, elevation, slope and orientation. For this study, we will use three different types of morphometric characteristics. These important quantitative parameters are used to understand the dynamics of a river and its watershed [23].

2.3.1. Geometric characteristics

- Surface and perimeter

As watershed is the receiving area for precipitation and stream feeding, the flows will be partly connected to its surface [25]. Watershed surface (S), usually expressed in km², represents the portion of the plan delimited by watershed contour. The perimeter (P) of the watershed, usually expressed in km, is the length of the contour line of the watershed. These two parameters provide valuable information in the study of watersheds. Their influence is manifested in the nature of the relationship between flow and time. They are often measured using digitization and delineation techniques using GIS software such as: ArcGIS, QGIS, ArcView, MapInfo, Global Mapper, etc. [23,31].

- Gravelius Index

The variable commonly used by hydrologists to characterize the shape of a watershed is the Gravelius compactness index. It allows comparing watersheds with each other and is defined mathematically by equation (1). This index gives an idea of the watershed shape, which influences the overall flow of the river and especially the shape of the hydrograph [22].

$$K_G = 0.28 \frac{P}{\sqrt{S}} \quad (1)$$

Where: S is the surface of the watershed (Km²); P is the perimeter (Km) given by the ArcGIS software.

The compactness of river basin indicates its ability to respond quickly or not to a flood event [25]. i) If the calculated value is greater than 1, then the watershed is elongated: the time taken by water to reach the outlet is important; the response time is longer and the peak flow can be attenuated by this delay. ii) If it is close to 1 the drainage basin is almost circular in shape it is said to be well drained with a greater infiltration potential than elongated ones [32].

- Horton Index

Another variable used to characterize the shape of a watershed is the Horton shape index. It defines the relation between the surface of the basin (S) (km²) and the length of the main river (Lp) in Km. It is given by equation (2) [25].

$$K_H = \frac{S}{L_P^2} \quad (2)$$

Where: K_H is Horton shape index; S is the surface of watershed (km²); L_p: Length of main stream (km).

This index is used to predict the flow intensity at the outlet of a watershed. According to [33], the shape factor shows an inverse relationship to the length of the main stream and has a direct relationship to peak flow at the outlet of the watershed. Depending on the index value, we can have different forms of watershed: i) the index is less than 1 for an elongated watershed; ii) it is greater than 1 for a picked up watershed; iii) it is less than 0.5 for an elongated watershed; iv) between 0.5 and 1, it indicates a rather circular watershed, and a high peak flow rate of relatively short duration [34].

- Equivalent Rectangle

It is a geometric transformation of the actual watershed in a rectangular watershed in which the same hypsometric distribution is maintained. According to [25], the distribution of the watershed by elevation in an equivalent rectangle is of paramount importance for hydrological studies because most meteorological and hydrological factors are influenced by altitude. This rectangle makes it possible to compare watersheds with one another, in particular with regard to the influence of their characteristics on the flow. The length and width of the equivalent rectangle are given by equations (3) and (4) respectively [30].

$$L = \frac{K_G \sqrt{S}}{1.12}\left(1 + \sqrt{1 - \left(\frac{1.12}{K_G}\right)^2}\right) \quad (3)$$

$$\ell = \frac{S}{L} \quad (4)$$

Where: L is length of equivalent rectangle (Km); ℓ width of equivalent rectangle in (Km); S is the surface of watershed (Km²); P is perimeter (km); K_G is Gravelius compactness index.

2.3.2. Topographic Features

Topography has a remarkable influence on the flow dynamics of a watershed. Many hydro meteorological parameters vary with the altitude (precipitation, temperature, etc.) and the morphology of the watershed. In addition, the slope affects the flow velocity. It is determined by means of indices or characteristics [25].

- Digital Terrain Model (DTM)

Digital Terrain Model (DTM) is a numerical representation of the terrain and therefore of the altitude values of a given area. It allows having a representation in 3 dimensions (3D) of the watershed. It is based on the digitized contours of the basin [35]. The altitudes are calculated at the points of a grid whose size of an elementary stitch determines the pitch of the model. We can derive indications on different parameters: mean altitude, direction of drainage, average slope, exposure, topographic surface forms etc. [36]. If we only represent the altitude of the bare ground, we speak of (DEM). If one takes into account the heights of all the objects placed on it such as buildings and vegetation, so-called "sursol", we speak then of Digital Altitude Model (DAM). The latter allows carrying out a representative spatial analysis because it reflects information about the morphological structure over the entire catchment area. It also provides forecasts of the nature and intensity of precipitation. The surfaces between the contours of the hypsometric map are represented in the form of classes, starting from the class of high altitude to that of low altitude.

