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Research article

Application of analytical hierarchy process to assess groundwater potential for a sustainable management in the Menoua Division

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A R T I C L E I N F O

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A B S T R A C T

Number of wells drilled by private and public stakeholders, as well as nongovernmental organizations in the Menoua Division are unproductive. This is due to the lack of preliminary surveys assessing groundwater potential (GWP). A combined remote sensing (RS) and analytical hierarchy process (AHP) approach handled on a geographic information system (GIS) environment is efficient for such an investigation. For this article, seven environmental parameters, with significant contribution to groundwater occurrence, are integrated. Those parameters are drainage density, elevation, lineament density, land use/land cover (LULC), rainfall, slope, and topographic wetness index (TWI). RS and GIS techniques said to be quick and simple for exploring GWP whatever the geological settings, have the advantage of investigating large areas with little financial resources. Although these techniques are widely used in the world, this is the first time they are applied in the Menoua Division. The outcome, which is a sound GWP map, has been sorted into five zones: very low potential for 13 %, low potential for 27 %, medium potential also for 27 %, high potential for 23 %, and very high potential for 11 % of the Menoua Division. This may help to reduce the rate of noncompliant hydrogeophysical surveys and the number of unproductive boreholes by converging hydrogeophysical surveys on high GWP sites.

1. Introduction

Nowadays, in industrialized countries, the main tasks concerning the sector of water resource management are about wastewater reuse, water efficiency, and water productivity. Yet, in developing countries, scientists are still conducting surveys on groundwater exploration and its sustainable exploitation] [1,2]]. Unfortunately, a blind and random exploration such as currently conducted in those developing countries requires important financial resources. Indeed, without a clear demarcation of areas with high GWP, the expensive hydrogeophysical surveys generally lead to non-compliant results because they are conducted on inadequate sites] [3,4]]. Consequently, one witnesses an important number of unproductive wells, wells with low yield, wells with temporary productivity, and seasonal wells [5]. This is the situation observed in Cameroon and especially in the Menoua Division which is the study area. In this

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Nomenclature

AHP	Analytical Hierarchy Process
CR	Consistency Ratio
DD	Drainage Density
DEM	Digital Elevation Model
GIS	Geographic Information System
GPI	Groundwater Potential Index
GWP	Groundwater Potential
LD	Lineament Density
LULC	Land Use/Land Cover
MCA	Multi-Criteria Analysis
RI	Random Consistency Index
RS	Remote Sensing
TRI	Topographic Ruggedness Index
TWI	Topographic Wetness Index
UTM	Universal Transverse Mercator
WGS	World Geodetic System
ROC	Receiver Operating Characteristic

region, private and public stakeholders, as well as non-governmental organizations, have been drilling wells for schools, health centres, households, and other public services. However, the lack of aforementioned preliminary investigations causes numerous unproductive wells. Several wells are temporarily productive and then, dry up definitively or seasonally [4]. Hitherto, RS is a substitute effective and affordable tool to evaluate GWP before implementing any exploration project] [2,6–10]]. This article aims to delineate GWP zones in the Menoua Division from satellite data using the AHP technique on ArcGIS.

GWP can be delineated using an approach which combines RS, multicriteria analysis (MCA), and GIS. This approach is effective (quick and simple) for GWP assessment regardless of the geological settings, and is widely used around the world. Dinesh Kumar et al. [11] carried out the combination of RS and GIS to delineate the GWP zones of the Muvattupuzha River basin in India and the results showed that about a half of the area investigated is classified as good or very good. By using a joint GIS-fuzzy algebraic model, Jesiya and Gopinath [12] addressed the response of hydrogeological parameters to the reduction of contaminants in the surface and subsurface hydrological regime in India. The results depicted that 71 % of urban and 22 % of peri-urban areas in the region investigated are vulnerable. Subsequently, they applied the multicriteria decision-making in a geospatial framework to evaluate the GWP of the region. It was found that 10 % of the peri-urban and 34 % of the urban areas have high potential in groundwater. Geophysical techniques and geospatial technology were combined to assess and delineate GWP zones in Dehradun [7]. AHP was combined with GIS to demarcate GWP zones in Edirne-Kalkansogut [13]. Biwas et al. [14] combined AHP, RS, and statistical techniques in a GIS environment to delineate the GWP zone in the Bankura district. From this approach, the authors classified the study area into five categories: very good (13.36 %), good (33.80 %), moderate (21.05 %), poor (19.02 %), and very poor (12.77 %) condition. The GWP was evaluated in South India by Bhadran et al. [15] using a joint GIS-AHP approach. In the aforementioned studies, the AHP techniques led to comprehensive results. In comparison with machine learning, this approach has the advantage of minimizing risk when solving complex problems in a broad spectrum of domains [15].

Unlike geophysical technologies which are expensive and time-consuming, the combined GIS-RS approach is valued in low-income countries to explore groundwater. Indeed, this approach is able to quickly investigate very huge zones with a moderate budget [16]. A suitable analysis of several environmental parameters, namely lineament density, slope, LULC, TWI, drainage density and rainfall using AHP on ArcGIS, enables demarcating GWP zones] [8,9]]. This processing may lead to a comprehensive map of areas where to concentrate hydrogeophysical prospections. Such an output is of paramount importance for stakeholders, planners, municipal authorities, and decision-makers. The main purpose of this article is to use AHP to delineate GWP zones of the Menoua Division for the sustainable management of (ground)water resources. For this, seven layers (drainage density, elevation, lineament density, LULC, rainfall, slope, and TWI) are selected. Although this research is not quite innovative, this article is the pioneer scientific contribution combining AHP, GIS, and RS to the sustainable management of groundwater resources in the Menoua Division. The key results will support stakeholders, planners, municipal authorities, and decision-makers in their action plans by supplying them with useful thematic maps identifying suitable sites where to concentrate hydrogeophysical investigations in groundwater projects.

2. Material and methods

2.1. A brief description of the Menoua Division

Menoua is one of the 58 administrative divisions that make up the Republic of Cameroon. It is located between longitudes 9°50′–10°20′ E and latitudes 5°10′–5°36′ N in the West Region. Its capital city is Dschang, which is also the former capital city of the Bamileke Region (Fig. 1). The Menoua Division is situated at 350 km northwest of the administrative capital Yaounde and at 213 km north of the business capital Douala, with an average altitude of 1300 m. With its 6 cities, MD has a total population of ~300,000 inhabitants with a density of 220 inhab/km^2. The Menoua Division is characterized by highlands (2000–2740 m) in the northern part, lowlands (705–1000 m) in the southern part and a plateau (1300–1500 m) in the central part. The region is also characterized by an important drainage network (Fig. 1).

The predominant climate in the region is the humid tropical climate of the Cameroonian type, characterized by one dry season from November to March and one rainy season from April to October, with a mean yearly rainfall of 1364 mm. The pluviometry peak is observed in August and September. The mean annual temperature is 22.5 °C [17].

The Menoua Division is characterized by fault-bounded horsts and grabens mainly oriented in N30^o E. A set of volcanic massifs such as mounts Cameroon, Bambouto, Rumpi, and Manengouba are observed in the region. The basement rocks consist of Neoproterozoic gneisses, granitoids intruded in granite-gneisses, and dykes cropping out in the two aforementioned units [17].

2.2. Key environmental factors involved in groundwater occurrence and their processing

Groundwater mainly occurs from vertical and horizontal infiltration of surface water. Hence, GWP on a site generally depends on two phenomena: surface water infiltration or recharge which is controlled by rainfall and LULC, and storage which is controlled by soil characteristics, geology, landform, topographic witness index (TWI), drainage density, and lineament density] [2,16,18]]. The aforementioned parameters, mainly derived from satellite data presented in Table 1, are those involved in the groundwater occurrence and are essential for groundwater modelling.

In this article, seven thematic layers were produced, processed, and integrated on ArcGIS to delineate the GWP map of the Menoua Division. Those thematic layers are drainage density, elevation, lineament density, LULC, rainfall, slope, and TWI shown in Figs. 2–8.

