Dynamics of Uranium Concentration in Groundwater of Mineralized Formations, Western Edge of Aïr Massif, Agadez Region (North Niger)

Illias Alhassane[1], Abdou Babaye Maman Sani[2] & Issa Malan S. Souleymane[3]

[1] Department of Geology, Faculty of Science and Techniques, Agadez University, Agadez, Niger

[2] Department of Geology, UMR SERMUG, Faculty of Science and Techniques, Dan Dicko Dankoulodo University, Maradi, Niger

[3] Department of Geology and Environment, Faculty of Sciences and Techniques, André Salifou University, Zinder, Niger

Correspondence: Illias Alhassane, Agadez University, PO Box 199 Agadez, Niger. E-mail: illiasalhassane@gmail.com

Received: August 8, 2024 Accepted: September 23, 2024 Online Published: September 25, 2024

doi:10.5539/ep.v13n2p11 URL: https://doi.org/10.5539/ep.v13n2p11

Abstract

The study area is located in Arlit region, which is a semi-arid zone and where groundwater is the main source of water resources. In this area, the host formations of uranium mineralization are also aquifers. Thus, the waters of these aquifers naturally contain significant amounts of uranium. The consumption of water from these wells can constitute a proven health risk for population. It is therefore urgent to analyses the groundwater from these aquifers in order to determine the uranium content of these waters. The objective of this study is to determine the uranium content in these aquifers. A methodological approach based on hydrochemical analysis methods has shown that the groundwater sampled contains very high levels of uranium ranging from 0.26 mg/L to 0.0024 mg/L, which is unsuitable for any human activity, outside the processing of uranium ores. In addition, these waters naturally contain uranium related to the geological context of this area. However, other external sources such as mining activities bring uranium through water seepage or accidents. Note that these waters are not used by population because they are located in the mining area. The water from these wells is used in the processing of uranium ore for the purpose of extracting uranium contained therein. This study made it possible to identify the uranium content of groundwater in mineralized formations of study area.

Keywords: uranium, water quality, natural pollution, groundwater, Niger

1. Introduction

The western edge of Aïr massif is a semi-arid to arid region. Thus, the only available water resource is groundwater. Surface water is scarce except for a few intermittent flows of korys (Akokan, Talak and Anoumakaran) during the rainy season. Despite the scarcity of surface water, the western edge of Aïr massif has considerable groundwater resources. This area also contains significant uranium deposits. These are contained in aquifers formations such as Tarat and Guezouman aquifers.

The distribution of radioelements in different environments is function not only of their physical and chemical behavior, but also their geochemical behaviour, which depends on natural conditions of environment (Rivers et al., 1996; Pagel et al., 2005; Hakam et al., 2006). Several authors have highlighted the presence and behavior of radioelements in groundwater and surface water (Asikainen and Kahols, 1979; Pagel et al., 2005; Baykara and Dogru, 2006; Hakam et al., 2006).

Although the presence of uranium and thorium radioelements in groundwater poses a health risk, it is not the case that it has advantages, particularly in geochemistry for uranium exploration, but also in the field of health. The radioisotopes of uranium and radium are generally used as tracers and in detection of processes of alteration of rocks as well as in the study of some natural phenomena. In the waters, uranium could come from various sources including the presence of radionuclides in air or soil, mineralized geological formations, uranium mines and radioactive mine discharges (Mangini et al., 1979; Asikainen and Kahols, 1979).

The determination of uranium concentrations in groundwater is of great interest because this element, once inhaled, stay in the human body inducing a dose of radioactivity and could be dangerous at certain doses. However, in groundwater, the concentration of uranium depend on the physico-chemical and lithological conditions of the soil which water could carry when it percolates into rocks. High concentrations of uranium and thorium are generally found in chlorinated and carbo gaseous springs due to their favourable conditions for solubilization of heavy elements (Hakam et al., 2006).

The main objective of this work is to determine the evolution of uranium concentrations in groundwater of western edge of Aïr massif.

2. Method

Study area is located in the department of Arlit. It is located in the northeast of Niger, more precisely between longitudes 7°15' and 7°30' East and latitudes 18° 15’ and 19°00' North, with an average altitude of 400 m, limited to the East by the crystalline basement of Aïr massif. (Fig.1). This region receives average annual rainfall heights ranging from 120 mm in Aïr massif (1000-2022 m of altitude) to 40 mm in the plains (Morel, 1972; Gallaire et al., 1995; Dodo and Zuppi, 1999) with an annual average evaporation around 4100 mm (Gallaire et al., 1995).

2.1 Geological and Hydrogeological Framework

Tim Mersoï basin constitute the northeast extension of Iullemmeden syneclise (Bigotte and Obellianne, 1968; Valsardieu and Dars, 1971; Yahaya, 1992; Moussa, 1992; Gerbeaud, 2006; Konaté et al., 2007 Wagani, 2007). It is bounded to east by Aïr massif, to north by the Hoggar massif, and to the west by In Guezzam ridge. It is extended to Algeria where it takes the name of the Tin Serririne basin (Coquel et al., 1995). The oldest sedimentary series are of Cambro-Ordovician age (Joulia, 1959) and one part of the basin contains a sedimentary cover with ages ranging from the Devonian (Teragh sandstone) in the Lower Cretaceous (Tégama group). Four major families of accidents are recognized in Tim Mersoï basin. These are N0° fault system known as Arlit fault, N30° fault system of Madaouela, Tin Adrar fault N70°- N80°, and N130° faults N140° (Sempere and Beaudoin, 1981; Clermonté et al., 1991; Yahaya and Lang, 2000; Cavellec, 2006; Gerbeaud, 2006; Jamet et al., 2024).

