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Research Article

Water Supply and Spring Discharges Assessment in the Foumban Locality, Western Highlands of Cameroon

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Abstract

Access to safe and sustainable water resources remains a major challenge in many sub-Saharan African urban centers, particularly in rapidly growing towns characterized by insufficient hydraulic infrastructure. This study investigates household water supply modes and evaluates spring productivity in the Foumban locality, situated in the Bamoun Plateau of the Western Highlands of Cameroon. It combines socio-economic surveys, hydrometric monitoring, geostatistical techniques, and multivariate statistical analyses to better understand the dependence of local populations on groundwater resources and the hydrodynamic behavior of springs in fractured basement aquifers. More than 500 households distributed across 13 localities were surveyed between 2014 and 2016 to assess water accessibility, consumption patterns, and socio-economic constraints related to water supply. In parallel, monthly discharge measurements were conducted on ten representative springs over one hydrological year using the volumetric gauging method. The results reveal that groundwater constitutes the principal source of domestic water supply in Foumban. During the dry season, 50% of households depend on springs, whereas 22.8%, 16%, 6.7%, and 4.5% rely respectively on CAMWATER, wells, boreholes, and rivers. In the rainy season, spring water remains dominant (39.7%), followed by CAMWATER (22.1%), wells (14.4%), rainwater (12.2%), boreholes (7.7%), and rivers (3.9%). Most households travel considerable distances to fetch water, reflecting the inadequacy of the public distribution network and the precarious socio-economic conditions of the population. Water-related diseases, notably typhoid and malaria, remain recurrent and are associated with the consumption of untreated water. Spring discharges vary significantly both spatially and temporally, ranging from 0.11 to 8.40 m^3/h, with the most productive springs generally located along major fracture. Spring discharge variations closely follow seasonal rainfall patterns, although delayed recharge responses indicate heterogeneous aquifer behavior. Principal Component Analysis, Hierarchical Cluster Analysis, and semi-variogram modeling reveal the coexistence of shallow weathered aquifers and deep fractured aquifers characterized by strong spatial heterogeneity. These findings provide valuable scientific information for sustainable groundwater management, urban water planning, and socio-economic development in Foumban and other basement regions of tropical Africa.

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Keywords

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1. Introduction

Water is a natural and essential resource for the vital needs of living beings. Access to this precious resource is a major challenge for the populations in developing countries in general and those situated in the south Saharan African part in particular [1-4]. According to the World Health Organization (WHO)/United Nations International Children's Emergency Fund (UNICEF) [5], 17% of the population in the world does not have access to safe drinking water and 42% does not have access to adequate sanitation. In this context, the sustainable management of water resources, the prediction of pollution risk and the protection of these resources as well as the control of the productivity of the groundwater and their protection become an urgent necessity. Indeed, the issue of access to water is always included in the various development agendas and programs both at the level of the United Nations' system and different countries. This is the case of international development instruments such as the Millennium Development Goals (MDGs) which expired in 2015. This project has been replaced by the Sustainable Development Goals (SDGs). The latter includes in its article six the equitable access of populations to basic social services such as water, hygiene and sanitation. As predicted by Rakotondrabe et al.; Mfonka et al.; Mfonka [1, 3, 6, 7], Cameroon's socio-economic development in recent years could affect water resources both qualitatively and quantitatively, due to global changes (climate variability and change, domestic and industrial pollution, artisanal and semi-mechanized mining exploitation, demographic boom, anarchic occupation of land...). Although the country has large quantities of water resources due to its geographical position, they are unevenly distributed between the North and the South, between the basement and sedimentary zones, and between the rural and urban areas [8, 9]. Similarly, its management is not controlled. In 1992, 20% of the population had access to drinking water [10]. This rate has risen to 26% in 2019 [11], an increase of only 6% in 27 years.

In Foumban (West-Region of Cameroon), the majority of households are not connected to the Cameroon Water's Utilities (CAMWATER) network. This situation is due to several factors, including: the poor extension of this distribution network, the high demographic pressure, the high cost of connection compared to the purchasing power of households, the lack of maintenance of the distribution system with a lot of loss of water resources, and the aging infrastructure. Faced with this dismal situation, the population is turning to natural water resources, such as wells, springs, boreholes and rivers of which neither the quality nor the quantity let alone the productivity is really known [1-3].

Several studies have been conducted in hydrology, hydrogeology, hydrogeochemistry and hydrobiology in the Foumban locality and its surroundings [1-3, 12-14]. No studies have been performed on the real water needs of the population of the zone, as well as the productivity of groundwater hydro-systems. Hence this study aims to evaluate: the access modes of water and the productivity of the springs in Foumban town. It should also be noted that the absence of basic social services such as water seriously handicaps the socio-economic development of the area, especially in terms of tourism, even though it is considered the arts capital of Cameroon. For example, there is the imposing and majestic Bamoun kingdom incorporated as a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site, the great biennial Nguon Festival which is also in the process of being incorporated as a UNESCO World Heritage Site, the Bamoun Kings' Museum with its exceptional architecture and many other natural sites which are real points of attraction for tourists.

2. Materials and Methods

2.1. Study Area

2.1.1. Geographical Sitting, Climate, Geology and Hydrogeology

Foumban is located in the highlands of West Region of Cameroon, particularly in the Noun division (Figure 1). It belongs to the Bamoun plateau with altitudes varying between 1051 and 1225 m. There are peaks and valleys that are sometimes deep and can be likened to real escarpments [1]. The Foumban town is drained by the Nchi River with its main tributaries (Manoun, Mafongué, Melap etc). The climate is that of tropical humid with two contrasting seasons, a long rainy season of 9 months and a dry season of three months. The average inter-annual rainfall for the period 2004-2019 is 1934.5 mm; temperatures range from 20.3 to 23.1 with an average of 21.3°C (Figure 2).

