Original Research Article

Evaluation of the behavior of the sealing grout of the mining holes and verification of the conformity of mixing water and Izegouandane and Tarat aquifers: Case of the Mining Company of AKOUTA (COMINAK): Geotechnical and Environmental Approach

Summary

The aims of this study is to identify the behavior of the sealing grout in the Izegouandane and Tarât aquifers, which are the main water supply sources in the northern region of Niger, in order to prevent contamination and reduce the impact of uranium mining activities on the groundwater. This study also made it possible to evaluate the conformity of the mixing water as well as the bearing capacity of the grout in the aquifers crossed in order to verify its conformity. The study area is located in a desert zone in the northern band of Niger, in Arlit city. The measured compressive strengths are 60 bars for cylinder A, 52.5 for cylinder B and 62.5 for cylinder C with an average value of 58.33 bars. The deduced base stress value is 2.24 MPa. These results suggest that the grout made with CPJ 35 can resist under its own weight. The sampled mixing water has a pH of 8.7 with a suspended solids content of 0.02g/l, a Cl- concentration of 93 mg/l and nitrate and nitrite concentration values that are 5 mg/l and 12 mg/l respectively. These waters comply with the general specifications of the standards relating to the quality of mixing water and can therefore be used to fill in boreholes. The analysis of groundwater shows that for Izegouandane and Tarat aquifers the values of concentration of suspended solids are respectively 0.04 g / L to 0.001 g / L. The values of Ph of these waters are 8.7 and 8.1 respectively for the water table of Izegouandane and Tarat. The analysis of Izegouandane aquifer showed that the concentrations of chloride, nitrates and sulfates are respectively 32 mg/L, 9 mg/L and 36 mg/L. Those of magnesium, ammonium and carbon dioxide, they are respectively 1.5 mg/L, 0.8 mg/L and 0.5 mg/L. For the Tarat aquifer, the concentrations of chloride, nitrates and sulphates are respectively 47 mg/L, 29.5 mg/L and 47 mg/L. As for magnesium, ammonium and carbon dioxide, they are respectively 10.02 mg/L, 1.6 mg/L and 1.6 mg/L. These results show that these waters comply with the minimum specifications for environments considered to be slightly aggressive to concrete.

Key words: Water of Gâchage; grouting of obturation; Nappes of **Izegouandane; Nappe of Tarat**

Introduction

The global need for metals has increased exponentially during the 20th century. Despite this large demand for metals, the discovery rates of host mineral deposits and the grades of mined deposits are declining (**Guj and Schodde, 2013**; **Hillis,et al., 2014**; **Fredj 2012**) nowadays. The fate of several countries of the world in general and African in particular seems to be marked by the mineral wealth buried in the bowels of its subsoils. Among these metals, uranium is one of the most important because of its use in the production of nuclear energy. The current international context marked by the war in Ukraine has led to a drastic increase in the price of hydrocarbons, forcing the major powers to turn to nuclear energy. Uranium is a silver-white metal and a primary energy source. After uranium is mined and crushed, it is converted into fuel to power nuclear reactors to produce electricity. The amount of electricity generated by nuclear power plants may increase in the coming decades, as this form of energy is one of the few that is proven, reliable, and relatively carbon dioxide free

(**Macfarlane et al., 2007**). Uranium is also used for other purposes (less than 1%), including the production of medical isotopes and fuel for research reactors (**Grenthe et al., 2008**).

Niger, one of the poorest countries in West Africa, has an important uranium deposit in its northern subsoil, carved into the Upper Carboniferous formations dating back some 330 million years and resting on the edge of the crystalline Air Massif, which dates back to the Precambrian period. In the early 1970s, the Nigerian mining sector finally made its contribution to the country's economic take-off. As soon as the first indications of this metal were discovered, aerial and ground prospecting as well as investigation by drilling made it possible to prove the importance of the geological framework in which the uranium concentrations originated and, finally, to appreciate the factors favorable to the reworking of these first concentrations and their evolution towards stratiform, economically exploitable uranium mineralization (**Bigotte and Obellianne 1968**). Uranium exploration and mining activities are concentrated mainly in the Arlit department in northern Niger, where two major mines, Société des Mines de l'AÏR (SOMAÏR) and Compagnie Minière d'Akouta (COMINAK), have been in operation since the 1960s (**Pagel et al., 2005**).

However, mining exploration operations continue even during the ore exploitation phase. During the uranium mining process, the mines use drilling processes that can reach depths of more than 108 m.

