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ARTICLE

Contribution of GIS to Hydromorphometric Characterization of the Nkoup Watershed (Nun Plain-Cameroon)

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ABSTRACT

The Nkoup watershed (10°35'-10°47'E and 5°27'-5°42'N) is a volcanic zone situated in Nun Plain West Cameroon. The high fertility of the soils makes it a strategic agropastoral area where water resources are heavily exploited and used for several purposes. Due to human activities, soils and water resources are deteriorating, giving birth to water pollution and hydromorphological hazards. This work aims to determine the hydromorphometric parameters of the Nkoup watershed so that the data obtained help in the sustainable management of water resources and conservation of soil. To achieve this aim, various data were collected from DEM dataset derived from SRTM and processed in specialized software (QGIS and ArGIS). The simplified hydrological balance was calculated using the upstream approach. The Nkoup watershed has: Axial length L_{ax} = **25.8** km, Axial Width W_{ax} **= 11.1** km, Perimeter **P = 132.6** km, Area **A** = **173.7** km^2, Average Altitude H_a = **1726.3** m, Compactness Index **Icomp** = **2.8**, Relief ratio Rr = **3.9** m/km, Circularity ratio **Rc = 0.1**, Elongation ratio **R = 0.1**, Drainage texture ratio **Rt = 0.6**, Drainage density D_d = **0.5** km/km^2. Stream Frequency **Fs = 0.4**, Channel Sinuosity Index **CSI = 0.8**, Stream gradient **Sg = 0.6** and global slope Index **Ig** = **6.8** m/km. The specific height Difference **Ds** = **89.4** m shows moderate relief. The precipitation and evapotranspiration are unevenly distributed. With **P** = **187.7** mm/an, **ETP** = **953.4** mm/an, **Q** = **4.2** m^3/s, **R** = **762.5** mm/an, **ETR** = **832.3** mm/an and **I** = **282.9** mm/an. The Nkoup, **36.9** km long, has a sinuous aspect due to the low slope and the high CSI. The piezometric levels vary according to the seasons and the groundwater flow follows the N-S direction as surface flow.

Keywords: Nkoup watershed; Water resources; Hydromorphometric parameters; Hydrological balance; Groundwater flows direction

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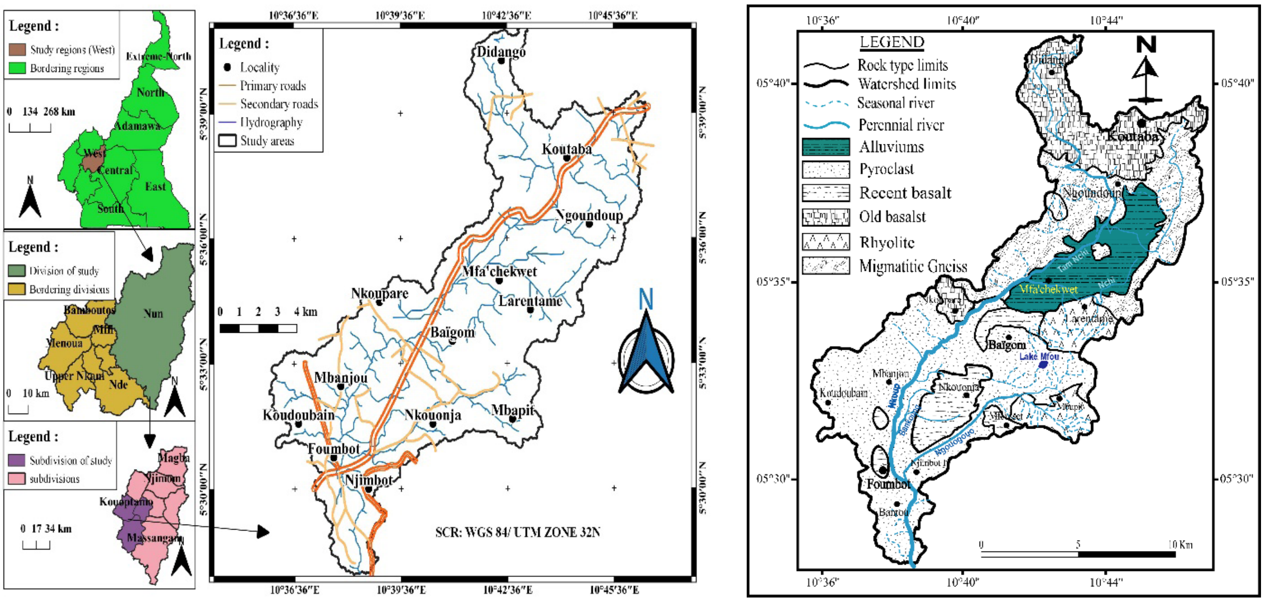
1. Introduction

The Nkoup watershed (173.7 km^2) is located in the South-East of the Nun Plain (West Region-Cameroon), between longitudes 10°35'-10°47'E and latitudes 5°27'-5°42'N. It is a volcanic zone that includes the localities of Foumbot, Baïgom and a part of Koutaba and Kouoptamo (**Figure 1a**). The high fertility of the soils makes it a strategic agropastoral area where water resources are heavily exploited and used for several purposes. Due to human activities, soils and water resources are deteriorating, giving birth to water pollution [1] and hydromorphological hazards. Thus, it is important to determine the hydromorphometric parameters of this watershed so that the data obtained contribute to the prevention of water pollution and help in the sustainable management of water resources (water-related conflicts); and conservation of soil in this area. A watershed is a natural hydrological unit that generates surface runoff from the rainfall which flows through channels, streams, rivers, lakes or oceans [2-5]. Prioritization of watershed is a crucial part of watershed management as it contains some sensitive information regarding surface hydrology and is able to answer some crucial questions such as where to construct check dam, reservoir, embankment, etc., to minimize soil erosion, flooding, bank erosion and maximize infiltration [4]. Morphometric characteristics influence watershed processes [6-9], describe geomorphology and hydrogeology features [10,11] and provide valuable information on water resources potential assessment and management [12]. The geomorphometric analysis was distinguished for the first time by Horton [13]; it was further reviewed by Evans [14]. The traditional approach in watershed prioritization from basin morphometry is based on calculating compound parameter values, as averages of individual parameter values [5]. In recent studies, Hamdan [6] notes that geospatial technology in earth science is an emerging tool by which the hydrogeologist can assess the watershed properties using Geographic Information System (GIS), Remote Sensing (RS) and Global Positioning System (GPS). Gis is ideal for morphometric analysis because of its strength in visualizing, processing and quantifying topographic attributes [15]. This study is very important due to the fact that it permits to implementation of some parameters of hydro-morphometric characteristics of Nkoup watershed and brings out the solutions to various hydrological problems for Nkoup watershed management. Located on the Cameroon volcanic line, it is marked by the following geological formations: Alluviums, Rhyolites, Basalts, Pyroclasts and migmatitic gneiss (**Figure 1b**). The **alluvial formations** are made up of a mixture of weathering products (mud and sand) and partly cover the gneissic bedrock. **Ryolites** outcrop in the form of domes and present a porphyritic texture made up of an arrangement of K-feldspars (Or_{97-89}), Na-feldspars (Ab_{99-88}), quartz and Fe-Ti oxides [16]. **Basalts** are present in two types: Old basalts or plateau basalts that present a porphyritic microlitic texture consisting of olivine and pyroxene phenocrists; and recent basalt (vacuolar) with porphyritic microlitic texture made up of olivine and pyroxene phenocrists. Microscopically, the mineralogy of these basalts is homogeneous: Olivine, clino-pyroxene, plagioclase, Fe-Ti oxide and chromite. The geochemistry of these lavas shows enrichment in SiO_2 (41.2-46.4%), Al_2O_3 (11.4-17.1%), Na_2O (2.4-3.9%), K_2O (1.0-1.9%) and impoverishment in MgO (13.8-4.6%), CaO (11.9-7.6%) [16]. **Pyroclastic formations** composed of Pumices, Slags, Lapillis and volcanic ashes occupy about a third of the watershed with thicknesses varying from 1 to more than 15 m. They have two colors (red and black) and are strongly concentrated around the craters forming cones. The bedrock consists of strongly fractured migmatitic gneiss and presents quartzo-feldspatic veins with N25°-40°E orientation. It has a migmatitic texture made from the following minerals: Quartz, Feldspars, Biotite, Amphibole and Muscovite.