In this study, lineament density is ranked as the first contributing factor to the groundwater occurrence with a normalized weight of

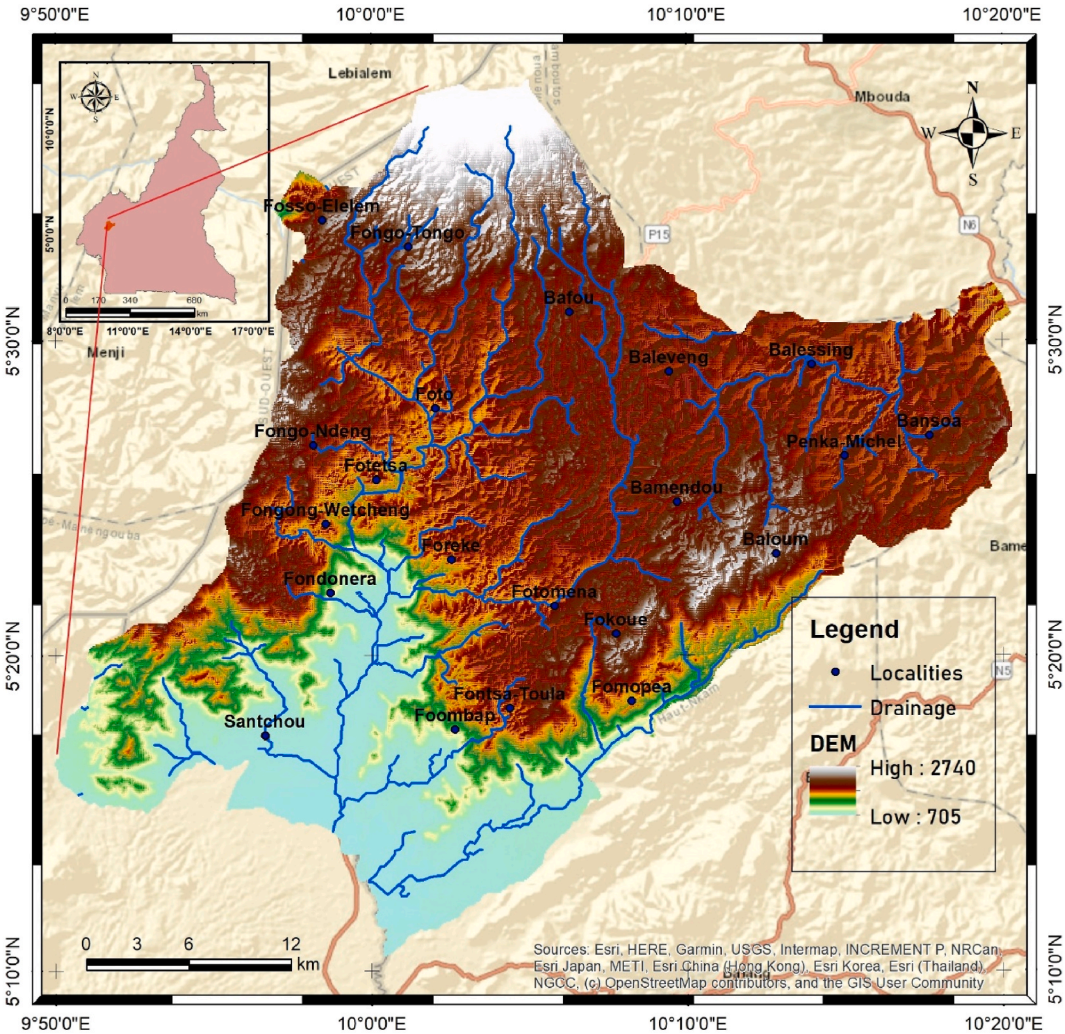

Fig. 1. The Menoua Division presented by its drainage network overlain on the elevation map.

Table 1
Description of the data used in this study.

Landsat OLI						
Date	Path/row	Sun elevation	Sun azimuth	Cloud cover	Sensor quality	Resolution
February 12, 2023	186/56	51.61	133.48	4.49	9	30 m
ALOS PALSAR 2						
Date	Polarization	Nadir angle (°)		Process level		Resolution
December 08, 2020	HH/HV	28.6		1.1		12.5 m

0.39. Its spatial distribution is classified into five categories.

Slope values range from 0 to 47° with a flat terrain in the southern part of the study area.

Rainfall is the third criterion with a normalized weight of 0.13. This parameter is the primary source of the vertical infiltration of surface water. It stands as a principal contributing factor to groundwater formation. However, the efficiency of its contribution strongly depends on the geological setting and LULC pattern. GWP is proportional to rainfall [17].

There are five main classes of land cover in the Menoua Division: vegetation, rangeland, built area, cropland and water body.

Those figures were displayed using ArcGIS 10.8. The resulting vectors were converted into polygons.

There is no underground river. All groundwater results from the horizontal (from rivers) or vertical (from rainfall) infiltration of surface water. The seven parameters selected for this study play a decisive role. Rainfall is the main source of surface water that infiltrates vertically. The effective amount of infiltrated water is proportional to the intensity of the rainfall. However, this surface

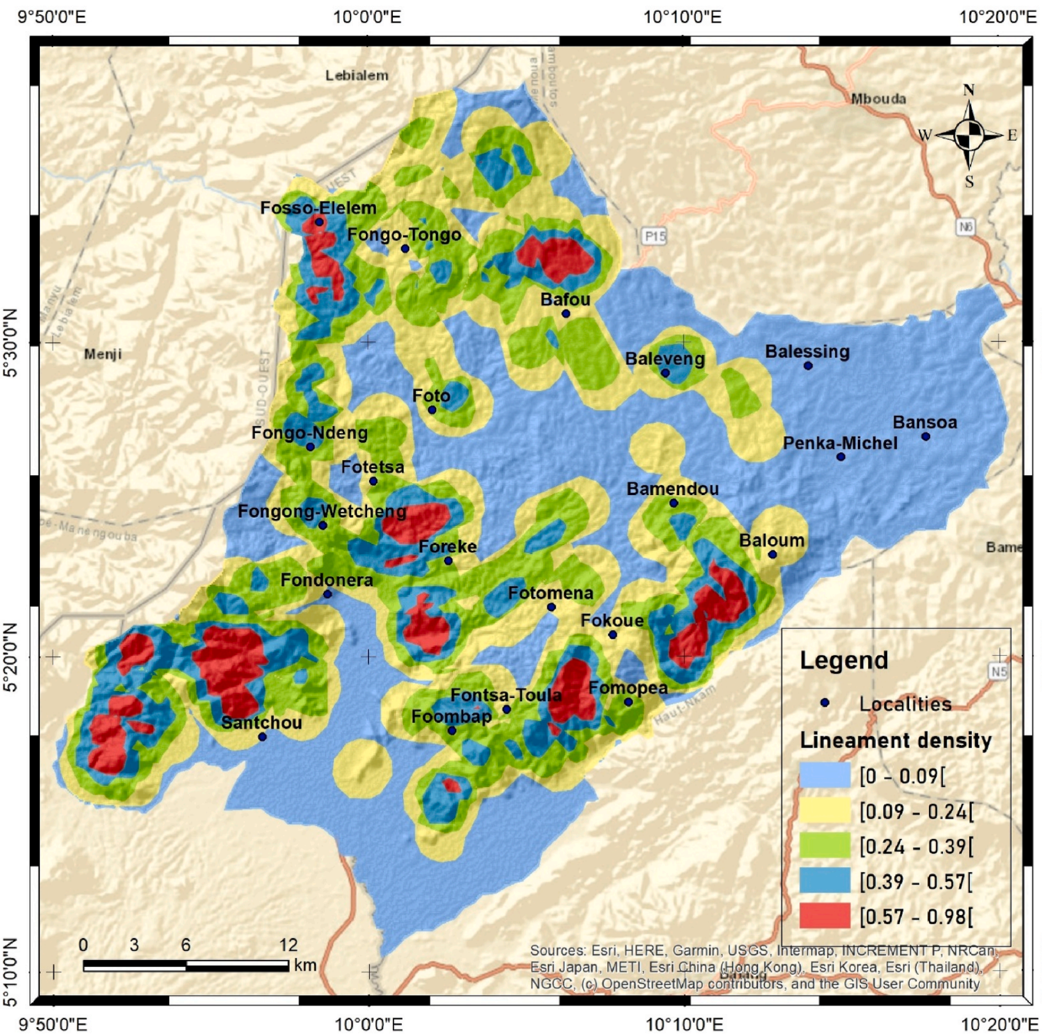

Fig. 2. Lineament density of the Menoua Division.

