

The Continental Intercalary in Algeria: Analysis, Survey and Perspectives for Green Agriculture Development

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Abstract. The Northern Sahara Aquifer System (NSAS) is a complex system that includes several aquifers overlying most areas. The Continental Intercalary, also known as the "Albian groundwater" is an aquifer with impressive characteristics. It extends over three countries: Algeria, Tunisia and Libya. Intended for crop irrigation, the boreholes drilled in this Algerian aquifer, the boreholes carried out on this aquifer are artesian in their totality, with flows and pressures reaching in some places considerable values, of the order of 0,4 m³.s⁻¹ for the flow and 3.106 Pa for the pressure. These two parameters are necessary to appreciate the energy potential of the Albian groundwater. A survey of the Continental Intercalary was carried out to study its energy potential. We were able to gather all possible data concerning the boreholes in the Algerian aquifer part. The study covered 295 boreholes that were identified and well documented, spread over 3 regions in southern Algeria. The water from the artesian boreholes in the Albian groundwater is transported to storage basins (for drinking water supply, irrigation and industry) for later use, or distributed directly to users after lowering the temperature of the water in the cooling towers. In these operations, all the hydraulic energy is lost and external energy is required from the electricity grid to meet the needs. The cumulative energy potential of all the boreholes identified has reached the theoretical value of 168GWh/year, the equivalent of 14520 toe (ton of oil equivalent) that are lost annually. Best management of this natural resource will not only enable resilient and sustainable management of the production systems and the environment, but also the energy needed to cool the water, as well as the energy needed for the maintenance of the boreholes and the facilities in the direct neighbourhood.

Keywords. Albian, Continental Intercalary, Green agriculture, Energy Potential, Groundwater, Algeria.

I. INTRODUCTION

Energy and water are two essential elements to human beings and, globally, their demands are constantly increasing. The sustained growth of the world's population and living standards amplifies this phenomenon. The increasing demands of countries for energy security and water resource management have made hydropower a prime source of energy in the world.

Currently, one-sixth of the world's electricity, equivalent to 4096 TWh, is provided by hydropower plants making hydropower a major source of renewable energy [1]. At the same time, the world's energy production is mainly provided by fossil fuels. Fossil fuels are responsible for a large amount of greenhouse gas (GHG) emissions into the environment, thus contributing to climate change. In countries with high rainfall and/or significant surface water sources, Hydroelectricity is generated by water using turbines. Most of its production is consumed locally. It is the world's largest source of renewable energy and provided 16% of the world's electricity in 2017, making it the third largest source of global electricity generation [2]. Currently, hydropower stay one of the most mature forms of renewable energy in the world. In Algeria, the hydropower contributes with only 5% of the national electricity production. This low capacity is due to the insufficient number of water sites (dams) and the non-utilisation of all existing hydraulic structure [3] and climate drought during last year's [4-6].

Unfortunately, Algeria abandoned hydropower around the end of 2014. The decision to give up dam's electricity production was motivated by the fact that the level of hydropower production remains "meaningless" and considered as very low contribution to Algeria's energy balance [7].

One of the future solutions for hydropower lies in small hydropower which can contribute with 2% of the world's energy production [8]. The reduction of fossil fuel reserves has encouraged energy production from renewable sources and, at the same time, has promoted the development of technologies to limit electricity consumption [9]. The Continental Intercalary (CI) aquifer, known as the Albian aquifer, is highly coveted for its water as a widely mobilised resource in the Northern Sahara. The geothermal energy of the Intercalary Continental has been the subject of several studies [10-13]. It was a means to study the different possibilities of exploitation of this energy in all fields, including agricultural. However, the hydraulic energy of this groundwater has never been studied and its potential has never been quantified. On the other hand, recent studies [14,15] have mentioned the considerable hydraulic energy released by the Albian aquifer. Unfortunately, this potential is very quickly lost by dissipation in basins after passing through cooling devices [16]. The water from these Albian boreholes is therefore not used to its full value.

The principle of hydroelectricity generation is well known in the scientific literature [17,18]. However, it is necessary to use conventional turbine generators with specific characteristics in order to adapt them to the albian boreholes. Small hydroelectric power plants seem to be the solution. The nature of the energy and the type of hydropower available determine the type of small hydroelectric power plants to be provided for the same facility. As the albian borehole has nothing in common with dams or run-of-river flows, it requires equipment and facilities adapted to its characteristics.

The valorisation of the hydraulic energy potential of the Albian aquifer can only be done by the integration of devices such as hydropower turbines. This will allow the soft exploitation of the hydroelectric energy of the CI groundwater especially in agricultural areas where there is no electricity supply.

