A Coupled Hydrogeophysical Approach to Enhance Groundwater Resources Management in Developing Countries

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Abstract

The present paper aims mainly at promoting an environment-friendly method to detect and locate aquifers in a context of effective and sustainable groundwater resources management. Concretely, it is a matter of illustrating how traditional hydrological and modern geophysical methods can be used conjointly to characterize aquifers. Main hydrodynamic characteristics of the Pan-African aquifer obtained in this survey could be observed in all regions worldwide where the Pan-African geological setting is extended. And this environment-friendly approach, using conjointly geophysical and hydrological methods, can be used to explore aquifers elsewhere in the context of sustainable management of groundwater resources.

Keywords

Developing countries • Groundwater • Hydrodynamic parameter • Sustainable management • VES

1 Introduction

Nowadays, water scarcity is a serious concern throughout the globe and especially in developing countries. Vörösmarty et al. [1] established that more than a third of humanity lives with less than 1.7 m^3 of water per year. In the area including more than 20 countries in North Africa and the Middle East, there is a situation of chronic shortage where each person must settle for less than 3 l of water per day. According to the same authors, 4 million people die every year in developing countries from diseases caused by the lack of good quality water, and 6000 children die every day for drinking unsafe water. In such a context, groundwater, because of its better quality compared to surface water, is a resource which is highly valued by humans. In fact, in addition to its potential availability, regardless of the spatial distribution of population, its relatively better physicochemical quality [2] may help reduce water scarcity that billions of people are experiencing worldwide. Hence, the present paper aims at promoting an environment-friendly method to detect and locate aquifers in a context of effective and sustainable groundwater resources management. Concretely, it is a matter of illustrating how traditional hydrological and modern geophysical methods can be used conjointly to characterize aquifers. The effective and sustainable management of groundwater resources also involves the method used for at least two reasons, namely the accuracy and the way (environment-friendly or not) aquifers are located.

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2 Materials and Methods

2.1 Gathering and Processing of VES

Local aquifer systems have been located thanks to 50 VESs carried out in the study area using the Schlumberger configuration. The Terrameter (ABEM SAS-1000) was used with a spacing of current electrodes ranging from 1 to 300 m to directly measure the resistance $\Delta U_{MN}/I$. Then, the latter parameter enabled us to compute the apparent resistivity of the rock using Ohm's law expressed by Eq. 1, taking into account the geometric factor of the quadrupole device expressed in Eq. 2.

$$\rho_a = k\frac{U_{MN}}{I} \quad (1)$$

where

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$$k = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)} \quad (2)$$

The resistivity curves are interpreted using the reference curves derived from the VES conducted close to the 14 control-boreholes. Then, these reference curves are used to calibrate the inversion software IPI2Win [3]. In a more quantitative interpretation of the VES curves. The quantitative interpretation of the VES curves is conducted on the basis of a double assumption: the earth is horizontally stratified with the last layer, having infinite thickness, and each layer is electrically homogeneous and isotropic [3].

2.2 Pumping Tests

Fourteen out of 50 VESs are carried out near the reference boreholes where pumping tests were performed in order to experimentally determine the values of the flow rate Q and the transmissivity T (Eq. 3) for each point. The hydraulic conductivity K is computed as shown in Eq. 4, then the calibration method developed by Asfahani [4] is applied to analytically determine K values for the remaining VES points.

$$T = \frac{0.183Q}{\Delta s} \quad (3)$$

$$K = \frac{T}{h} \quad (4)$$

Q, h and Δs represent respectively the flow rate, the aquifer thickness and the drawdown difference according to Jacob [5].

The methodology consists in three major steps:

(1) Establishing an empirical relationship between R values obtained by interpreting the 14 reference VES, and $K\sigma$. In this relation, K is the hydraulic conductivity obtained by pumping tests and σ is the aquifer electrical conductivity.
(2) Using Eqs. 5 and 6 to determine the transverse resistance R and the longitudinal conductance S for the other 36 VES points where no borehole exists.

$$R = \sum_{i=1}^{n} h_i \rho_i \quad (5)$$

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad (6)$$

h_i and ρ_i are respectively the thickness and the resistivity of the ith layer.