In the study area, water resources are essentially covered by two superimposed aquifers: the IZEGOUANE aquifer, which corresponds to the water table, and the TARAT aquifer, which is located between the Tchinézogue and the Arlit base formations and contains uranium deposits (**Pallier 1984; Mamadou 2016; Mamadou et al. 2022)**. Indeed, the pollution of the water table during the exploitation of useful substances is a current problem that concerns all regions concerned with maintaining their water heritage at a high level of quality. At the level of the Société des Mines de l'AÏR (SOMAÏR) and the Compagnie des Mines d'Akouta (COMINAK), these extractive activities are carried out and developed below the level of the water tables. This situation has as main consequences the pollution of the groundwater of the region. In fact, in addition to the pollution due to the mining operations, the exploration drillings that continue during the mining operations also constitute a real channel for rapid contamination of the groundwater. Therefore, to mitigate this pollution, it is essential to plug these drill holes using appropriate materials.

The objective of the present study is therefore to identify the behavior of the sealing grout in the Izegouandane and Tarât aquifers, which are the main sources of water supply in the northern region of Niger, in order to prevent contamination and reduce the impact of uranium mining activities on the groundwater. This study also aims to evaluate the bearing capacity of the grout in the crossed aquifers in order to verify its compliance. Indeed, in order to set up anti-pollution measures for the crossed groundwater during the drilling operations and in the framework of the protection of the health and safety of the personnel and also of the local population, the mining companies must have an idea on the results of the physico-chemical analyses of the mixing water and on the physical measurements of the grouting.

Material and methods

Presentation of the study area, geological and hydrogeological context

The study area is located in a desert zone in the northern band of Niger, in the Agadez region, more precisely between latitudes 18°35'North and 18°43'North and longitudes 7°15'East and 7°20'East. This area is located in Niger, 240 kilometers north of Agadez, in the desert plains (less than 100 mm of average annual rainfall) of the western Air Massif, inhabited by a small number of Tuareg nomads (mainly Kel Tadele). The town, whose creation is linked to the inauguration of the factory in 1971, has not stopped expanding until recently: the construction of the paved Tahoua-Arlit road has made it possible to link the mine to the port of Parakou in all seasons (**Bernus and Lhote 1989**). The town of Arlit is part of the northeast extension of the Iullemenden Basin (671,000 km2) and this northeast extension covers approximately 100,000 km2. The climate of this northeastern extension of the Iullemeden Basin is continental arid/semi-arid with average annual temperatures ranging from 7.6°C to 43.7°C. In this region, the average annual precipitation is about 101.83 mm, decreasing from south (136.57 mm) to north (59.88 mm), and precipitation occurs mainly from July to September. Potential evapotranspiration in the basin is up to 2650 mm/year, ten times the annual precipitation (**Joseph 1991**; **Dobi 2021**).

On a local scale, the natural environment and the desert climate of the city of Arlit are relatively hostile, especially with the almost permanent sunshine. Maximum temperatures can exceed 40°C from March to October and border on 45°C from May to July. The nights are generally cool during the cold season with temperatures below 20°C. The warmest temperatures of the year are observed in the months of May and June with an average of 34.2°C at this period. The coolest temperatures are observed in January with the average temperature is 18.8 °C (SRK 2015; *Yaou Korgom 2019)*. Sandy winds and violent thunderstorms despite low rainfall (~50 mm/year on average) are observed in the region. This low rainfall results in the non-renewal of the water table. Indeed, there is no permanent watercourse. However, despite the low rainfall, the phenomena of runoff are important and there is a fossil hydrographic network still functional although degraded (kory Tim Mersoï, kory Talak, Etaghas...). Numerous dry valleys drain the meagre rains that fall on the region. The low permeability of the land (crystalline rocks, clayey sandstone, quartz sandstone, silty clay) and the absence of vegetation cover explain this runoff and the stagnation of water, even long after the rains. The vegetation is almost non-existent. Only a few groups of shrubs exist along the edges of seasonal koris. The runoff is very important in this area, characteristic of an indurated terrain. A network of koris drains the few rains in the area.

