VARIATION OF THE WATER TABLE AND SALINITY IN ALLUVIAL AQUIFERS OF UNDERGROUND DAMS IN THE SEMI-ARID REGION OF RIO GRANDE DO NORTE, BRAZIL

VARIAÇÃO DO NÍVEL FREÁTICO E DA SALINIDADE DO AQUIFERO ALUVIAL EM BARRAGENS SUBTERRÂNEAS NO SEMIÁRIDO DO RIO GRANDE DO NORTE

Alexandre de Oiveira LIMA¹; Francisco Pinheiro LIMA-FILHO²; Nildo da Silva DIAS³; René Chipana-RIVERA⁴; Miguel FERREIRA NETO⁵; Anderson de Medeiros SOUZA⁵; Priscila Regina do Aragão REGO⁶; Cleyton dos Santos FERNANDES⁷*

¹. Professor, Universidade do Estado do Rio Grande do Norte, Mossoró, RN, Brazil; 2. Professor, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil; 3. Professor, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil; 4. Professor, Universidade Mayor de San Andrés, La Paz, Bolivia; 5. Professor, Instituto Federal da Paraíba, Picuí, PB, Brazil; 6. Instituto Nacional de Colonização e Reforma Agrária, Natal, RN, Brazil; 7. Doutorando em Fitotecnia, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil, cleyton1959@hotmail.com.

ABSTRACT: Despite the growing progress in the construction of underground dams, there are few studies to evaluate and monitor these reservoirs after their construction. Thus, a research study was carried out to evaluate the water table level in alluvial aquifers and water salinity in four underground dams selected in the Cobras river basin, Parelhas municipality, Rio Grande do Norte. Water level variation was monitored using the traditional method and the Ground Penetrating Radar with generation of 3D virtual models. Water samples were collected between the months of December 2010 and December 2011 for electrical conductivity analysis. The results indicate that the accumulation of groundwater and salinity (expressed by electrical conductivity) in the reservoirs were affected by the spatial position within the hydrographic basin (limited occurrence of alluvial aquifer recharge area in headwater sectors) and the presence of surface reservoirs (upstream dams), which promote a more continuous recharge, greater renovation, and reduction of the salinity of the waters of the alluvial aquifer downstream.

KEYWORDS: Salinity. Desertification. Hydrochemistry.

INTRODUCTION

The growing demand for water for human supply is making countries maximize the use of their water reserves. In this context, alternatives have been used to increase water availability, mainly for the diffuse rural demand existing in arid and semi-arid zone (LIMA et al., 2013).

In recent years, the number of underground dams built in Brazil has increased, especially due to the increased Federal public financing, which has prioritized this technology to meet the water needs of rural populations.

In spite of the quantitative advances, there is little research on the environmental impacts of this technology after their construction, involving aspects such as temporal variation and evolution of salinity, and variation of the water level in artificial underground deposits. These parameters are important to guarantee the sustainable use of water by the communities and families that benefit from this rainwater collection and storage technology (SHADEED; LANGE, 2010). Therefore, greater attention must be paid to the management and monitoring of groundwater in a sustainable manner, that is, without causing environmental, economic or social consequences (RAJU et al., 2006; ERTSEN; HUT, 2008; EL-HAMES, 2011; SANTOS et al., 2016).

A study carried out by Fontes Junior et al. (2012) brings important contributions to understand the water quality dynamics from underground dams. However, these investigations do not include a study integrating geological sciences (in particular hydrogeology), with the spatial position within the hydrographic basin associated with existing surface and underground deposits, and local rainfall.

In this context, the objective of this work was to evaluate water salinity and groundwater level variation in the alluvial aquifer in four underground dams of the micro basin of the Cobras river, RN, in the Brazilian semi-arid zone.

MATERIAL AND METHODS

Characterization of the study area

The studies were carried out in four underground dams of the micro basin of the Cobras...
Variation of the water…

LIMA, A. O. et al
Biosci. J., Uberlândia, v. 35, n. 2, p. , Mar./Apr. 2019

Variation of the water level, in the semi-arid region of the state of Rio Grande do Norte. An outstanding characteristic of this micro basin is its location within the area considered as one of the most affected by the desertification process, being inserted in the Seridó desertification nucleus (NUDES). The climate of the region is classified as BSw’h according to criteria established by Köppen (BRASIL, 2002). Based on information from the meteorological station of the municipality of Parelhas/RN, it was possible to define that the rainy season occurs between January and May, with an average annual rainfall of 612.4 mm, average annual temperature of 26.1 °C, with a minimum of 21.1 °C and a maximum of 32.0 °C.