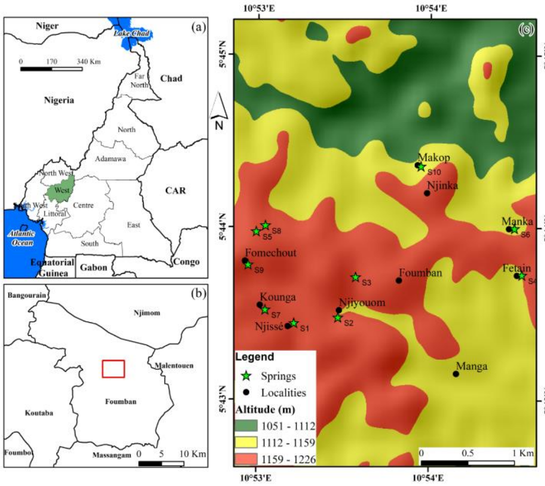

Figure 1. *Location of the study zone: (a) West Region of Cameroon with their bordering countries; (b) Foumban in the Noun division of the West region; (c) studied zone.*

As far as geology is concerned, Foumban, is located in the Cameroon Volcanic Line (CVL) and based on Precambrian crystalline-crystallophyllian bedrock. This substratum is made up of plutonic (anatexis and syntectonic granites) and/or metamorphic rocks (orthogneiss, mylonite, biotite and amphibole gneiss) on which volcanic outflows consisting mostly of plateau basalt (Figure 3) [15-17]. As far as the hydrogeology aspect is concerned, little work has been done there such as [1, 14]. [1, 2] focused on the hydrodynamic and vulnerability assessment of the sub-surface aquifers using DRASTIC and GOD models and geographic information system (GIS). [14] are assessing the hydrogeology potential of the zone using the GIS platform and multi-criteria analysis. That entire author's work emphasizes that this zone, like most basement environments in the humid tropical zone, is made up of two types of superposed and spatially discontinuous aquifers due to polyphase alteration, the morphology of the zone which is not uniform. There are subsurface aquifers with interstitial porosity found in the altered and isalteritic formations and fractured or fissured aquifers found in rocks with fracture porosity. These aquifers are exploited by the population for their water needs through wells, boreholes and springs, of which there are several in the locality.

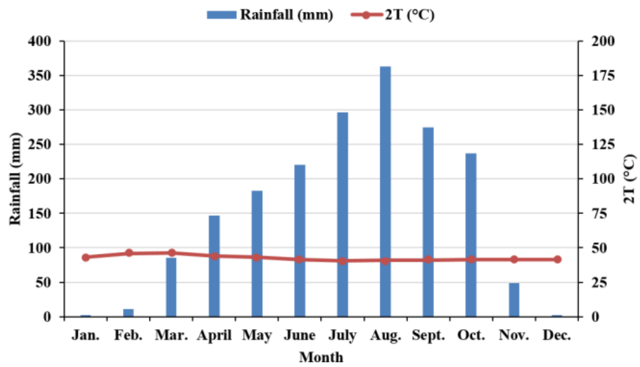

Figure 2. *Ombrothermal diagram of the Foumban city, based on the mean monthly variations of rainfall and air temperature for the period of 2004 to 2019.*

Figure 3. *Some geological formations in the study area: a, b, c= magmatic rock; d, e, f= metamorphic rocks.*

2.1.2. Population and Socio-Economic Activities

The Foumban locality has an estimated population of 83,522 inhabitants and a density of 123.8 inhabitants per km² [18]. Apart from a few state agents assigned to the locality, the economy is sustained by activities such as small-scale trade and especially handicrafts. There are almost no private, public or semi-public companies that provide jobs and wealth. This is at the origin of the precarious situation of the population whose means do not allow them to have easy access to basic social facilities.

2.2. Field Campaign

Several field campaigns were carried out between 2014 and 2016, ranging from the collection of different data, namely social surveys on water access modes, and measurements of spring discharge.

2.2.1. Household Surveys on Water Access Modes Conditions in the Study Area

a) Purpose, consistency and nature of the questionnaire designed

The survey was planned to identify the ways and means of accessing water in the town of Foumban and to understand the constraints associated with its daily management. So a list consisting of forty-one (41) questions divided into four axes was administered to the populations of the urban zone of the study area. These are questions related to 1) general household information (the size of the family; 2) the level of education of the head of the household, his occupation, etc.), availability criteria (different types of water supply sources in the area, places where households obtain water) (distance travelled to access the nearest water point; best time to collect water) 3) water for domestic needs, 4) those related respectively to accessibility and quality criteria (amount of water used for drinking and other household tasks; households' perceptions of the water quality intended for human consumption) water used in households as well as the impact of this water quality within households (socio-economic consequences of difficulties in accessing water in households; any problems with access to water in households in the study area). Regarding the form or nature of the questions, the choice was directed towards closed questions for this study, since these are important in more ways than one. Indeed, it consists in offering the respondent a choice of previously defined answers, which generally facilitates the interview and gives a good orientation to the interviewee on their answers. This technique also promotes the easy and fast processing of the information collected, to automate the analysis of the data as well.

b) Type of adopted survey

The type of survey chosen is sampling collection. The latter is carried out on a representative sample of the population, unlike the exhaustive type of survey, which is more precise since it is destined for the entire population. The sampling method adopted is bunch/cluster sampling [19]. It is adapted to large populations (over 5,000 inhabitants) and requires a map of the study area and knowledge of the size of the population for its implementation. During data collection, families were interviewed randomly while respecting the sampling step defined in relation to the size of the area, the distance between the water supply points and the living standards of the populations to be interviewed. Thus, among the 13 localities that make up the bulk of the urban perimeter of Foumban, averages of forty cards were administered in each of the 13 localities. A total of more than 500 households were interviewed.

A second social data base is the statistics on the recurrence of water-borne diseases (malaria, cholera, typhoid). These were obtained from the Foumban District Hospital, the largest hospital in the area. These are summary sheets of the tests carried out by this hospital during January, February, March, July and August, covering the dry and rainy periods.

2.2.2. Discharge Measurement of the Springs in the Study Site

Ten (10) springs whose geographical and environmental characteristics are presented in Table 1 and Figure 4 were identified in the urban perimeter of Foumban and were subject to hydrometric monitoring. These flow measurements were carried out at a monthly frequency from September 2015 to

August 2016, covering one hydrological year. The volumetric gauging method was highlighted. This method is well suited to measuring the flows of springs and small streams. It consists in placing at the outlet of the siphon, a graduated bucket of known capacity (V=5 l) and to evaluate thereafter the time of filling using a chronometer. The timer is started when the first drop of water falls to the bottom of the bucket and is immediately stopped when the water reaches the gauge line. The time taken to fill the bucket is then read. The same operation is repeated at least five times to reduce uncertainty. The flow rate is obtained using the following formula:

$$Q=V/t \quad (1)$$

With: Q = flow rate (liter/second or m^3/hour); V = bucket volume (liter or m^3); t = filling time (second or hour).

