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Assessment of the Exploitation Rate and Sustainability of an Alluvial Plain in Southwestern Burkina Faso

Nestor Fiacre Compaoré[1], Amagana Emmanuel Dara[2], Mahamadou Koïta[2]
Djamilatou Mody Dao[3] & Hamma Fabien Yonli[4]

Abstract

The alluvial aquifer of Karfiguéla in the Comoé province (southwestern Burkina Faso) is increasingly being used for irrigation. Despite its crucial importance for farmers, the exploitation rate of this aquifer and its water supply are poorly known. In this context the assessment of the exploitation rate and sustainability of the Karfiguéla alluvial aquifer was initiated for a better management of groundwater resources in the Southwest of Burkina Faso. The assessment of the exploitation rate requires both the evaluation of groundwater extraction and recharge. These two parameters were determined respectively by the quantification of groundwater extraction volumes for crop needs and water balance methods. The annual recharge is substantially identical to the annual renewed water volume of the aquifer. This recharge is around 1,885,000 m^3 or about 4% of the average annual rainfall. Groundwater extraction is low and represents 10% of the renewed water volume. So, the alluvial aquifer of Karfiguéla has a sufficient recharge to compensate groundwater extraction. The sustainability of its exploitation does not seem to be threatened.

Keywords: alluvial aquifer, exploitation rate, groundwater extraction, recharge, sustainability, Karfiguéla, Burkina Faso

1. Introduction

Located in West Africa, Burkina Faso is a landlocked and Sahelian country. It covers an area of 274000 square kilometers. Its population was estimated in 2010 at 15,370,000 with an annual growth rate of 3.1% (INSD, 2006).

The economy of Burkina Faso is mainly based on the primary sector, which provides nearly 80% of the country's export-related revenues, employs about 86% of the active population and contributes 40% of the Gross Domestic Product, of which 30.7% represents the agriculture sub-sector. Despite its relative importance for the economy, agriculture is facing the effects of the climate change which cause large fluctuations in agricultural production from year to year. This is why successive governments in Burkina Faso have taken strong action in favor of the irrigation sector. In fact, irrigation appears as one of the alternatives to minimize the influence of the major limiting climatic factors of traditional rainfed agriculture through additional production in dry season and securing winter production with supplemental irrigation. In Burkina Faso, uncertainties about the beginning and end of seasons, the increase in the number and duration of dry pockets duringwet seasons, the scarcity or seasonality of surface waters are factors contributing to the pressure on groundwater resources (N'go et al., 2005). Indeed, groundwater has been considered as less vulnerable to drought (Taylor et al., 2009). Access to groundwater is conditioned by the drilling wells or boreholes of good quality, able of lasting over time.

[1] Direction régionale de l'eau et de l'assainissement des hauts-bassins, Bobo-Dioulasso, Burkina Faso
[2]Institut International d'Ingénierie de l'Eau et de l'Environnement, Ouagadougou, Burkina Faso, Rue de la science, BP 594 Ouagadougou 01
[3] Direction régionale de l'eau et de l'assainissement du Centre-Nord, Kaya, Burkina Faso
[4] Ecole Nationale Supérieure d'Ingénieurs de Fada N'Gourma/Université Ouaga I Professeur Joseph KiZerbo, 94, rue 28-09, Ouagadougou, 01 BP 6689 Ouagadougou 01, Burkina Faso

These boreholes should be located in aquifers with significant storage and / or recharge (Parry et al., 2007). Outside, these conditions are often poorly assured because of the complexity of the geology of Burkina Faso consisting of 85% of basement formation (Savadogo, 1984). This situation accentuates the pressure on easily accessible alluvial aquifers whose hydrogeological characteristics are better known. The alluvial plain of Karfiguéla, located in the Cascades region, is an area with strong aquifer potential and therefore suitable for the practice of irrigated agriculture during dry season. However, the establishment of a sustainable management of groundwater resources in the alluvial plain of Karfiguéla will require the estimation of its potentialities to satisfy populations' long-term needs. It is within this framework that this study was initiated. It aims to determine the exploitation rate and sustainability of groundwater resources of the alluvial aquifer of Karfiguela.

2. Study Area

An alluvial plain is a relatively flat surface, located at the bottom of a valley, consists of alluvium (pebbles, gravel, sand, clay, silt...) and comparable to the flood zone of a stream (Sauret, 2013) which generally flows on its alluvium (fine or coarse grains alternately deposited or taken up by the current) covering the bedrock. The sides of the stream of an alluvial plain are bordered by natural plants called riverines. The extent of this vegetation is variable because it can be limited to a narrow tree-line running along the channel of the stream or it can be a real forest, rich in terms of floristic diversity, which can extend over several tens or even hundreds of meters on both sides of the stream channel.