Hydrogeological studies in Arlit region have revealed the presence of four (4) permeable horizons constituting an aquifer system with bottom-to-top following layers: Guezouman aquifer, Tarat aquifer, Izegouande aquifer and Téloua (Cazoulat, 1985; Sanguinetti et al., 1992; Dodo and Zuppi, 1999; Boko et al., 2017; Illias et al., 2021).

2.2 Sampling Procedures

The sampling sites are selected according to the hydrogeological characteristics of aquifers, so as to sample the aquifer throughout area. Moreover, given that aquifer is not so deep (70 m) in the study area, it represents the main source of water supply in and it has been subject to much more sampling than the other units. All the wells are georeferenced and plotted on geological map (Fig. 3). The network of piezometers to monitor are in Tarat aquifer and in mining sector.

Piezometers which captured Tarat aquifer are around the mine, located in Arlit city. Twelve (12) wells are regularly monitored and were sampled each July.

2.3 *Analyses of samples*

In this study, the determination of uranium concentration and sampling were carried out in the wells network set up after pumping at least 30 minutes of pumping to obtain a more representative water of aquifer. The chemical analyses carried out by usual methods mainly concerned two parameters, nitrate and sulfates. The main focus of the chemical data processing is on the elaboration of temporal evolution graphs for one parameter mainly uranium.

3. Results

3.1 Uranium Concentration in the Groundwater

The evolution of uranium levels in well P_1 (Fig.4) shows that uranium concentrations vary from 0.26 mg/L in 1991 to 0.17 mg/L in 1995. When the well was constructed, the uranium content was 0.20 mg/L, reflecting a natural anomaly. However, these levels increase in a discontinuous manner in the time, probably reflecting external inputs that may come from mining activities. For 2010, uranium concentration decreased relatively to 0.20mg/L, which is the same as when well P_1 was realized.

The monthly evolution of uranium contents in well P_2 (fig.5) shows that uranium concentration vary from 0 mg/L in 2011 to 0.22 mg/L in 2002. The highest level was recorded during 2002. This value is higher than that taken when drilling P_2. It is higher than the normal geochemical background of the region. This could be in relation to a possible source of external input, mainly mining activities. However, the levels of uranium were drastically reduced from 2003 to 2004 with constant values of 0.18 mg/L, still higher than the initial values in 1982 which were 0.096 mg/L or 0 mg/L in 2011 (0 mg/L). This decrease of uranium concentrations could probably be explained by some actions taken during mining activities with actions attenuations of uranium sources. With the construction of structures which allowed the creation of a protective radius in the various mining areas, and in turn, in the basins for chemical treatment of uranium.

In well P_3, the evolution of uranium (fig.6) shows that concentrations of uranium in groundwater range from 0 mg/L in 1978 to 2011 to 0.05 mg/L in 2000 and 2002. In the water the uranium content was zero when the well was realized in 1978. However, from 2000 year, when the sample was taken, for checks, a relatively high concentration of 0.05 mg/L was recorded. This reflects a possible source of external input of uranium in connection with the activities of uranium extraction. Nevertheless, from 2004 the content of uranium in well P_3 have significantly decreased with very low values from 2004 to 2010 and may be 0 mg/L in 2011. This is related to the implementation of mitigation measures, including the creation of protection radius at the level of ore processing areas.

The evolution of uranium levels in well P_4 water (fig.4) shows that these levels vary from 0 mg/L in 1978 and 2011 to 0.05 mg/L in 2000 and 2002. The content of uranium is zero when well P_4 is realized. However, these values probably began to appear before the 2000s, because measurements were not carried out until the 2000s. From 2002, these levels dropped from 0.01 mg/L in 2004 to 0.006 mg/L in 2010 and to 0 mg/L in 2011. The absence of uranium in well P_3 is probably due to the measures taken to reduce the spread of external sources. The evolution of uranium contents in wells P_3 and P_4 shows a broadly similar trend as the decrease of uranium contents over time.

The mean evolution of the uranium contents in well P_5 waters (fig.5) ranges from 0 mg/L in 1970 to 0.05 mg/L in 2002. The highest concentrations were observed in 2002 and these levels are significantly higher than the uranium geochemical background which was 0 mg/L at the drilling of P_5. However, these values of uranium decreased from 0.01 mg/L in 2004 to 0.0024 mg/L in 2010.