(a) (b)

Figure 1. (a) Localisation and (b) geological units of the Nkoup watershed.

2. Methodology

The Digital Elevation Model (DEM) is the major dataset for various applications [17,18]. Hydrological analysis in particular relies heavily on DEM data [20-22]. To achieve this aim, GIS data were collected from DEM dataset derived from Shuttle Radar Topography Mission (SRTM) with 30 m resolution and processed in specialized software. Several types of data were used: Cartographic data (Landsat ETM+ images downloaded in April 2020 from the website www.earthexplorer.usgs.gov); Radar SRTM images downloaded in April 2020 from the website www.earthexplorer.usgs.gov; Google earth images; 1/200000 scale geological maps from National Institute of Cartography of Cameroon); Climatic data (precipitation and temperature obtained in four meteorological stations (Foumbot, Kouoptamo, Koutaba and Baïgom) downloaded in April 2020 from the website www.climate-data.org; Evapotranspiration (ETP and ETR) calculated from the precipitation and temperature of each station and piezometric data. These data were stored and processed in specialized software (QGIS and ArGIS 10.3). Geomorphometric information was digitized and georeferenced with WGS84/UTM zone 32°N in order to produce thematic maps. Some of the parameters were measured using ArGIS tools and calculated using mathematical formulas developed by several authors and vector models.

The simplified hydrological balance was calculated using the upstream approach. It was a question of determining the numerical value of each term of the following hydrological balance formula (Equation (1)).

$$\mathbf{P = I + R + ETR} \tag{1}$$

In this formula, the hard-to-quantify real evapotranspiration was determined from the monthly rainfall data and the potential evapotranspiration. It is therefore necessary to calculate the ETP. Its expression is given by the Thornthwaite [23] formula as Equation (2):

$$\mathbf{ETP = 16\left(10\frac{T}{I}\right)^{a})\lambda} \tag{2}$$

with: $\mathbf{a = 6{,}75.10^{-7}\,I^3 - 7{,}71.10^{-5}I^2 + 1{,}79.10^{-2} + 0{,}49239;}$

$\mathbf{I} = \sum_{i=1}^{12}(\boldsymbol{i})$ **and** $\boldsymbol{i} = \left(\frac{T}{5}\right)^{\mathbf{1{,}514}}$.

with: **ETP** = mensual potential evapotranspiration for the fictitious month of 30 days and a theoretical period of 12 hours sunshine; **T** = Monthly average temperature in °C for the month considered; **I** = Annual thermal Index; **a** is a function of thermal index and **λ** = Correction coefficient according to the latitude and the month.

To determine **ETR**, Thorntwaite's algorithm was used. It is based on the easily usable reserve (RFU) according to the following situations for **i** ranging from **1** to **12** in Equations (3)-(7).

a) If $P_{(i+1)} \geq ETP_{(i+1)}$ hence $ETR_{(i+1)} = ETP_{(i+1)}$ (3)

b) If $P_{(i+1)} = ETP_{(i+1)}$ hence $ETR_{(i+1)} = ETP_{(i+1)} = P_{(i+1)}$ (4)

c) If $P_{(i+1)} < ETP_{(i+1)}$ hence:

- $ETR_{(i+1)} = RFU_i + P_{(i+1)}$ *if* $RFU_i + P_{(i+1)} < ETP_{(i+1)}$ (5)
- $ETR_{(i+1)} = ETP_{i+1}$ if $RFU_i + P_{(i+1)} \geq ETP_{(i+1)}$ (6)
- $ETR_{(i+1)} = P_{(i+1)}$ if $RFU_i + P_{(i+1)} < ETP_{(i+1)}$ with $RFU_i = 0$ (7)

The easily usable reserve (RFU) is determined as Equation (8):

$$RFU_{(i+1)} = RFU_i + P_{(i+1)} - ETP_{(i+1)} \text{ ; with } 0 \leq RFU \leq 100 \quad (8)$$

IfP ≥ ETR, there is an excess **P – ETR** which is assigned in priority to the **RFU** and if **RFU = RFU-max(100)**, this excess is rather assigned to the flow. After the calculation of the RFU, any negative value is reduced to zero while any value greater than 100 is reduced to 100.