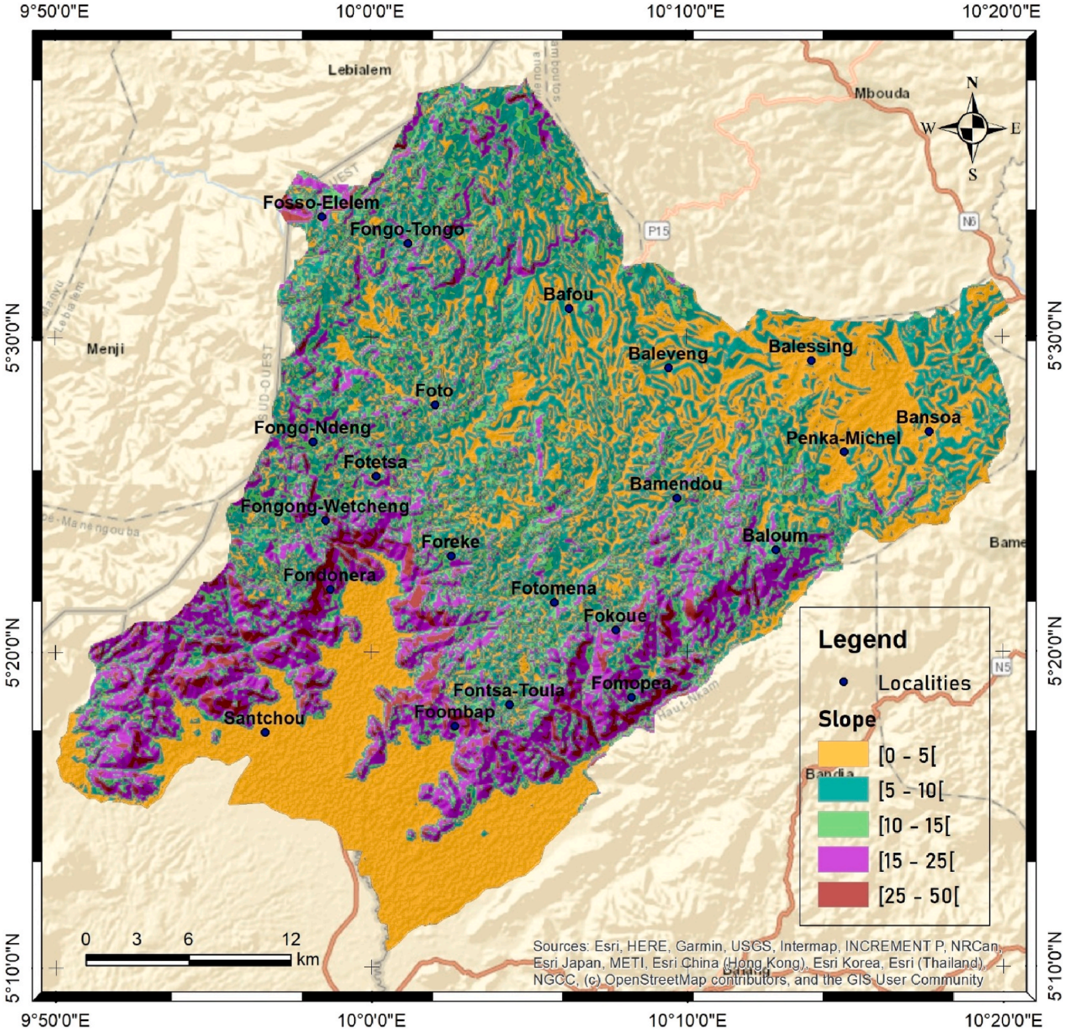

Fig. 3. Slope of the Menoua Division.

water infiltrates through micro faults and other tectonic signatures called lineaments. These lineaments are formalized in the form of LD. Thus, LD plays a key role in the formation of groundwater. Also, infiltration is greater when water is standing for a long time or when runoff is slow. Thus, the steeper the slope, the more intense the infiltration. LULC is also a determining parameter. Indeed, certain ground covers such as cement (tarred roads, developed areas) are not favorable to the infiltration of surface water, whereas vegetation and bare land are very favorable. DD is an important indicator. It can indicate the impermeability of the soil, and therefore the low rate of infiltration. On the other hand, TWI indicates a high groundwater potential. Finally, the geomorphology distinguishes the lowlands from the hills. Lowlands are more favorable to the accumulation of groundwater.

Fig. 9 summarises the methodological steps.

2.3. Dataset and processing on ArcGIS

The dataset is collected from diverse sources: WorldClim 2.1 for rainfall, Landsat 9/OLI for LULC, and ALOS PALSAR 2 for elevation, drainage density, TWI, slope, and lineament density maps. The seven parameters integrated on ArcGIS 10.8 to assess the GWP are extracted from the abovementioned dataset. Lineaments were extracted both automatically (from enhanced ALOS Palsar raster by principal component analysis) and manually from various hillshade maps of the region. For automatic extraction, the PCI Geomatica software, namely its LINE module, was used] [2,19]]. The ALOS Palsar DEM was used to generate the geomorphology, drainage density, and slope maps on ArcGIS 10.8. All those images were transformed into raster format and properly pondered (with weightages) according to their significance to groundwater formation.

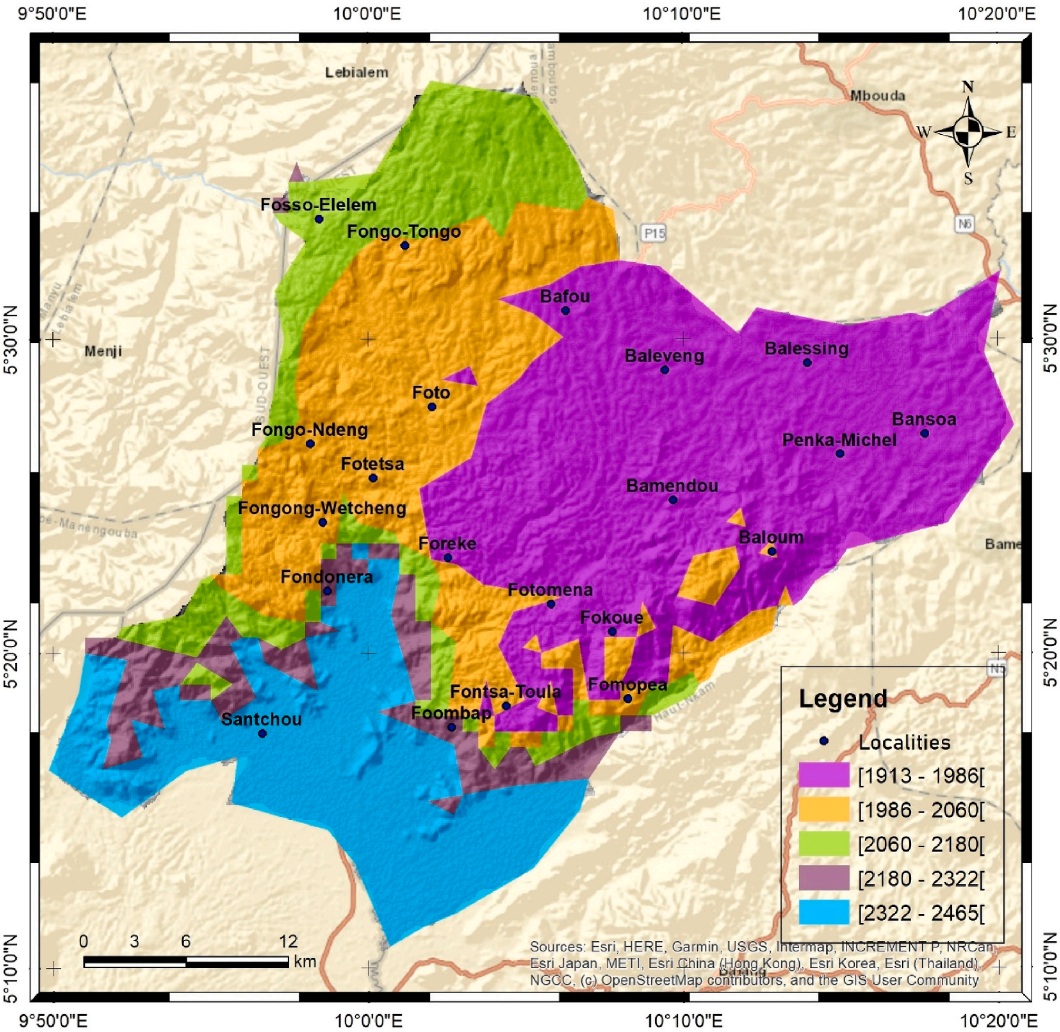

Fig. 4. Spatial distribution of rainfall in the Menoua Division.