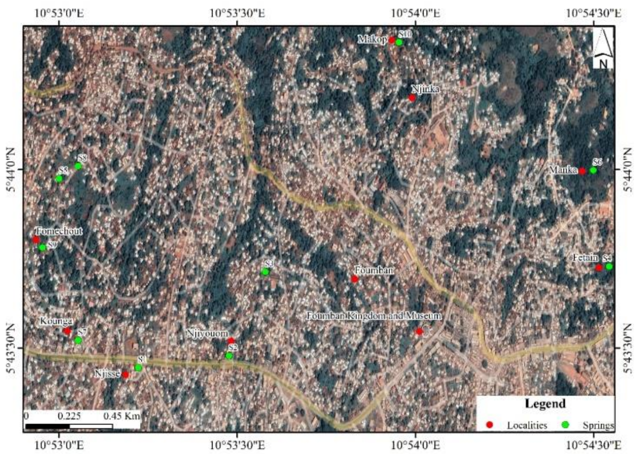

Figure 4. *Google image of the urbanized zone of the Foumban locality illustrating ten (10) springs.*

Table 1. *Location and characteristics of the spring environment in the Foumban locality .*

Locality	Springs	Longitude	Latitude	Altitude (m)	Description of the spring environment
Njissé	S1	E010°53′ 13.3″	N05°43′26,7″	1169	Fitted spring equipped with a siphon, located under a tree; presence of tree-lined and verdant vegetation.
Njiyouom	S2	E010°53′28,6″	N05°43′28,7″	1159	Fitted spring equipped with two siphons. There is and outcrop upstream of the spring and a nearby swamp.
Koukwuet	S3	E010°53′34,7″	N05°43′42,8″	1156	Fitted spring equipped with two siphons. There is a coffee plantation nearby. This spring is widely used by the population.
Fentain	S4	E010°54′32,6″	N05°43′43,7″	1140	Fitted spring equipped with a siphon. It is located behind the Kueka hospital. We note the presence of palm trees nearby.
Njindaré	S5	E010°53′00,0″	N05°43′58,5″	1143	Fitted spring equipped with a siphon situated behind the Technical High School. There are trees and latrines in the surroundings.
Manka	S6	E010°54′29,9″	N05°43′59,9″	1132	Fitted spring equipped with a siphon situated behind Beauregard Hotel. There are houses and latrines around. It is poorly maintained.
Fomchout	S7	E010°53′03,2″	N05°43′31,3″	1173	Fitted spring equipped with two siphons. Situated near the passenger station, facing the municipal lake and in the swamp. It utilized by almost all the populations of Foumban.
Njintout	S8	E010°53′03,2″	N05°44′00,6″	1182	Fitted spring equipped with a siphon. It is situated behind Ngapout Foundation. There are house and latrines around.
Kounga	S9	E010°52′57,2″	N05°43′46,9″	1176	Fitted spring equipped with a siphon situated behind the water tank of the Foumban city. There are nearby houses.
Makop	S10	E010°53′56,4″	N05°44′22.6″	1109	Fitted spring equipped with two siphons situated behind Brasserie of Foumban.

2.2.3. Data Treatment

a) Processing of Socio-Economic Survey Data

The survey data on access to water was processed by uni-variate statistical analysis, i.e. a simple flat sorting of the different variables of interest. This involves the statistical distribution of respondents according to the variables that appear to best describe the constraints and factors related to access to water in households.

To do this, two software packages were used: CSPRO (Census and Survey Processing System) for entering and building the database, and SPSS (Statistic Package for Social Sciences) for constructing the analysis files (clearing the database, recoding and building certain variables, producing Figures).

b) Processing of Hydrometric Data and Mapping

These data were digitized and processed using XLSTAT (multivariate statistical analysis), Surfer (variographic analysis) and Arcgis (production of some maps).

c) Multivariate statistical analysis

The spring discharge data were subjected to Multivariate Statistical Analyses (MSA) using the XLSTAT 2014 software, available at http://www.xlstat.com Principal Components Analysis (PCA) and Hierchical Clusterin Analysis (HCA) were used. Multivariate Statistical Analysis broadly refers to the various statistical techniques that can be used to analyze two or more variables simultaneously, and it is difficult to analyze multivariate data containing several variables [3, 20, 21]. PCA is a multivariate statistical technique that is used to reduce data and decipher patterns within large sets of data [6]. This method is widely used in hydrogeological studies. Data reduction is performed by transforming data to a new set of variables (principal components) that are derived from linear combinations of the original variables and classified in such a way that the first principal components (typically two or three) are responsible for most of the variation in the original dataset. As concern HCA, it is data classification technics, which are also used in geosciences. In HCA, objects are grouped such that similar objects fall into the same class. The levels of similarity at which observations are merged are used to construct a dendrogram [21, 22]. In this study, HCA was used to analyze the similarity between the springs from their discharge.

d) Semi-Variogram Model Analysis

The semi-variogram is a mathematical function used in geostatistics, in particular for kriging. Variographic analysis or structural analysis is the estimation and study of a variogram on a random variable.

The semi-variogram is obtained through the following equation:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i,j \in N(h)} (Zi - Zj)^2 \qquad (2)$$

Where:

N(h) is the number of observation pairs (i, j) separated by a spatial distance h.

The terms Zi and Zj are the attribute values of observations i and j respectively.

In fact, the function calculates the attribute difference between neighbouring data separated by a distance h to assess whether these observations have similar information. In geosciences, as in most disciplines, data are generally spatially correlated; this means that as the spatial distance between observations increases, the semi-variance is also likely to increase because spatially close observations are more likely to share similar features than distant observations [2, 23, 24]. There are three parameters of the semi-variogram to be analyzed. The nugget effect called C_0 which represents the small scale spatial variations and indicates how noisy the spatial structure is; the range which corresponds to the value obtained when the semi-variance reaches a certain threshold and stabilizes. The last parameter is the range which is the spatial distance from which the observations are no longer self-correlated. Whichever pair of points is examined at this level, the observations are too different and do not share a relationship between them.