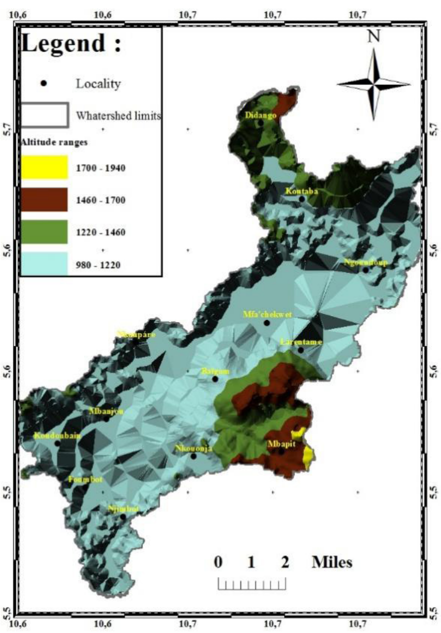
3. Results and interpretation

3.1 Relief of the Nkoup watershed

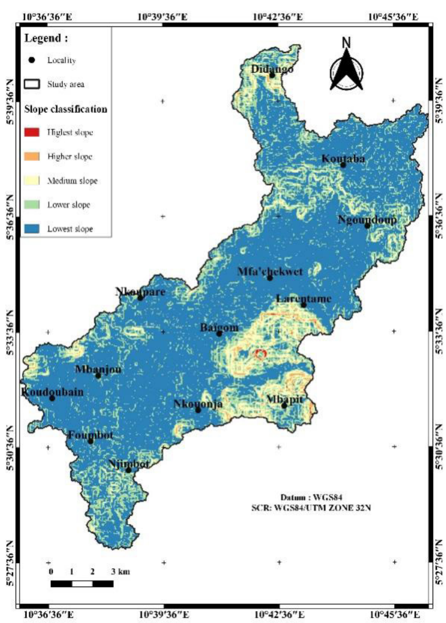
The relief of the Nkoup watershed is marked by a vast plain surrounded by cones/summits at varying altitudes, which the highest, Mount Mbapit culminates at 1840 m. This relief is the result of an important more or less recent volcanic activity. The lower part covers about 85% of the watershed and is made up of geomorphological units located between 980 and 1220 m (**Figure 2a**). The steep slopes are encountered in the East and the far North where the geomorphological units are the highest (**Figure 2b**).

3.2 Climate of the Nkoup watershed

The climate of the Nkoup watershed is tropical sudano-guinean with two seasons [24]. The rainy season extends from mid-March to mid-November and the dry season from mid-November to mid-March (**Figure 3a**). The average annual rainfall is 156.5 mm with minimums in December and maximums in August. It varies decreasingly according to the year (between 2016 and 2020) with the rainy year 2016 and the least rainy year 2017 (**Figure 3b**).

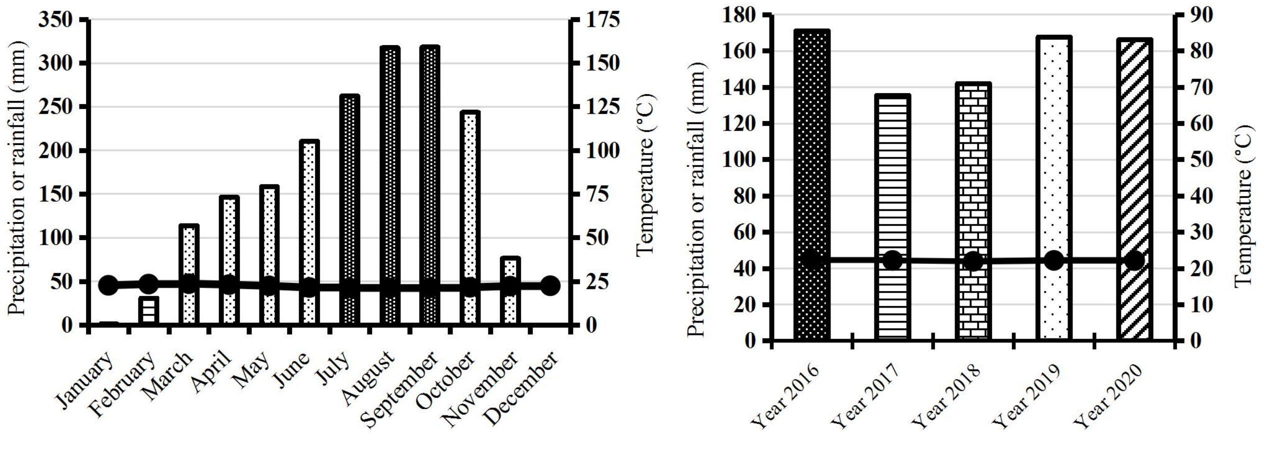


(a)



(b)

Figure 2. Maps showing (a) the relief units; (b) the distribution of slopes in the Nkoup watershed.



(a) (b)

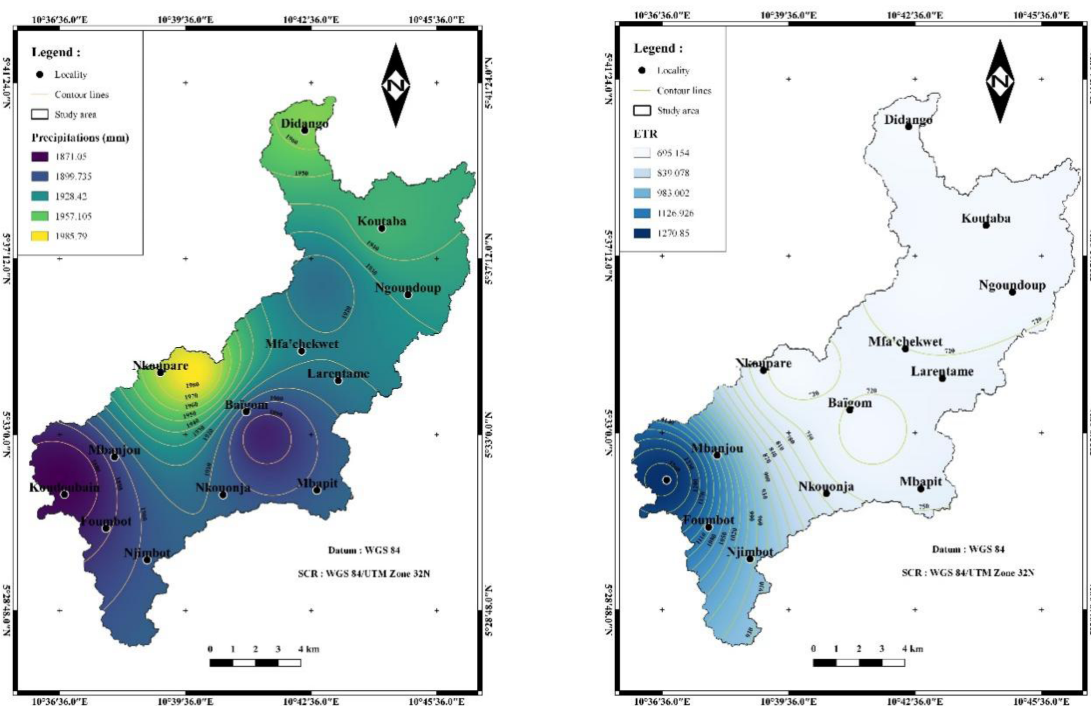
Figure 3. Ombrothermal diagram of (a) monthly averages (b) annual rainfall averages over 5 years, from 2016 to 2020 from Foumbot meteorological station [25].

The cartographic interpolation of data from the following meteorological stations: Foumbot, Kouoptamo, Koutaba and Baïgom makes it possible to note unequal distribution of rainfall and evapotranspiration in the watershed. Rainfall is low in the South-West and the East; and high in the West and far North (**Figure 4a**). The ETR is low in the centre and the North; and high in the extreme South-West of the watershed (**Figure 4b**).