Monitoring of water level
The investigation was carried out in three underground dams (UD1, UD2 and UD4). These three were chosen because they were built at the same time, year 2010, and because they were located in the upper, middle and lower part of the watercourse of the micro basin (Figure 1).

Monitoring of groundwater electrical conductivity
Samples for analysis of the water Electrical Conductivity (ECw) were collected monthly between the months of January and December 2011. The ECw was measured and monitored with a portable conductivity meter model Oakton PC 10 series, obtaining the temporal variation of water salinity.

GPR imaging and 3D virtual modeling
For this procedure, only the underground dam UD1 was selected and the area within the hydrographic basin was imaged to detect basement irregularities, the sedimentary package and the height variation of the groundwater level in the studied area.
Variation of the water…

The choice of only one dam was based on an experiment and on the belief that the imaging of one dam represents the others.

The GPR used was the Sir 3000 model of Geological Survey Inc (GSSI) with shielded antennas, resistant connectors, coated and sealed electronic boards, shielding to eliminate interference generated on the ground. After field data acquisition, these were processed in Reflex 5.0 software. In the next step, the radar images were exported and interpreted in the software Opendtect v 4.4.0, where the 3D model of the alluvial body imaged was created.

Data analysis

The salinity of the groundwater (expressed by the electrical conductivity) of the micro basin was compared with the rainfall and the variation of the water level monitored during the collection period, and these were plotted using Excel 2010 software.

RESULTS AND DISCUSSION

Characterization of water salinity in underground dams

In the collection of samples made at the end of the dry season, in the month of December 2010 (corresponding to the first water collection), the ECₘ increased from upstream to downstream, while in the second collection carried out in June 2011, end of the period in which the dams were at maximum storage capacity and dilution, as well as in the third collection (end of the dry period, December 2011), the increase in water salinity in the downstream direction ceased to exist (Figure 2).

![Figure 2. ECₘ of the water in underground dams located along the micro basin of the Cobras river, Parelhas/RN, in the period 2010-2011.](image)

This aspect can be explained by the water accumulation with the functioning of underground dams, which naturally changed the flow dynamics in terms of the presence, accumulation and dilution of the salts. In this condition, salinity is strongly influenced by factors related to the capacity of accumulation and water recharge existing in each underground dam or alluvial aquifer, which in turn reduces ionic concentration (ANDRADE et al., 2010, BAHIA et al., 2011; LIMA et al., 2013).

The water samples collected in the months of July and December of 2011 (rainy and dry periods, respectively) in the dams located downstream of the basin (UD₃ and UD₄), due to the large recharge area showed higher effects of ions dilution and the consequent reduction of ECₘ in comparison to samples collected in December 2010 (dry). Another aspect worth mentioning is that, although UD₃ has been built twenty-seven years ago and UD₄ was only one year old, these dams had very close ECₘ values. One of the possible explanations for the control of salinity in UD₃ over the years is the frequency of water use for domestic consumption of five families, about 270 m³ of water per month.

Although studies must continue in other underground dams, these results indicate that if there is consumption there will be renewal of water and salts, therefore the salinization process will not be triggered. Other studies also show that rainfall and the continuous use of water from an underground dam exert a strong influence on salinity levels in dry periods of the year (LOPES, 2013, LIMA et al., 2017).
Variation of salinity associated with the water level of underground dams

The water stored in the UD1 had a reduction in the ECw between the months of January and March 2011 due to the rainy season in the region (Figure 3). This reduction in ECw was possibly due to the dilution of the salts present in the deposit by the rainwater. As of the month of April, the gradual increase in ECw predominated, reaching 0.85 dS m⁻¹ in December.

Figure 3. Monthly variations of ECw and depths of the water table of UD1, upstream, near the source in the micro basin of the Cobras river, RN, between January and December 2011.

With respect to the variation of the groundwater level of UD1, there is an elevation of the water table (decreasing its depth and tending to be flat) between January and March 2011, as can be seen in Figure 3. This fact is associated with the water supply coming from the recharges by the precipitations that occurred in the period. Between March and May there is a stabilization of this fluctuation, while a gradual decline of the water table begins in May, resulting in an almost total emptying of the underground dam, in the middle of December.

With the descent of the phreatic level, water salinity increased in the alluvial aquifer (Figure 3), establishing a relation between the greater depth of the phreatic level, greater emptying of the reservoir, and greater concentration and/or precipitation of salts, especially salts with lower solubility.