- Hypsometric curve

The hypsometric curve provides a synthetic view of the slope of the watershed and represents the distribution of the surface of the watershed according to its altitude. It shows on the abscissa the percentage of area (cumulative surface) of the basin above the altitude represented on the ordinate [37]. This curve reflects the potential dynamic equilibrium state of the basin and remains a practical tool to compare several watersheds with one another or with the various sections of a single basin. It can also be used to determine average rainfall in a catchment area and to provide information on the hydrological and hydraulic behavior of the catchment and its drainage system. According to [32], this curve makes it possible to judge the age and degree of erosion of watersheds and is also a tool for comparison between sub-watersheds. Indeed, the shape of the hypsometric curve is characteristic of the state of maturity of the relief (young, balanced and old) as well as its erosive capacity. According to [38], the shape of the hypsometric curve characterizes the erosion cycle of the relief. Indeed, a convex curve is characteristic of a marked and young relief where erosion is still intense, whereas a concave shape reflects an old, non-rejuvenated relief where erosion has become weak and stable [39]. Ultimately, three types of basins are conceivable: (i) the younger basins show a small area compared to the initial altitude change, which is characteristic of steep basins; (ii) the old basins present large flat topographies where the altitude varies very little, and (iii) the basins, corresponding to the intermediate curve of the first two, are basins close to the so-called equilibrium or mature state [25].

- Characteristic altitudes of watershed

In general, we are not interested in average altitude but rather in the dispersion of altitudes. This dispersion is translated by the hypsometric curve which represents the distribution of the watershed surface as a function of its altitude. This curve provides a synthetic view of the slope of the basin, hence the relief [30].

  - Maximum and minimum altitudes

Maximum altitude represents the highest point of the basin while the minimum altitude considers the lowest point, usually at the outlet. These altitudes allow establishing certain relationships involving climatological variables such as temperature and precipitation. They determine the altimetric amplitude of the watershed and are also used in the calculation of the slope. They are obtained directly from the topographic maps or the hypsometric curve [40].

  - Average altitude

Average altitude is not very representative of reality. However, it is sometimes used in the evaluation of certain hydrometeorological parameters or in the implementation of hydrological models [37]. It is estimated by equation (5):

$$H_{moy} = \frac{1}{S} * \sum S_i * h_i \quad (5)$$

Where: H_{moy} is average altitude of basin (m); S_i is area between two contours (Km^2); h_i is mean altitude between two contours (m); S is total surface of watershed (Km^2)

  - Median altitude

Median altitude (H_{med}) is determined from the hypsometric curve and corresponds to the altitude read at the abscissa point 50% of the total surface of the watershed, on the hypsometric curve. This parameter approximates the mean altitude, in the case where the hypsometric curve of the basin concerned presents a steady slope. According to [25], if the average altitude is lower than the median altitude, the slope is irregular, i.e., too high in upstream of the basin, where the high reliefs predominate, softening down in downstream where low plateaus and plains dominate.

- Watershed slopes determination
  - Slopes Map

Slope is an important parameter in the development of a watershed. It gives information, more than the profile, on the more or less great ability to run off the land. This parameter has a very strong influence on the hydrograph: the concentration time will be lower the higher the slope [25]. According to [41], the slope conditions the drainage and affects in a direct way by its intensity, the phenomena of infiltration, runoff and erosion, its form, and the length on which it acts. Usually, the mean value of this parameter is used in watershed management. Given the heterogeneous nature of this parameter, it is often recommended to have information on the different slope values [41]. Such information coupled with others such as land tenure may assist the manager in determining areas of priority interventions. With the GIS processes, we are able to obtain in a short time an image containing the value of all the slopes of the watershed.

  - Watershed characteristic slopes
    - ✓ Average slope

The average slope of a basin is a parameter that has an important and complex relationship with infiltration, surface runoff and water saturation of the soil. It controls the run-off time and the concentration of rainwater in the drainage arteries. Several methods have been developed to estimate the average slope of a watershed [37].

They are all based on reading a real or approximate topographic map or from a digital altitude model DAM using the GIS as is case in this work. The method proposed by [42], consists in calculating the weighted average of the slopes of all the elementary surfaces between two given elevations. An approximate value of the mean slope is then given by the relation (6) [43]:

$$I_{moy} = \frac{d * L_C}{S} \quad (6)$$

Where: I_{moy} is Average slope (%) ; L_C is total length of contours (km); S is Watershed surface (km²); d is equidistance between two contours in (Km).

✓ Global slope

Relief plays an important role because it largely controls the runoff capacity of the land. Its apprehension can be made using the index of global slope given by relation (9) [30]. It allows characterizing and classifying the relief of the watershed. According to [25], in a region of homogeneous geomorphology, the slope decreases from the upstream to the downstream, consequently, Ig decreases for the same basin when the surface increases. On the hypsometric curve, one takes the points such that the top or bottom surface is equal to 5% of the total surface. $D_{5\%}$ and $D_{95\%}$ are the altitudes between which 90% of the total surface of the watershed enrolls.

$$I_g = \frac{D}{L} \quad (9)$$

Where: I_g is Global slope (m/km);D is the global gradient, expressed in (m) defined by the difference in altitude (equation 10) between D5% and D95% which are determined on the hypsometric curve; L is Length of the equivalent rectangle (Km).

$$D = D_{5\%} - D_{95\%} \quad (10)$$

This slope is used to characterize the watersheds relief and has led to a first classification of ORSTOM represented by (Tab.1).