2.4. MCA using AHP

The pairwise comparison [20] between a set of criteria, helps make multifaceted decisions. In this paper, the criteria considered to assess the GWP are drainage density, elevation, lineament density, LULC, rainfall, slope, and TWI. First, the thorny decision-making procedure between primary parameters is transformed into a single level by a pairwise comparison matrix expressed in Equation (1). Saaty's 1–9 [20] significance scale is used to compare those parameters (Table 2).

$$A = \begin{bmatrix} a_{21} & \cdots & a_{2n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

In this judgement matrix, the elements are $a_{21} \ldots a_{nn}$.

The geometric average of the criteria, expressed in Equation (2), is used to calculate the normalized weights.

$$W_n = \frac{G_i}{\sum_{i=1}^{n} G_i} \tag{2}$$

G_i and W_n respectively represent the geometric average and the eigenvector of the judgment of the ith row. Finally, the consistency of the normalized criteria weights is assessed using Equation (3). For a normalized weight to be deemed consistent, the consistency ratio (CR) should be lower than 0.10.

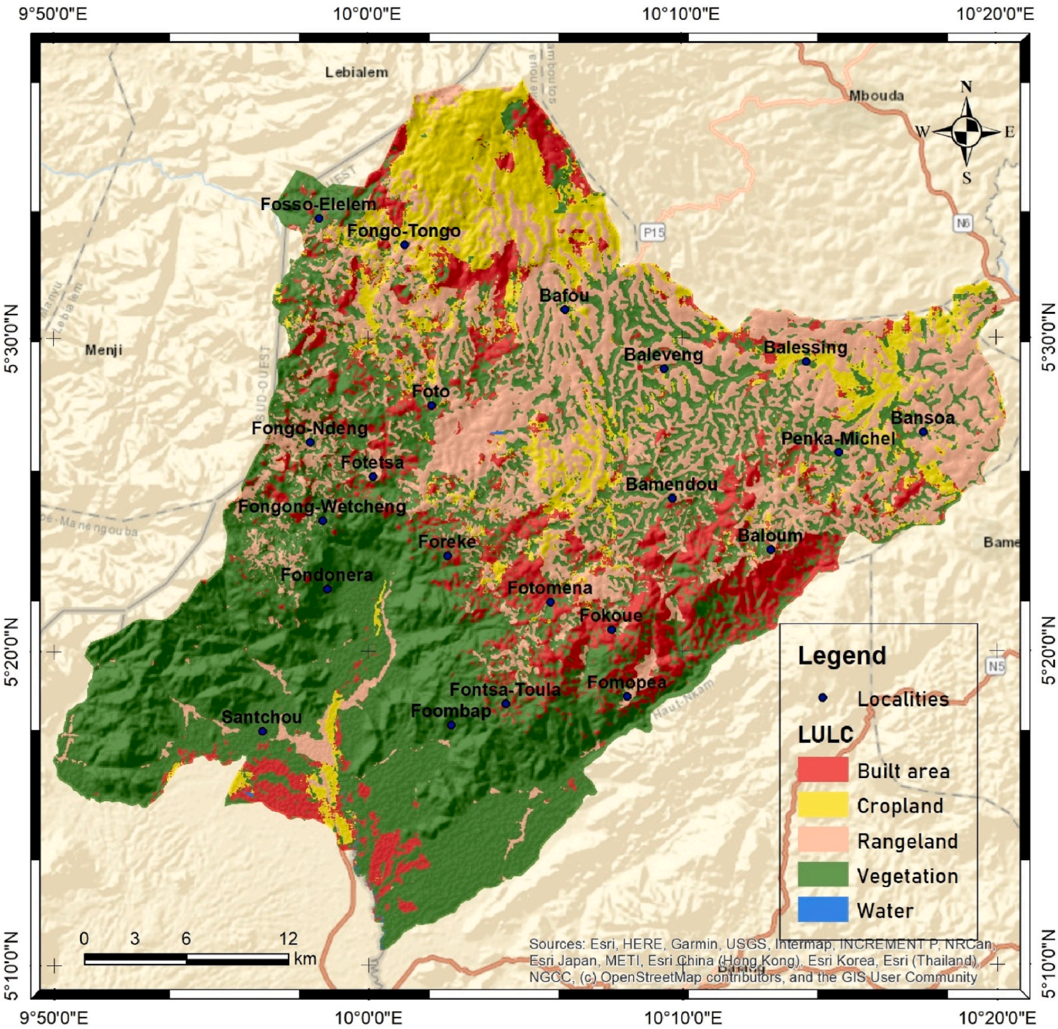

Fig. 5. LULC pattern of the Menoua Division.

$$CR = \frac{CI}{RI} \tag{3}$$

The consistency index (CI) is expressed in Equation (4) while the random consistency index (RI) is given in Table 3 [20].

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

$\lambda_{\max}$, derived from Equation (5), is the maximum eigenvalue of the judgment matrix.

$$\lambda_{max} = \frac{1}{n}\sum_{i-1}^{n}\frac{(A_w)_i}{w_i} \tag{5}$$

Table 4 displays the normalized weight and the values of pairwise comparison matrix. CR values are compliant because they are less than 0.10.

2.5. *Criteria calibration and GWP mapping*

The decision-making becomes easy when all criteria are standardized. Hence, it is essential to apply the same scale of measurement [21–23]. In this study, the criteria are ranked from 5 to 1 as depicted in Table 5 (very high, high, moderate, low, and very low). From this ranking, the GWP index is calculated as shown in Equation (6) using the weighted linear combination method [24].

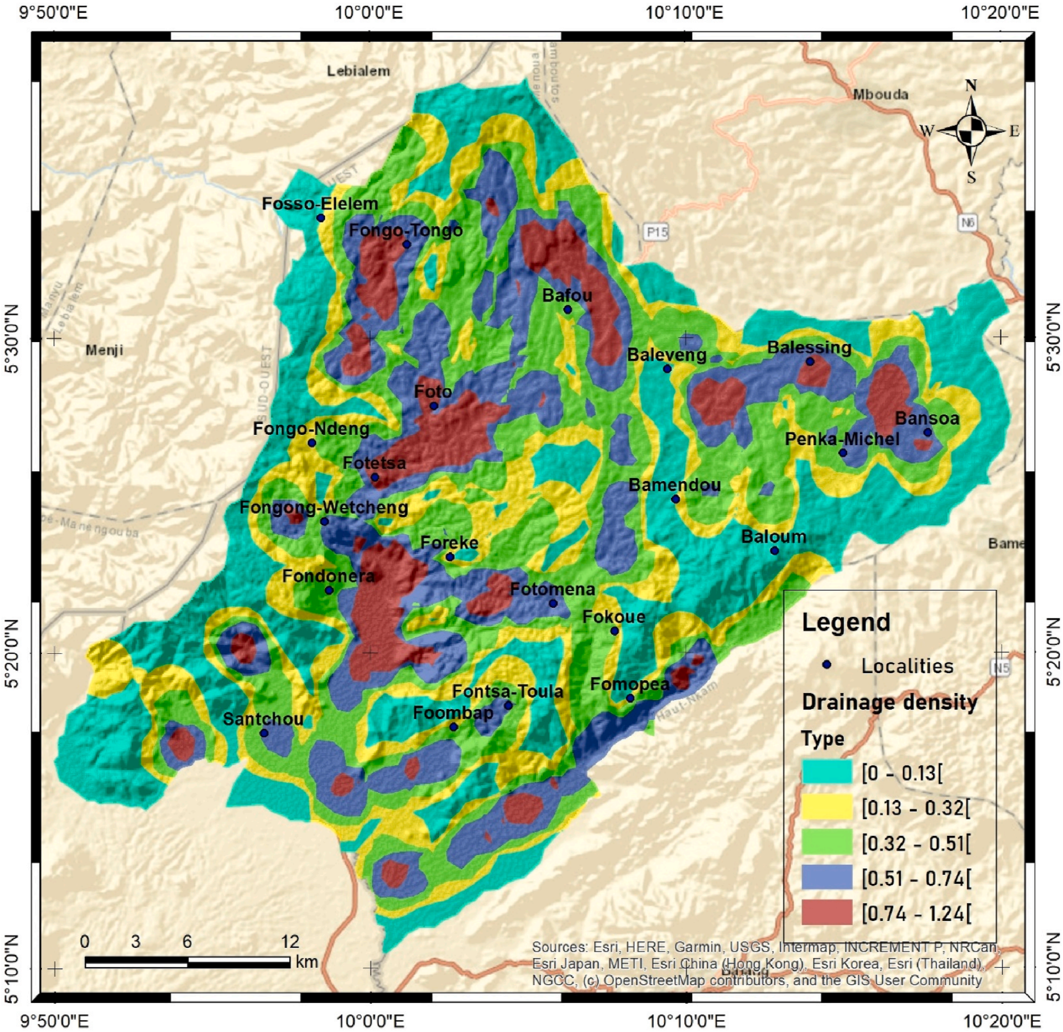

Fig. 6. Drainage density of the Menoua Division.

$$GPI = \sum_{i=1}^{n} w_i \times r_i \tag{6}$$

In this Equation, w_i and r_i are respectively the relative weight and the standardized rating of criterion i.