Considered a first in the region, a study of different boreholes in the Albian was carried out, taking into account the different aspects related to their construction, location and operation, in order to understand the distribution of the energy potential of the Albian aquifer. This approach will not only allow researchers to better understand the mechanisms and approaches used, but will also allow decision-makers to move towards green energy for sustainable development of the most disadvantaged sectors

II. THE CONTINENTAL INTERCALARY, PART OF THE NORTHERN SAHARA AQUIFER SYSTEM

The Northern Sahara Aquifer System (NSAS), shared between Algeria, Libya and Tunisia, contains very considerable quantities of water with very low renewability [19,20]. Over the last thirty years, the exploitation of NSAS water by drilling has increased from 0.6 to 2.5 billion m³ per year [21]. These formations are poorly supplied: about 1 billion m³ per year in total, infiltrated mainly in the foothills of the Saharan Atlas in Algeria, as well as on the Dahar and Jebel Nefoussa in Tunisia and Libya [22,23]. However, the study conducted by [], shows that the supply of these formations is very satisfactory, to the point of describing them as a renewable source. The NSAS occupies an area of more than one million km² in the western part of North Africa: with about 700,000 km² in Algeria (fig. 1), 80,000 km² in Tunisia and 250,000 km² in Libya.



FIGURE 1. Distribution of Continental Intercalary in Algeria [15].

The horizontal structure of the CI presents it in three sub-basins from West to East: the Western, the Central and the Eastern Basin. The vertical structure (fig. 2), presents it as a large multi-layered sedimentary entity [24,25].

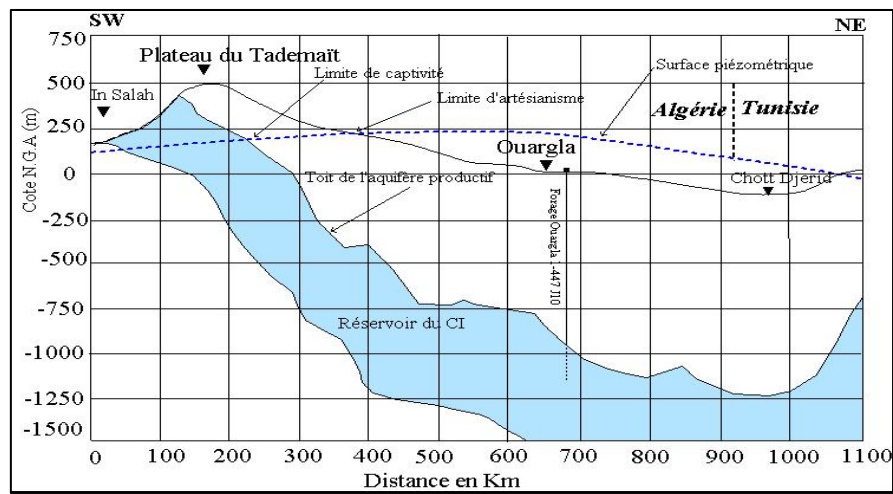


FIGURE 2. Longitudinal section of the Continental Intercalary [21].

The Algerian Sahara has an average geothermal gradient of around 4°C per 100 m. In the northern part of the Sahara, the average geothermal gradient is 3°C per 100 m. The temperature of the groundwater varies between 25 and 70°C, with an estimated average level of salinity between 0.5 and 6 g.l⁻¹ [13].

The Continental Intercalary (CI) is a deep reservoir in the Northern Sahara, with a depth to roof between 20 and 2000m, consisting of truly continental clastic (clay-sandstone) deposits that form a more or less homogeneous reservoir filled with fresh water. The Continental Intercalary aquifer has been exploited in the Algerian Lower Sahara since 1954 [26].

The volume of water contained in the CI is considerable. It can be estimated at 35,000 billion cubic metres, with an average supply of approximately 270 Hm³ per year and a flow rate between 0.05 to 0.4 m³.s⁻¹ [15]. These characteristics, put together, inform us on the immensity of this groundwater as well as on the potentialities of the latter from the regional, environmental and energetic strategy perspective.

III. METHODOLOGY

The survey was conducted on the boreholes of the Continental Intercalary in the Algerian territory. The data were collected from several organisations. We can mention as an example: ANRH-Alger (National Water Resources Agency), ANRH-Ouargla, ANRH-Touggourt, CRSTRA (Scientific and Technical Research Centre on Arid Regions), ONID-Alger (National Irrigation and Drainage Office), ONID-Ouargla, ONID-Touggourt, ABHS-Ouargla (Sahara River Basin Agency). We were able to synthesise all these data from the various organisations consulted. The parameters collected are multiple:

- Identification and location parameters: including the borehole name and reference number, which change depending on the agency. Also includes the Wilaya, region and commune where the well is located.
- Borehole type and completion parameters: including aquifer and groundwater type, completion date and current status of the borehole.
- Geolocation parameters: including the geographical coordinates of the borehole
- (altitude, latitude and longitude).
- Energy parameters: including the exploitable flow rate, pressure and temperature of the borehole.
- Other parameters: including dry tailings rate and water use from the borehole.

The main objective of this survey is to collect as much data as possible on the boreholes of the Continental Intercalary and to synthesise the data in a comprehensible and easily manipulated form. We focused on parameters that can give an idea of the energy potential, such as pressure, flow rate and temperature. Among the boreholes that we were able to identify, a significant number do not have geolocation or energy data; this led us to exclude them from the beginning of our study. The remaining boreholes were considered.