3. Results and Discussions

3.1. General Characteristics of the Household Surveyed

These characteristics include: the size of each family, the level of education of the head of the household and his occupation. The questions related to educational attainment show that 41.00% of the heads of households surveyed have the primary level, while 41.4% have the secondary level. 10.9% have no level of schooling while 6.7% have reached the higher level (Figure 5a). Regarding the occupation of the head of household, 41% do not have a permanent job. Commercial activity is practiced by 19% of household heads, while agriculture, crafts, technical/small trades and civil service are the activities that occupy the rest of the respondents daily, i.e. less than 10% for each type of activity (Figure 5b). In view of these small trades practiced by the heads of households, it is extremely difficult to be able to connect to the CAMWATER water supply system and pay the monthly bills and other services (maintenance). The prevalence of these activities of heads of households who are more or less precarious are indeed an indicator of poverty and low standard of living, especially in a generalized context of high cost of living marked by dizzying increases in the prices of consumer products. As they do not have sufficient financial resources, they cannot invest in connecting their respective families to the company in charge of distributing water to the populations. Most of the income is therefore directed towards expenditure deemed essential such as nutrition and health. With regard to the size of the households, the families of more than ten heads represent approximately 20%, against 30.4 and 49.4% respectively for families whose number of people is between [1-5] and [6-10]. As for the number of children under 5, these are found in 73% of households (Figure 5c). These numbers within households in the city of Foumban contrast on the one hand with the income of the head of the family who has several financial commitments, namely: schooling of children, family nutrition, health coverage and many others vital needs within families.

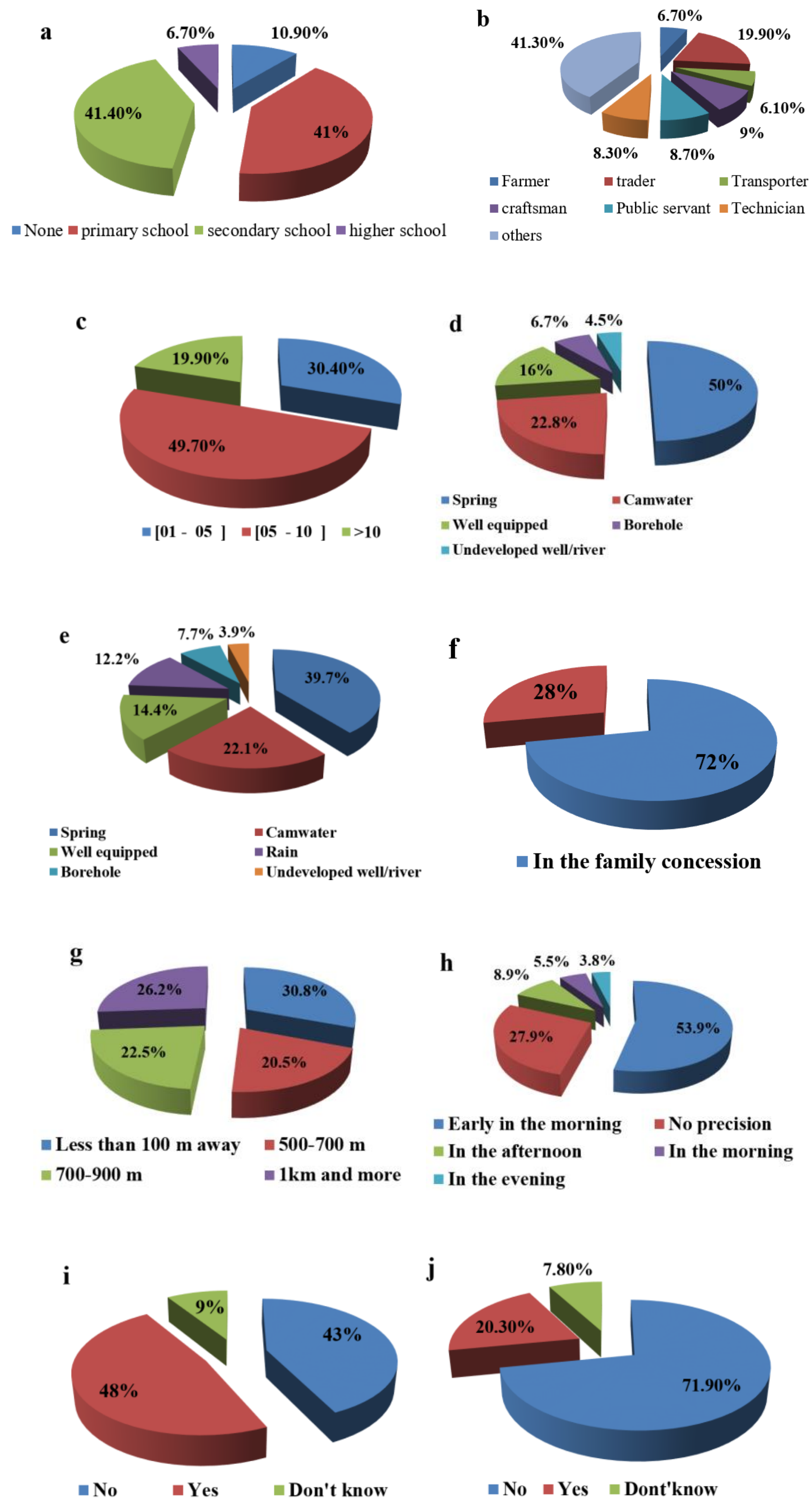

Figure 5. (a) Statistic data relating to the instruction level of the parents in the households; (b Statistic data relating to the parent economic activities; (c) Statistic data relating to the households size; (d) Distribution of the households surveyed in% according to the main source of drinking water supply in the dry season; (e); Distribution of the households surveyed in% according to the main source of drinking water supply in the rainy season; (f) Statistical data on water supply locations within households; (g) Statistical data on the distance between the concession and the nearest water supply point; (h) Statistical data relating to the best moments for the supply of drinking water to households (i) statistical data on the question relating to the need for treatment of water intended for drinking; (j) statistical data relating to paramount necessity to treat water before consumption.

3.2. Water Supply in the Foumban Locality

Three and four water resources types are heavily used by households for multiple purposes respectively in the dry and rainy season. These are, in decreasing order: groundwater (springs, wells and boreholes), surface water (rivers used directly by households), Water from CAMWATER network and rainy water. Statistically, on the one hand, it appears that in the dry season, 50% of households get their water from springs, 22.8% use water from CAMWATER, while 16%, 6.7% and 4.5% use water from constructed wells, boreholes and undeveloped wells/rivers respectively (Figure 5d). In the rainy season, on the other hand, 39.7% use spring water, 22.1% use the CAMWATER network, 14.4% use water from wells, 12.2% use rainy water, 7.7% use boreholes and 3.9% of the population surveyed use undeveloped wells/rivers (Figure 5e). These results on the different sources of drinking water supply and other domestic uses by the population in the study zone are related to those presented by [25] as alternative water supply point (springs, boreholes, wells) used for drinking purpose and other services in the Dschang locality, Western-Cameroon. This is linked to the CAMWATER network which is limited and does not provide access to water for large number of population.