3. Results

The seven environmental parameters designated to assess GWP in the Menoua Division were separately valued and multiplied by their respective AHP-derived weights. Outcomes are summed up to delineate GWP in the Menoua Division. Five main classes are highlighted on this GWP map (Fig. 10).

A visual analysis of the GWP map, in comparison with the maps of various contributing factors, reveals that high GWP zones (in the southern part of the Menoua Division) coincide with low slope, high lineament density, high rainfall, vegetation cover, low drainage density, high TWI, and lowlands. This result highlights the role of those contributing factors in the groundwater occurrence.

The predominant class is low GWP. It expands on 375 km^2 (27 % of the Menoua Division). Globally, 40 % (561 km^2) of the Menoua Division is characterized by a poor GWP. The classification of the GWP is summarised in Table 6.

Such a sound GWP map is of paramount importance in the context of sustainable management of water resources for, it assists policymakers, decision-makers, and planners in their respective duties, by focusing their attention and financial resources on promising sites. Hydrogeophysical field investigations should be concentrated on those sites to reduce loss of time and money. This GWP map was validated by a field survey consisting in an analysis of existing boreholes and wells. Unproductive (too deep and dried-up) boreholes were effectively found in localities with low GWP. On the other hand, productive wells were located in high GWP zones.

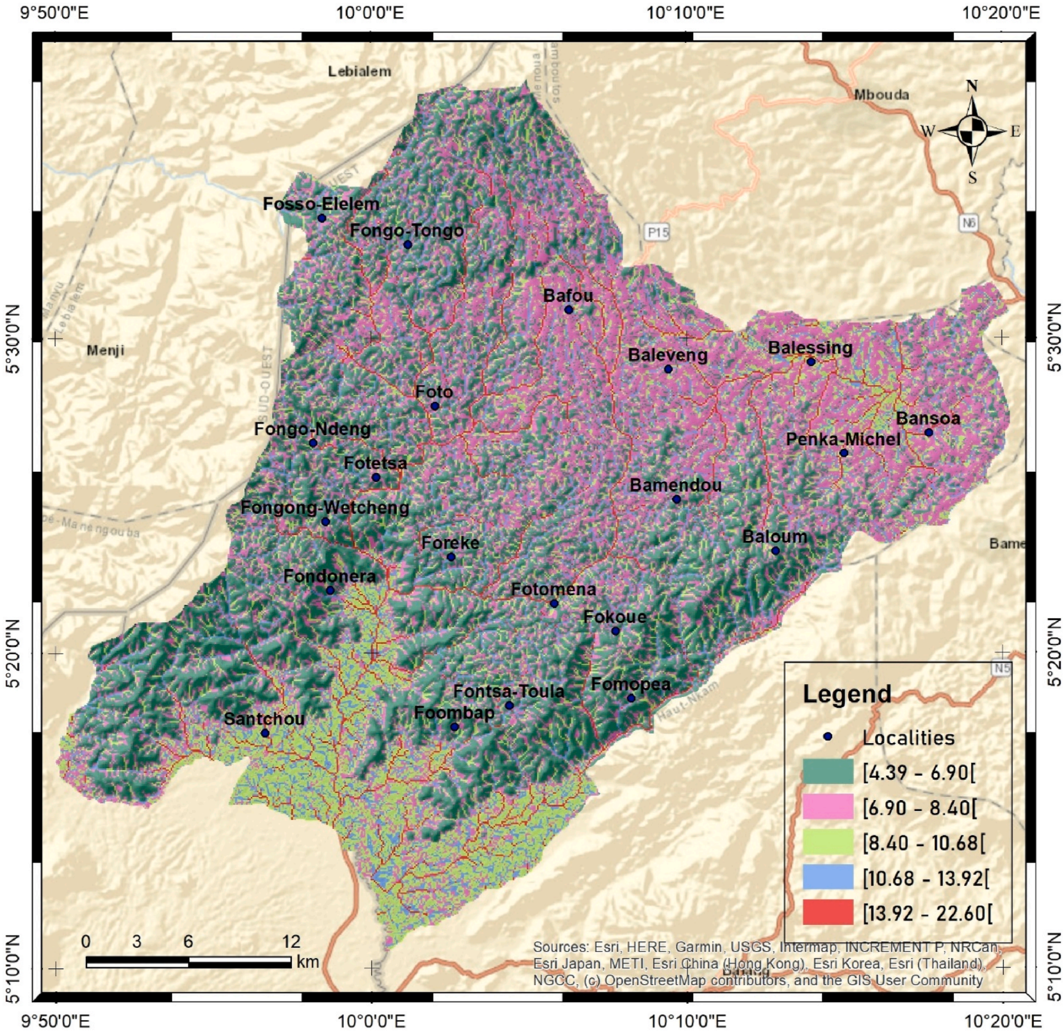

Fig. 7. Spatial distribution of TWI in the Menoua Division.

Further analysis and investigation would be possible if hydrodynamic parameters (discharge and charge proportion, hydraulic conductivity, porosity, transmissivity, etc) of those wells and boreholes existed. Upcoming investigations will aim at establishing strong relationships between those hydro-parameters and the GWP distribution. In the Menoua Division, there are no existing similar results, and no possibility of comparing these results with any other one. Nevertheless, the spatial distribution of GWP is in accordance with different contributing parameters.

There are many unproductive wells throughout the Menoua Division. Indeed, most of them have been drilled without prior hydrogeophysical investigation. A hydrogeophysical survey conducted without a GWP assessment generally results in a non-compliant conclusion, with an important loss of time and money as a consequence. The use of RS and GIS is an alternative solution. The Menoua Division gives room to this investigation to explain how low-income countries can significantly reduce the water stress they are facing every day by efficiently exploring and exploiting groundwater resources with a moderate budget at the local scale, by delineating GWP zones. RS and AHP are conjointly used on ArcGIS to evaluate the GWP from seven thematic layers (slope, lineament density, rainfall, LULC, TWI, drainage density and geomorphology). Up to 35 % of the Menoua Division is characterized by a good GWP. Moderate GWP zones represent 27 % of the Menoua Division. GWP is poor in 40 % of the Menoua Division.

The predominant group of lineament density is]0–0.09] which corresponds to "very low", covering 522 km^2 (38 % of the Menoua Division), followed by]0.09–0.24] corresponding to "Low", covering 330 km^2 (24 % of the Menoua Division);]0.24–0.39] corresponding to "Moderate", covering 296 km^2 (21 % of the Menoua Division),]0.39–0.57] corresponding to "High", covering 159 km^2 (12 % of the Menoua Division) and]0.57–0.98] corresponding to "Very high", covering 76 km^2 (5 % of the Menoua Division). 852 km^2 of the Menoua Division are characterized by a very coarse or coarse lineament density. Consequently, for 62 % of the Menoua Division, the tectonic features are not the main drivers of surface water infiltration.