The processing of the raw data obtained from the survey shows 192 boreholes still in operation. We highlighted all the boreholes with flow data, which are 147. After placing the boreholes on the map of Algeria, we were faced with the necessity of removing 14 boreholes from the region of El Borma in the extreme east of the Wilaya of Ouargla, which were considered to be very far away geographically and could constitute outliers that could compromise the analysis.

The Continental Intercalary groundwater has a high-energy potential. Two parameters are sufficient to obtain the exploitable energy potential translated by the useful driving power of a pump: the exploitable or turbinable flow and the pressure. The exploitable flow rate is the quantity of water arriving at the inlet of the turbine-generating unit.

This flow rate is equal to the exploitable flow rate of the borehole itself, which is measured in the field by the concerned services and organisations. Once the values of the flow rate and pressure have been obtained (measured in the field or obtained by estimation/calculation), it is possible to define the exploitable potential by the relationship derived from the fundamental power equation. The exploitable potential or the power developed is expressed as follow in equation (1):

$$P_{exp} = p_r \cdot Q_t \quad (1)$$

With:

P_{exp} : power in W.

p_r : pressure in Pascal.

Q_t : exploitable/turbinable flow ($m^3 \cdot s^{-1}$)

IV. RESULTS AND DISCUSSION

The analysis of the data collected through the survey revealed several results. The parameters "flow rate" and "pressure" are represented by only 50% of all boreholes and the parameter "temperature" by only 6% for a total of 295 boreholes as shown in fig. 3. However, as these three parameters represent the energy component of the boreholes, only those in operation should be considered. These percentages will therefore become 77% for flow, 77% for pressure and 10% for temperature, for a total of 192 boreholes currently in operation (fig. 3).

After grouping the data relating to the general state of the boreholes, we were able to classify them into two categories: "exploited boreholes" and "non-functional boreholes", with 65% and 35% of the total number respectively. Non-functional boreholes represent boreholes that are not operated, abandoned, blocked, stopped, closed or not found in the field (fig. 4).

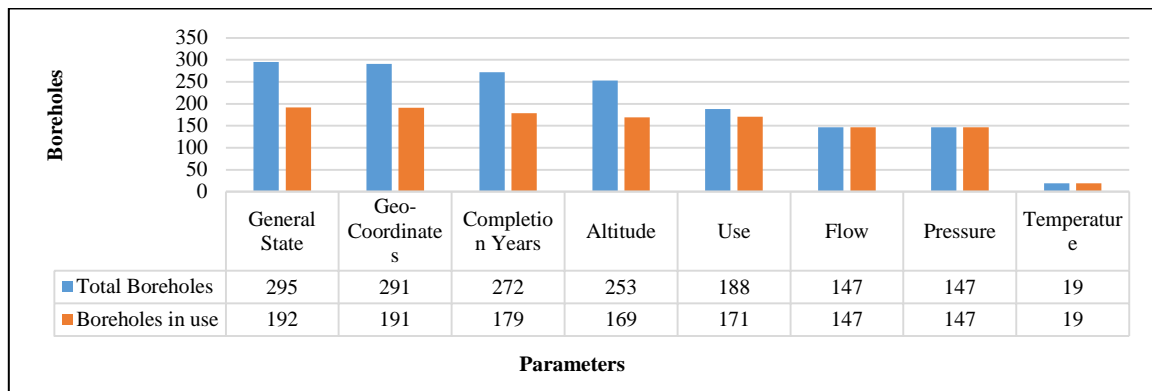


FIGURE 3. Number of boreholes by parameter and type of borehole.

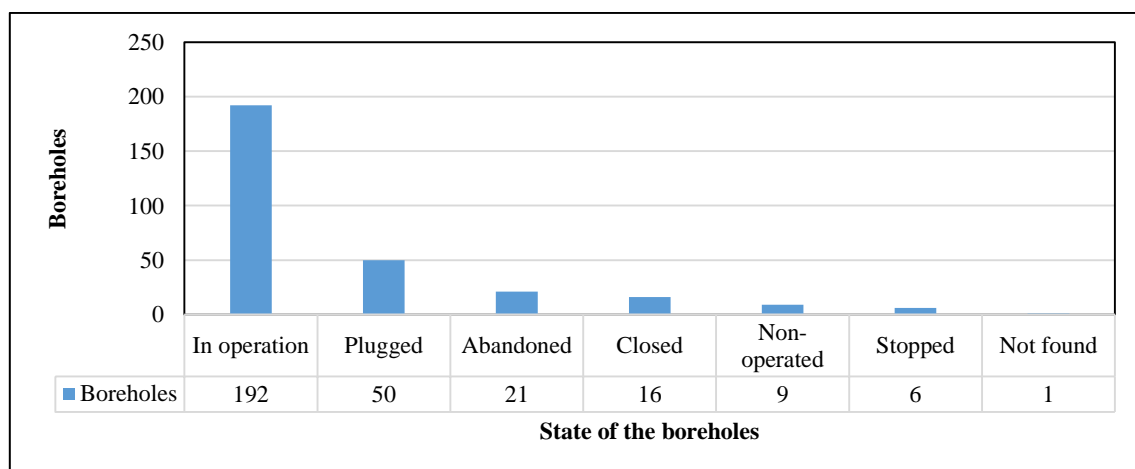


FIGURE 4. Distribution of boreholes according to their general condition.