The alluvial plain of Karfiguéla is located in the Comoé province in southwest of Burkina Faso between longitudes 4°50'0"W and 4°42'0" W and latitudes 10°44'0 N and 10°28'0"N (Figure 1). It covers an area of 46496 km² and is 28 km long. In addition, the alluvial plain of Karfiguela houses the localities of Karfiguela, Tengrela, Nafona, Lemouroudougou, Kribina-Lena, Tiekuna, Niankar, Bounouna, Kossara, Diarabakoko, Sitiena and Banfora.

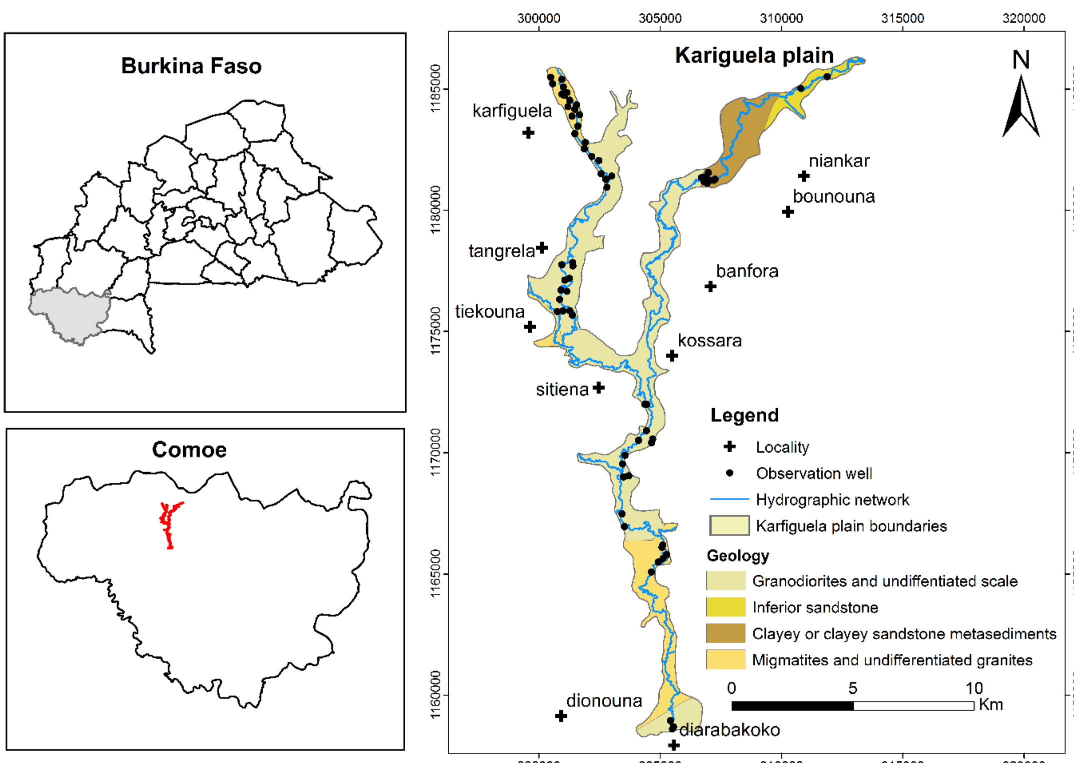

Figure 1: Location of the Karfiguéla plain in Burkina Faso, showing the extent, geology and locations of the river, observation wells, villages.

In the alluvial plain of Karfiguela, the mean annual rainfall of the last thirty years is 1034 mm. Daily temperatures vary from 17° to 36° C (GIRE 2001). The air relative humidity is variable during the dry season (20% to 80%) while during the rainy season it can reach an average of 94.04%.

Four types ofsoils are generally encountered in the Comoé province:

- kaolinitic soils, ocher red tropical ferruginous type, which ensure good drainage;
- brown montmorillonite soils with imperfect drainage;
- sandy-clay soils that provide medium drainage;
- hydromorphic soils flooded in the wet season.