Tab.1: Relief organization according to global slope

Class	Type of relief	Definition field
1	Very low	$I_g <$ 0,002
2	Low	0,002 < I_g < 0,005
3	Quite low	0,005 < I_g < 0,01
4	Moderate	0,01 < I_g < 0,02
5	Quite high	0,02 < I_g < 0,05
6	High	0,05 < I_g < 0,1
7	Very high	0,1 < I_g

✓ Specific gradient

Specific gradient therefore only depends on the hypsometry and the watershed shape. It allows comparing watersheds of different sizes, defined by equation (11) [44, 45].

$$D_S = I_g \sqrt{S} \quad (11)$$

Where: D_S is specific gradient (m); Ig is Global slope (m/km); S is Watershed surface (km²).

This parameter is a relief general index of watersheds. It can explain the speed of watersheds response; the larger the Ds, the more the watersheds will be reactive to a rainy event. The specific density leads to a second classification of (ORSTOM) represented by (Tab.2) [46].

Tab 2: Relief organization according to specific gradient

Type of relief	Definition field
Very low	$D_S <$ 10
Low	10 < D_S < 25
Quite low	25 < D_S < 50
Moderate	50 < D_S < 100
Quite high	100 < D_S < 250
High	250 < D_S < 500
Very high	500 < D_S

2.3.3. Hydrographic characteristics

Hydrographic network is a hierarchical and structured set of channels that ensure superficial, permanent or temporary drainage of the watershed [47]. Differentiation of watershed hydrographic network is due to four main factors (geology, climate, ground slope and human presence). It can be characterized by four elements: its hierarchy, development (numbers and lengths of rivers), average slope and its long profile.

- Hydrographic Network hierarchy

To cipher the hydrographic network ramification, each watercourse receives a number, depending on its importance. This numbering, called river order differs according to the authors. Among all these classifications we shall adopt that of [22] for its popularity: (i) any stream with no tributary is said to be of order 1; (ii) at the confluence of two rivers of the same order n, the resulting stream is of order n + 1; (iii) a stream receiving a lower order tributary retains its order, which can be summarized as follows:

(n + n) = n + 1 and order of (n + m) = max (n, m)

- Hydrographic network parameters
  - Stream average slope

Average slope of the Stream (or watercourse) determines the speed with which the water reaches the outlet of the basin, thus the time of concentration. This variable influences the observed maximum flow. A steep slope favors and accelerates surface flow, while a gentle slope or zero gives the water time to infiltrate, in whole or in part, into the soil [25]. The average slope of the watercourse is calculated from the longitudinal profile of the main watercourse. The method consists in dividing the altitude difference between the extreme points of the profile by the total length of the stream given by the relation (12) [37].

$$I_{mce} = \frac{\Delta H}{L_p} \quad (12)$$

Where: I_{mce} is stream average slope (m/km) ; L_p: Length of main stream (km) obtained after classification of the hydrographic network according to the system of [22]; ΔH is maximum denivellation of the river (m) given by equation (13)

$$\Delta H = H_{max} - H_{min} \quad (13)$$

Where: H_{max} is altitude of the highest point (m); H_{min} is altitude of the lowest point (or outlet) (m).

These maximum and minimum altitudes are obtained directly from the topographic maps or from the DEM using GIS software.

- Degree of hydrographic network development
  - ✓ Drainage density

Network drainage density is a measure of the degree of river dissection. It depends on the geology (structure and lithology) of the topographic characteristics of the watershed and, to some extent, on climatic, anthropogenic and vegetation conditions [48]. Thus, for the same surface, the more branched the hair of stream, the more the drainage density impacts on the reactivity of the basin to a rainy episode. In general, a low drainage density indicating a highly permeable soil, relatively dense vegetation and a low slope, thus promoting infiltration, in contrast to a high drainage density which represents a poorly permeable soil, low vegetation and a steep slope , thus promoting surface runoff [34] . The drainage density is given by relation (13) [49]:

$$D_d = \frac{1}{S} * \sum_{j=1} L_j \quad (13)$$

Where: D_d is drainage density (km/km²); L_j is Cumulative length of stream of order j (km); S is Surface of the watershed (Km²).

On the basis of qualitative approach, it is advised to adopt the classification presented in the (Tab. 3) for the density of drainage [50].