Slope is classified into five categories: 0–5° corresponding to very high GWP, 5–10° corresponding to high GWP, 10–15° corresponding to moderate GWP, 15–25° corresponding to poor GWP, and 25–50° corresponding to very poor GWP. Those categories

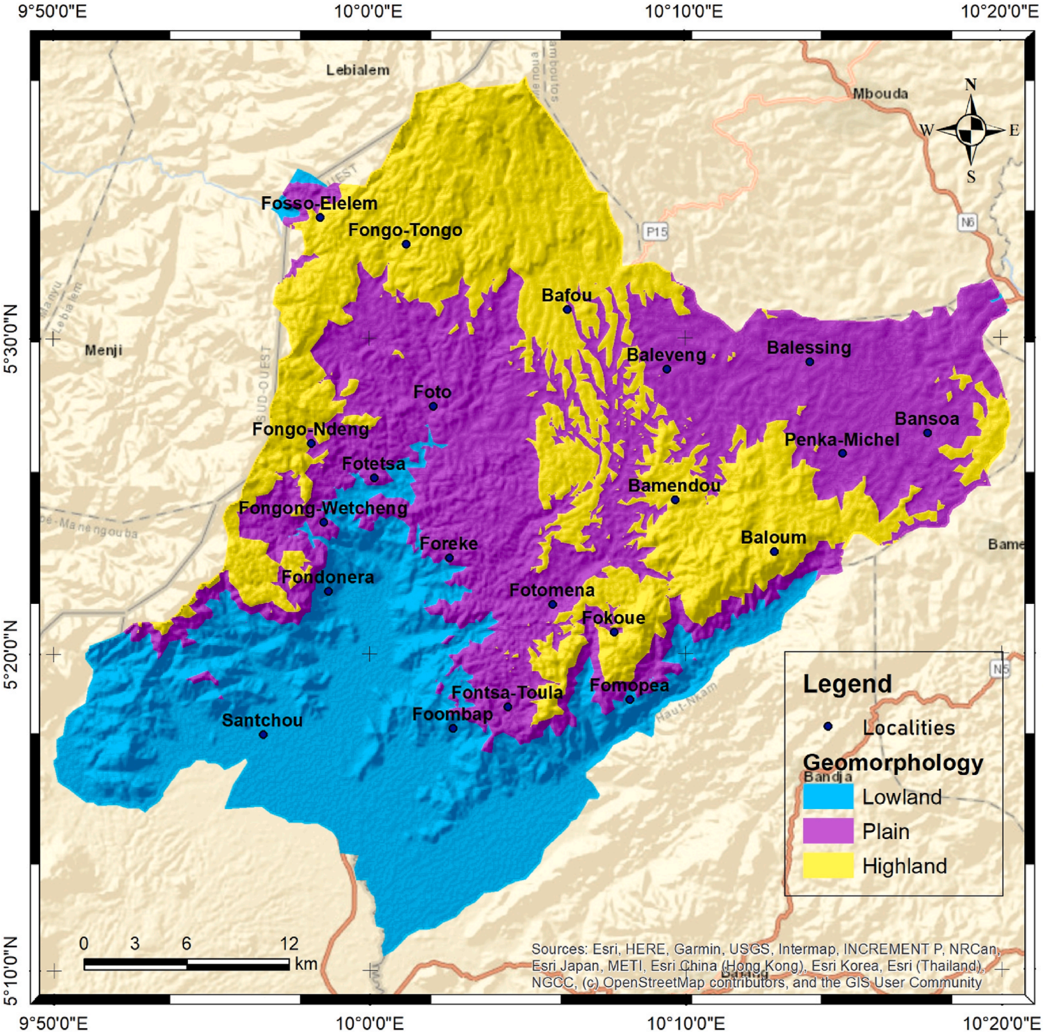

Fig. 8. Geomorphology of the Menoua Division.

expand respectively on 476 km^2 (34 % of the Menoua Division), 399 km^2 (29 % of the Menoua Division), 221 km^2 (16 % of the Menoua Division), 229 km^2 (17 % of the Menoua Division) and 52 km^2 (4 % of the Menoua Division). Slope stands as the second parameter contributing to the groundwater formation with a normalized weight of 0.19.

The annual rainfall average of the Menoua Division ranges from 1913 to 2465 mm, divided into five classes:]1913–1986] covering 538 km^2 (39 % of the Menoua Division),]1986–2060] covering 325 km^2 (23 % of the Menoua Division),]2060–2180] covering 188 km^2 (14 % of the Menoua Division),]2180–2322] covering 84 km^2 (6 % of the Menoua Division) and]2322–2465] covering 251 km^2 (18 % of the Menoua Division).

LULC is ranked fourth out of seven selected criteria with 0.10 of normalized weight. It is divided into five classes (Fig. 5): water body (0.04 % of the Menoua Division), vegetation cover (50.88 % of the Menoua Division), cropland (11.87 % of the Menoua Division), rangeland (24.72 % of the Menoua Division) and built area (14.13 % of the Menoua Division). Such a pattern may strongly promote surface water infiltration.

In this study, drainage density is the fifth most important criterion with a normalized weight of 0.08. It is classified into five categories:]0–0.13] covering 371 km^2 (27 % of the Menoua Division),]0.13–0.32] covering 268 km^2 (19 % of the Menoua Division),] 0.32–0.51] covering 364 km^2 (26 % of the Menoua Division),]0.51–0.74] covering 268 km^2 (19 % of the Menoua Division) and] 0.74–1.24] covering 122 km^2 (9 % of the Menoua Division). Contrarily to other factors, drainage density behaves like slope; it is inversely proportional to GWP.

TWI is the sixth predominant criterion with a normalized weight of 0.06. It is classified into five categories:]4.39–6.90] covering 514 km^2 (37 % of the Menoua Division),]6.90–8.40] covering 460 km^2 (33 % of the Menoua Division),]8.40–10.68] covering 242 km^2 (17 % of the Menoua Division),]10.68–13.92] covering 114 km^2 (8 % of the Menoua Division) and]13.92–22.60] covering 45 km^2 (3 % of the Menoua Division). The areas with low or very low TWI values are dominant.

With its 0.06 normalized weight, geomorphology stands as the last criterion contributing to the groundwater occurrence in the

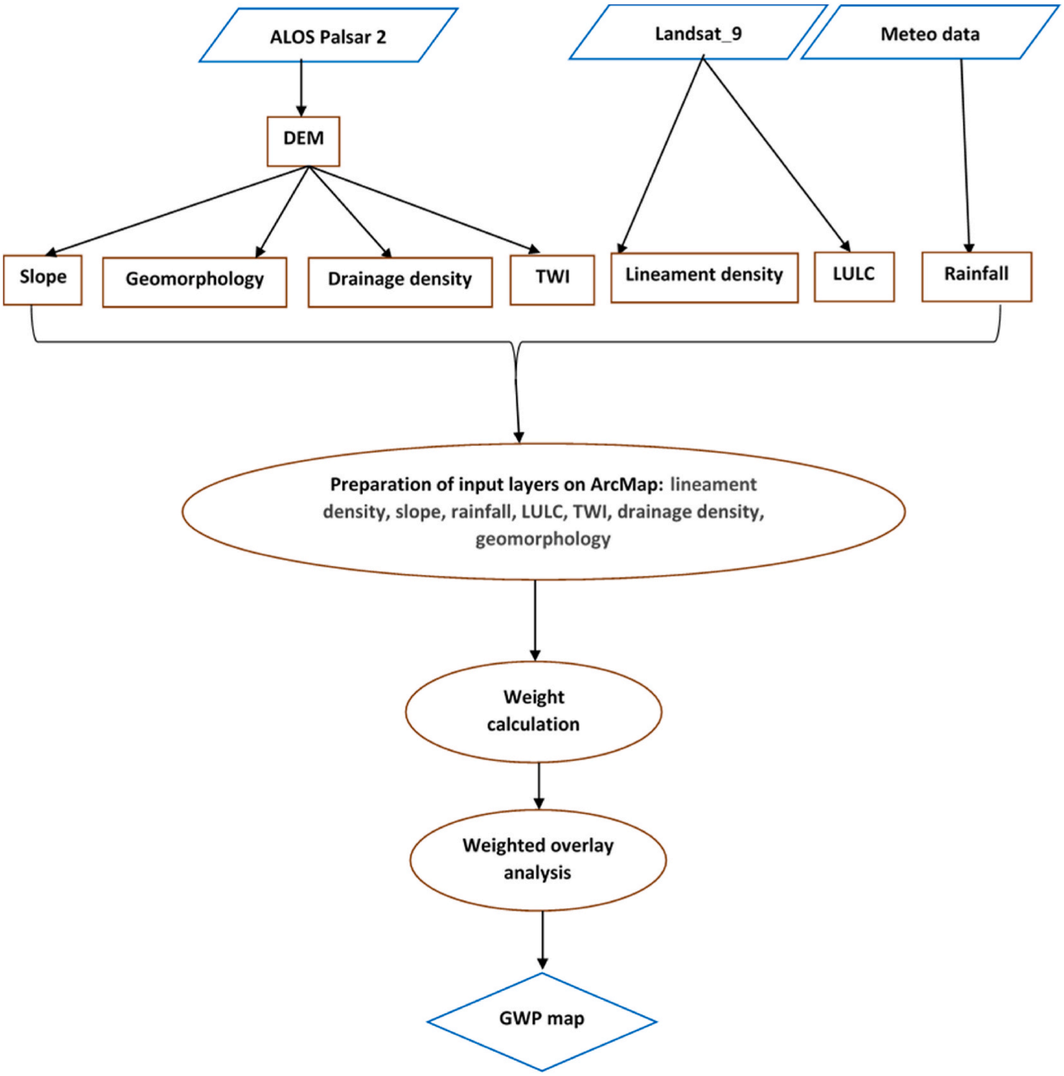

Fig. 9. Flowchart for GWP assessment.