The monthly evolution of uranium levels in well P_6 (fig.6) shows that these levels vary from 0 mg/L in 1985 and 2011 to 0.05 mg/L in 2000 and 2002. The highest values were observed in 2000 and 2002, and they are higher than the values measured in the well P_6 which were 0 mg/L. This could be linked to an external source such as mining activities. However, from 2004 to 2010, the levels of uranium generally declined in waters that were 0 mg/L in 2011. In addition, in 2010, the water from well P_6 showed a uranium content of 0.029 mg/L, probably reflecting a possible point pollution at well P_6. This could be related to the exploitation of "satellite" deposits. In 2011, the uranium contents are 0 mg/L due to the mitigation and installation of water pumping wells to return them to the level of uranium processing basins and recover the uranium contained

4. Discussion

In the host formations of mineralization as well as uranium-bearing formations in sedimentary environments can constitute aquifers. This is the case of western edge of Aïr massif, where the uranium deposits are found in aquifer formations. Thus, the waters will naturally be radiated with the natural presence of uranium in very high levels. The presence of uranium in these formations is normal, given the anomalies of uranium levels that are significantly above normal levels in groundwater.

This is in line with work carried out in Morocco (Hakam, 2000; Choukri et al., 2005) have shown the natural presence of uranium, without any source of pollution in groundwater, especially the waters of Moroccan mineral springs. High levels in Eocene formations may come from various sources (Asikainen and Kahols 1979; Baykara and Dog 2006) as natural sources related to lithology and the nature of geological formations.

Several studies around the world have shown the presence of uranium in natural groundwater or surface water (Mangini et al., 1979; Kumar et al., 2003). Nevertheless, the presence of uranium in groundwater can be from sources of pollution such as those from mining and agricultural activities (Mangini et al., 1979; Asikainen and Kahols, 1979).

5. Conclusion

Analysis of water samples from six wells revealed the presence of uranium in groundwater and it is related to the geological context of the study area and possible sources of pollution from mining activities. However, the water from these wells is not intended for human consumption but for wells that provide the industrial water needs of the uranium processing. Thus, the presence of these high levels does not constitute a risk or damages to population. However, the waters coming from these area must be forbidden to any domestic or agricultural uses or some others activities that have been excepted industrial activities such as the uranium processing.