We tried to find a link between the "state of the boreholes" and the "date of their completion" for all boreholes. After statistical analysis, we conclude that there is no significant correlation between these two variables. Indeed, none of the pairs of variables shown on the Pearson correlations table has probability values below 0.05, indicating a correlation coefficient not significantly different from 0 at the 95% confidence level (table 1).

TABLE 1. Presentation of the correlations through multiple regression, between age of completion and drilling status (C:Correlation ; S : Sample Size ; P : Probability).

	Year	Status
Year		C : 0,0550 S : (272) P :0,3663
Status	C : 0,0550 S : (272) P : 0,3663	

We noted that several boreholes are more than 40 years old and are still in operation. On the other hand, there are some very recent boreholes that are not operational. The reasons for this phenomenon are therefore not natural but probably follow a political logic or other measures linked to the socio-economic aspect, such as: strategic drilling, temporary drilling, change of use of neighbouring land, relocation of people, new agricultural decisions, etc. As temperature data are very scarce, we focused on flow rate and pressure corresponding to the data that can be used when calculating or estimating the hydraulic energy of CI boreholes. In this context, the number of boreholes with the "pressure and flow rate" data pair is 147, corresponding to 50% of the total number of boreholes surveyed, which remains low. It should be noted that only 18 boreholes have all the energy data (pressure, flow and temperature), representing 9% of the boreholes currently in operation. This lack of flow, pressure and temperature data disadvantages the study of the energy potential of CI boreholes. It is obvious that the operators directly and indirectly responsible for the boreholes were satisfied with listing the boreholes and recording only the information judged to have priority, such as the general state of the boreholes, their location and eventually the flow rate. The result of the survey in terms of "water use" is presented in figure 5. More than 10% of the wells in operation are for "undefined use". The industrial sector accounts for 43% of the boreholes in operation, which is still very important, followed by irrigation with 28% currently in operation against only 11% for drinking water supply.

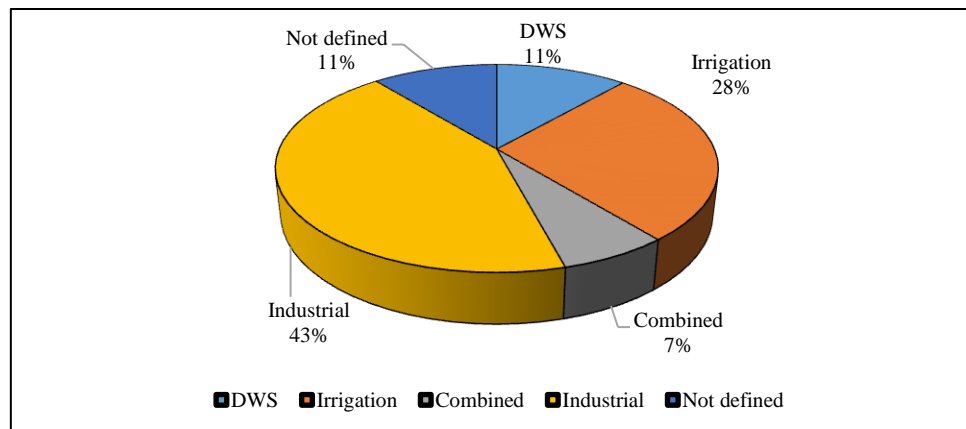


FIGURE 5. Use of groundwater from the CI.

The low share dedicated to water supply is not an indicator in itself, given that there are other aquifers such as the Terminal Complex which is often used for this purpose, thus compensating for the shortfall in this category. The boreholes intended for industry are all located in the wilaya of Ouargla, with its various industrial zones, the most important is Hassi Messaoud, which accounts for more than 57% of these boreholes. The regions most represented by agricultural use are located in the North-East of the CI aquifer (El-Meghaier, Djamaa, M'rara and N'Goussa).

The dominance of boreholes dedicated to irrigation in this region goes hand in hand with the Algerian policy of agricultural development of the Saharan zones. Indeed, the programmes launched in this respect have been accompanied by the drilling of boreholes for irrigation [15].

Irrigation is most often accompanied by an increase in the supply of drinking water due to the displacement of populations to these areas. This is reflected in the drilling of boreholes for drinking water in the agglomerations. Dual-use boreholes (representing 7%) are relatively old (before 1989); they were made to support small population with modest agricultural requirements (fig. 5). The most of the identified boreholes are distributed between the wilaya of Ouargla and the wilaya of El Oued with 79% and 11% respectively (fig. 6), followed by the wilaya of Touggourt with 5%. The rest of the boreholes (17%

of the total number of identified boreholes) are distributed among several other wilayas. Ghardaïa is represented in this survey by only 7 boreholes. This amount does not represent the reality at all, as the region of El Goléa (El Menia) is supposed to be well endowed with boreholes intended for irrigation according to the development plan of the Ministry of Agriculture, Rural Development and Fishing in collaboration with the national banks (ETTAHADDI and IMTYAZ agricultural credit granting formulas). The data on these boreholes will probably be classified in a future inventory.