The geology of the region is characterized by two main features: the Aïr massif and the Tim Mersoï basin. The study area is located in the Tim Mersoi sedimentary basin. This basin is a sub-basin of the Iullemenden Basin (Phanerozoic) developed on the basement of the West African Proterozoic shield. The Iullemenden Basin covers most of the western part of the Niger Republic and extends into

Algeria (Tin Serine Basin), Mali, Benin and Nigeria. It opens and deepens towards the south and west. The Tim Mersoi Basin forms an appendage at the N-E end, and is located in a N-S trending "gutter" of the basement (*Ministry of Mines 2013)*. The stratigraphic division of the Arlit region includes the Precambrian composed of crystalline and crystallophyllous rocks; the Permo-Carboniferous including the Upper Tagora, Lower Tagora and Teradah series. Each of these three Permo-Carboniferous series begins with fluvio-glacial sandstones at Terag in the Teradah, a fluvio-estuarine formation at Gezouman in the Lower Tagora (with the radioactive conglomerate of Teleflak at the base) and fluvio-deltaic at Tarât, in the Upper Tagora the Permian, which corresponds to two cycles, including successively a fluvial episode (sandstones of the Izégouande and Tamamaït series) and a lacustrine episode (mudstone of the Téjia and Moradi series); the Triassic represented by the fine sandstones of the Téloua 1 and the Lower Cretaceous constituted by the lacustrine clay formation of the Irhazer (Rachid 2013; *Yaou Korgom 2019*)

The mining district of the town of Arlit records the deposits exploited by the Compagnie minière d'Akouta (COMINAK) and by the Société des Mines de l'Aïr (SOMAÏR). These uranium deposits are located on the eastern edge of the Tim Mersoi intracratonic basin near the Aïr massif. These mines are located in the area between latitudes 18°35'N and 18°43'N and longitudes 7°15'E and 7°20'E for COMINAK, and more precisely between 7°15' and 7°30' East longitudes, 18°30' and 19° North latitudes for SOMAIR. (Figure 1) Each of these deposits begins with a sandstone formation, fluvio-glacial in the Teragh in the Terada, Fulvio-deltaic in the Guezouman in the Lower Tagora, with the radioactive conglomerate of Teleflak at its base, and in the Tarat in the Upper Tagora (Lang et al. 1991).

Indeed, the water resources are essentially encompassed in two superimposed layers which are the layer of IZEGOUANE corresponding to the water table in the study area; it is strongly lowered in this part because of its proximity to the flexure and the influence of pumping. However, in the western part of the flexure, the hydrodynamic investigations made during the realization of the wells are part of "carbonated waters, with a suitable chemical quality, although it is mineralized. Piezometric measurements from 1971 show that the water flow is in a south-north direction. COMINAK's activities expose the waters of this aquifer to surface pollution"; and The TARAT aquifer is located between the Chinézogue and the Arlit base formations. This aquifer contains the SOMAÏR uranium deposits.