 Usually alluvial aquifers, in the areas closest to the springs/headwaters, have limited accumulation/retention potential of the recharge waters, and are easily affected by dry periods or by large exploitations, due to the reduced size of the alluvial sedimentary deposits associated with greater slope and gradient in the headwaters of the river basin, which interfere in the sedimentary dynamics.

In this case, the transport of sediments in the headwaters of rivers exceeds the deposition, and the lower the alluvial sediment deposition, the lower the capacity of the alluvial aquifer reservoir to be formed upstream of the underground dams, limiting the formation of saturated thicknesses and underground reserves.

Lima et al. (2013) show the importance of not constructing underground dams near the springs due to the limited accumulation / retention capacity of the recharge waters. Cirilo et al. (2003), when evaluating underground dams constructed in the state of Pernambuco, also pointed to this limited recharge area as one of the main causes of the failure of some underground dams in that state.

In relation to UD2 (Figure 4), the variations of ECw and water table level were very different from those observed in UD1, that is, there is no clear relation between ECw increase with groundwater retraction (increase in depth). The variation of the water table in UD2 was approximately 0.57 m, value much lower than the 2.85 m found in UD1 (Figure 3) and the 3.08 m observed in UD4 (Figure 5). As of July, there is a gradual decrease of both monitored parameters until the month of October, during which time the water table continues to fall and the salinity starts to have a slight tendency to increase.

It was also verified, as already observed for the water table, a low amplitude of variation of ECw in UD2. This specific characteristic can be explained by the presence of a dam upstream of this underground dam. This water body maintains a continuous recharge of the alluvial aquifer in the downstream section over time, a fact that can lead to less abrupt changes in salinity at the moment of rainfall, as occurred in UD1.
Thus, the influence of surface works, such as the dams built along the semi-arid basins, which influence the frequency of recharge, renewal and reduction of the salinity of the alluvial aquifers of the underground dams, suggesting the need for integrated management of surface and groundwater.

Regarding UD4, it was observed that the rains tend to occur between January and April, reducing from May to December. The beginning of the occurrence of the rains also marks the period of recovery/rise of the water table (becoming flatter), in general between January and April, remaining at a constant level until the beginning of June, and then progressively decreasing to a critical level in the month of December, when the saturated thickness of the aquifer is very small or zero.

In relation to the electrical conductivity of water in UD4 (Figure 5), with the increase of rainfall between January and April, there is a tendency of ECw reduction, which shows an abrupt fall between January and February (probably due to the dilution of salts with recharge of the aquifer), and a continuous and progressive trend of reduction from February to December.

Two aspects deserve to be highlighted in UD4: the first was the high ECw reduction, reaching December with the lowest water salinity (0.813 dS m⁻¹) among the three dams monitored. The second was that between the beginning and the end of the monitoring (January and December 2011) the water table level increased by 0.87 m (Figure 5). It should
be noted that at the beginning of monitoring this underground dam had the highest salinity.

A common feature in the three monitored dams was that since June there was a gradual reduction in the water table, although with different intensities, mainly in UD$_2$, since the deposits did not remain static.

Three factors may explain this phenomenon: the first refers to the decrease of rainfall as shown in Figures 3, 4 and 5; the second, and most probable, results from the existence of fractures, very common in the crystalline basement of the region in which the micro basin is inserted, located under the influence of metamorphic mica schists of the Seridó Formation. This type of rock has generally vertical foliations which would facilitate the losses in the reservoirs, making it possible for the water accumulated in the underground dams to feed the fissure aquifer and maintain the waters of this reservoir with salinity levels lower than those in other regions of the Rio Grande do Norte state. Thus, when planning the underground dams, this fracturing condition of the crystalline basement that serves as the basis for the reservoir needs to be observed with greater attention. For Cirilo et al. (2003), in a study of underground dams monitoring, stated that problems related to the placement of the impermeable septum (200-micron-thick plastic tarpaulin) are one of the main factors of failure of underground dams. The third factor is related to losses by the impermeable septum used to block the passage of water.

**Water level imaging in UD$_1$**

The literature on water level imaging in underground dams in the northeastern semi-arid region is very scarce, making it difficult to discuss the results obtained in this study.

The water table in the entire catchment area of the underground dam UD$_1$ was identified in the 3D GPR profile (Figure 6). Lahouar and Al-Qadi et al. (2014) reported good sensitivity of the GPR to map the water level and its temporal variation, since they were able to detect the presence of the water table within multiple and ambiguous reflectors to a depth of approximately 8 m.