Tab.3: Classes of drainage density

Type of Drainage	Definition field
Limited	$D_d < 6$
Medium	$6 < D_d < 12$
Marked	$12 < D_d$

✓ Coefficient of stream stability

Physically, it represents the surface of the watershed required to maintain stable hydrological conditions in a unitary hydrographic vector. This constancy depends on the type of soil, its permeability, climate, relief and vegetation cover. Generally, a High Stability Coefficient indicates high soil permeability and vice versa. It is given by the inverse of the drainage density symbolized by equation (15) [49]:

$$C_S = \frac{1}{D_d} \quad (15)$$

Where: C_S is Coefficient of Stream stability; D_d is Drainage density (km/km²)

✓ Hydrographic density

Hydrographic density is the number of flow channels per unit surface. In general, regions with a high hydrographic density (i.e.,> 5) occur in an impermeable rock, a restricted vegetation cover and a mountainous relief: these regions are characterized by a high surface runoff and a pronounced slope. By cons, a low hydrographic density (i.e, <5), occurs in a very permeable bedrock region, with important vegetation cover and slightly accentuated relief [49]. This density estimated by equation (16) [25,51].

$$D_h = \frac{1}{S} * \sum_{j=1} N_j \quad (16)$$

Where: D_h is hydrographic density (km^{-2}) ; N_j is Number of rivers of order j

✓ Drainage Texture

Drainage texture (or torrentiality coefficient) determines the relative spacing between the diversion bays in a terrain dissected by erosion [52]. It depends on several natural factors, such as climate, precipitation, vegetation cover, soil type, infiltration capacity and terrain. The drainage texture for stream of order 1 estimates the adaptability of a drainage basin to surface flow or infiltration. It is given according to order I of stream by the relation (18) [53].

$$T_j = D_d * \frac{N_j}{S} \quad (18)$$

Where: T_j is torrentiality coefficient of stream of order j (Km / km4); N_j is Number of rivers of order j; S is Surface of the watershed (Km²); D_d is drainage density (km/km²). The drainage texture leads to the classification of [54], presented in (Tab.4)

Tab. 4: Drainage texture organization according to Smith

Type of Drainage	Definition field
Coarse	$Tj < 4$
intermediate	$4 < T_j < 10$
Fine	$10 < T_j < 15$
Ultra fine	$15 < T_j$

✓ Bifurcation ratio

Bifurcation ratio (or ratio confluence) is a non-dimensional number that expresses the degree of ramification of drainage network, and establishes correlations from one region to another, hence its importance [52]. This parameter is an excellent indicator of the hydrological behavior of the watershed: a high bifurcation ratio (elongated watershed) implies a slow hydrological response, while a low bifurcation ratio (rounded basin) generally produces a rapid hydrological response commonly called "flash flood". According to [22], this ratio generally varies from 3 to 5 for a region where geology has no influence. It is given by relation (20).

$$R_B = \frac{N_j}{N_{j+1}} \quad (19)$$

Where R_B is bifurcation ratio; N_j is number of rivers of order j; N_{j+1} is number of rivers of order j+1.

Hydrographic networks are always dendritic, i.e., ramified like the branches of a tree. Some authors distinguish three main types of networks represented by (Tab.5).

Tab.5: Typology of Hydrographic Network

Definition field	**Type of Hydrographic Network**
R_B< 3	**Pin or Funnel:** River basin characterized by a concentration of concluences in the upstream sector from which emerges a trunk that no longer receives important tributaries
3 < R_B< 5	**Oak:** Well developped ramification with a regular spacing of the confluences
10 < R_B	**Poplar or Corridor:** River basin clearly longer than broad,with many parallel tributaries

2.4. GIS Tool presentation: ArcGIS software

In this study, Digital Terrain Model (DTM) from the images SRTM (Shuttle Radar Topography Mission), with a resolution of 30m, was used for the extraction of the various physiographic parameters of the Karcia watershed. To develop this approach, software dedicated to GIS (Geographic Information Systems) such as ArcGIS, QGIS, ArcView, MapInfo, Global Mapper, IDRISI, etc., are very necessary [25]. Geographic Information Systems (GIS) are types of databases used to manage descriptive data to a localized physical entity [55]. It is also a powerful tool for the storage, management and exploitation of spatial data. GIS integrates knowledge from multiple sources and creates a multi-sector environment that is ideal for collaboration [56]. They can be tackled not as tools but as a science offering tools to manage, retrieve, transform, create and publish geographic data. They combine a powerful visualization environment and a powerful analytical and modeling infrastructure specially adapted to geography [12]. GIS works like tracing paper by superimposing elements on top of each other. In general, each category of object is assimilated to a layer and these layers will be stacked in a well defined order to represent a map and be able to be analyzed [57]. Among these tools, ArcGIS is world renowned for its performance and results in the work of GIS. It is software of the firm ESRI (Environmental Systems Research Institute), world leader in GIS that has a data storage mode of its own with Shape Files for vector data and GRID files for Raster data. It includes a suite of applications integrated with each other: ArcMap, ArcCatalog, ArcToolbox, including several extensions [55] by using these applications and extensions together, ArcGIS can perform various GIS tasks, such as delimitation Watersheds, mapping, geographical analysis, editing, management, visualization and exploration of spatial data or geoprocessing [57]. Within the Karcia Watershed, ArcGIS has enabled us to superimpose the different layers of geo-referenced information needed to characterize the watershed (hydrographic network, slopes, topography, etc.) and to produce thematic maps as needed. In short, the GIS tools allow a representation of the space and the interactions occurring within this space and also an updating structure to guarantee the durability of the data.