(3) computing $K\sigma$ and, therefore, K for all VES locations from the empirical equation obtained in step 1.

3 Results and Discussion

3.1 From Pumping Tests

Pumping tests were carried out from 25th June to 19th August, 2016, in the Pan-African context of the Adamawa-Cameroon region by making flow levels, with constant flow for a short period of 1 to 8 h. Three parameters (time, drawdown and flow) are measured. Each flow level is followed by a pumping break for a period at least equal to the rise of water level, and by measuring the residual drawdown. 14 pumping tests were performed and pumping curves were plotted. These pumping tests enabled us to directly measure the flow rate, transmissivity and hydraulic conductivity values of the 14 experimental boreholes presented in Table 1. Note that this is an unconfined aquifer since water seeps from the ground surface directly above the aquifer.

3.2 Calibration Line

Hydrodynamic parameters have been deduced from the relationship established between R and $K\sigma$ and summarized in Table 2.

3.3 Contribution to the Sustainable Management of Groundwater Resources

Actually, an efficient and sustainable management of groundwater resources involves mainly the use and conservation of this resource, and the protection and the control of the environment and populations from hazards associated with it. This involves further care and precaution to conserve groundwater quality and quantity for a long-lasting use [6]. This paper contributes upstream to the efficient and sustainable management of groundwater resources. Indeed, before launching any action or investigation regarding the physico-chemical analysis, productivity, vulnerability, pollution and contamination, environmental impacts or sustainability and management improvement of groundwater resources, aquifers should first be detected and located accurately and then evaluated. Geophysical methods, such as VES, can contribute significantly to the precision in the location of aquifers and pumping tests to the determination of their hydrodynamic parameters. It's worth mentioning

Table 1 Parameters obtained from 14 experimental boreholes by pumping tests

VES N°	Q (m^3h^{-1})	σ (Ω^{-1})	T (m^2day^{-1})	K ($\times 10^{-6}$ m/day)	$K\sigma$ ($\times 10^{-4}$)
1	0.2	20	0.46	14.06	2.78
3	1.8	41	2.73	7.23	3.00
12	8.1	40	7.48	6.36	2.52
13	0.9	101	8.21	2.35	2.38
16	2.1	5	9.25	3.70	0.20
17	3.0	67	9.54	2.67	1.78
21	0.4	12	12.5	11.05	1.39
22	3.2	70	12.85	2.20	1.53
27	0.8	22	15.37	10.02	2.85
28	4.2	8	15.65	2.52	2.20
34	2.3	96	18.54	1.04	1.00
38	4.1	57	21.03	0.88	0.50
42	1.8	18	23.7	6.44	1.99
50	12.0	3	46.01	0.99	0.03

Table 2 Summary of Pan-African aquifers' characteristics

	σ ($\times 10^{-4}/\Omega$)	ρ (Ω.m)	T (m^2day^{-1})	K ($mday^{-1}$)	S (Ω^{-1})	$K\sigma$ ($\times 10^{-4}$)
Min	1.60	3	0.46	0.01	0.004	1.5
Max	122.15	825	46.02	1.68	5.25	428.5
Mean	17.29	228	15.46	0.46	0.61	28.5
SD	18.61	215	10.33	0.40	0.9	99.0

that the VES technique introduced and used in this study is "very" environment-friendly as it doesn't require any ground drilling.

4 Conclusions

In this study, the conjoint use of both hydrological and geophysical (VES in this case) methods is presented as a proficient approach for the efficient and sustainable management of groundwater resources. VES, which is environment-friendly, can contribute significantly to the precision in the location of aquifers, and hydrology (pumping tests in this case) helps in the determination of their hydrodynamic parameters. The present paper has clearly illustrated how hydrological and geophysical methods can be used conjointly to characterize aquifers. This ecological approach can be used to explore aquifers elsewhere in the context of a sustainable management of groundwater resources.

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