![Figure 6](image-url)

**Figure 6.** Imaging of the crystalline basement of the hydrographic basin area (A), topographic surface and crystalline basement (B), view of the reservoir, highlighting the water level in the imaging (C) and lateral view of the basin of the monitored underground dam (D).

The water level generates a reflection with higher energy due to the decreasing velocity at the water level, as well as the difference in the dielectric properties of the fluid in comparison to the other materials in the place (CASSIDY, 2007).

In the case of the use of GPR for the leasing process in an area where there is a high water table, depending on recharge process in that location, it will be possible to determine its position, and with that, to anticipate additional costs arising from the need for lowering the water level. In addition to this factor, additional care with the people involved with the construction process may have an impact on the financial costs of the work. In this way, the information generated with the previous imaging
will be of fundamental importance for the planning of the process of construction of underground dams. Therefore, it will be possible to propose a model of sustainable management of aquifers, allowing a planning that takes into account local water availability with the needs of rural communities, in order to ensure access to water during the most critical period of the year.

CONCLUSIONS

The accumulation of water and the salinity of the groundwater of the alluvial aquifer in the underground dams are strongly influenced by the spatial position within the hydrographic basin (limited occurrence of recharge area due to lower deposition rate and accumulation of alluvial sediments in headwater sectors of the river), presence of surface reservoirs (upstream dams), which promote a more continuous recharge, greater renovation, and reduction of the salinity of the waters of the alluvial aquifer downstream.

The open fracture planes of the fractured crystalline aquifer rocks may favor a greater transfer of water from the overlying alluvial aquifer by descending vertical drainage to the underlying crystalline aquifer, which could promote the renewal of alluvial aquifer reserves and reduce the salinity of the groundwater.

However, this structural conditioning and hydraulic interconnection between the alluvial aquifers and the underlying "fractured" aquifer need to be studied, confirmed and quantified in greater detail in the light of temporal and spatial monitoring data in the area, with no elements still to affirm that these factors act decisively to diminish the salinity of the waters of the alluvial aquifer implanted in the underground dams in the studied domain.

The 3D GPR profile method of the alluvial body, corresponding to the UD, hydrographic basin, identified the irregularities of the basement, the space occupied by the sedimentary package and the water table of the reservoir, and could be used later to monitor the water level fluctuation in these reservoirs.

RESUMO: Apesar do crescente avanço na construção de barragens subterrâneas, há poucos estudos de avaliação e monitoramento das barragens subterrâneas após a sua construção. Assim, foi realizada uma pesquisa com o objetivo de avaliar a salinidade da água e a variação do nível freático em aquífero aluvial em quatro barragens subterrâneas selecionadas na microbacia do rio das Cobras, município de Parelhas, Rio Grande do Norte. As amostras de água foram coletadas entre os meses de dezembro de 2010 a dezembro de 2011 para análise da condutividade elétrica. A variação do nível da água foi monitorada utilizando método tradicional e o Ground Penetrating Radar com geração de modelos virtuais 3D. Os resultados indicam que a acumulação da água subterrânea e a sua salinidade (expressa pela condutividade elétrica) nos reservatórios foram afetadas pela posição espacial dentro da bacia hidrográfica (ocorrência limitada de área de recarga do aquífero aluvial em setores de cabeceiras do rio) e pela presença de reservatórios superficiais (açudes à montante), os quais promovem uma recarga mais contínua, maior renovação, e redução da salinidade das águas do aquífero aluvial à jusante.

PALAVRAS-CHAVE: Salinidade. Desertificação. Hidroquímica.

REFERENCES

ANDRADE, E. M.; LOPES, F. B.; PALÁCIO, H. A. Q.; AQUINO, D. N.; ALEXANDRE, D. M. B. Land use and groundwater quality: The case of Baixo Acaraú Irrigated Perimeter, Brazil. Revista Ciência Agronômica, Fortaleza, v. 41, n. 2, p. 208-215, 2010. http://www.ccarevista.ufc.br/seer/index.php/ccarevista/article/view/635

BAHIA, V. E.; FENZL, N.; LEAL, L. R. B.; MORA-LES, G. P.; LUÍZ, J. G. Caracterização hidrogeológica das águas subterrâneas na área de abrangência do reservatório de abastecimento público do Utinga – Belém (PA). Revista Águas Subterrâneas, Cotia, v. 25, n. 1, p. 1-14, 2011. http://dx.doi.org/10.14295/ras.v25i1.19499