3. Application

The objective of this work is limited to the characterization of the morphometric and relief features of the Karcia catchment area in the middle Casamance in southern Senegal. The availability of information on morphological parameters facilitates informed decision making on watershed management projects related to the rational use of its waters. To achieve our objectives, we exploited the DEM with a resolution of 30m. The choice of DEM as a based data is related to the fact that: i) it is very suitable for modeling the flow of surface water in space; ii) it allows to have a 3-dimensional representation of the catchment, to study the distribution of the characteristics of the relief (indices and slopes), to draw the drainage network automatically and to have quantified and precise descriptive data. For this study, we downloaded the DEM of Senegal from the images SRTM on the site USGS. We then extracted that of the Karcia watershed using the ArcGIS software. We also delineated the watershed, generated the digital altitude model (DAM) and traced the hydrographic network. This allows extracting and calculating variables involving the geology, topography, pedology, hydrography and hydrology of the watershed. In this study, emphasis is placed on simple morphometric characteristics (area, perimeter, length, width, length of main channel, total length of stream (all orders combined), number of stream of order (j), total number of stream of all orders, and the maximum and minimum elevation) and compounds morphometric characteristics (circularity, shape factor, elongation ratio, compactness coefficient, drainage density, constancy of maintenance of stream, Frequency of streams, drainage texture , relative drainage density, elevation difference, mean elevation, mean slope, relief ratio and specific gradient). The results obtained made it possible to draw up an overall picture of the watershed relative to its physical environment, in particular for a good knowledge of the watershed, its main characteristics, its resources and its problems. This perfectly meets the requirements of rational exploitation of surface water for irrigation application.

4. Results and discussion

4.1. Geometric characteristics

We present in (Tab.6) parameters related to the geometry. Thus, Karcia watershed spreads over an area S = 106.65 Km^2 and has a perimeter P = 76.33 Km. Compactness index is K_C = 2.07, which translates an elongated shape indicating that Karcia watershed is subject to erosion and low flood peak flows due to the high concentration time or water travel time to its outlet. Horton index is K_H = 0.29, indicating an elongated form, reflecting the ability of the watershed to generate diluvial flows during periods of stormy precipitation. For the equivalent rectangle, equivalent length is L = 35.13 Km and the equivalent width is l =3.04 Km. These dimensions reflect that the length is 11 times greater than the width. In sum, Karcia should have very few case of flooding even during high water.

Tab.6: Parameters relating to geometry

Parameters	Symbols	Units	Value
Surface	S	Km^2	106.65
Perimeter	P	Km	76.33
Gravelus index	K_G	..	2.07
Horton index	K_H	...	0.29
Equivalent rectangle length	L	Km	35.13
Equivalent rectangle width	ℓ	KM	3.04

4.2. Topographic Characteristics

4.2.1. Digital Elevation Model (DEM)

We present in (Fig. 2) the Digital Elevation Model (DEM) of Karcia watershed. Its reading shows that topography decreases from NE towards the center, then from the South towards the center. The maximum altitude is equal to 50 m, located in upstream and the minimum equal to 2m, specifically in the central part from East to West (downstream). The topographic denivellation is therefore equal to 48m.

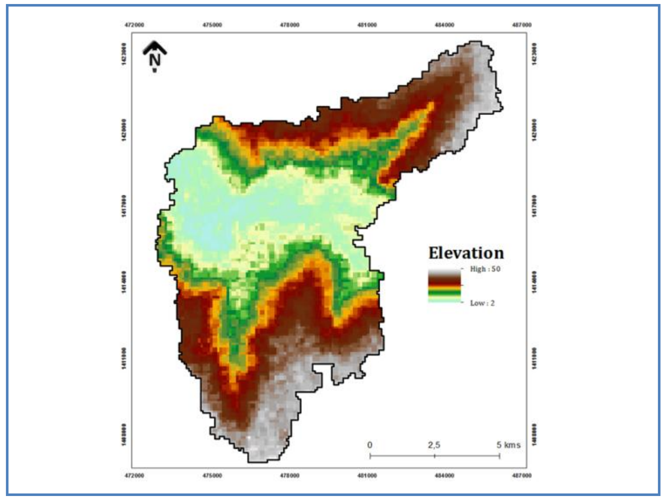

Fig.2: Digital Elevation Model of Karcia Watershed

4.2.2. Digital Altitude Model (DAM)

We present in (Fig.3) the Digital Model of Altitude (DAM) of Karcia Watershed. Surfaces between the contours are shown as different color classes, starting from high-altitude class, of which the highest point stands at 50 m to the low-altitude point, of which the lowest point equal to 0 m. The DAM presents 5 tranches of equidistant altitudes of 10m. The high altitudes are found in the NE and south; the low altitudes zones are located in the central part. In sum, the structure of the watershed is in stairs form, from the center to the NE and then from the center to the south; relief being dominated here by stepped plateaus.