In the Karfiguela plain, soils are generally deep and are of tropical ferruginous type (PADI, 2014) with a clay-silty texture at the top. The soil diversity of the area is undoubtedly a huge potential for agricultural activity. Most of these soils are light and sensitive to erosion, which is accelerated by anthropogenic action (extensive production systems, excessive cutting of firewood and anarchic land occupation). The floodplain is mostly occupied by areas dedicated to agriculture. The predominant crop in the winter season is rice. Vegetable crops such as cabbage, cucumber, eggplant, chilli and crops such as maize, sorghum and groundnuts are also highly developed in the Karfiguela plain during the dry season.
Geologically, the following formations can be listed:

- A tonalite set consisting of granodiorite, tonalite and quartz diorite;
- The formation of Kawara-Sindou Sandstone (GKS) formed by coarse conglomerate sands. With a thickness ranging from 60 to 350 meters, it overlays on the Lower Sandstones;
- Formation of Lower Sandstone with a thickness ranging from 50 to 300 meters. These lower sandstones are from top to bottom: arkosic fine red sandstones, fine quartzite sandstones, pink schistose sandstones. (HUGOT, 2002);
- A group of schists and volcano-sediments such as pelites, sandstone shales, gray-black gloss schists, tuffaceousschists and rare quartzite horizons. (Ouedraogo, 2006).

In addition, all these terrains are covered by late loose formations that support crop-friendly soils. These are recent alluvial sediments (in the valleys) or old (on the "plateau") as well as colluvial deposits at the base of the reliefs.
Concerning the hydrogeology, the alluvial plain of Karfiguela comprises two main entities:

- The sedimentary zones

The sedimentary zone consists of a thick series of rocks that contains several aquifers. It is an ancient sedimentary basin, mostly sandy. Some aquifers provide very high flows of the order of several tens of cubic meters per hour (GIRE, 2001).

- The basement rocks

The crystalline basement zone is predominantly granitic with schists, green rocks and dolerites. The exploitable discharges are modest. Water resources are either in the weathering zone or in fractured rock (GIRE, 2001).
In addition, hydrogeological studies carried out by the Valorization of Water Resources Program of South-West Burkina Faso (Gombert, 1998) show that the distribution of aquifer reserves is very uneven. Indeed, the sedimentary zone that covers 20% of the basin contains more than half of the aquifer reserves.

3. Materials and Methods

The rate of exploitation of an aquifer, defined as the ratio between the annual volume of extracted water and the volume of water annually renewed by rainfall recharge (equation 1), is frequently used as quantitative indicator of the degree of exploitation of the groundwater resource (Orban et al., 2006).This indicator suggests that the sustainable use of the groundwater resource is not to exceed its annual renewal rate; neglecting the fact that groundwater provides many other essential uses, such as the base flow of stream during dry season or the supply of springs. The exploitation of the Karfiguela aquifer is mainly intended for agricultural purposes. These operations are done with various water extraction ways (pedal pumps, motor pump, and watering cans). Referring to the above definition of the exploitability rate, we will first estimate the volumes of water extraction from the plain and secondly we will estimate the volume of water that recharges the plain.

$$\theta(\%) = \frac{V_p}{R} \times 100 \qquad \text{equation 1}$$

Where Vp (m^3) the annual volume of water extracted from the plain, R (m^3) the annual recharge.

3.1. Estimation of water extraction

The method used for water extraction estimation is based on the sum of the volumes of water pumped and extracted manually by farmers in the alluvial plain during the dry season from October to May. The water extraction ways are motor pumps, pedal pumps and watering cans. The implementation of this method of estimating the volumes extracted required field surveys. These surveys covered the number of motor pumps, pedal pumps and watering cans as well as their respective discharge, also taking into account irrigation schedules for each speculation.
Two major assumptions are made for the estimation of the volumes of water extracted. These include:

- The drought period extends over a period of 8 months, from October to May, allowing two off-season agricultural campaigns to be conducted.
- In the case of farms with a variable irrigation schedule (due to the plurality of crops), the maximum duration (in hours) of daily irrigation as well as the maximum of days of irrigation are considered for calculations.

3.2 Recharge and groundwater storage change estimation

For the estimation of groundwater recharge and groundwater storage change, we used Thornthwaite and water table fluctuation methods, respectively.