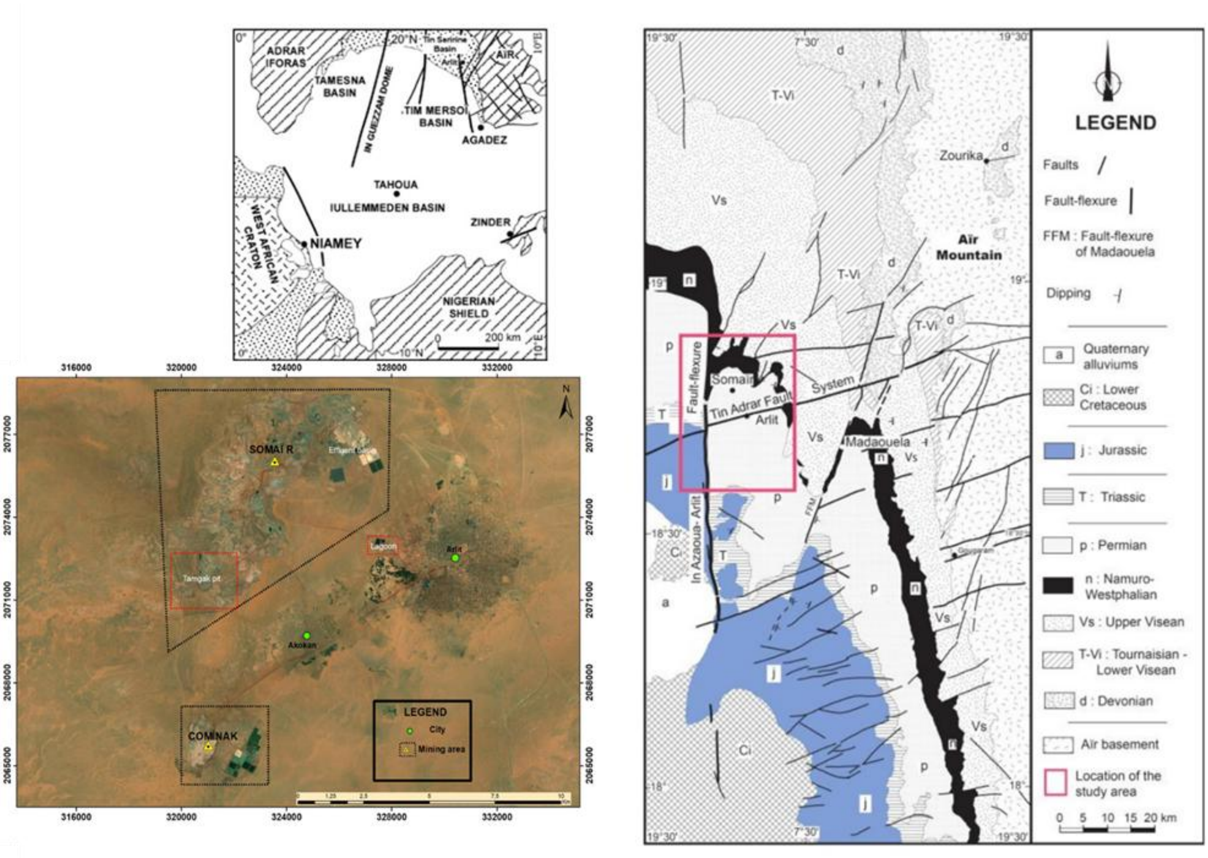

Figure 1: Presentation of the study area and the geological context (Alfidja et al. 2021)

Sampling Method

Core sampling

As part of the development of mining activities, deep drill holes are dug to better understand the deposits. At COMINAK, as at SOMAÏR, these drillings are carried out with a "MAZIER" type core drill, minus a plastic tube for core recovery. Four drill cores, with a depth of 108 m, were carried out in order to perform chemical analyses and mechanical tests.

Concrete preparation

For the filling of the boreholes, it is necessary to determine the mechanical characteristics of the injected concrete and also to determine the characteristics of the concrete components made. In this study, samples of concrete are made with the proportion of each element of the mixture, namely: water, binder, aggregate and possible reagents for the preparation of concrete, including high quality concrete with high strength (A); concrete with low permeability (B) and low strength concrete with little or no reinforcement (C). 200 Kilograms of sand and 200 Kilograms of gravel were used to make the concrete. Physical measurements of the grout were carried out to evaluate the bearing capacity for the indicated depth (108 m); and laboratory tests were carried out to identify the behavior of the grout in time and in the water of the crossed aquifers.

Sampling and analysis of mixing water and groundwater.

Samples of the mixing water and water table Izegouandane and Tarat were taken. Thus, the physico-chemical analysis of the mixing water was carried out to verify its compliance and to assess the level of aggressiveness of the water table Izegouandane and Tarat.

Indeed, the use of water in the mixing of a concrete requires the knowledge of a certain number of fundamental qualities resulting from specific physico-chemical analyses. These analyses, which determine the quality, the alterability and the interactions between the different constituents of the future concrete (mortar or grout), are diverse and are the subject of several standards, including the French standard NF P 18-303 and the French standard NF EN 1008. In addition to the requirements of the mixing water, the water of the crossed layers must be the subject of other specifications by comparing them to the standards in force, namely the French standard NF P 18-011 dedicated to the classification of the aggressive environments and the French standard NF EN 206-1 (P 18-325-1) allowing to know better the constituent elements of the concrete, the specification, the performances, the production and the conformity. The physico-chemical analyses of the water have thus focused on the proportion of suspended solids (SS), chlorides, sulfates, nitrates, nitrites, ammonium, dissolved carbon dioxide, magnesium and pH. These analyses are performed with an Innov-X XRF OMEGA. It uses the principle of X-ray fluorescence to characterize the elements. The results are given in real time, expressed in ppm with an indication of the accuracy and as the acquisition time increases, the accuracy improves (**Weindorf et al., 2014**; **Harper et al., 2007**)

Mechanical resistance tests

Mechanical strength tests were conducted on the cylinders of the grouting mortars and determined the compressive strength, breaking load, density and average compressive strength. Compressive strength is the ability of a material to resist vertically applied pressure without excessive longitudinal and transverse deformation. The breaking load is the force that causes the specimen to break in a tensile, compression, bending or torsion test. Density is the ratio of the mass of a body to that of the same volume of water (or air, for gases) (**Agati et al., 2004**; **Coutinho 1969; Baron 1982**).