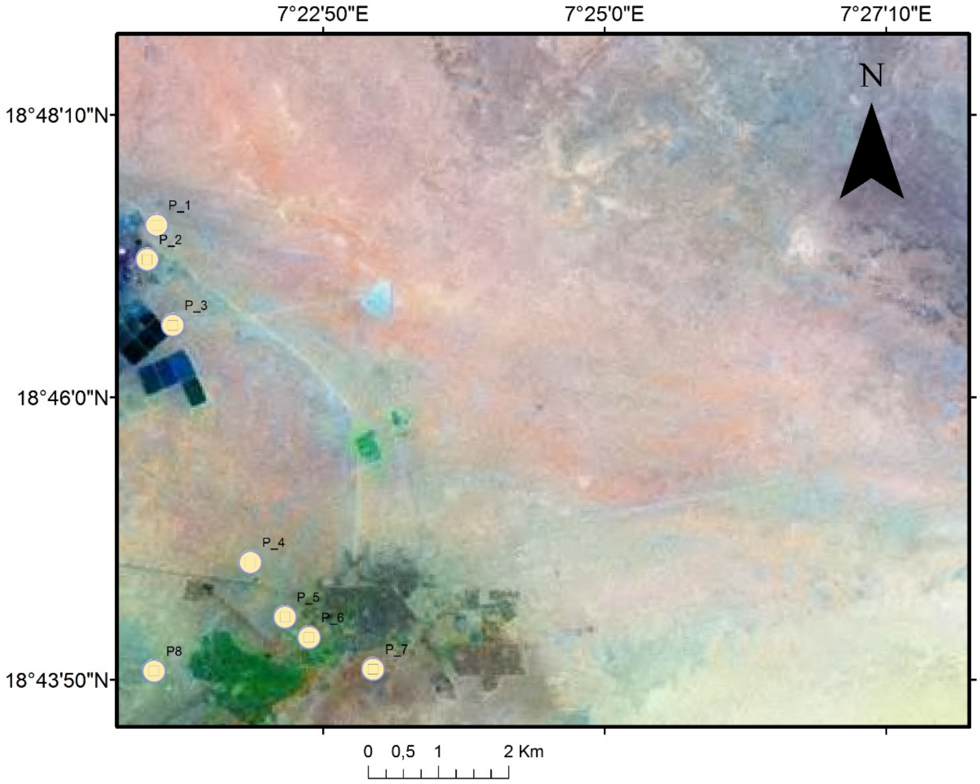

Figure 1. Location map of study area

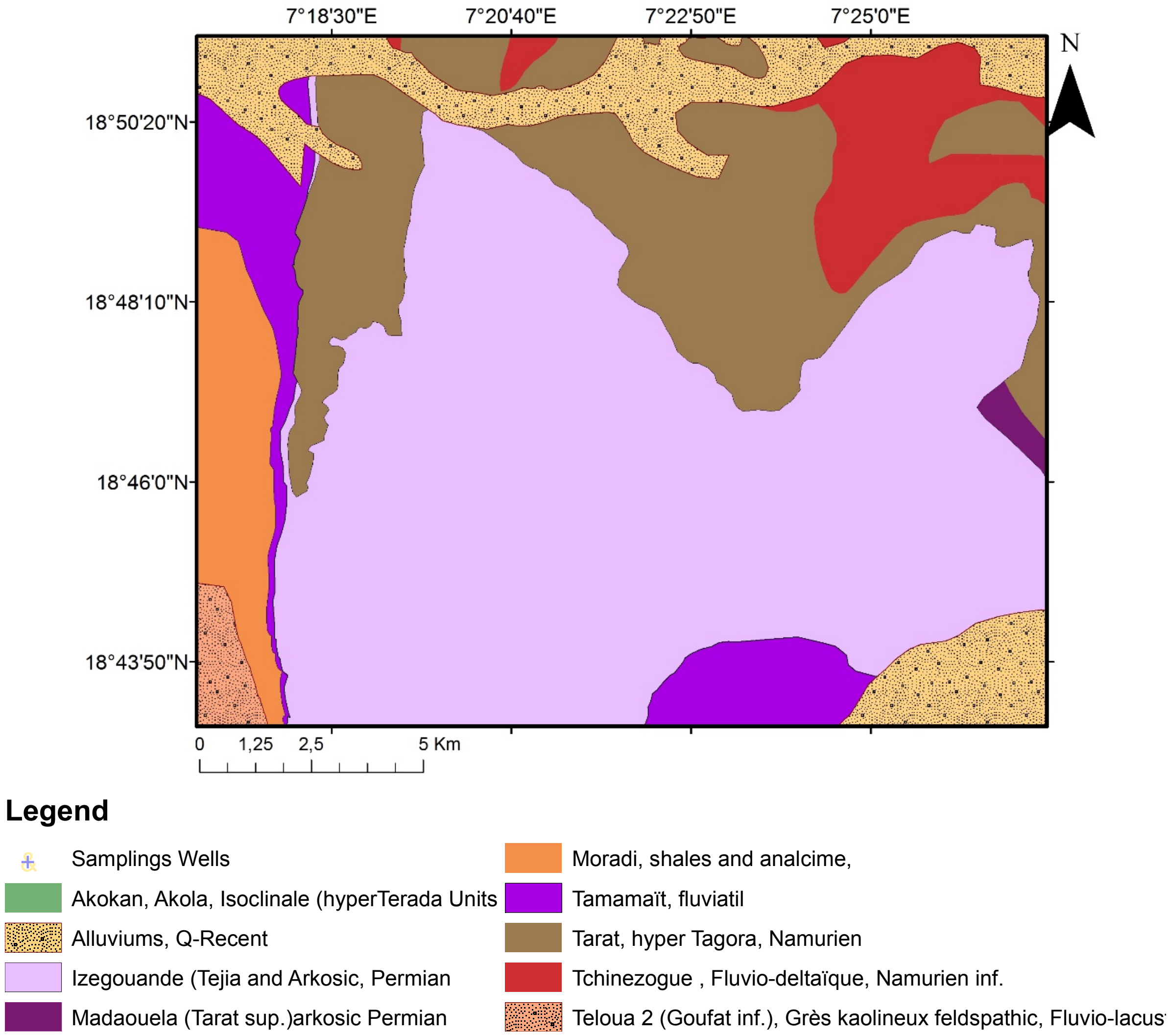

Figure 2. Gelogical map of study area

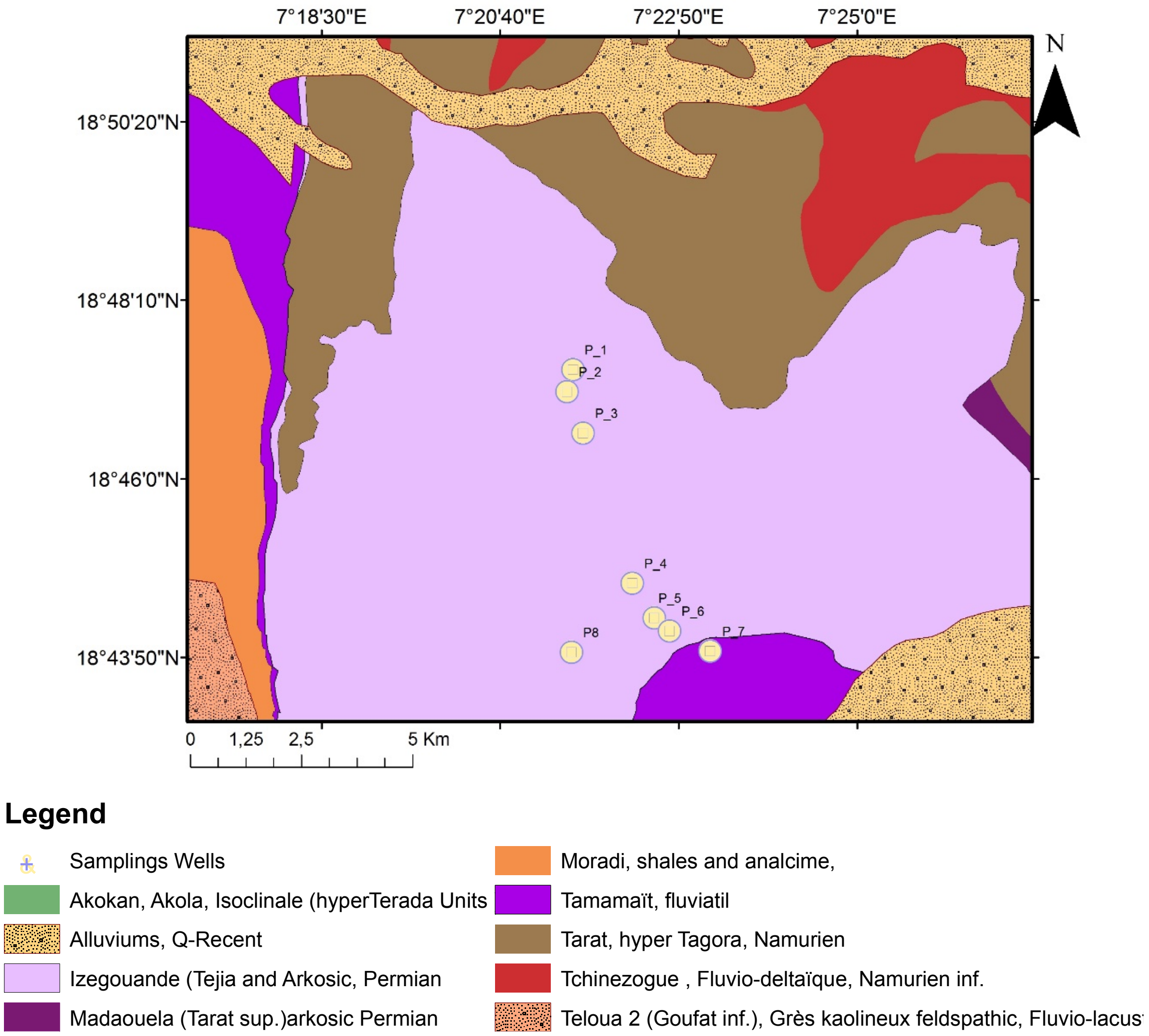

Figure 3. Location of sampling wells

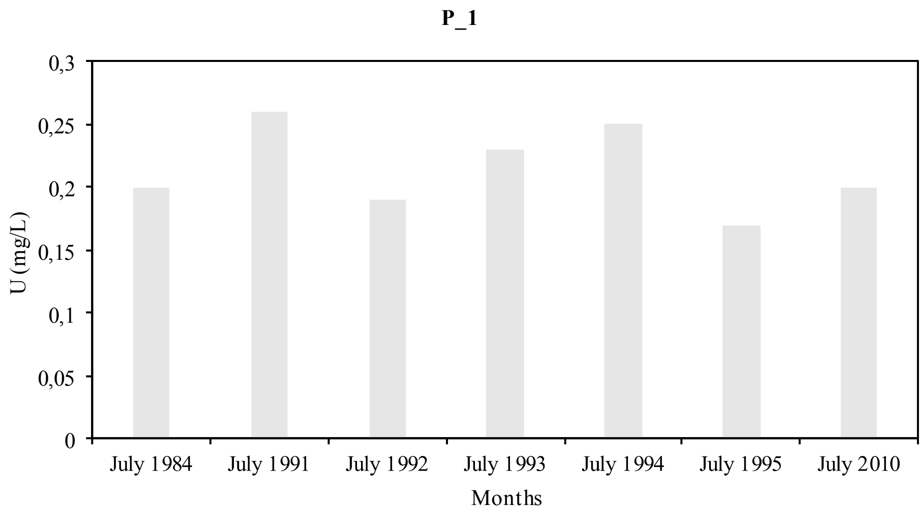

Figure 4. Evolution of uranium concentration in the water of well P_1

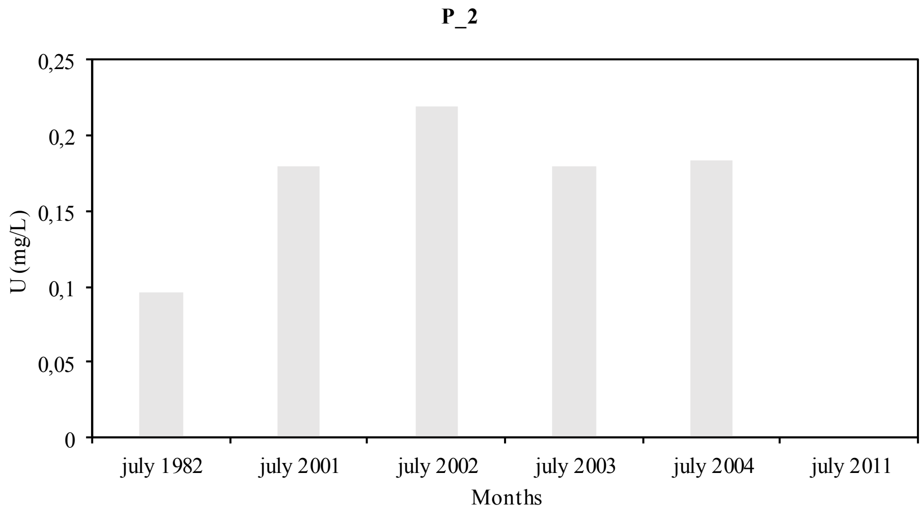

Figure 5. Evolution of uranium concentration in the water of well P_2

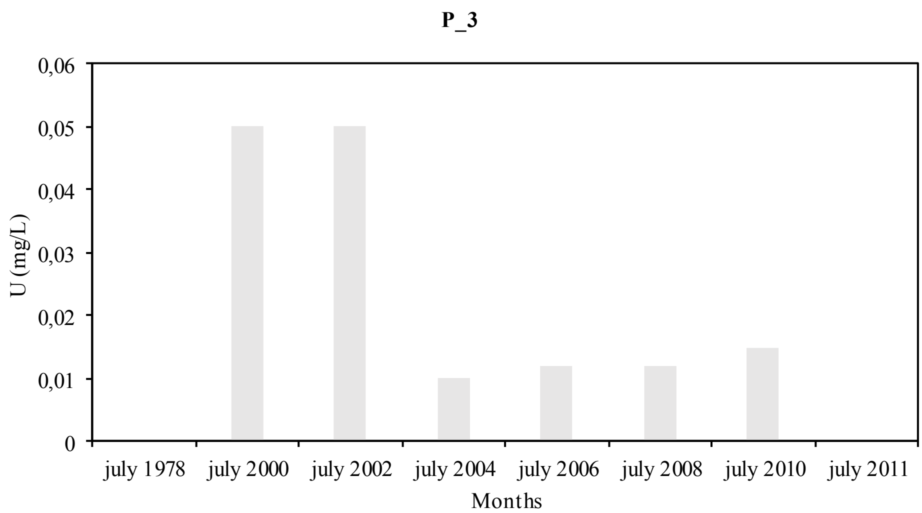

Figure 6. Evolution of uranium concentration in the water of well P_3

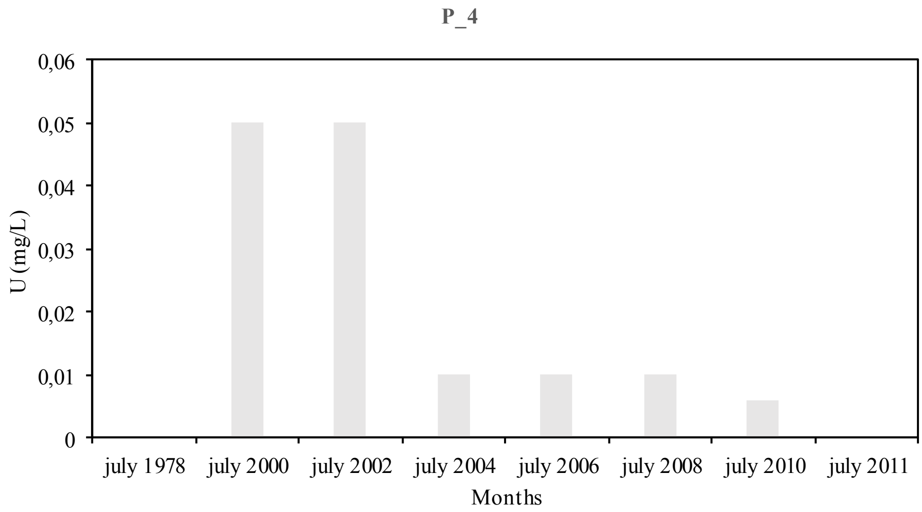

Figure 7. Evolution of uranium concentration in the water of well P_4

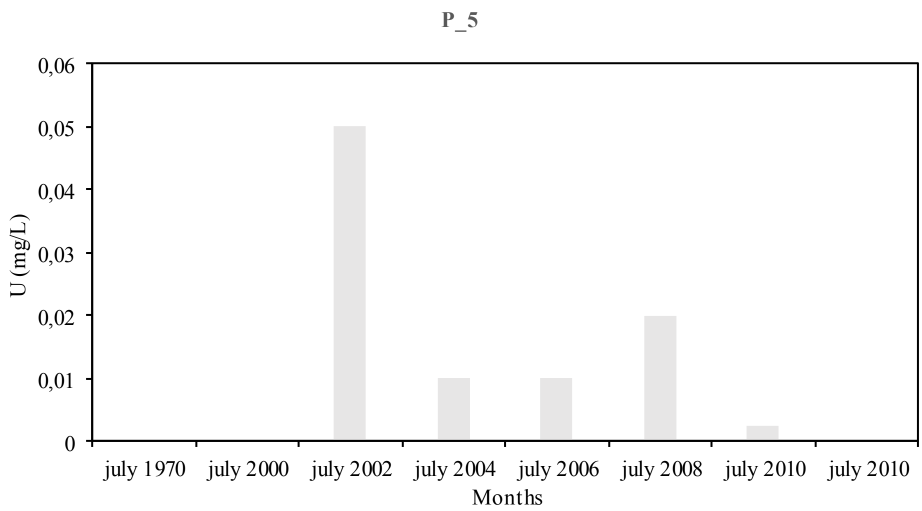

Figure 8. Evolution of uranium concentration in the water of well P_5

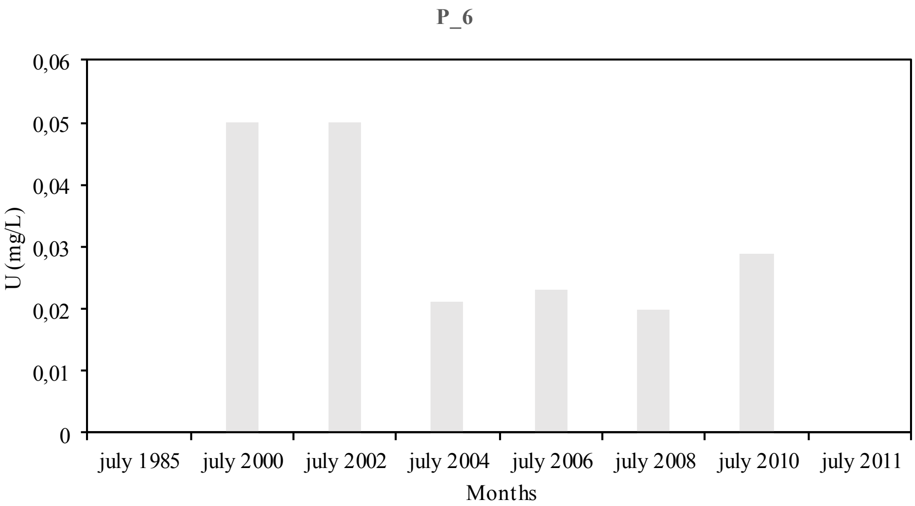

Figure 9. Evolution of uranium concentration in the water of well P_6

References

Abdou Babaye, M. S. (2012). Evaluation des ressources en eau souterraine dans le bassin de Dargol (Liptako-Niger). *Thèse de Doctorat, université de Liège*.