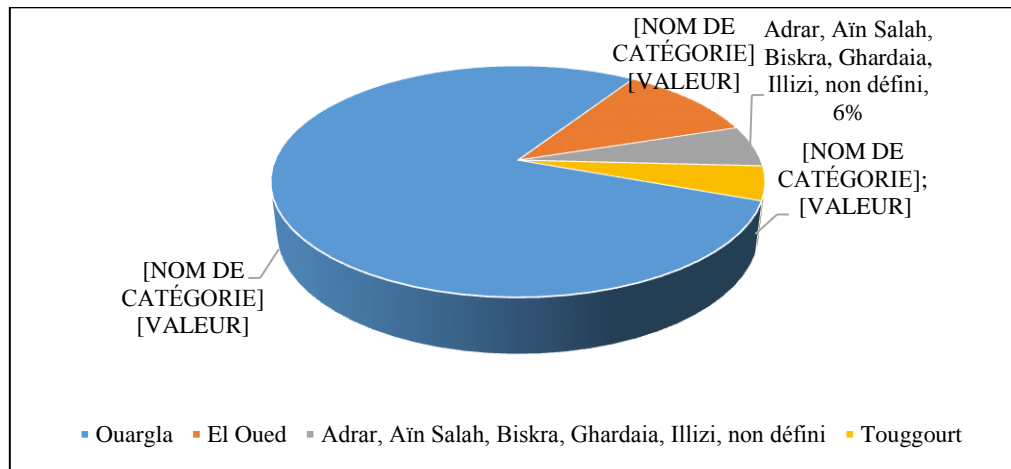


FIGURE 6. Distribution of boreholes by Wilaya.

Almost half of the boreholes in the wilaya of Ouargla (47%) are located in the commune of Hassi Messaoud and are mostly intended for use outside the agricultural sector. This is due to the industrial nature of the region, which is mainly used for hydrocarbons. The region of Djamaa is represented by 47% of the boreholes identified in the wilaya of El Oued. The vocation of the region is expressed by the number of boreholes intended for agricultural use, representing 60% of the boreholes in the locality. The rest of the boreholes are intended for drinking water supply.

It should be noted that the region of Oued Righ, an agricultural region located between the wilaya of El Oued and the wilaya of Touggourt, has 78% of the boreholes of the 2 wilayas. This is not negligible, as the region has benefited from agricultural re-launch projects in the 2000's [27-29]. The analysis of the "date of commissioning of boreholes" is important, as it mainly tells us about the longevity of artesianism. The boreholes drilled for each date class, from 1951 to 2010 is presented under the fig. 7. It should be noted that 23 boreholes have an unknown date of completion.

The period from 1951 until 1960, before Algeria's independence, present a clear increase in the number of boreholes, coinciding with the period of awareness of the immensity of the Continental Intercalary aquifer [30]. The period from 1971 to 2000 is characterised by a clear improvement in the realisation of boreholes, which is mostly explained by Algeria's intention to launch the agricultural sector in arid zones [31-33].

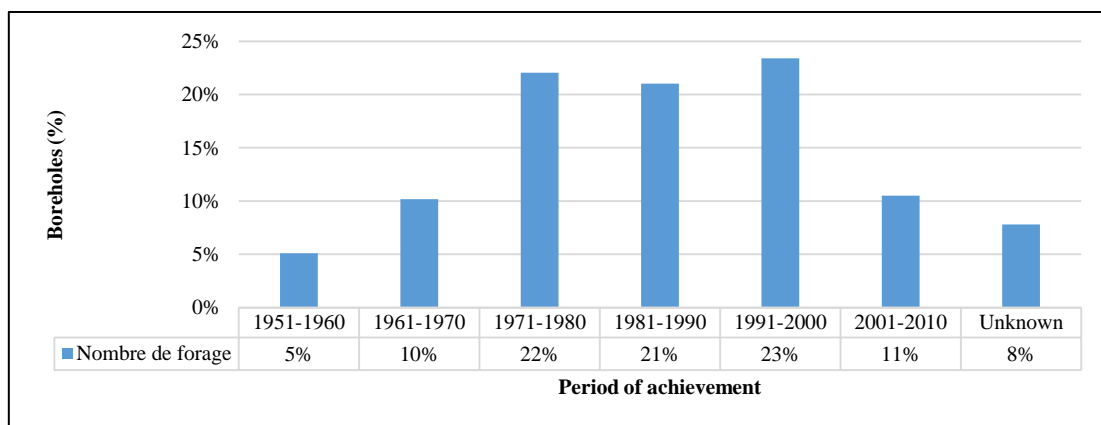


FIGURE 7. Distribution of boreholes surveyed by date of commissioning.