Results and Discussions

Mechanical tests

The mechanical tests were performed on the cylinders of the grouting mortars and determined the compressive strength, the breaking load, the density and the average compressive strength. The diameter of the test hole is 16 cm, the density value of the grout considered is 1.9 at a depth of 108 m. The results of these tests are presented in **Table 1**. The analysis of this table shows that for the cylinders A, B and C whose weight of each is 10 Kg, the values of density for each of the cylinders are 1.9 and the values of loads of rupture are respectively 120 KN for the cylinder A, 105 KN for the cylinder B and 125 KN for the cylinder C. The values of compressive strength are 60 bars for cylinder A, 52.5 for cylinder B and 62.5 for cylinder C with an average value of 58.33 bars. The value of stress at the base deduced is 2.24 MPa. Thus, in view of these results, it appears that the grout made with CPJ 35 can resist under the effect of its own weight. After this phase of determination of the mechanical characteristics of the grouting, laboratory tests were also carried out. These laboratory tests consisted in determining the mechanical characteristics of the grouting, to submit intact portions of the latter to a stay of two months in the crossed waters (water of TARAT and Izegouandane). After the stay, the portions of the grout are removed and dried. Observations with a binocular magnifying glass were then made to see the state of these materials. It appears that no visible alteration of the grout was observed following these observations.

Table 1: Results of compressive strength, tensile strength and density tests

Test	**N° 1**	**N° 2**	**N° 3**
Cylinder number	**A**	**B**	**C**
Weight in Kg	**10**	**10**	**10**
Density	**1.9**	**1.9**	**1.9**
Breaking load (KN)	**120**	**105**	**125**
Compressive strength (bar)	**60**	**52.5**	**62.5**
Average resistance (bars)	**58.33**		

Compliance of the Physico-chemical Parameters of the Drainage Water

Mixing water is an essential element in the manufacture of concrete. It is added during the mixing process to hydrate the cement and to bind the concrete components together. Water also makes the mix much more manageable, making it easier to apply the concrete. Water is an essential part of the concrete mix and must be clean and must not be added in excess. If these two conditions are not respected, the concrete may be fragile and its performance will be altered (**Dreux 1981**; **Nedjmeddine and Eddine 2022**). Thus, before using water for mixing concrete, it is necessary to know its physical and chemical characteristics. These analyses, which determine the quality, the alterability and the interactions between the different constituents of the future concrete (mortar or grout), are various and are the subject of several standards including among others: the French standard NF P 18-303 and the French standard NF EN 1008. The water according to the NF P 18 303 standard must be free of organic matter, sulfates and have an acidity higher than 4 (***Aoual et al., 2009*)**. The results of physico-chemical analysis of the mixing water sampled in the present study are presented in **Table 2**. The analysis of this Table shows that the sampled mixing water has a pH of 8.7 with a proportion of suspended solids of 0.02g/l, a concentration of Cl^- of 93 mg/l and concentration values of nitrates (NO_3^-) and nitrites (NH_4^+) which are respectively 5 mg/l and 12 mg/l. It should be noted that the water used for the mixing of concrete must not contain suspended matter in excess of the following proportions: 2 g/L for type A and B concrete; and 5 g/L for type C concrete. Sulphate (SO_4^{2-}), magnesium (Mg^{2+}) and carbon dioxide concentrations are 1000 mg/l, 63.2 mg/l and 1.3 mg/l respectively. These results of physico-chemical analysis show that these mixing waters used by COMINAK are in conformity with the general specifications of the standards relating to the quality of the mixing waters and can thus be used to fill the holes.

Table 2: Comparative matrix of chemical characteristics of mixing water.

Elements	Results obtained	Permissible values	Observations
pH	7,4	More than 4	Condition verified
Suspended matter	0.02 g/l	Up to 5g/l	Condition verified
Sulphates	1000 mg/l	2700 mg/l	Condition verified
Salts	1183,2	5000 mg/l	Condition verified

Conformity of the Physico-Chemical Parameters of the Water of Izegouandane and Tarat