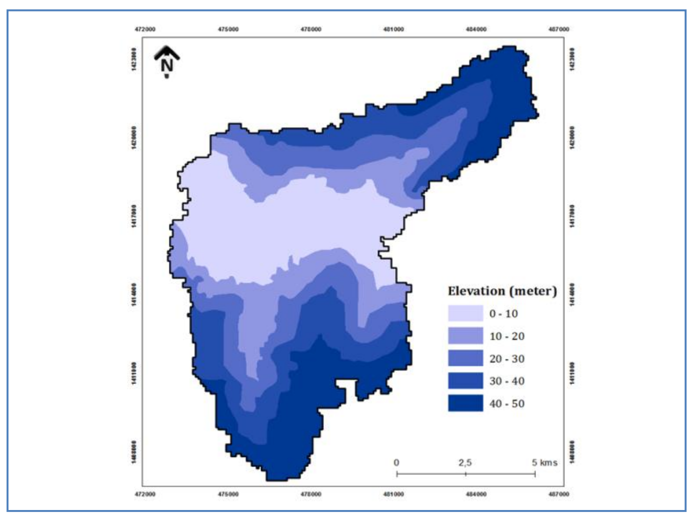

Fig.3: Digital altitude model of Karcia watershed

4.2.3. Hypsometric curve

We present on (Tab.7) distribution of the altitudes by surface and in (Fig.4) hypsometric curve of Karcia watershed. Examination of the table shows that 76% of total surface has an altitude greater than 10m and only 24% are lower. Hypsometric curve shows a slight convexity towards the high altitudes. Karcia watershed is in a state of youth, we can already say that in this watershed, relief is accused and young; the erosive power associated with water is relatively developed there: it is an abrupt basin.

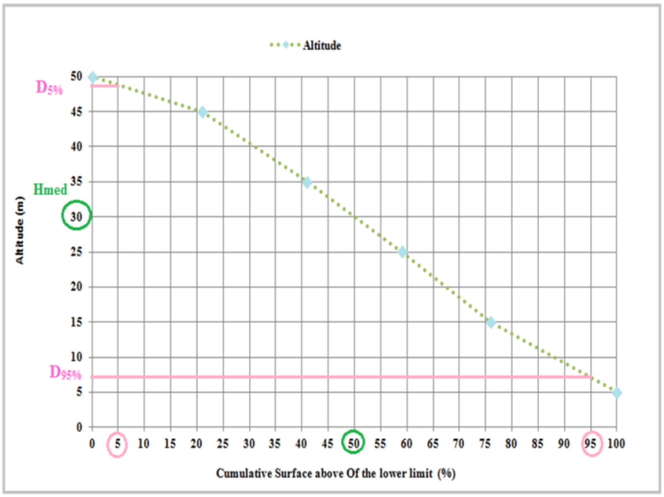

Fig.4: Hypsometric curve of Karcia watershed

Tab.7: Altitude distribution by surface

Altitude class	Partial surface (Km²)	Partial Surface(%)	Cumulative surface above lower limit (%)
0-10	25.65	24	100
10-20	18.02	17	76
20-30	19.26	18	59
30-40	21.49	20	41
40-50	22.24	21	21

4.2.4. Watershed characteristic altitudes

(Tab.8) presents the variables related to the altitude of the Karcia watershed. The extreme altitudes, extracted from DEM and hypsometric curve are: minimum altitude H_{min} = 0 m, maximum altitude H_{max} = 50 m, altitude at 5% of total area $D_{5\%}$ = 48.5 m, altitude to 95% of the total area $D_{95\%}$=7m. Maximum altitude represents highest point of the basin while the minimum altitude considers the lowest point, usually at the outlet. These altitudes enabled us to determine the altimetric amplitude of the slopes of the Karcia watershed. Average altitude of the watershed is H_{moy} = 24.69m which is lower than the median altitude H_{med} = 30 m. Average slope is therefore irregular. It is too strong in upstream, where the high reliefs predominate, and softened downward towards downstream, where low plateau and plains dominate.

Tab.8: Parameters relating to altitude

Parameters	Symbols	Units	Value
Maximum altitude	H_{max}	m	50
Minimum altitude	H_{min}	m	0
Altitude at 5% of total surface	$D_{5\%}$	m	48.5
Altitude at 95% of total surface	$D_{95\%}$	m	7
Average altitude	H_{moy}	m	24.69
Median altitude	H_{med}	m	30

4.2.5. Determination of slopes

- Slopes map

We present in (Fig.5) slopes map, established from the DEM and in Table 8 the distribution of slopes by surface. (Fig.5) examination shows that medium to high slopes are located in the northern and southern part of watershed. Low to very low slopes develop in the central, NE and SE parts of watershed. In sum, slopes map shows that more than 76% of topography has a slope less than 1.8% and the remainder, a slope which varies between 1.8% and 7.2%. (Tab.9) shows that on 106.65 km² representing total surface of watershed, only 29.33Km² has slopes higher than 1.8%, the rest (76.82Km²) develops lower slopes. This distribution would be linked to the geological structure and especially to the lithology of the land which would determine their behavior with regard to erosion.