Alhassane, I., Sani, A.B.M., Ibrahim, W., & Boureima, O. (2021). Proposal of a dewatering system for uranium mineralization in the Tim Mersoï basin in Arlit region (North Niger): Case of the Apophyse Ariège deposit. *International Journal of Innovation and Applied Studies 34, 268–275.* http://www.ijias.issr-journals.org/

Baykara O., & M. Dogru (2006). "Measurements of radon and uranium concentration in water and soil samples from East Anatolian Active Fault Systems (Turkey)", Radiat. Meas., 41-362-367. *Journal of Radiation Research and Applied Sciences, 41*(3), 362-367 https://doi.org/10.1016/j.radmeas.2005.06.016

Bigotte, G., & Obellianne, J. M. (1968). Découverte de minéralisations uranifères au Niger. *Mineralium Deposita, 3*, 317–333. https://doi.org/10.1007/BF00207524

Boko, B. A., Konaté, M., Rabani, A., & Abdoulaye, A. (2017). Influence of drainage system on the vulnerability to pollution of the aquifers of the Tim Mersoï basin, North Niger. *Afr. Sci, 13*, 261–274. Retrieved from http://www.afriquescience.info

Cavellec, S. (2006). Evolution of the diagenetic of the Tim Mersoï basin and consequences for the genesis of uranium mineralization in the carboniferous formations of the Guezouman and the Tarat (district of Arlit-Akokan, Niger). *Thése de Doctorat, Université de Paris 11*. https://theses.fr/2006PA112137

Cazoulat, M. (1985). Geologic environment of the uranium deposits in the Carboniferous and Jurassic sandstones of the western margin of the Air Mountains in the Republic of Niger. (COGEMA, Branche Uranium Naturel, Departement des Prospections et Recherches Minieres, Velizy-Villacoublay (France). *Geological environments of sandstone-type uranium deposit*. International Atomic Energy Agency (IAEA) 16049771.

Choukri, A. O-K., Hakam, H., Bounouira, M., & Al Ibrahimi J-L. Reyss (2005). Measurement of uranium (238U, 234U) and isotopic ratio 234U/238U in natural water samples in Morocco using alpha spectrometry. *Afrique Science, 1*(2), 239-251. Retrieved from http://www.afriquescience.org

Coquel, R., Lang, J., & Yahaya, M. (1995). Palynology of the Carboniferous North Niger and the Saharan platform-stratigraphic and palaeogeographic implications. Review of Palaeobotany and Palynology 89, 319–334. *Review of Palaeobotany and Palynology, 89*(3-4), 319-334. https://doi.org/10.1016/0034-6667(95)00035-2

Dodo, A., & Zuppi, G. M. (1999). Climatic variability during the Quaternary in the Tarat Basin (Arlit, Niger). Reports of the Académie des Sciences. *Series IIA-Earth and Planetary Science, 328*, 371–379.

Gallaire, R., Fontes, J. C., & Zuppi, G. M. (1995). Isotopic characterization and origin of rainwater on the Aïr massif (Niger). IAHS Publications-Series of Proceedings and Reports. *Intern Assoc Hydrological Sciences, 232*, 293–304. https://doi.org/10.1016/S1251-8050(99)80102-5

Gerbeaud, O. (2006). Structural evolution of the Tim Mersoï basin: the role of the deformation of the sedimentary cover on the installation of uranium deposits in the Arlit sector (Niger). *Thése de Doctorat, Université de Paris 11*. Université de Paris-Sud. Faculté des sciences d'Orsay (Essonne)

Illias, A., Babaye, M. S. A., Baraou, I. S., Ousmane, B., & Adamou, R. (2019). Influence of the fracturing system on the hydrodynamic parameters of Tarat aquifer, Tim Mersoï Basin, and Northern Niger. *Afr. Sci, 15*, 81–95.