The aridity index $\mathbf{I_a}$ is calculated by De Martonne [26] formula:

$$\mathbf{I_a = 12P_m/T_m + 10} \tag{9}$$

with $\mathbf{P_m}$ and $\mathbf{T_m}$ respectively the average monthly rainfall and temperature. De Martonne defines the following aridity index classes: $\mathbf{I_a < 20}$ (arid); $\mathbf{20 <}$



(a) (b)

Figure 4. Map showing the distribution of (a) precipitation, (b) ETR in the Nkoup watershed.

I_a < 50 (semi-arid); **50 < I_a** (wet). It appears from the results in **Table 1** that December, January and February are the arid months; November and March are semi-arid months; and the months from April to October are wet. Overall, with an average aridity index of **58.39**, the Nkoup watershed is located in a wet zone.

3.3 Hydro-morpho-metric parametres of the Nkoup watershed

Hydrography and hydrographic network density of the Nkoup watershed

The Nkoup is the main river of the watershed and Nchi, Tam Nchi and Ngouogouo are its important tributaries. Lake Mfou, located on one of the peaks of the Mbapit massif constitutes the most important surface water plan. It is a crater lake that has no (visible) outlet. It is noted the predominance of seasonal streams and dry drains to the East of the watershed and around Mount Mbapit. According to the Schumm [27] classification, the Nkoup watershed has an arborescent hydrographic network made up of third-order rivers. The source of the river Nkoup is located at an altitude of **1224** m (Didango) and its outlet is situated at Mbatou, at an altitude of **980** m (**Figure 5**).

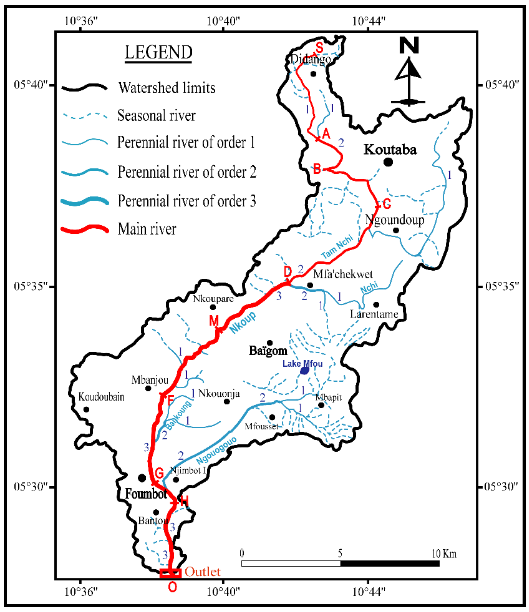


Figure 5. The main rivers map of the Nkoup system.

The stream frequency

The Stream Frequency (**Fs**) is the ratio between the number of flow channels per unit area of the watershed [13]. It is expressed by Equation (10):

$$\mathbf{Fs} = \mathbf{Ni/A} \tag{10}$$

Ni = Number of flow channels (**Ni** = **71**) and **A** = Area of the watershed (**173.7** km^2), the Stream Frequency of Nkoup watershed is **Fs** = **0.41** km^{-2}. This value is related to the high relief of the zone [28].

Table 1. Aridity index of the Nkoup watershed.

Month	P_m (mm)	T_m (°C)	$12P_m$	T_m+10	I_a	Observations
January	0.6	22.58	7.2	32.58	0.22	Arid
February	30.74	23.28	368.88	33.28	11.08	Arid
March	113.66	23.52	1363.92	33.52	40.69	Semi-arid
April	146.26	22.98	1755.12	32.98	53.22	Wet
May	158.32	22.28	1899.84	32.28	58.86	Wet
June	210.34	21.34	2524.08	31.34	80.54	Wet
July	262.12	21.1	3145.44	31.1	101.14	Wet
August	317.48	21.04	3809.76	31.04	122.74	Wet
September	318.26	21.12	3819.12	31.12	122.72	Wet
October	243.56	21.46	2922.72	31.46	92.90	Wet
November	76.4	22.12	916.80	32.12	28.54	Semi-arid
December	00.00	22.34	00.00	32.34	00.00	Arid
Average	156.48	22.1	1877.76	32.1	59.39	Wet zone

Drainage density

The drainage density (**D_d**) is the ratio of the total stream lengths in the hydrographic network per unit area of the watershed [13]. It is determined by Equation (11):

$$D_d = \frac{\sum_{i=1}^{n} L_i}{S} \quad (11)$$

L_i = Total Stream Lengths (**$\sum L_i$ = 83.376** km) and **A** = Area of the watershed (**173.7** km^2), **D_d = 0.48** km/km^2. The cartographic interpolation of the data made it possible to obtain **Figure 6**.

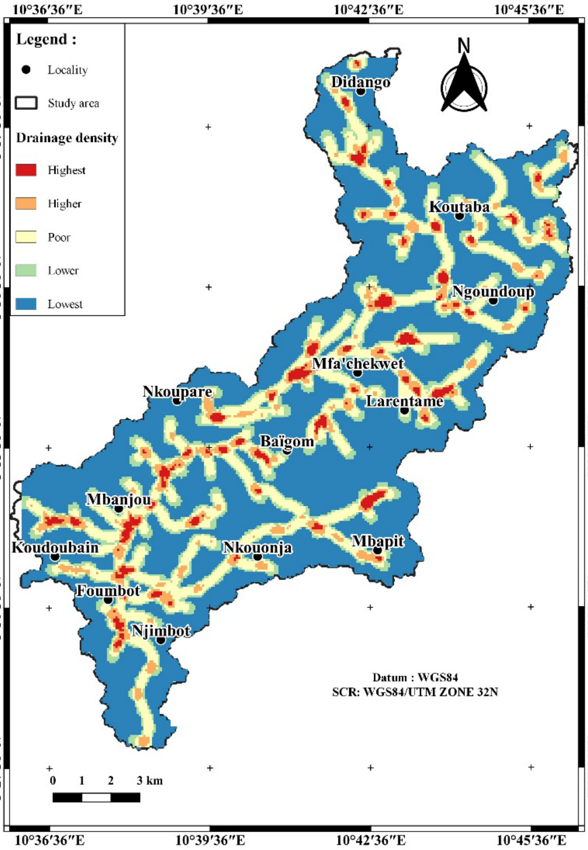


Figure 6. The drainage density map of the Nkoup system.

The constant of Channel Maintenance (**C**) is the inverse of drainage density and corresponds to the area required to maintain stable hydrological conditions in a unit hydrographic vector of the watershed [26,27]. It is determined by Equation (12):

C = 1/Dd (12)

with **D_d** = drainage density (**0.48** km/km^2), **C = 2.083** km^2/km.

Hypsometry of the Nkoup watershed

Figure 7 shows the delimitation of the Nkoup watershed according to the contour lines. The Nkoup watershed has: Axial length **L_{ax} = 25.83** km, Axial width **W_{ax} = 11.11** km, Perimeter **P = 132.645** km and an area **A = 173.7** km^2.