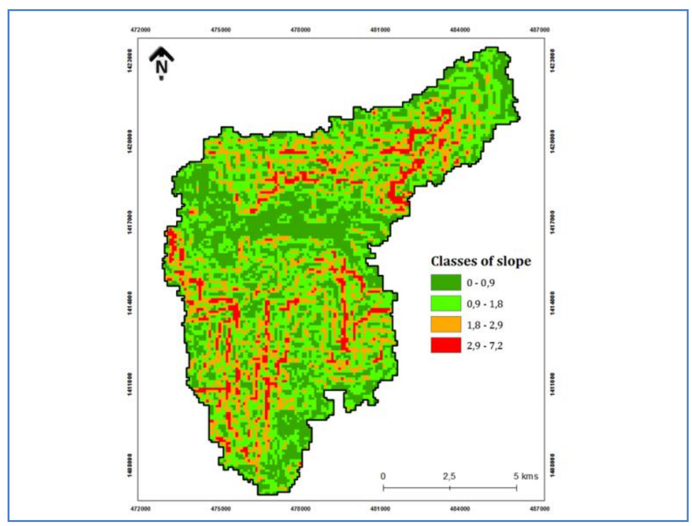

Fig.5: Map of Karcia watershed slopes

Tab.9: Distribution of Slopes in the Watershed

Nature of slope	Class of slope (m/Km)	Surface (Km²)	Surface (%)
Very low	0-0.9	34.48	32.33
Low	0.9-1.8	42.35	39.71
Medium	1.8-2.9	22.15	20.76
High	2.9-7.2	7.68	7.20

- Watershedcharacteristics slopes

(Tab.10) presents characteristic parameters of watershed slopes .Average slope I_{moy} = 2.77% is soft, reflecting a long duration of runoff water concentration in the tributaries, thus favoring infiltration, especially when the lithological formations have a high permeability. Global slope I_g = 1.18 m / Km = 0.00118, reflecting a very low relief, which will probably cause very high erosivity in upstream. Specific gradient Ds is equal to 12.20m. This reflects a low relief indicating the very pronounced influence of the plateaus and plains in this watershed. Ultimately, the distribution of slopes is closely influenced by morpho-structural conditions in the Karcia watershed, characterized by deposits in its meanders and poorly developed floodplains.

Tab.10: Parameters relating to slope

Parameters	Symbols	Units	Value
Average altitude	I_{moy}	m/Km	2.77
Average altitude	I_g	m/Km	1.18
Specific gradient	D_S	m	12.20

4.3. Hydrographic characteristics

4.3.1. Structure of hydrographic network

In (Fig.6), we present the ramification level of hydrographic network. By identifying the order level of main stream, the order of watershed, used as a classification criterion, is automatically determined with ArcGIS software. Thus, Karcia watershed is of order 3. This value reflects a poplar (or corridor) hydrographic network type, i.e. presenting many parallel tributaries. It is a watershed that is considerably longer than wide.