In terms of the location of water supply point, 72% of households obtain their water away from their compounds, compared with 28% who obtain it from within the family concession; this may be a well, a borehole or a CAMWATER network (Figure 5f). 26% of households walk around 1,000 m (1km), 43% walk between 500-900 m, while the rest (30.8%) walk less than 500 m (Figure 5g).

In view of the high demand for the same water point by several families, 55% of households prefer to collect water very early in the morning, while 30% do not give any details on this question. Four, five and 9% of households draw the water in the evening, late morning and afternoon respectively (Figure 5h). The choice of the morning and afternoon is linked to the fact that these are the times when children, most of whom are pupils or students, have to go to school. They therefore have to carry out these tasks either before leaving for school or in the evening after returning home.

To the questions relating to the need for water treatment before consumption, 48% answered in the affirmative, 43% said they did not find it necessary because the water they consume (springs) is of good quality, while 9% said they did not know (Figure 5i). 71.9% of households stated that the water available to them does not meet potability standards, compared with 20.3% who said the opposite and 7.8% with mixed views (Figure 5j). Similarly, 28% of households attributed the recurrence of illnesses within the family to the poor quality of the water consumed, compared to 72% who said the opposite.

Statistical data on water quality coupled with health problems mirror those of malaria and typhoid tests obtained at the Foumban District Hospital (Figure 6). The pathological tests obtained over a five-month period covering the dry and rainy seasons show a high proportion of typhoid cases compared to malaria. These diseases have higher prevalence rates in the rainy season than in the dry period (February, March). It should be remembered that not all patients who test positive necessarily get the disease.

In terms of volume, the quantity of water used for drinking varies from one family to another. It varies between 2 and 45 ± 8 l/d, with an average of 11 l/d (Table 2). The amount of water used for other domestic tasks ranges from 20 to 500 ± 137 l/d, with an average of 144 l/d. These volumes of water are a function of the household size and of the standard of living.

Table 2. Description of the water used per day in the households of the Foumban urban area.

Daily water consumption (liter)	Min	Max	Mean	SD
Water for drinking	2	45	11,40	8,143
Water for other domestic work	20	500	144,35	137,142

3.2. Socio-economic Impacts Related to Difficulties in Accessing Water in Households in the Town of Foumban

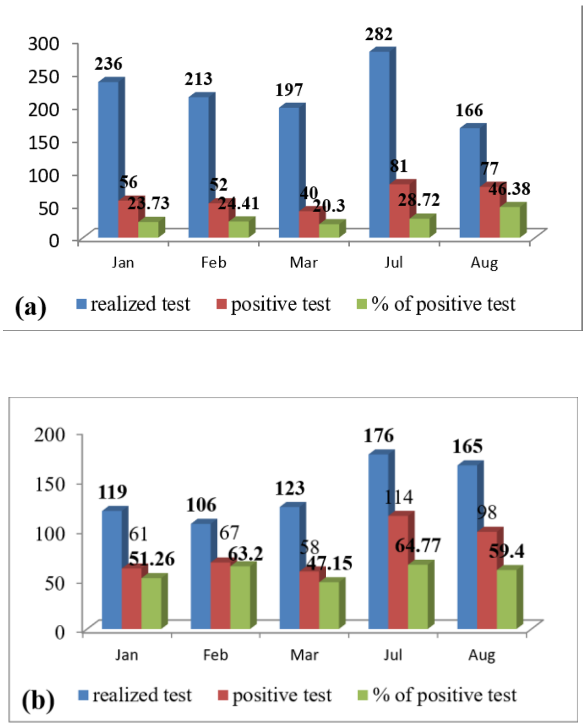

Figure 6. Water-related pathology statistics test at Foumban district hospital (a) malaria; (b) typhoid.

On the social level, there is a high percentage of school dropouts, especially among young girls who have to help their mothers in household tasks. From a health point of view, there are many water-related diseases such as typhoid, amoebic dysentery, cholera, which sometimes leads to epidemics, and other gastroenteritis. The statistics on water-related diseases at Foumban District Hospital for the period covering the dry and rainy seasons presented in Figure 6 is a perfect illustration. It should be remembered that not all patients who have tested positive necessarily become ill. In terms of expenditure on health problems within families, this ranges from 20,000 to over 40,000 CFA/month, which is exorbitant for low-income families.

At the economic level, heads of families lose a lot of money through the numerous hospitalizations of pregnant women and children, not to mention the many cases of death that also weaken families in financial terms.

In view of these results on the access modes to water, it is clear that groundwater and in particular springs are heavily used. The question that arises is that of the productivity of this water.

3.3. Order of Magnitude of the Flow Rates of the Studied Springs

Statistical data on flow rates are presented in Table 3. Overall, these flows vary between 0.11 m^3/h (S10) and 8.4 m^3/h (S7). The most productive springs are S1, S7 and S8 with flows ranging from 3 to 8 m^3/h. The annual volumes of water flowing from these springs reach 34,339.2 m^3/year (S7); this shows that these resources play a considerable role in reducing the problems of access to water, especially for populations with low purchasing power. These flows are almost of the same order of magnitude as those of the springs in the city of Yaoundé in the same bedrock environment, which have been studied by several authors [26-32] (Table 4).