Illias, A., Sani, A. B. M., Souleymane, I. M. S., & Boureima, O. (2021). Evolution of Pumping and Piezometry of the Carboniferous Aquifers, Western Border of Aïr Massif: Case of the Tarat Aquifer in the Arlit Sector. *Global Journal of Earth Science and Engineering, 8*, 72–79. https://doi.org/10.15377/2409-5710.2021.08.6

Jamet, M., Ballas, G., Soliva, R., Gerbeaud, O., Lefebvre, T., Leredde, C., & Loggia, D. (2024). Naturally fractured reservoir characterization in heterogeneous sandstones: insight for Uranium in Situ Recovery (Imouraren, Niger). *EGUsphere [preprint], 4/egusphere*-2024-435, 2024. https://doi.org/10.5194/egusphere-2024-435-supplement

Konaté, M., Denis, M., Yahaya, M., & Guiraud, M. (2007). Structuration extensive and transtensive au Dévono-Dinantien du bassin de Tim Mersoï (bordure occidentale de l'Aïr, Nord Niger). In *Annales de l'Université de Ouagadougou.* pp. 1–32.

Kumar, M., Kumar, A., Singh, S., Mahajan, R. K., & Walia, T. P. S. (2003). Uranium content measurement in drinking water samples using track etch technique. *Radiat. Meas., 36*, 479-481. https://doi.org/10.1016/S1350-4487(03)00176-8

Mangini, A. C. Sonntag, G. Bertsch, E. Muller. (1979). Evidence for a higher natural uranium content in World Rivers. *Nature, 278*, 337-339. https://doi.org/10.1038/278337a0

Morel, A. (1972). Remarks on the model of two high massifs of Aïr (Southern Sahara). *Bulletin de l'Association de Géographes Français, 49*, 213–225. https://doi.org/10.3406/bagf.1972.6023

Moussa, Y. (1992). Sedimentary dynamics of Gezuman and underlying visean formations in connection with tectonics, volcanism and climate: Paleo sites of uranium deposits of Arlit (Niger). *Thése de Doctorat, Université de Dijon.*

Pagel, M., Cavellec, S., Forbes, P., Gerbaud, O., Vergely, P., Wagani, I., & Mathieu, R. (2005). Uranium deposits in the Arlit area (Niger), in: Mineral Deposit Research: Meeting the Global Challenge: Proceedings of the Eighth Biennial SGA Meeting Beijing, China, 18–21 August 2005. Springer, pp. 303–305. https://doi.org/10.1007/3-540-27946-6_79

Rivers, C. N., Hiscock, K. M., Feast, N. A., Barrett, M. H., & Dennis, P. F. (1996). Use of nitrogen isotopes to identify nitrogen contamination of the Sherwood sandstone aquifer beneath the city of Nottingham, UK. *Hydrology Journal, 4.* https://doi.org/10.1007/s100400050099

Sanguinetti, H., Nedjari, A., Aouami, I., Din, C., Cazoulat, M., Tiemogo, M., & Corbin, J. C. (1991). Uranium mineralization research in the Tim mersoï basin (Republic of Niger). A review of prospecting guides.

Sempere, T., & Beaudoin, B. (1984). Discontinuities and sequences in the Tarat formation (Upper Visean) and the Arlit Unit (Namurian-Westphalian) at Arlit (Niger). Sedimentary climatic and tectonic evolution of the area during Carboniferous. Bull. Soc. Geol. Fr. (France) 26.

Semperé, T., & Beaudoin, B. (1981). Discontinuities and sequences in the formation of Tarat (Viséen supkrieur) and the unit of Arlit (Namuro-Westphalien), (Niger). Sedimentary, climatic and tectonic evolution of the region in the Carboniferous.

Valsardieu, C., & Dars, R. (1971). Presence of moraines on the western edge of the Aïr at the boundary between the Devonian and the Carboniferous. Region of Agades (Republic of Niger). *Geological sciences, bulletins and memoirs, 24*, 269–276. https://doi.org/10.3406/sgeol.1971.1396

Yahaya, M., & Lang, J. (2000). Tectono-sedimentary evolution of the Akokan Unit during the Visean in the Tim Mersoï basin (Arlit region, Niger). *Journal of African Earth Sciences, 31*, 415–431. https://doi.org/10.1016/S0899-5362(00)00097-X

Hakam, O.-K. (2000). Study of the distribution of uranium and radium radioisotopes in natural waters and radon in air in dwellings in Morocco. *These d'Etat, Univ. Med V*, 212 p.

Acknowledgments

In this study, we express our sincere thanks to all the Professors of Geology Department of Sciences and Techniques Faculty of Abdou Moumouni University, to the staff of the mining society of Aïr and for this information as well as to Agadez University.

Authors contributions

Not applicable.

Funding

This work was supported by the Mining Company of AKouta (CK).

Competing interests

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.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.