This period (1971-1990), coinciding with the agrarian revolution and the nationalisation of hydrocarbons and their exploitation [34-36], and the one that followed (1991-2000) influenced the exploitation of the CI. Indeed, 41% of these boreholes are intended for the hydrocarbon industry, while irrigation and water supply share 59% of the boreholes, without taking into account the boreholes with unknown year of completion. This can certainly be explained by the expansion of urban areas in the South of Algeria [37]. As a consequence of the rising waters problems in the wilaya of El Oued [38-40], we believe that the State has significantly decreased the number of boreholes in the region to a number of 11 boreholes drilled in

10 years (period 2000-2010). However, this figure remains modest and can be completed by boreholes with unknown completion dates, as we found a record of 09 boreholes completed between 2004 and 2008 according to a consortium of drilling companies. A comparison between the number of boreholes currently in operation and all the boreholes drilled in the same periods is presented on fig. 8.

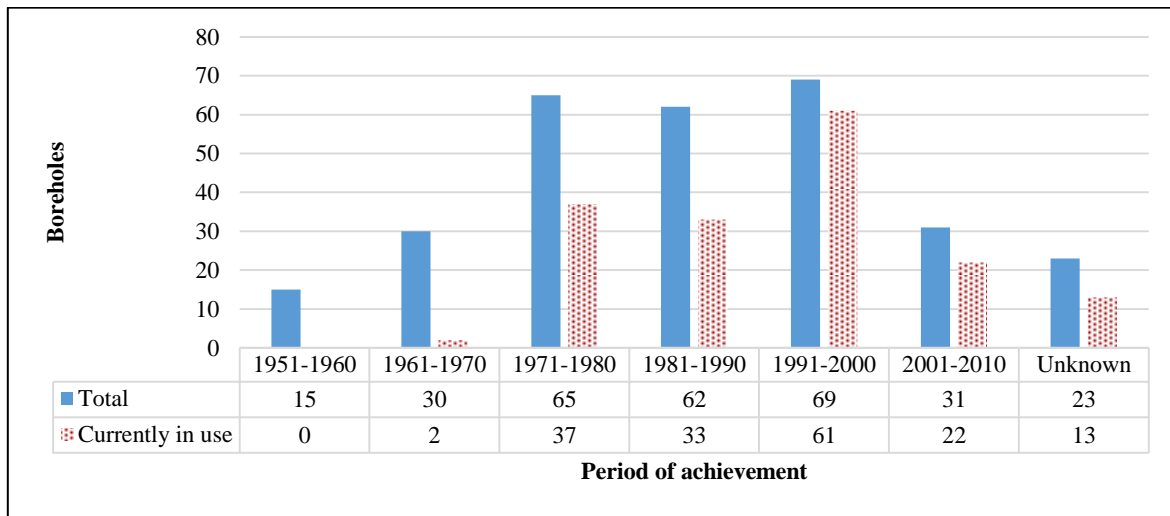


FIGURE 8. Comparison between the number of boreholes currently in operation and all boreholes drilled for the same periods.

There has been more efficiency in the implementation and management of boreholes since 1990; there are fewer non-functional boreholes [41-44]. On the other hand, we note that an average of 50% of the boreholes recorded over the period from 1970 to 1990 are currently non-functional. The evolution of the average number of boreholes operated per year for each year class is presented under fig. 9. It clearly shows the progressive evolution from 3 boreholes per year to 7 boreholes per year for the period between 1961 and 1980. Then, the balance during the period 1980 to 2000 with an average of 7 drillings per year.