Table 3. *Springs discharge satistics (m^3/h) in the Foumban locality.*

Spring	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Min	Max	Mean	Med	SD	V/day	V/Annual
S1	0.46	0.45	1.76	1.78	2	2.55	3.56	3.6	4.67	4.35	3.94	3.57	0.45	4.67	2.72	3.06	1.44	65.28	23827.2
S2	0.41	0.38	0.45	0.43	0.54	0.9	1.16	1.45	1.5	1.8	2.09	2.29	0.38	2.29	1.12	1.03	0.70	26.88	9811.2
S3	1.06	0.52	0.36	0.4	0.54	0.72	1.47	2.4	1.94	2.1	2.29	1.84	0.36	2.4	1.3	1.27	0.79	31.2	11388
S4	0.35	0.34	0.17	0.12	0.2	0.23	0.26	2.86	1.66	1.8	1.64	1.16	0.12	2.86	0.9	0.35	0.90	21.6	7884
S5	0.48	0.44	0.42	0.4	0.39	0.67	0.72	0.79	0.84	1.15	1.49	1.5	0.39	1.5	0.78	0.70	0.41	18.72	6832.8
S6	0.44	0.36	0.27	0.26	0.22	0.26	0.32	0.72	0.7	1.05	1.26	1.14	0.22	1.26	0.58	0.40	0.38	13.92	5080.8
S7	0.86	0.84	0.79	0.8	0.67	1.8	3.56	7.2	7	7.41	8.4	7.77	0.67	8.4	3.92	2.68	3.32	94.08	34339.2
S8	1.29	0.74	0.48	0.54	1.45	1.92	2.24	3.6	2.8	3.58	4.2	3.8	0.48	4.2	2.22	2.08	1.35	53.28	19447.2
S9	0.46	0.77	0.49	0.44	0.41	0.73	1.48	3.6	2.52	2.68	2.8	2.76	0.41	3.6	1.6	1.13	1.19	38.4	14016
S10	0.36	0.35	0.27	0.13	0.1	0.16	0.29	1.08	2.29	2.32	2.34	1.81	0.11	2.34	0.96	0.36	0.95	23.04	8409.6

Legend: Min (minimum), Max (maximum), Av (Average), Med (median); SD (Standard deviation); V (Volume)

Table 4. *Comparison between the springs flow rate of the Foumban locality and those of other basement environment milieu in Cameroon.*

Autors	Site	Locality	Discharge (l/s)	Discharge m3/h	Period
[26] Kalla Mpacko	Ntem basin	Centre Region of Cameroon	0.1 to 0.87	0.36 to 3.13	2007
[27] Kuaté Deffo	Biyémé basin		0.04 to 0.75	0.144 to 2.70	2008
[28] Ewodo Mboudou	Mingosso basin		0.06 to 1.20	0.216 to 4.32	2012
[28] Ewodo Mboudou	Abiergué basin		0.04 to 6	0.144 to 21.60	2012
[29] Ngouh	Nkié basin		0.06 to 0.86	0.21 to 3.09	2012
[30] Tabué Youmbi	Mingoa		0.06 to 0.70	0.216 to 2.52	2013

Autors	Site	Locality	Discharge (l/s)	Discharge m3/h	Period
[31] Ntep et al.	Biyémé basin		0.1 to 0.9	0.36 to 3.24	2014
[32] Bon	Olézoa basin		0.01 to 0.88	0.036 to 3.16	2016
Present study	Foumban locality	West-Region of Cameroon	0.0128 to 2.333	0.046 to 8.40	2016

3.4. Spatial and Temporal Variations in the Flow Rates of Springs in the Foumban Locality

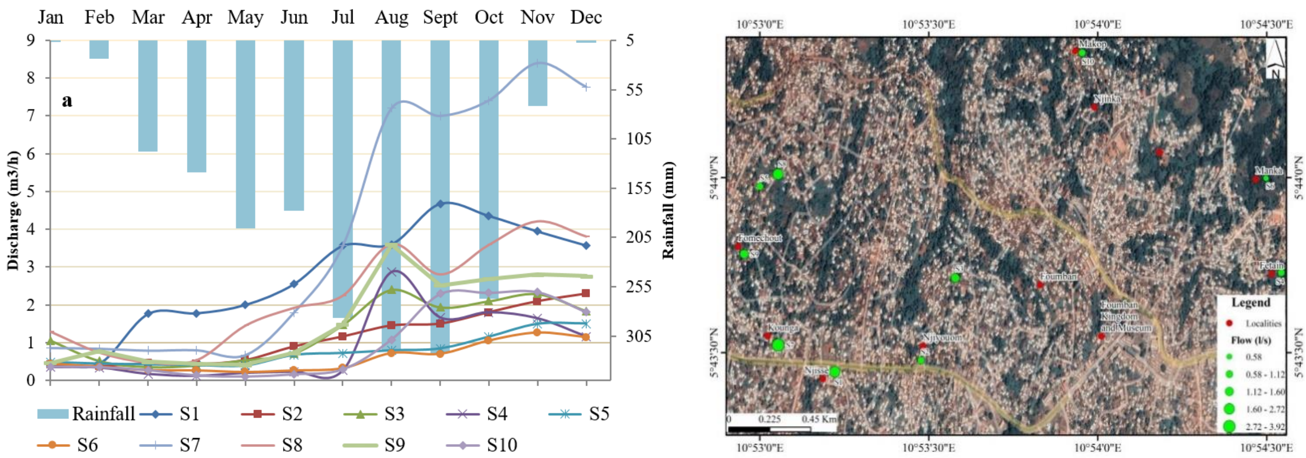

Figure 7. (a) Temporal (a) and spatial (b) variations of spring discharge in the study area.

Figure 7a shows the temporal variations of the flows rate vs rainfall. It can be seen that: 1) the variation in flow rates clearly follows the rainfall cycle in the area. The lowest flows are observed in the dry season (January, February, March) while the highest flows are recorded in the rainy season (August, September, October, November). The peak flows are observed in August (S4, S3), September (S1), November (S6, S7, S8) and December (S2); 2) in some springs, there is a certain delay between the start of the rainy season and the increase in flow, and the same is true between the end of the rainy season and the decrease in flow (discharge of the water table). These delays are linked to several factors, particularly: the nature and depth of the aquifer (sandy-clay) on which depend the phenomena of recharge and discharge of the water table, of which these springs are the outlets, the topography (very steep area) which favors the process of run-off rather than infiltration, the fissured state and the varied direction of the drainage axes; 3) certain springs (S1, S7 and S8) react fairly quickly to rainfall events. These springs would be the outlets of the generally shallow weathering aquifers. Other springs react quite slowly (S2, S3, S4, S5, S6, S7, S9 and S10). These springs are thought to drain deep fracture aquifers or deep porous aquifers.

Spatially, the average flows have been divided into five classes for better readability (Figure 7b). Class 1 with flow rates between 2.72 and 3.92 includes springs S1 and S7, the second group includes springs S8 and S9 with flow rates between 1.6 and 2.72, the third group with flow rates between 1.12 and 1.60 includes springs S2 and S3, the fourth group includes springs S4, S5, S10 and finally the group of springs with flow rates approximately equal to 0.58 includes spring S6. The variations in the flow rates of the springs in the Foumban locality would be strongly influenced by fractures in the bedrock obliterated by the clay minerals. Similarly, the springs with the highest flow rates (S1, S7, S8 and S9) would be located on the main drainage axes corresponding to the main fracture lines.