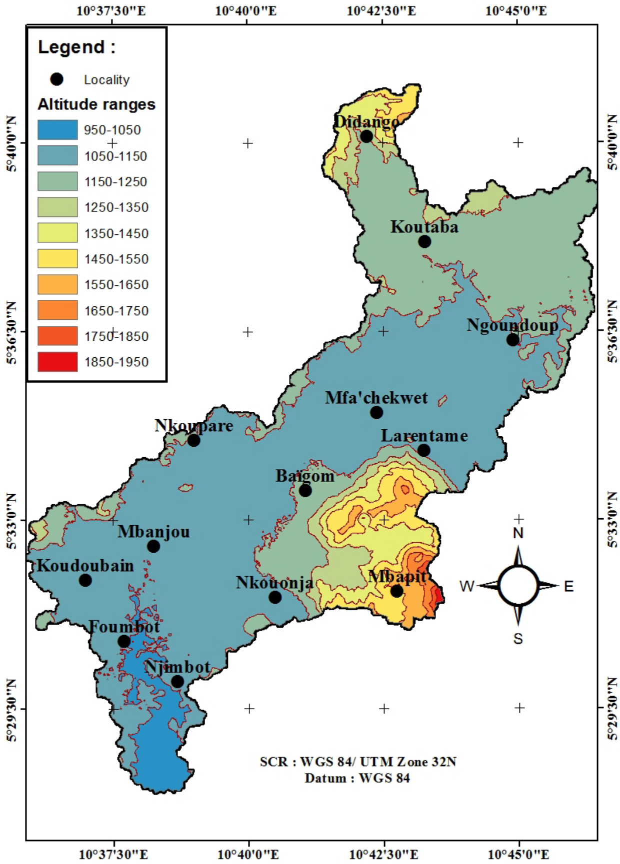


Figure 7. Hypsometric map of the Nkoup watershed.

This distribution made it possible to obtain 10 intervals of 100 m equidistance. The partial and cumulated areas of each slice are presented in **Table 2**.

The hypsometric curve in **Figure 8** is established by planimetry of the surfaces corresponding to the definition of the ordinate for each of the contour lines [29]. This curve is a representation of "altitude range as a function of areas and cumulated areas".

The Nkoup watershed has an average altitude of **1726.31** m; **$H_{5\%}$ = 1473** m; **$H_{50\%}$ = 1130** m and **$H_{95\%}$ = 1048** m (**Figure 8**). The average slope (S_s) of the stream was determined between points **A** and **H** by Equation (13):

Table 2. Distribution of the surface area of the Nkoup watershed by altitude range.

Altitude bands (m)	Median altitude (H_i)(m)	Surface area		S_iH_i (km^3)	Cumulated area	
		km^2	%		km^2	%
950-1050	1000	7.2	4.1	7.2	7.2	4.1
1050-1150	1100	93.7	53.9	103.0	100.9	58
1150-1250	1200	46.6	26.8	55.9	147.5	84.8
1250-1350	1300	7.8	4.5	10.1	155.3	89.3
1350-1450	1400	7.6	4.4	10.6	162.9	93.7
1450-1550	1500	6.6	3.8	9.8	169.5	97.5
1550-1650	1600	3.1	1.8	4.9	172.6	99.3
1650-1750	1700	0.9	0.5	1.5	173.5	99.8
1750-1850	1800	0.2	0.1	0.4	173.7	99.9
1850-1950	1900	0.1	0.1	0.2	173.8	100.0
Total		173.8	100	203.7	173.8	100

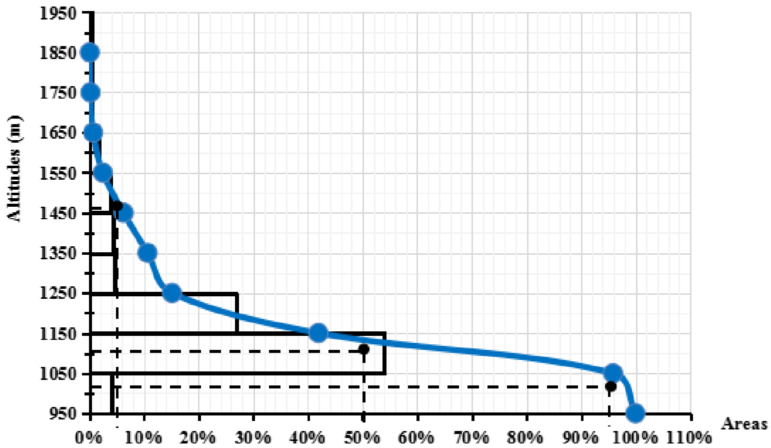


Figure 8. Hypsometric curve of the Nkoup watershed.

$$H_a = \frac{\sum_{i=1}^{n} A_i H_i}{A} \quad (13)$$

with H_i = median altitude of a slice delimited by two consecutive H_a and H_b level curves: $H_i = \frac{Ha + Hb}{2}$.
A_i = Partial area of the slice between two consecutive contour lines H_a and H_b; A = Total area of the watershed. The Nkoup watershed has an average altitude H_a = **1726.31 m**.

The relief of the Nkoup watershed is the result of the following products: Pyroclasts, basalts and rhyolites. The Nkoup watershed is characterised by high relief with steep slop resulting from significant volcanic activities.

Stream gradient of the Nkoup River

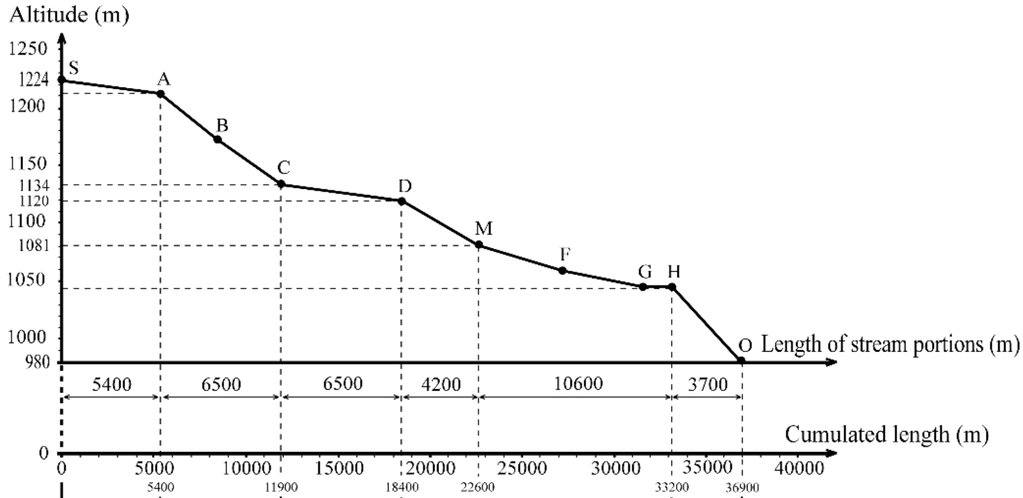
By subdividing into 14 portions according to the variations in the sinuosity of the main stream, the longitudinal profile of the Nkoup River was produced (**Figure 9**). The average slope of the stream (S_g) was determined between points **A** and **H** of the longitudinal profile by Equation (14):

$$S_g = \frac{\Delta H}{\Delta L} \quad (14)$$ [30]

with **ΔH** = altitude difference between two chosen points and **ΔL** = distance in meters between the two chosen points.