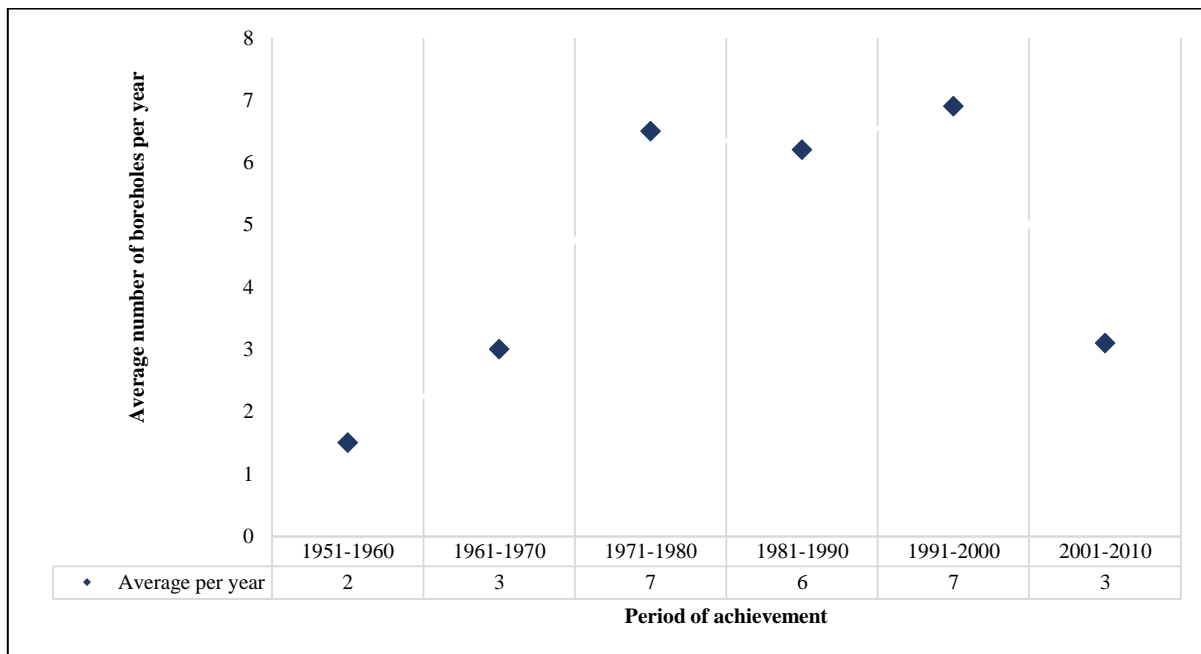


FIGURE 9. Evolution of the annual average number of drillings per year class.

The last period shown in figure 9 marks a turning point in the management of boreholes in the CI. Indeed, after the creation of a consultation entity (Observatoire du Sahara et du Sahel) between the countries sharing the Continental Intercalary aquifer, the number of boreholes was reduced in order to preserve the water of this aquifer [45].

The CI groundwater is covered for its artesianism. The analysis of the period of operation of the boreholes is very important, as it tells us mainly about the longevity of this artesianism. Indeed, from fig. 10, we can see that several boreholes are still in "artesian" operation, and this since 1960 to date. In the period from 1991 to 2000, we note that 40% of the boreholes currently in operation have flow and pressure data. This period has seen an increase in awareness of energy-related

data collection in the field. We believe that agricultural support and promotion programmes have done much to promote this kind of approach.

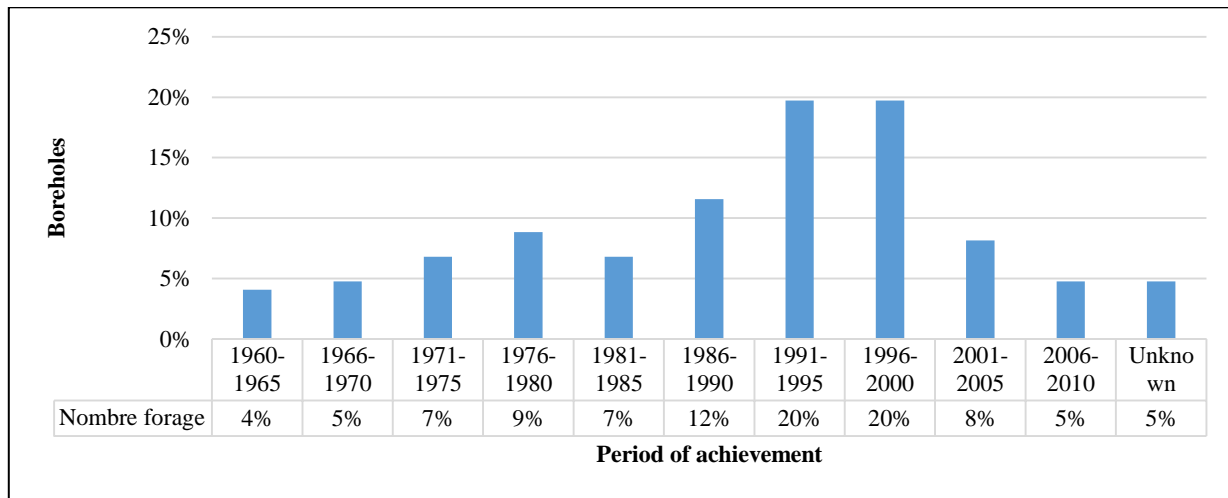


FIGURE 10. Distribution of boreholes currently in operation with "flow and pressure" data by period of completion.

The data related to the "energy" aspect of the Continental Intercalary boreholes currently in operation, together with the energy potential calculated using the formula presented in the methodology, have been synthesised and are presented in fig. 11. This figure allows us to clearly visualise the energy potential by categorising the boreholes. The cumulative hydropower of all the boreholes exceeds 19MW which is lost every second, throughout the year, as it is not exploited. The calculation of the not exploited energy from all the Albian boreholes during a year, brings us to more than 168.9 GWh per year, corresponding to more than 14520 toe. The production of the hydropower in Algeria represented only 389.4 GWh of the 28950 GWh produced by the national electricity office. Most of the electricity production in 2014, i.e. 18,723 GWh, was generated by thermal generator using gas-fired. The maximum energy potential is reached by a borehole in the region of Hassi Ben Abdallah, wilaya of Ouargla, with almost 1.3 MW, which accounts alone for 7% of the cumulative energy potential of all the boreholes currently in operation with "flow-pressure" data. We noticed that 6% of the boreholes have a potential of more than 500kW, accounting for 30% of the cumulative energy potential. These boreholes are mostly located (75%) in the wilaya of El Oued (Oued Righ region) and are intended for irrigation. This places the Oued Righ region at the top of the list of sites with significant exploitable energy potential.