3.2.1 Recharge estimation

Thornthwaite's approach uses the water balance at the catchment scale. It is based on the assumption that for a given time interval, the total inflow of water into a catchment is equal to the total of water outflows summed by the positive or negative water stock change.
This balance can be written in the form of an equation involving various parameters:

$$P = E + I + R + \Delta S \qquad \text{equation 2}$$

Where P(mm) is rainfall, E(mm) potential evapotranspiration, I(mm) infiltration that recharges the aquifer, R(mm) is runoff and ΔS is soil water stock change.
The equation 2 can be rewritten involving the easily usable reserve (RFU) of soil (equation 3).

$$RFU_{i-1} + P_i - ETo_i - RFU_i = I_i + R_i \qquad \text{equation 3}$$

Where for a given month i, RFU_{i-1}(mm) is Easily Usable Reserve of the previous month, P_i(mm) is precipitation, ET_{oi}(mm) is Potential Evapotranspiration, RFU_i(mm) is Easily Usable Reserve, I_i(mm) is water infiltrated (recharge), R_i(mm) is runoff.

The computing of this equation allows us, on the one hand, to find the actual evapotranspiration values for each month. On the other hand, it allows us to find the annual value of the effective rainfall from which the part of runoff must be deducted to find the infiltration in the alluvial aquifer according to the equation 4:

$$\text{Recharge (I)} = (I + R) - R \qquad \text{equation 4}$$

Where I(mm) is water infiltrated (recharge) annually and R(mm) is annual runoff.
The portion of runoff can be determined from the computation of Runoff Coefficient (C_r) formula which is the ratio of the rainfall participating in the runoff to the actual rainfall recorded at the ground (equation 5):

$$C_r = \frac{Le_R}{Le_p} \leftrightarrow Le_r = R = C_r \times Le_p \qquad \text{equation 5}$$

Where Cr (%) is runoff coefficient, Le_R(mm) is rainfall participating in runoff, Le_P is rainfall recorded at the ground. The computation of the runoff coefficient for a given period involves the decomposition of the flood hydrograph plotted from the data collected by the gauging stations in the study area.

The runoff coefficient of the alluvial aquifer of Karfiguéla is estimated at 9.830% (Sankande, 2012).The average monthly rainfall and temperature data from 1981 to 2014 were used to calculate the various parameters.

3.2.2 Estimation of groundwater storage change

Various methods in aquifer recharge estimation exist. Most of them are tributary to recharge mechanism, climate conditions and estimation hypothesis. The WTF method among others is seen to be one of the most used methods (Healy et al., 2002) for its independence from climate conditions as stated Scanlon et al. (Scanlon et al., 2002) and the recharge mechanisms. The method's popularity comes from its straightforward use and general availability of water table data for recharge estimation (Obuobie, 2012). WTF method is based on hypothesis that any water table rise in unconfined aquifer is due to recharge (Cai and Ofterdinger; 2016). The employed methodology is based on applying the WTF method in conjunction with the groundwater budget method developed by Marechal et al. (2006). The WTF method allows estimating change in groundwater storage based on water level fluctuation (equation 6).

$\Delta S = Sy * \Delta h$……………………………………………………………….Equation 6

Where ΔS is change in groundwater storage; S_y is specific yield or the quantity of water drains from the aquifer by the gravity force; Δh is water level fluctuation.

The WTF Δh is estimated from hydraulic head measurements from piezometers of the site which are not influenced by water abstractions from pumping boreholes. Daily monitoring from 2013 to 2015 of piezometers taping the aquifer provided data for Δh determination. The specific yield S_y of the alluvial aquifer of Karfiguela was determined by pumping tests (long-term tests). The average value of S_y estimated in the alluvial plain of Karfiguela is 0.842%.

3.3 Estimation of the sustainability of the aquifer exploitation

The sustainability of the groundwater resource in the alluvial aquifer of Karfiguela depends on many internal and external factors. A balance of inputs and outputs (ΔQ) in this aquifer (equation 7), related to the volume of the exploitable resource, could be used to estimate the number of years of exploitation (equation 8):

$\Delta Q = \left(V_R + V_{Ri_p} + V_{Ap_p}\right) - \left(V_P + V_{P_{Ri}}\right)$……………………………………Equation 7

Where V_R (m^3) is recharge; V_{Rip} (m^3) aquifer water inflow from the stream to the aquifer; V_{APp} (m^3) is water inflow from the deep aquifer; V_P (m^3) is water extracted; V_{PRi} (m^3)is water outflow from the aquifer to the stream;

$X = \frac{V_{RESE}}{|\Delta Q|}$………………………………………………………………….Equation 8

Where X is number of years of future exploitation and V_{RESE} (m^3) is volume of the exploitable water resource.