Table 2
The rating scale of Saaty's AHP.

Less significant				Equally significant	More significant			
Extreme rank	Very strong rank	Strong rank	Moderate rank	Equal rank	Moderate rank	Strong rank	Very strong rank	Extreme rank
1/9	1/7	1/5	1/3	1	3	5	7	9

Table 3
The RI ratio of the different values of n.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.89	1.12	1.25	1.32	1.40	1.45	1.49

Menoua Division. Geomorphologically, the Menoua Division is divided into five sectors (expressed in meters above the sea level):] 705–1000] covering 299 km^2 (22 % of the Menoua Division),]1000–1300] covering 128 km^2 (9 % of the Menoua Division),] 1300–1500] covering 532 km^2 (38 % of the Menoua Division),]1500–2000] covering 385 km^2 (28 % of the Menoua Division) and]

Table 4
Normalized weights of various parameters for pairwise comparison.

Parameters	LD	Slope	Rainfall	LULC	DD	TWI	Geomorphology	Normalized weight
LD	1							0.39
Slope	3.50	1						0.19
Rainfall	2.33	2.00	1					0.12
LULC	1.75	1.50	1.25	1				0.10
DD	1.40	1.20	1.00	0.80	1			0.09
TWI	1.17	1.00	0.83	0.67	0.50	1		0.07
Geomorphology	1.00	0.86	0.71	0.57	0.43	0.29	1	0.06
Total								1.00

Table 5
The seven parameters used for GWP assessment ranked in descending order.

Factor	Weight	Rank
Lineament density	38.57	**1**st
[0.14–0.28]		5
[0.09–0.14]		4
[0.05–0.09]		3
[0.02–0.05]		2
[0–0.02]		1
Slope	13.28	**2**nd
[0–3]		5
[3–6]		4
[6–12]		3
[12–20]		2
[20–62]		1
Rainfall	12.86	**3**rd
2137–2497		5
1909–2137		4
1738–1909		3
1618–1738		2
1478–1618		1
LULC	9.64	**4**th
Water body		5
Flooded vegetation		4
Vegetation		3
Bare land		2
Built areas		1
Drainage density	7.71	**5**th
[0–0.22]		5
[0.22–0.30]		4
[0.30–0.36]		3
[0.36–0.42]		2
[0.42–0.57]		1
TWI	6.43	**6**th
15.72–26.52		5
12.24–15.72		4
9.71–12.24		3
7.89–9.71		2
4.23–7.88		1
GEOMORPHOLOGY	5.51	**7**th
[0–100]		5
[100–300]		4
[300–600]		3
[600–800]		2
[800–1566]		1

2000–2740] covering 49 km^2 (4 % of the Menoua Division).

Rainfall is important (up to 2465 mm) in the region, resulting in a significant possibility of surface water infiltration. Slope plays a decisive role in the rate of runoff or infiltration [25]. This parameter governs the quantity of surface water infiltrated. Runoff speed and duration are strongly correlated to the area slope. The rate of infiltration is very important in flat areas because surface water festers there for a long time [24]. As slope, areas with low drainage density also give room to important infiltration and high recharge capacity [26]. High drainage density is a synonym for weak infiltration and high runoff velocity, while low-slung drainage density is a synonym for surface water stagnation. Lineament density plays the inverse role [2]. Shao et al. [27] linked drainage density to the permeability of the underlying rocks. In general, zones with important drainage density contribute less to groundwater formation while areas with weak drainage density contribute more [28]. LULC describes the external cover of an area, including vegetation and wetness. It

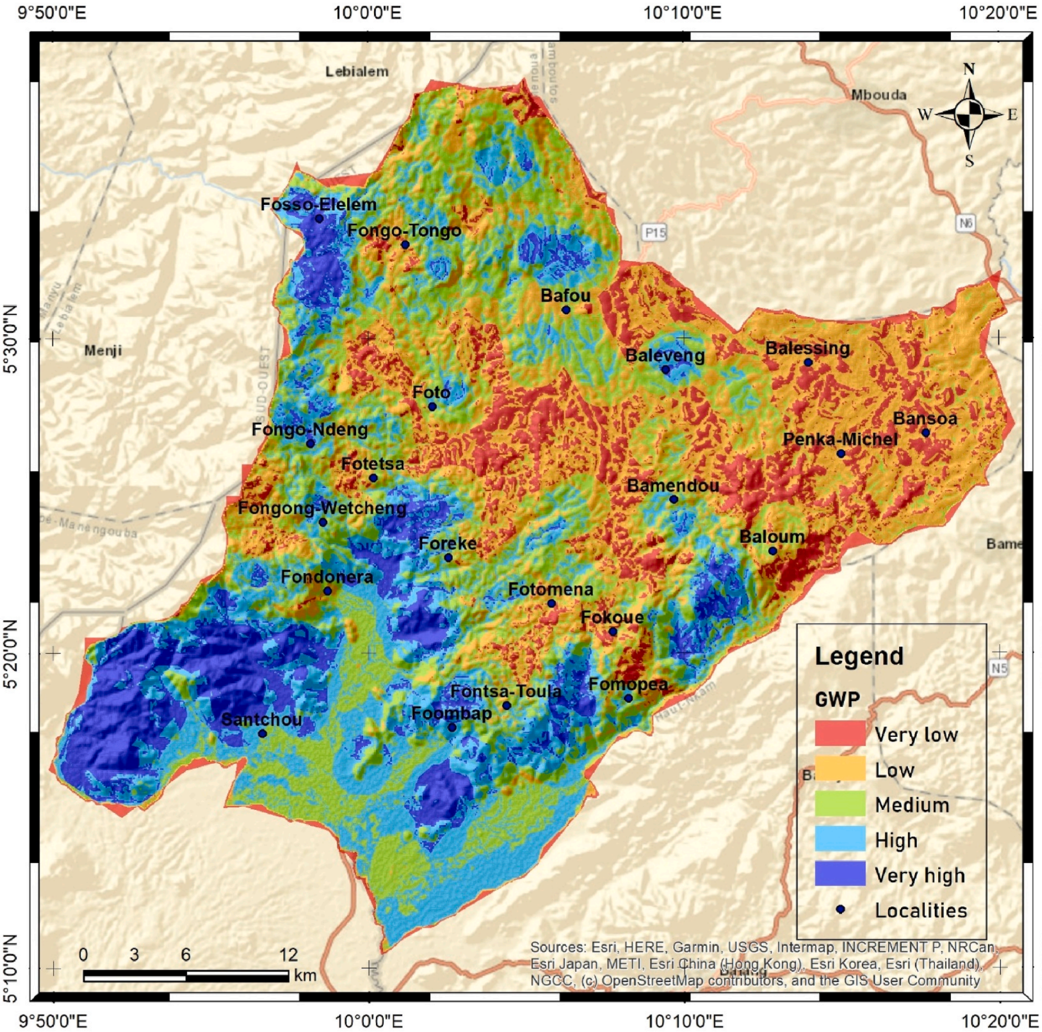

Fig. 10. Map of GWP distribution in the Menoua Division.

Table 6
Classification of GWP in the Menoua Division.

GWP class	Area covered (km^2)	Proportion (%)
Very low	186	13
Low	375	27
Medium	371	26
High	324	23
Very high	156	11
Total	1423	100

therefore has an impact on some natural and environmental phenomena (e.g., runoff, evapotranspiration, condensation, surface water infiltration) and especially on groundwater storage and recharge] [2,16]]. The lineament pattern is the topographical witness of all geological cut-offs such as faults and fractures. As a result, zones with important lineament density endorse water infiltration [29]. In the assessment of the GWP, lineaments are systematically converted into their density.