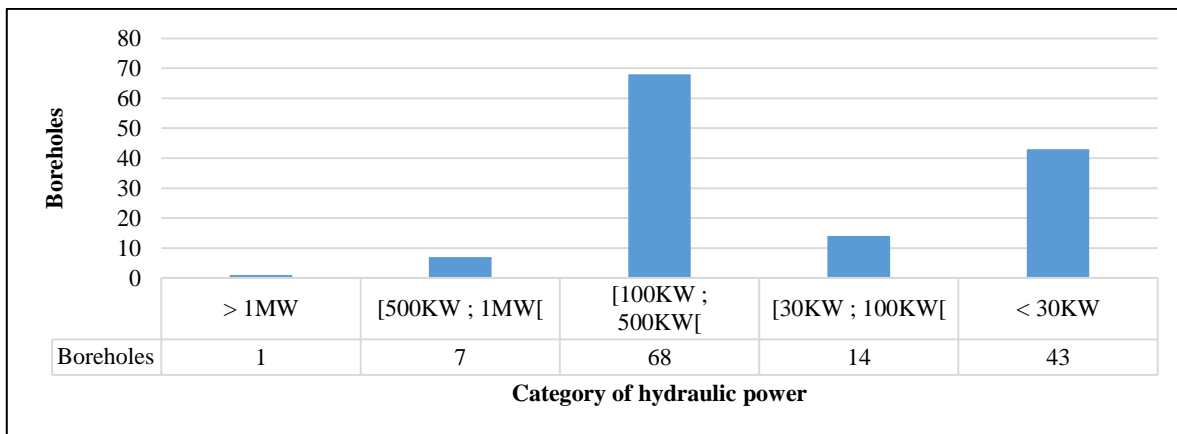


FIGURE 11. CI boreholes currently in operation by hydraulic capacity category.

Other boreholes, which are 68 and representing 51% of these boreholes, have a very satisfactory energy potential, varying between 100kW and 460kW. These boreholes, with their well-developed potential, can meet the needs of neighbouring farms, local homes and almost the entire region if a serious and well-studied project is initiated to integrate a hydraulic energy conversion system into electrical energy.

The minimum power required on a borehole is the power needed to lower temperature of the water in that borehole. During our field visit, we took the electrical power of the motors running the fans on the cooling towers, which is around 30kW. The 43 boreholes with a hydropower of less than 30kW (representing 32%) can be considered uneconomic for individual projects. However, these boreholes remain interesting if there is the possibility of combining their capacity, which exceeds 480 kW together.

CONCLUSION

The water of the Continental Intercalary with "artesian" character makes it very coveted by the agricultural sector, which benefits from a water resource that can be immediately mobilised in sufficient quantity and without pumping. It is endowed with energy in the form of pressure and flow rate that reach very high values. Unfortunately, this energy is dissipated in nature without being used. The borehole itself as well as the neighbouring farms require electrical energy for their operation (cooling water for irrigation, air conditioning of livestock buildings, etc.). To meet their energy needs, farmers rely on the public electricity distribution network [15], whereas the energy potential of the water in the Albian aquifer can meet their needs, or even achieve self-sufficiency, by integrating a device for transforming hydraulic energy into electrical energy. The results of the field survey conducted carried out to quantify the energy potential of the Albian aquifer are summarised as follows:

- We identified 295 boreholes with minimal data. However, we know that the number of boreholes is much higher, as a result of our repeated field trips. Unfortunately, we did not find any written record of their presence. From the documents collected from the relevant agencies, there are only 192 boreholes that are currently in operation. We notice the lack of information on the boreholes in the wilaya of Ghardaïa, particularly those in the region of El Ménéa (el-Goléa), which is known for its agricultural vocation.

- Of these 192 wells currently in operation, only 147 have "flow and pressure" data. "Temperature" data is only available for 10% of the wells currently in operation. We have no information justifying the non-availability of these data. Only 18 boreholes have all the energy data, representing 9% of the boreholes currently in operation. This lack of flow, pressure and temperature data reflects the neglect and disregard of the energy potential of Albian boreholes. Only 133 boreholes correspond to the criteria for the census of boreholes with energy-related data. Only these boreholes were included in the energy potential study.

- There are boreholes with a very high potential, exceeding 1 MW of power, and others with an output of just 1 kW. The calculated theoretical capacity of all the boreholes combined is 19 MW, bringing the annual energy lost to 168 GWh per year, corresponding to over than 14520 toe.

It would be appropriate, in the future, to consider the development of this energy by the integration of hydropower plant. However, this integration must be considered by the initiation of a thorough study of integration of these devices, so as to have a good coverage of the potentialities of the drillings. To achieve this goal, the creation of an entity or company that can provide the service and manage the production is more than necessary.

From another point of view, the study provided a global vision on the potential of the region in terms of green energy for a green agriculture. Decision-makers can take advantage of this study for a better mobilisation of resources and their effective and efficient management. Neighbouring countries (Libya and Tunisia) having the CI can also account for their potential energy for a development of green agriculture.

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