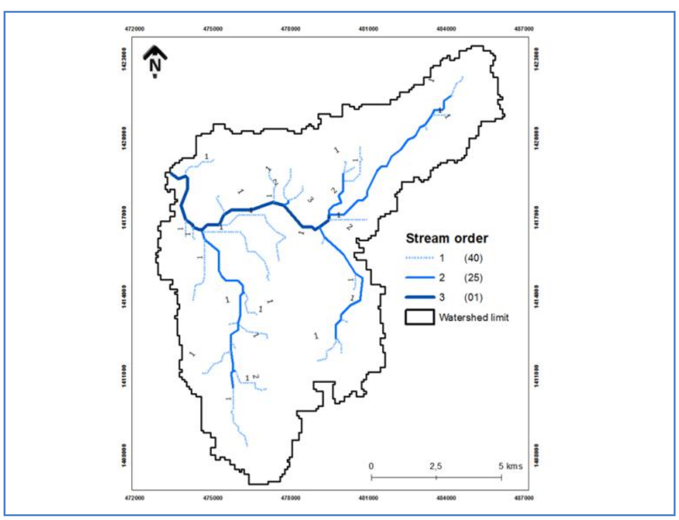

Fig.6: Hierarchy of Karcia watershed

4.3.4. Hydrographic network parameters

(Tab.11) illustrates hydrographic network parameters of Karcia watershed. Average slope of river I_{mce} = 2.61% is soft, Maximum flow of Karcia watershed is thus low, giving water time to infiltrate, in whole or in part, into soil. Drainage density D_d = 2.77 km / km^2 indicating limited drainage density type. This reflects that the basin presents a permeable geological formation, dense vegetation with a developed root system resulting in a rather limited flow and an infiltration accentuated. Coefficient of stability C_S = 0.36 is relatively high, reflecting a relatively high permeability of soil and few steady hydrological conditions. Hydrographic density D_h = 0.62 km^{-2} is low. This value therefore indicates that study basin presents a permeable bedrock region, with a large plant cover and a slight hilly relief. Drainage texture $T_{j=1}$=1.04 km/km^4 translates a coarse-type watershed (permeable formations), thus not representing morphometric characteristics adapted to the flow, however, infiltration is important. Mean of bifurcation ratio R_B = 13.3 is high, confirming a watershed significantly longer than wide (elongated form). This value also indicates that it has many parallel tributaries and a slow hydrological response.

Tab.11: Parameters of Karcia Hydrographic Network

Parameters	Symbols	Units	Value
Stream average slope	I_{mce}	m/Km	2.61
Density of drainage	D_d	km / km^2	2.77
Coefficient of stability	C_S	-	0.36
Hydrographic density	D_h	km^{-2}	0.62
Texture of drainage	T_j	km/km^4	1.04
Bifurcation ratio	R_B	-	13.3

5. Conclusion

The current article deals with the Karcia watershed in the middle Casamance in the Sedhiou region in southern Senegal. The objective targetted here is, to establish the global portrait of physical environment of Karcia watershed by evaluating its morphometric characteristics. Such characterization is an essential step in the realization of an integrated agricultural water management project. In that respect, emphasis is placed on geometrical, topographic and hydrographic characteristics, such information constitute key elements for any reflection related to predetermination river basin response to rainfall elements and characterization of its flow. DEM of 30m of resolution covering the area was exploited due to its suitability for surface water flow modeling, while using the GIS software, ArcGIS. In order to reach this objective, we have initially delimited watershed, generated digital altitude model (DAM) and traced hydrographic network. We have subsequently created the thematic maps, extracted automatic parameters intervening in the hydrological behavior and calculated physiographic indexes including simple and compound morphometric variables. The results obtained are overall reliable, convincing and promising. From the geometry point view, Karcia watershed spreads over an area S = 106.65 Km^2 and has a perimeter P = 76.33 Km. Compactness index and Horton index are respectively K_C = 2.07 and K_H = 0.29 indicating an elongated form. The length of equivalent rectangle is L = 35.13 Km and its width is l =3.04 Km, reflecting that the length is 11 times greater than the width. From the topography point view, Karcia watershed altitudes decrease from NE towards the center, then from the South towards the center. The maximum altitude is equal to 50 m, located in upstream and the minimum equal to 2m, specifically in the central part from East to West (downstream). The topographic denivellation is therefore equal to 48m. The hypsometric curve shows a slight convexity towards the high altitudes indicating a state of youth of Karcia watershed. Average altitude of the watershed is H_{moy} = 24.69m while the median altitude H_{med} = 30 m, meaning that slopes are high in upstream and low in downstream. Slopes map shows that more than 76% of topography has a slope less than 1.8% and the remainder, a slope which varies between 1.8% and 7.2%.From a hydrographic point of view, watershed has generally weak parameters, a 3rd order stream, a poplar network hierarchy type, and coarse-type drainage. The interpretation of the results leads to the following conclusions: i) Karcia watershed presents a young relief, relatively developed erosion, few stable hydrological conditions, low peak flows, high concentration time (or delivery time of water to the outlet) ;ii) it presents as a whole, a permeable geological formation, an important vegetation cover, limited flow and accentuated infiltration ; iii) slopes are relatively high in upstream, where high reliefs predominate, and soften downwards towards downstream where low reliefs predominate ;v) relief is dominated by low plateau and plains ; iv) Watershed is considerably longer than wide with many parallel tributaries; vi) Karcia watershed has accentuated morpho-structural conditions characterized by deposits in its meanders, poorly developed floodplains. Geomorphologically, distribution of altitudes is linked to watershed topography composed of more or less staggered units, corresponding to trays arranged in stairs steps and passing in downstream to plains. Concerning erosion, it is on the one hand mechanical, linked to intensification of anthropogenic action through modern deposits at the bottom of valley and, on the other hand natural, linked to geological structure, lithology of soils and the degradation of bioclimatic conditions. Karcia watershed is one of basins that are expected to experience very little flooding in riparian communities even during high water periods. The results obtained from this study; show that GIS and digital elevation models are very robust tools for analyzing and evaluating weight of geomorphology on the flow of surface water for the Watershed. These techniques allow gaining time, effort and costs. These results obtained in the framework of this study, provide valuable insights for watershed specialists for many applications such as irrigation and flood protection projects. However, it must be recognized that the global portrait of watershed must not only be limited to the physical environment. It must necessarily consider portraits of biology, human activity and agricultural enterprises to be viable. The reality on the field would also be an asset no less important.

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