<u>**NA**</u>: $S_g = \frac{1212-1045}{|5400-33200|}$ = **0.006 or 0.6%**

The maximum flow length of the Nkoup River is L_f = **36.93** km. Its average slope is very low (**0.6%**) over the first 33 kilometers from the source and high (**18%**) at the outlet due to the presence of the Mbatou waterfall. This low slope influences the flow of



Value	0.002	0.012	0.002	0.009	0.003	0.18
Slope (%)	0.2	1.2	0.2	0.9	0.3	18
Average value		0.006				
Average slope (%)		0.6				

Figure 9. Longitudinal profile of the Nkoup River.

surface water, thus justifying a high sinuosity coefficient (75%).

Channel sinuosity index

The Channel Sinuosity Index (**CSI**) [29] is the relationship between the length of the bird's-eye stream from source to outlet and the actual length of the main stream. It is calculated by Equation (15):

$$\mathbf{CSI} = \mathbf{Ld/Lf} \quad (15)$$

with $\mathbf{L_d}$ = length of the bird's-eye stream from source to an outlet (**27.7** km); $\mathbf{L_f}$ = Actual length of the main stream (**36.93** km).

<u>NA</u>: CSI = **27.7/36.9** = **0.75**; or **75%**

This high Channel Sinuosity Index CSI = 0.75 is justified by the low slopes observed along the stream.

Gravelius compactness index

The Gravelius Compactness Index or Coefficient of Form (**Icomp**) [30] is determined by Equation (16):

$$Icomp = \frac{0.282 \text{ x P}}{\sqrt{S}} \quad (16)$$

P = watershed perimeter (**132.645** km) and **A** = watershed area (**173.7** km^2).

$$\underline{\text{NA}}\text{: } Icomp = \frac{0.282 \text{ x } 132.645}{\sqrt{173.7}} = 2.8$$

Equivalent rectangle

The equivalent rectangle is a purely geometric transformation in which the lines parallel to the widths of the rectangle and the outlet are the short side of the rectangle [31]. In a watershed, it is assumed that the flow is almost the same as on a rectangle of the same area under climatic, hypsometric, land cover and drainage density conditions. The dimensions of the equivalent rectangle for the Nkoup watershed are determined as Equations (17) and (18):

- The equivalent rectangle Length:

$$\mathbf{Leq} = \sqrt{\mathbf{A}}\ X \left(\frac{I_{comp}}{1.128}\right) X \left[1 + \sqrt{\left(1 - \left(\frac{1.128}{I_{comp}}\right)^2\right)}\right] \quad (17)$$

$$\underline{\textit{NA}}\text{: } \mathbf{Leq} = \sqrt{173.7}\ X \left(\frac{2.8}{1.128}\right) X \left[1 + \sqrt{\left(1 - \left(\frac{1.128}{2.8}\right)^2\right)}\right] = 62.7 \text{ km}$$

- The equivalent rectangle Width:

$$\mathbf{Weq} = \sqrt{\mathbf{A}}\ X \left(\frac{I_{comp}}{1.128}\right) \left[1 - \sqrt{\left(1 - \left(\frac{1.128}{I_{comp}}\right)^2\right)}\right] \quad (18)$$

or $\boldsymbol{W}\mathbf{eq} = \frac{A}{L_{eq}}$ *NA:* $\mathbf{Weq} = \sqrt{173.7}\ X \left(\frac{2.8}{1.128}\right)\left[1 - \sqrt{\left(1 - \left(\frac{1.128}{2.8}\right)^2\right)}\right]$

$$= 2.8 \text{ km}$$

Relief Ratio

The Relief Ratio (**R_r**) of the Nkoup watershed is given by Equation (19) [27]:

$$\mathbf{R_r} = \frac{\Delta_{max}}{\mathbf{Leq}} \quad (19)$$

where Δ_{max} = **Hmax –Hmin (**Δ_{max} = *maximum height dif ference***)**. **Hmin** = Minimum altitude (980 m), **Hmax** = Maximum altitude (1224 m) and **Leq** = Equivalent rectangle length (62.7 km).

$$\underline{\mathbf{NA}}: \boldsymbol{R_r} = \frac{1224-980}{62.7} = 3.89 \text{ m/km}$$

The Relief Ratio **R_r = 3.9** shows that the area has low slope that can not create high potential energy for transporting water and sediment down slope [4].

Global slope index

The Dubreuil [32] global slope Index (**Ig**) of the Nkoup watershed is calculated from the hypsometric distribution using Equation (20):

$$\mathbf{Ig} = \frac{D}{L_{eq}} \quad (20)$$

where **D = H5% – H95%** with **$H_{5\%}$** = Altitude having 5% of the watershed above (**1473** m) and **$H_{95\%}$** = Altitude having 95% of the watershed below (**1130** m).

$$\underline{\mathbf{NA}}: \mathbf{Ig} = \frac{1473-1130}{62.7} = 6.78 \text{ m/km}$$

Specific height Difference

The specific height Difference (**Ds**) is given by Equation (21):

$$\boldsymbol{Ds} = \mathbf{Ig}\ \mathbf{x}\ \sqrt{\boldsymbol{A}} \quad (21)$$

With **Ig** = global slope Index and **A** = watershed area. **NA:** $\boldsymbol{DS} = \mathbf{6.78\ x\ \sqrt{173.7} = 89.36\ m}$.

Elongation ratio

The elongation ratio (**R**) is defined as the ratio of the diameter of a circle of the same area as the watershed to the maximum watershed length [27]. Its value varies from 0 (highly elongated shape) to 1 (round shape).

$$\mathrm{R} = \frac{2}{\pi}\sqrt{\frac{A}{L^2}} \qquad \underline{\mathbf{NA}}: \mathrm{R} = \frac{2}{\pi}\sqrt{\frac{173.7}{62.7^2}} = 0.13$$

The elongation ratio R = 0.1 shows that the watershed is a more elongated shape. So the Nkoup river shows the a longer lag time and a low risk of soil erosion and flooding [11,34,35].

Circularity ratio

The Circularity ratio (**Rc**) [33] is the ratio of the watershed area to the area of a circle having the same perimeter as the watershed. It is ranging from 0 to 1 and be calculated as follows:

$$Rc = \frac{4\,\Pi A}{P^2} \qquad \underline{\mathbf{NA}}: \quad Rc = \frac{4*3.14*173.7}{132.6^2} = 0.12$$

The Circularity ratio Rc = 0.1 showing that the Nkoup watershed is elongated in shape and may have lower runoff potential resulting from the presence of highly permeable pyroclastic materials [9].