4. Discussion

This article demarcates five GWP classes: very high, high, moderate, low, and very low potential, covering respectively 13 %, 27 %, 27 %, 23 % and 11 % of the Menoua Division. While low-potential areas commonly occupy the eastern part (Bansoa, Penka-Michel, Balessing, etc.) of the study area, high-potential areas are concentrated in the southern part (Santchou, Foombap, etc) as shown in

Fig. 10.

The GWP obtained in this study from the AHP is acceptable according to the depth of hand-dug wells observed in the region. Without existing previous investigation concerning GWP in the Menoua Division, these results are compliant with the literature, where it is established that GWP maps derived from AHP strongly overlap with the yield and discharge of the wells located in the Menoua Division] [30,31]].

LULC pattern affects groundwater occurrence as it controls surface runoff through evaporation and vegetation. In addition, water bodies rivers, lakes, and ponds are permanent sources for groundwater recharge. This explains why areas covered by water bodies generally have high GWP [30,32–34]. Floodplains and croplands are very porous, increasing water percolation into the subsurface. On the contrary, bare lands and built-up areas where the surface runoff is intense have low GWP. In the GWP map, croplands effectively overlap with the (very) high-potential classes. These findings are similar to results previously found in other regions [35]. In general, LULC is the main factor controlling the accumulation of groundwater in the study area. Vegetation and cropland areas are those with a high GWP, due to their permeability. However, some areas such as those around the locality of Baloum have high GWP even though they are located in built-up areas, which are impermeable. This phenomenon could be due to the low drainage density on those areas.

Lineament with its components (faults, fractures, and joints), is the parameter that directly controls permeability, and boldly contributes to the groundwater formation. Surface water infiltrates more rapidly and abundantly in areas with high lineament density, increasing GWP [34].

Slope plays an essential role in groundwater formation and recharge as it directly affects the surface runoff process. In compliance to existing similar investigations, areas with low slopes have a high potential for groundwater storage due to the longer residence time for water to percolate. Analogically, the surface runoff is very intense in areas with high slopes, resulting in a low GWP [35]. In this study, high GWP areas effectively coincide with low slope values in the southern part (Santchou) and the eastern (Penka-Michel, Bansoa) parts of the Menoua Division. However, by observing the map of GWP and that of the slope (Figs. 3 and 10), it is clear that the zones of very high GWP correspond to the zones of steep slope. This could mean that slope is not a determining factor of the groundwater accumulation in the study area. The very high GWP potential at these locations could be justified by the presence of vegetation and the relatively high rainfall.

Drainage density is directly linked to the saturation of the subsurface rocks. This factor prevails in the surface water infiltration [36]. Concretely, low drainage density means high permeability of the sub-soil rocks and high GWP. In this article, low values of drainage density are scattered through the Menoua Division, covering also areas with high GWP.

TWI is a secondary indicator of GWP that depends on the soil depth and texture, and on the local slope gradient. High values of TWI, ranging between 10 and 27, are mainly concentrated in the eastern part of the study area, coinciding with high GWP. GWP areas are mainly located in places where TWI is low. This parameter therefore has a negligible impact on the accumulation of groundwater in the study area.

An analysis of the rainfall map reveals that the highest values of the annual mean rainfall (2322–2465 mm) fall in the southern part of the Menoua Division where the GWP is the highest. However, some areas such as Baloum, Baleveng, Bafou, and Bamendou have high GWP, yet fall into low rainfall areas. This can be attributed to other factors such as the low drainage density in these places, as areas of low drainage density are known to favor groundwater accumulation.

The southern part of the Menoua Division is a huge valley, containing sediments and rocks with high permeability, where surface water quickly infiltrates to the ground. The very high GWP zones are much more located in low-altitude areas in the south of the study area. However, some of them are also found in high-altitude areas and could be due to the influence of other factors mentioned above.

Globally, the final GWP map is compliant with the seven environmental factors used to assess it. High GWP zones match with high TWI, lowlands, weak drainage density, gentle steep or flat terrain, important rainfall, and high lineament density. Those zones (with high GWP) also include cropland, vegetation, and water bodies. It is not possible to compare these results with any other previous ones because of the absence of similar investigations in the Menoua Division. Nevertheless, there is a similarity between the results obtained in this article and those obtained in other tropical regions with similar physical features] [2,5,6,13,16,24,37–39]].

The key findings of this article confirm the results obtained in the neighboring region of Foumban [2]. Local authorities will take advantage of this article by improving their Communal Development Plans (CDPs), strategic documents in which they set out the needs and desires of the communities, display the expected socioeconomic objectives of the council, and indicate the required budget. Unfortunately, those CDPs generally fail, partially because of the absence of adequate management of water resources. The map of spatial distribution of rainfall presented in this article is very helpful for selecting suitable crops, promotion of agroforestry, and mitigation of the effects of climate variability. Various thematic maps provided in this article can boldly improve those CDPs and make them more effective and reliable.

In general, the AHP technique leads to a solid outcome. Its advantages include the fact that it has a broad spectrum of applications and minimalizes the risk when solving complex problems. However, AHP uses a large number of pairwise comparisons. Hence, this method requires a high computational capacity even for small problems. It also has a subjective nature and relies on emotions to be transferred to numerical judgments. Experts' judgment is considered to select parameters to be used and also to rank them. For example, rainfall is the determining parameter that governs the total probable amount of surface water to be infiltrated. However, according to the size of the study area and the fact that rainfall almost has the same value everywhere, this parameter is not ranked number 1. A similar judgment is made for all other parameters.

Experts' judgment plays an important role from the selection of contributing factors to their ranking. For the Damoh district in central India, the selected layers were geology, slope, geomorphology, aspect, lineament density, drainage density, TWI, topographic ruggedness index (TRI), and LULC [40]. Furthermore, they validated their results using Receiver Operating Characteristic (ROC) curves. In another investigation, the thematic layers used are LULC, DEM, hillshade, slope, soil texture, groundwater depth, Normalized Difference Vegetation Index, geomorphology, and flow direction and accumulation [41]. Although the key findings of this article are consistent with the results of abovementioned investigations, additional techniques such as ROC curves]44], and multi influencing factor [42] need to be involved in the upcoming investigations. It is also strongly recommended to explore other methods such as fuzzy algebra, deep or machine learning [43]. Upcoming investigations will consist in comparing these results with those obtained from machine or deep learning.

5. Conclusion

This article assessed the GWP in the Menoua Division from an integrated GIS-AHP approach. Seven thematic layers namely lineament density, slope, rainfall, LULC, TWI, drainage density, and geomorphology were selected, valued, and appropriately processed on ArcGIS. In this investigation, lineament density is ranked as the first contributing factor to the groundwater occurrence with a normalized weight of 0.39. Slope is the second one with a normalized weight of 0.19. Rainfall is the third one with a normalized weight of 0.13. LULC is the fourth important criterion in the GWP assessment with a normalized weight of 0.10. Drainage density is the fifth contributing factor with a normalized weight of 0.08. TWI (normalized weight of 0.06) is ranked the sixth layer. Geomorphology is the seventh criterion. The GWP map is sorted into five zones (very high, high, moderate, low, and very low potential), covering respectively 186 km^2 (13 %), 375 km^2 (27 %), 371 km^2 (27 %), 324 km^2 (23 %) and 156 km^2 (11 %). In addition to the compliance of the GWP map with the spatial distribution of the contributing parameters, the results were validated by the field survey. This article is the pioneer one in the region, and the results will contribute to implement a comprehensible groundwater resource management policy that considers the context of sustainable development. The results of this article should be improved in the future study by involving additional techniques such as ROC curves and multi influencing factor. It is also strongly recommended to explore other methods such as fuzzy algebra or machine learning. Upcoming investigations will consist in comparing these results with those obtained from machine or deep learning.

Data availability statement

Data associated with the study is not deposited into a special public repository. However, it is included in the supplement material.

CRediT authorship contribution statement

Dady Herman Agogue Feujio: Methodology, Investigation, Data curation. **Zakari Aretouyap:** Writing - original draft, Supervision, Software, Investigation, Conceptualization. **Sandra Celeste Tchato:** Writing - review & editing, Visualization, Project administration, Formal analysis. **Charles Ngog II Legrand:** Resources. **Ernest Djomdi:** Software, Resources. **Nidelle Nague Madadjeu:** Writing - review & editing, Project administration. **Cedric Nguimfack Nguimgo:** Funding acquisition, Data curation. **Abas Ndinchout Kpoumie:** Writing - review & editing, Visualization, Software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24310.

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