In addition to the requirements of the mixing water, the water tables including the water tables of Izegouandane and Tarat crossed must meet the requirements. It is therefore necessary to know its physico-chemical characteristics and to check whether these characteristics are in accordance with the standards in force, in particular the NF P 18-011 standard (classification of aggressive environments) and the NF EN 206-1 standard (***Delort 2004***) (P 18-325-1, Concrete, specification, performance, production and compliance). The following **Table 3** presents the results of physico-chemical analysis of the waters of Izegouandane and Tarat. The analysis of this table shows that for the water table of Izegouandane and Tarat the values of concentration of suspended solids are respectively 0.04 g/L to 0.001 g/L. The values of Ph of these waters are 8.7 and 8.1 respectively for the water table of Izegouandane and Tarat. For the water table of Izegouandane, the concentrations of chloride, nitrates and sulfates are respectively 32 mg/L, 9 mg/L and 36 mg/L. As for magnesium, ammonium and carbon dioxide, they are respectively 1.5 mg/L, 0.8 mg/L and 0.5 mg/L. For the Tarat aquifer, the concentrations of chloride, nitrates and sulphates are respectively 47 mg/L, 29.5 mg/L and 47 mg/L. As for magnesium, ammonium and carbon dioxide, they are respectively 10.02 mg/L, 1.6 mg/L and 1.6 mg/L.

The waters of the Izegouandane and TARAT aquifers comply with the minimum specifications of environments considered as weakly (or not) aggressive to concrete.

Table 3: Results of physico-chemical analysis of the waters of Izegouandane and Tarat.

Tablecloth of the Izegouandane		*Tarat Tablecloth*		*Permissible values*
pH	8,7	pH:	8,1	Above 6.5
Suspended matter	0.04 g/l	Suspended matter	0.001 g/l	
Chlorides	32 mg/l	Chlorides	47 mg/l	
Nitrates	09 mg/l	Nitrates	29.5 mg/l	
Sulphates	36 mg/l	Sulphates (SO_4^{2-})	47 mg/l	Up to 200 to 600 mg/l
Mg^{++}	1.5 mg/l	Mg^{++}	10.2 mg/l	Up to 100 to 300 mg/l
NH_4^+	0.8 mg/l	NH_4^+	1.6 mg/l	Up to 15 to 30 mg/l
CO_2	0.5 mg/l	CO_2	0.7 mg/l	Up to 15 to 40 mg/l

Conclusion

The present study has allowed to evaluate the bearing capacity of the grout in the crossed layers of Izegouandane and Tarât in order to verify its conformity and to determine the physico-chemical characteristics of the water of the mixtures and of these layers at the level of the Mining Company of AKOUTA (COMINAK). The results of this study showed that for the cylinders A, B and C whose weight of each is 10 Kg, the values of density for each of the cylinders are 1,9 and the values of loads of rupture are respectively of 120 KN for the cylinder A, 105 KN for the cylinder B and 125 KN for the cylinder C. The values of compressive strength are 60 bars for cylinder A, 52.5 for cylinder B and 62.5 for cylinder C with an average value of 58.33 bars. The value of stress at the base deduced is 2.24 MPa. Thus, in view of these results, it appears that the grout made with CPJ 35 can resist under its own weight. The sampled mixing water has a pH of 8.7 with a proportion of suspended solids of 0.02g/l, a Cl concentration^{-} of 93 mg/l and concentration values of nitrates (NO_3^-) and nitrites (NH_4^+) which are respectively 5 mg/l and 12 mg/l. It should be noted that the water used for the mixing of concrete must not contain suspended matter in excess of the following proportions: 2 g/L for type A and B concrete; and 5 g/L for type C concrete. Sulphate (SO_4^{2-}), magnesium (Mg^{2+}) and carbon dioxide concentrations are 1000 mg/l, 63.2 mg/l and 1.3 mg/l respectively. The analysis of groundwater shows that for the water table of Izegouandane and Tarat the values of concentration of suspended solids are respectively 0.04 g / L to 0.001 g / L. The values of Ph of these waters are 8.7 and 8.1 respectively for the water table of Izegouandane and Tarat. For the water table of Izegouandane, the concentrations of chloride, nitrates and sulfates are respectively 32 mg/L, 9 mg/L and 36 mg/L. Those of magnesium, ammonium and carbon dioxide, they are respectively 1.5 mg/L, 0.8 mg/L and 0.5 mg/L. For the Tarat aquifer, the concentrations of chloride, nitrates and sulphates are respectively 47 mg/L, 29.5 mg/L and 47 mg/L. As for magnesium, ammonium and carbon dioxide, they are respectively 10.02 mg/L, 1.6 mg/L and 1.6 mg/L. These results show that these waters comply with the minimum specifications for environments considered to be weakly (or not) aggressive to concrete

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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