Drainage texture ratio

Drainage texture ratio (**Rt**) [13] is the ratio between the total length of stream segments of all orders and the perimeter of the watershed. It is expressed by the following formula:

$$\boldsymbol{Rt} = \frac{\mathbf{Li}}{\mathbf{P}}$$

Li = total length of stream segments of all orders; and P = perimeter of the watershed.

$$\mathbf{NA:}\ \boldsymbol{Rt} = \frac{\mathbf{83.376}}{\mathbf{132.6}} = \mathbf{0.63}$$

The texture ratio is classified into four categories < 4 per km coarse, 4-10 per km intermediate, 10-15 per km fine and > 15 per km ultra fine [35]. The Drainage texture ratio **Rt** = 0.6 indicating that the Nkoup watershed falls in coarse category.

3.4 Simplified hydrological balance of the Nkoup watershed

Table 3 presents the average values of the data obtained from the meteorological stations of Foumbot, Kouoptamo, Koutaba and Baïgom.

Table 3 shows that the Nkoup Watershed has a precipitation of 1877.74 mm/year, a Potential Evapotranspiration of 953.42 mm/year, for a Real EvapoTranspiration of 832.31 mm/year. The outlet is located in Batou with coordinates 5°30'31.20"N,

Table 3. The different values of ETP, RFU and ETR.

Month	P (mm)	T (°C)	i	a	λ	ETP (mm)	RFU	ETR (mm)
January	00.60	22.58	09.80	0.503	1.02	79.90	00.00	00.60
February	30.74	23.28	10.26	0.503	0.93	71.55	00.00	30.74
March	113.66	23.52	10.43	0.502	1.03	78.75	34.91	78.75
April	146.26	22.98	10.07	0.503	1.02	78.70	100.00	78.70
May	158.32	22.28	9.60	0.503	1.06	82.48	100.00	82.48
June	210.34	21.34	9.00	0.504	1.03	81.27	100.00	81.27
July	262.12	21.1	8.85	0.504	1.06	83.87	100.00	83.87
August	317.48	21.04	8.81	0.504	1.05	83.15	100.00	83.15
September	318.26	21.12	8.86	0.504	1.01	79.91	100.00	79.91
October	243.56	21.46	9.98	0.503	1.03	77.13	100.00	77.13
November	76.40	22.12	9.50	0.504	0.99	77.40	99.00	76.40
December	00.00	22.34	9.64	0.503	1.02	79.31	19.69	79.31
Total	1877.74	265.16	123.8	6.04	12.25	953.42	853.6	832.31
Average	156.48	22.10	10.32	0.503	01.02	79.45	71.13	69.36

10°37'52.7"E and 980 m.

The runoff of a watershed is a function of the following parameters: The flow rate of its main river taken at the outlet, its area and the time of year (Equation (22)).

$$\mathbf{R} = (\mathbf{Q} \ \mathbf{x} \ \mathbf{t})/\mathbf{A} \tag{22}$$

with: **Q** = average annual flow in m^3/s of the Nkoup; t = time in seconds; **A** = Nkoup watershed area in m^2. The flow rate (**Q**) is a function of the speed (**V**) of the current and its flow section (**S**). It is expressed mathematically as follows: **Q** = **VS**. The flow calculation takes into account the following situations: The speed of the current at the surface is greater than the speed of the deeper parts of the stream; The speed of the current in the middle is greater than the speed at the edge of the stream. Thus the value of the flow rate obtained is corrected by a coefficient "**B**" such as **0.6** < **B** < **0.8**; thus the flow rate formula becomes Equation (23):

$$\mathbf{Q} = \mathbf{BVS} \tag{23}$$

The Nkoup River has flow rates that vary according to the seasons (1.0-8.6 m^3/s) for an annual average value of 4.2 m^3/s. For **Q** = 4.2 m^3/s; t = 1 year = 31,536,000 s and A = 173.7 km^2 = 173,770,000 m^2. R = (4.2 × 31,536,000)/173,700,000 = 0.76253 m. <u>NA</u>**:** **R** = **762.53** mm.

The infiltration is calculated using the following hydrological balance formula (Equation (24)):

$$\mathbf{P} = \mathbf{I} + \mathbf{ETR} + \mathbf{R} \tag{1}$$

$$\rightarrow \mathbf{I} = \mathbf{P} - (\mathbf{ETR} + \mathbf{R}) \tag{24}$$

<u>NA</u>**:** **I** = 1877.74 – (832.31 + 762.53)

I = **282.9** mm/year. Hydrologically, the Nkoup Watershed has the following parameters: Total precipitation **P** = **1877.74** mm/year; Total potential evapotranspiration **ETP** = **953.42** mm/year; Real evapotranspiration, **ETR** = **832.31** mm/year, that is 44.3% of precipitation; Runoff **R** = **762.53** mm/year, that is 40.6% of precipitation; Infiltration **I** = **282.9** mm/year, that is 15.1% of precipitation.

The runoff parameters are very important because water resources management decisions depend on the timings of runoff characteristics of a watershed [36]. Rainfall and evapotranspiration are influenced by Mount Mbapit and are unevenly distributed in the watershed (**Figure 4**). The infiltration (15% of precipitation) is partly linked to the very low slope and the permeability of recent basaltic formations in the lower zone which covers around 85% of the watershed (**Figure 2 and 7 and 8**).

3.5 Groundwater flow

The piezometric levels vary according to the seasons. They increase to 2 or 7 m depending on the work. These variations have very little influence on the direction of groundwater flow. The highest piezometries are observed in the Northern part (Koutaba) while the lowest piezometries are found in the South of the watershed. The underground flow follows a North-South direction (**Figure 10**).

Groundwater recharge is very rapid with an increase in the piezometric level to 2 to 7 m in September. The direction of the groundwater flow is North-South and is very weakly influenced by seasonal variations in the piezometric level. The high piezometries are observed in the high zone and the shallow piezometries are located in the lower zone.