BRASIL. Caracterização dos recursos naturais de uma área piloto do núcleo de desertificação do Seridó, Estados do Rio Grande do Norte e da Paraíba. Rio de Janeiro: Embrapa Solos, 2002. 53 p.
CASSIDY, N. J. A review of practical numerical modelling methods for the advanced interpretation of ground-penetrating radar in near-surface environments. *Near Surface Geophysics*, Houten, v. 5, n. 1, p. 5-21, 2007. http://dx.doi.org/10.3997/1873-0604.2006014

CIRILO, J. A.; COSTA, W. D.; GOLDEMBERG, D.; ABREU, G. H. F.; AZEVEDO, L. G. T.; BALTAR, A. M. Soluções para o suprimento de água de comunidades rurais difusas no semi-árido brasileiro: Avaliação de barragens subterrâneas. *Revista Brasileira de Recursos Hídricos*, Porto Alegre, v. 8, n. 4, p. 5-24, 2003. https://www.abrh.org.br/SGCv3/index.php?PUB=1&ID=34&SUMARIO=1533

EL-HAMES, A. S. Determination of the transient water table rise behind constructed underground dam. *Arabian Journal of Geoscience*, Riade, v. 5, n. 6, p. 1359-1366, 2011. https://doi.org/10.1007/s12517-011-0299-2

ERTSEN, M.; HUT, R. Two waterfalls do not hear each other. Sand-storage dams, science and sustainable development in Kenya. *Physics and Chemistry of the earthe*, Amsterdã, v. 34, n. 1-2, p. 14-22, 2008. https://doi.org/10.1016/j.pce.2008.03.009

FONTES JUNIOR, R. V. P.; MONTENEGRO, A. A. A.; MONTENEGRO, S. M. G. L.; SANTOS, T. E. M. Estabilidade temporal da potenciometria e da salinidade em vale aluvial no semiárido de Pernambuco. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 16, n. 11, p. 1188-1197, 2012. http://dx.doi.org/10.1590/S1415-43662012001100007

LAHOUAR, S.; AL-QADI, I. L. Automatic detection of multiple pavement layers from GPR data. *NDT & E International*, Amsterdã, v. 41, n. 1-2, p. 69-81, 2008. https://doi.org/10.1016/j.ndteint.2007.09.001

LIMA, A. O.; DIAS, N. S.; FERREIRA NETO, M.; SANTOS, E. J.; REGO, P. R. A.; LIMA-FILHO, F. P. Barragens subterrâneas no semiárido Brasileiro: Análise histórica e metodologia de construção. *Irriga*, Botucatu, v. 18, n. 2, p. 200-211, 2013. http://dx.doi.org/10.15809/irriga.2013v18n2p200

LIMA, A. O.; LIMA-FILHO, F. P.; DIAS, N. S.; REGO, P. R. A.; FERREIRA NETO, M. Mechanisms controlling surface water quality in the Cobras river sub-basin, northeastern Brazil. *Revista Caatinga*, Mossoró, v. 30, n. 1, p. 181-189, 2017. http://dx.doi.org/10.1590/1983-21252017v30n120rc

LOPES, H. L.; CABRAL, J. J. S. P.; ARAÚJO FILHO, J. C.; MONTENEGRO, S. M. G. L. Mapeamento de áreas aluvionares no semiárido brasileiro por meio de dados colaterais e imagens orbitais. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 17, n. 7, p. 763-769, 2013. http://dx.doi.org/10.1590/S1415-43662013000700011

RAJU, N. J.; REDDY, T. V. K.; MUNIRATHNAM, P. Subsurface dam to harvesting rainwater. A case study of the Swarnmukhi river basin, Souther India. *Hydrogeology Journal*, Menlo Park, v. 14, n. 4, p. 526-531, 2006. https://doi.org/10.1007/s10040-005-0438-5

SANTOS, S. M; PAIVA, A. L. R; SILVA, V. F. Qualidade da Água em Barragens Subterrâneas no semiárido. *Revista Brasileira de Agricultura Irrigada*, Fortaleza, v. 10, n. 3, p. 651-662, 2016. https://doi.org/10.7127/RBAIV10N300394

SHADEED, S.; LANGE, J. Rainwater harvesting to alleviate water scarcity in dry conditions: A case study in Faria Catchment, Palestine. *Water Science and Engineering*, Amsterdã, v. 3, n. 2, p. 32-143, 2010. https://doi.org/10.3882/j.issn.1674-2370.2010.02.002