4. Results and Discussion

4.1Estimation of water extraction

The volumes of withdrawals according different water extraction ways in the alluvial plain are recorded in Table 1. The values show that almost all the groundwater withdrawals in the aquifers are carried out by motor pumps. In addition, these groundwater withdrawals concern a part of the localities hosted in the alluvial plain, namely the villages of Karfiguéla, Kitobama, Lemouroudougou and Siniena. However, farmers in the villages of Karfiguéla and Lemouroudougou extract more groundwater while those in the villages of Siniena and Kitobama have lower percentages of exploitation.

Table 1. Volume of water withdrawals according to extraction ways in the alluvial plain of Karfiguéla

Withdrawalway	Volume (m^3)
Motorpumps	199680.00
Pedalpumps	0.00
Wateringcans	152.00
Total	199832.00

4.2 Estimation of groundwaterrecharge

The table 2 shows the effective annual rainfall. The annual runoff obtained from the total annual rainfall recorded at the ground and runoff coefficient is estimated at 101.8 mm/ year. This value subtracted from the effective annual rainfall (I + R) allows us to estimate an annual groundwater recharge of 40.5 mm / year. Therefore, considering the surface of the alluvial plain (46 496 000 m²), the volume of water having recharged the aquifer is estimated at 1 884 891.950 m³.

Table 2: Values of effective rainfall computed using Thornthwaite water balance method applied to the alluvial plain of Karfiguéla.

Month	ETP (mm)	P (mm)	RFU (mm)	ETR (mm)	I+R (mm)
January	193.299	1.155	0.000	1.155	0.000
February	180.537	1.797	0.000	1.797	0.000
March	197.079	16.770	0.000	16.770	0.000
April	187.203	60.670	0.000	60.670	0.000
May	178.559	101.888	0.000	101.888	0.000
June	148.607	145.530	0.000	145.530	0.000
July	134.796	184.233	49.438	134.796	0.000
August	126.758	265.458	100.000	126.758	88.137
September	132.314	186.439	100.000	132.314	54.126
October	159.478	62.236	2.758	159.478	0.000
November	168.056	7.194	0.000	9.952	0.000
December	183.467	1.464	0.000	1.464	0.000
Total (mm/year)		1034.833			142.263

4.3 Estimation of groundwater storage change

The use of the water table fluctuation method in the alluvial plain of Karfiguela shows that the interannual mean of the positive piezometric head variations (Δh) is equal to 4804.7 mm. The water storage change is then estimated at 1881039.98 m³.The recharge value estimated using Thornthwaite method and the groundwater storage change value estimated using water table fluctuation method are substantially identical. In other words, the annual recharge is approximately identical to the annual volume of renewable water.

4.4 Estimation of the exploitation rate of alluvial plain of Karfiguéla

The exploitation rate of the alluvial aquifer of Karfiguela is estimated at 10.60%. This rate indicates a low use of groundwater. In fact, among the 212 farmers in the plain, only 12 farmers use groundwater for irrigation. These situations are related to the easy access to surface water in the plain. Indeed, a supply from the Comoériver serves irrigated perimeters from surface water which remains sufficiently abundant despite the multitude of operators and climatic hazards. Moreover, the exploitation of groundwater in the plain would probably be limited red by the relatively high realization costs of wells and boreholes.

4.5 Estimation of the exploitation sustainability of the alluvial plain

In the alluvial aquifer of Karfiguéla groundwater abstractions are minimal compared to the annual recharge. This annual recharge largely balance the amount of water with drown by farmers and the sustainability of the water resource does not seem to be at risk. However, the change in the rate of exploitation by intensification of water abstraction caused by the arrival of new farmers should be regulated by local sensitization actions and field visits to better manage the groundwater resource. Environmental protection can also contribute to sustainable management by preserving the vegetation cover, which plays an important role in runoff and water infiltration. In addition, further studies on this aquifer, including the aquifer/river exchanges, would make it possible to understand the contribution of surface and groundwater on order to support a sustainable management with easy access.

5. Conclusion

The study of exploitation rate and sustainability of the alluvial aquifer of Karfiguéla revealed that the annual recharge is substantially identical to the variation of the groundwater stock. This recharge is around 1885000 m^3. Water abstracted from the aquifer is much lower than the volume of water renewed, about 10%. Therefore, the alluvial aquifer of Karfiguéla has sufficient recharge to compensate the withdrawals, so the sustainability of its exploitation does not seem to be threatened. The complete characterization of the studied aquifer is an asset in the search for its exploitation rate and facilitates the deductions relating to its durability. The work carried out during this study shows that sustainable management of the groundwater resource of the alluvial aquifer of Karfiguéla requires the union of stakeholders in their exploitation, namely farmers, policy makers and development partners.

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