4. Conclusions

The Nkoup watershed has five geological formations: The basement rock (migmatitic gneiss), rhyolites, plateau basalt, recent basalt and pyroclasts, which cover an area of 173.7 km^2. These formations are fractured in two major directions (N20°-50°E and N50°-90°W). The Nkoup, 36.9 km long is the main river. It takes its source at 1224 m altitude in Didango and flows along a meandering stream with an average slope of 0.6%, up to 980 m altitude at its outlet at Mbatou. Its average annual flow rate is 4.2 m^3/s and a particle that leaves the main source will take 4 hours 57 minutes to reach the outlet. With a total annual rainfall of 1877.74 mm, infiltration represents 15.1%, against 44.3% and 40.6% respectively for the ETR and the Runoff. According to the following parameters: Axial Length Lax = 25.8 km, Axial Width Wax = 11.1 km, Perimeter P = 132.6 km, Area A = 173.7 km^2, Average altitude Ha = 1726.3 m, Compactness Index Icomp = 2.8, Relief ratio Rr = 3.9 m/km, Circularity ratio Rc = 0.1, Elongation ratio R = 0.1, Drainage texture ratio Rt = 0.6, Drainage density Dd = 0.5 km/km^2. Stream Frequency Fs = 0.4, Channel Sinuosity Index CSI = 0.8, Stream gradient Sg = 0.6 and global slope Index Ig = 6.8 m/km. The specific height Difference Ds = 89.4 m; the Nkoup River shows a longer lag time and low risk of soil erosion and flooding. The relief of Nkoup watershed is characterised by moderate slop resulting from significant volcanic activities. That relief is the result of the following products: Pyroclasts, basalts and rhyolites. The watershed is more elongated in shape and may have lower runoff potential resulting from the presence of highly permeable pyroclastic materials. The Nkoup watershed has an aquifer potential that should be identified through the distribution of water structures and in-depth studies of each geological formation.

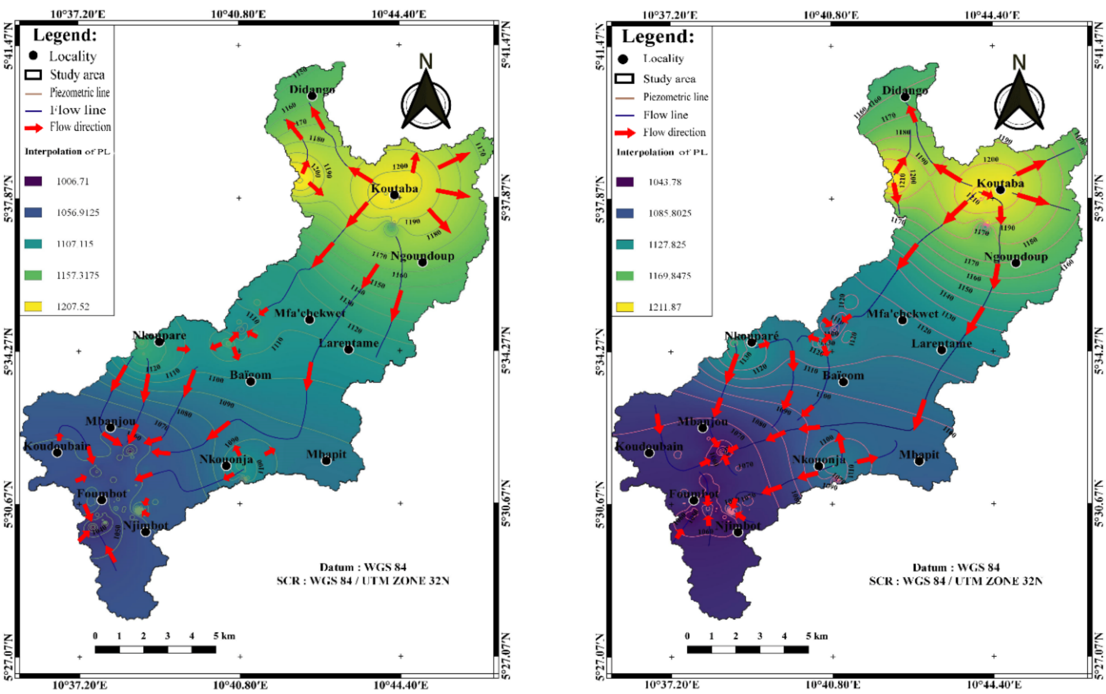


Figure 10. Piezometry and direction of groundwater flow in the Nkoup watershed (a) April and (b) September.

Author Contributions

Paul Bertrand TSOPKENG: Choice of theme and study area; constitution of the work team; direction of work; collection, processing and synthesis of data; consolidation of the final document; financing of all works. Josiane FEUGUE KENFACK: Collection and processing of climate data, field assistance. David Guimolaire NKOUATHIO: Advice and guidance on the choice of theme and site. Charles Antoine BASSEKA: Advice and assistance for data processing. Leonel KOUDJOU TSAGUE: Assistance for the production of certain thematic maps.

Conflict of Interest

The authors declare that they have no competing interests.

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Appendix

Appendix 1. Temperature in °C.

Month / Year	Jan.	Feb.	March	April	May	June	July	August	September	October	November	December	Average
2016	23	23.4	23.6	23.1	22.4	21.4	21.1	21.2	21.3	21.6	22.3	22.5	22.24
2017	22.8	23.4	23.6	23	22.3	21.3	20.9	21	21.1	21.5	22.2	22.4	22.13
2018	22.5	23.1	23.3	22.8	22.1	21.2	20.8	20.9	20.8	21.2	21.9	22	21.88
2019	22.8	23.2	23.5	22.9	22.2	21.3	21.2	21.1	21.2	21.6	22.2	22.5	22.14
2020	21.8	23.3	23.6	23.1	22.4	21.5	21.5	21	21.2	21.4	22	22.3	22.09
Average	22.58	23.28	23.52	22.98	22.28	21.34	21.1	21.04	21.12	21.46	22.12	22.34	22.1

Appendix 2. Precipitation (rainfall) in mm.

Month / Year	Jan.	Feb.	March	April	May	June	July	August	September	October	November	December	Average
2016	0	30.2	127.8	204.8	160.7	123.9	253.7	392.1	284	312.6	163.3	0	171.09
2017	0	6.5	90.3	141.1	137.1	144	266.8	216.1	281.6	279	62.9	0	135.45
2018	0	0	106.5	74.8	149.5	318.1	271.4	266.3	285.3	198.5	33.3	0	141.98
2019	3	0	50.4	187.6	212.2	199.3	266.5	344.4	450.7	227	71.2	0	167.69
2020	0	117	193.3	123	132.1	266.4	252.2	368.5	289.7	200.7	51.3	0	166.18
Average	0.6	30.74	113.66	146.26	158.32	210.34	262.12	317.48	318.26	243.56	76.4	0	156.48

Appendix 3. Altitudes of points and length of different portions of the Nkoup stream.

Points	S	A	B	C	D	M	F	G	H	O
Altitudes (m)	1224	1212	1172	1134	1120	1081	1059	1046	1045	980
Cumulated lengths mesured in the field (km)	0	5.4	8.4	11.9	18.4	22.6	27.2	31.5	33.2	36.9
Portions of the Nkoup stream	SA	AB	BC	CD	DM	MF	FG	GH	HO	
Length mesured on the map (cm)	9.8	5.4	6.4	11.7	7.6	8.3	7.7	3.2	6.7	
Length mesured in the field (km)	5.4	3.0	3.5	6.5	4.2	4.6	4.3	1.7	3.7	