3.5. Relation Discharge vs Topography

Figure 8a shows a close relationship between topography and flows. Indeed, the highest flows are observed at high altitudes particularly in the plateau zone (S1, S7, S8, S9), while low flows are found in the lower altitude areas. These results are supported by the correlation line (Figure 8b) which shows the average flows as a function of topography. It gives an average correlation, with r equal to 0.64, (r^2=0.45). This correlation is roughly equal to that obtained by Bon [32] in the Olézoa sub-catchment (0.6). It is much higher than that obtained by Ngouh [29] (2012) in the Nkié sub-catchment (-0.17) which are all nested sub-catchments of the Mfoundi in the city of Yaoundé. These multiple values of the correlation coefficient in the same basement environments. They nevertheless show that there would be an evolutionary trend between flows and spring elevations. According to Parriaux and Bussard [33] this evolutionary trend between spring flows and topography would reflect the influence of the latter on groundwater flow, particularly for thin aquifers.

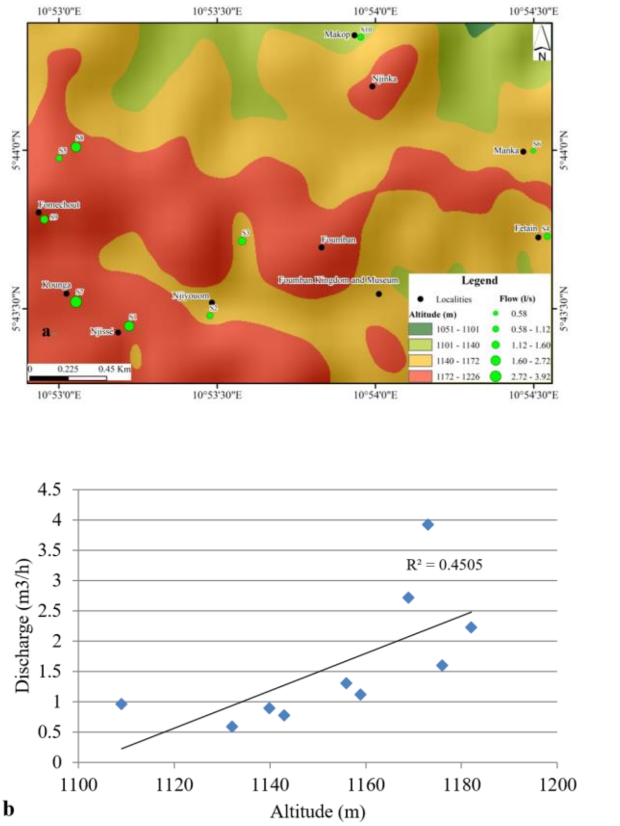

Figure 8. (a) Map presenting the relation between topography and spring discharge (b) correlation curve between topography and spring discharge.

3.6. Multivariate Statistical Analysis Result

To better understand the productivity of these springs in these rather complex fractured basement environments, multivariate statistical analysis was also highlighted through principal component analysis and hierarchical clustering analysis.

3.6.1. Principal Component Analysis Result

Figure 9a highlights the results of the principal component analysis. Two major factors are derived from this analysis, namely factors F1 and F2, which account for 69.65% and 17.84% respectively, i.e. a total of 87.49% of the variables expressed. Four groupings emerged from this analysis:

1) The first one in which we find most of the sources, notably S2, S3, S4, S5, S6, S10. The latter are characterized by a standard deviation that varies very little: S1 (1.44), S2 (0.70), S3 (0.79), S4 (0.90), S5 (0.41), S6 (0.0.38), S10 (0.95).
2) The sources S8 and S9 which constitute the second grouping with SDs equal to 1.35 and 1.19 respectively;
3) The other two groupings highlighting S1 and S7 have SDs equal to 1.44 and 3.32 respectively.

This disparity between the SD values shows that the flow values are highly variable in time and space. Therefore, not all of these springs would be outlets of a single aquifer type. Some would be outlets of fracture aquifers while others could be outlets of sub-surface aquifers. Similarly, some springs are outlets of deep aquifers while others are outlets of shallow aquifers.

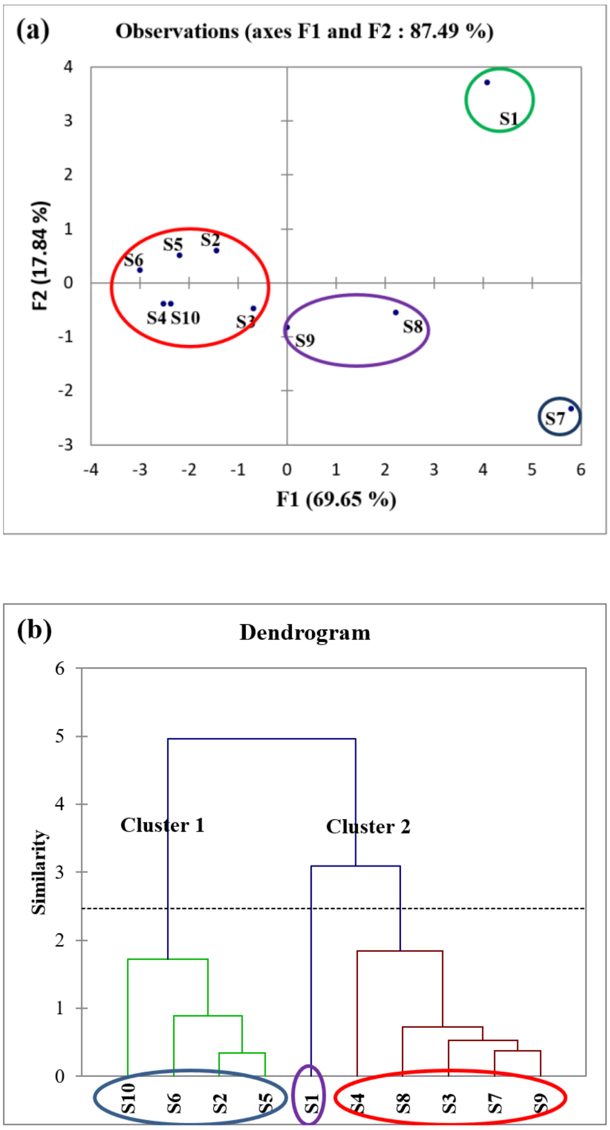

Figure 9. (a) Principal Component Analysis (PCA) for sampling points (b) Dendrogram of Hierarchical Cluster Analysis, based on monitoring sites.

3.6.2. Hierarchical Clustering Analysis Result

The hierarchical clustering analysis results are presented in Figure 9b. Two major clusters emerge. The first one in which we find S2, S5, S6, S10, the second cluster which is subdivided in two, the first one being only composed of S1 and the other one in which we find S3, S4, S7, S8, S9.

3.7. Semi-variographic Results

Figure 10 shows the semi-variograms model obtained from the average and November flow rates for the ten monitored points. The sill is 1.1 m^3/h and 0.11 m^3/h for the average and the November data flows respectively. The range is 180 and 300 m for the average and November flow rate. These two parameters provided by the variographic models describe respectively the value obtained when the semi-variance reaches a so-called "plateau" and stabilises and the spatial distance from which the observations (spring flows in this case) are no longer self-correlated. This discrepancy between these two parameters highlights the complexity of the functioning of the aquifer systems in basement areas in general and the productivity of springs in these environments in particular. These results provided by the principal component analysis, the hierarchical clustering analysis and the semi-variographic models highlight the heterogeneous character of the aquifers of which these springs are the outlets, as well as the nature of the aquifer rock and the thickness of the vadose zone of the study zone.

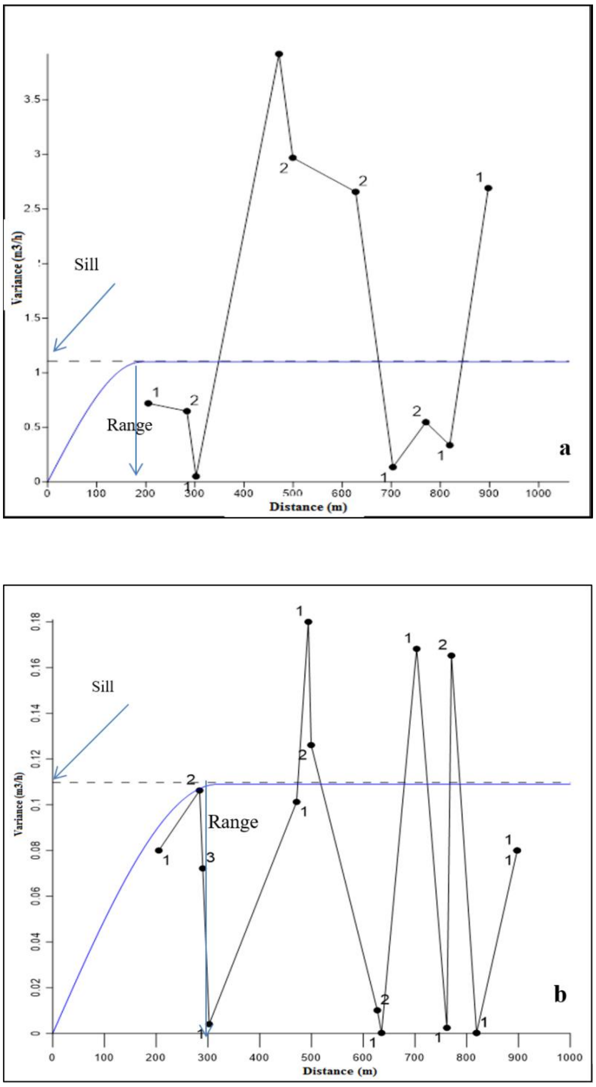

Figure 10*. Semi-Variograms model obtained from spring discharge data in the Foumban (a) mean annual data (b) data of November month.*

4. Conclusion

The Foumban locality (West Cameroon), like a good number of African towns in the south of the Sahara is faced with difficulties in accessing basic social services, including drinking water. In view of their precariousness, the populations resort to groundwater for their supply. The objectives of this study were to evaluate the access modes to water in the town of Foumban as well as the productivity of the springs in this area. A multidisciplinary methodology integrating socio-economic surveys, monthly monitoring of spring flows and multiple data processing techniques (uni and multi-variate statistical analyses, semi-variogram tests) allowed the following results to be obtained.

For the daily drinking water needs of households, four types of resources are used in the rainy season, namely groundwater (54.1%), rainwater (12.2%), CAMWATER (22.1%) and surface water (3.9%). In the dry season, the population uses groundwater (66%), CAMWATER network (22.8%) and surface water (4.5%). This implies that, there is a high demand for spring water respectively of 39.7% and 50% in the dry and rainy seasons. This high demand is mainly explained by the high level of poverty among the population. There is also a high frequency of water-related diseases throughout the year, as shown by the statistical results obtained in the hospital of the locality. The large numbers within households, the low incomes of heads of household, to which must be added the difficult national economic context, the latter being materialized by the generalized increases in the prices of consumer goods, therefore constraining households to the use of resources in alternative waters (groundwater and rain). The little income is much more spent on children's schooling, family nutrition, health coverage and many other vital needs.

In terms of the productivity of the springs, the flow rates vary between 0.58 and 8.4 m^3/h. The springs with high flow rates are observed in the high altitude zones (S1, S7, S8), in contrast to the springs with low flow rates. Similarly, the productivity of these springs is a function of rainfall, with peaks obtained in August, September, October and November, depending on the case. The particularities observed in the productivity of the springs in the town of Foumban (delays or anticipations in the recharge and discharge, spatio-temporal variation of the flows) are linked to the characteristics of the natural environment, notably the permeability, the depth of the vadose zone, the topography, the texture of the soil through which the infiltration water passes, etc. Semi-variographic models, statistical tests through PCA and HCA show that these springs are outlets of two types of discontinuous and heterogeneous aquifers found in the locality, namely sub-surface aquifers and fracture aquifers. These results on the constraints related to access to water and the productivity of springs in a basement environment where the aquifers are extremely complex constitute an important database for the efficient management of water resources in the town of Foumban in a context of deficient hydraulicity.

Abbreviations

WHO	World Health Organization
UNICEF	United Nations International Children's Emergency Fund
MDGs	Millennium Development Goals
SDGs	Sustainable Development Goals
CAMWATER	Cameroon Water's Utilities
UNESCO	United Nations Educational, Scientific and Cultural Organization
CVL	Cameroon Volcanic Line
GIS	Geographic Information System
PCA	Principal Component Analysis
HCA	Hierarchical Cluster Analysis

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Mvondo Owono François: Writing – review & editing

Etame Jacques: Supervision, Validation, Visualization

Ndjigui Paul-Desire: Supervision, Validation, Visualization

Ndam Ngoupayou Jule Remy: Supervision, Validation, Visualization

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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