WaterJPI project

SMARTControl

Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge (MAR) applications

Deliverable D5.6

Installation of real-time monitoring system pilot site in Recife

Authors

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https://www.smart-control.inowas.com

November 2022

Project funded by:

Deliverable D5.6

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Short summary

This report aims to present the results of the Recife case study activities developed throughout the SMART-Control project. The main activities developed were the real-time monitoring system installation at Landelino Rocha school, located in the Pina neighborhood, Recife. Three static level sensors and one rain gauge were installed. In addition, an initial risk analysis was carried out to investigate the health and environmental risks of the MAR system that is being implemented. All these activities contributed to the pilot MAR system planning and installation in Recife.

Work package	WP5: Demonstration
Deliverable number	D5.6
Partner responsible	Federal University of Pernambuco (Brazil)
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Quality assurance	Jana Glass (Technische Universität Dresden)
Planned delivery date	February 2022
Actual delivery date	November 2022
Dissemination level	PU (Public)

ABSTRACT

The SMART-Control project aims to minimize risks associated with the application of sustainable groundwater management techniques. For this purpose, a real-time monitoring and control (RMCS) web system was installed in combination with a risk assessment and an injection test to understand and control the aquifer behavior. The general project foresees the installation of 6 pilot schemes of managed aquifer recharge (MAR). Recife's pilot system is in the process of being built at the Landelino Rocha school, in the Pina neighborhood, Brazil. An ASR (Aquifer Storage and Recovery) well will infiltrate rainwater, pretreated, collected from the roof of the school, in the confined coastal aquifer. The implementation of the pilot-scale ASR scheme aims to mitigate the flood problem, protect and restore underground water resources and prevent saline intrusion. For the installation, some steps are necessary: injection test in the aquifer, monitoring of the potentiometric level, and assessing the risk. An injection test was performed to evaluate the aquifer recharge rate. As a result, a recharge rate of 1.2 L / min was obtained, a value lower than expected, according to the literature. Concerning the monitoring network, there are three multilevel piezometers located in the neighborhoods of Pina and Brasília Teimosa, where static level and electrical conductivity data are collected. A real-time monitoring system composed of 3 sensors to monitor the piezometric level and a rainwater gauge were installed on the site and data are available on the INOWAS platform. The ASR implementation risk assessment was carried out based on the Australian guide (NRMMC-EPHC-AHMC, 2006), which considers factors such as saturated layer thickness, risk of filter clogging, water quality injected, aquifer water quality, among others. The study showed a low risk for the technical application, being feasible and not presenting risks to the environment. The greatest risks observed are related to operational issues of the system. Although the system was not fully implemented, through activities within SMART-Control important information for the system implementation process were obtained.

CONTENT

FIGURES

1 INTRODUCTION

Recent droughts (1998-1999, 2012-2016) (Petelet-Giraud et al. 2018) and the increase in water demand in the last three decades due to constant population growth have brought impacts such as the overexploitation of groundwater resources (Coelho et al. 2018; Luna et al. 2017), saltwater intrusion (Cary et al. 2015), water quality degradation (Bertrand et al. 2016), as well as potential subsidence (Luna et al. 2017) in the Recife Metropolitan Area (RMR) in Brazil. At the same time, the RMR is exposed to frequent extreme rainfall events during 4 to 5 months of the rainy season each year and surface runoff causing urban flooding (Silva Junior et al. 2017). MAR (Managed aquifer recharge) and, in particular, the ASR (Aquifer Storage and Recovery) technique can provide a mitigating solution to the aforementioned challenges (Coelho et al. 2018; Zuurbier, 2014).

Recife has been developing research on artificial aquifer recharge as a strategy to improve the state's water security. In managed aquifer recharge, a water source under controlled conditions is used to recharge an aquifer. This source can be reused water (for example, derived from urban stormwater or treated sewage) or natural water (for example, from a lake or river). The aquifer is used to store surplus water, which can be used later or generate environmental benefits (NRMMC; EPHC; NHMRC, 2009).

For some years, the water resources group from the Federal University of Pernambuco (UFPE) has been developing international partnership projects, such as the BRAMAR, Subsol, COQUEIRAL, WATER4COAST, and DIGIRES projects, focusing on managed aquifer recharge. The German-Brazilian partnership research project BRAMAR suggested that water injection and recovery solutions into the aquifer can be applied against water scarcity in semi-arid regions of the country, while rainwater harvesting and subsurface storage can reduce runoff and, subsequently, contribute to flood mitigation.

SMART-Control aims to reduce the risks of managed aquifer recharge facilities by developing real-time online monitoring and control tools in combination with risk assessment and management tools. In Recife, the main objetive was to install a real-time observation system to monitor the piezometer level of the Cabo aquifer and the rainfall. In addition, an injection test was carried out to determine the aquifer recharge rate and an initial assessment of the risks of implementing the pilot system.

2 SITE DESCRIPTION

The study area is placed in the Metropolitan Region of Recife (RMR). The RMR is located on the northeast coast of Brazil in the state of Pernambuco and includes the city of Recife, the capital of Pernambuco, and 13 surrounding municipalities (Cabral et al. 2008). With a total area of 2,768 km², the RMR has a population of around 4 million inhabitants (IBGE, 2018), with high densities in neighborhoods such as Boa Viagem and Pina (Cabral et al. 2008). The pilot system that is being developed is located at the Landelino Rocha public school, in the Pina neighborhood, at coordinates 8°05'35"S and 34°53'01"W. The school is located about 340 meters from the sea and is shown in Figure 1.

Figure 1. Location of the monitoring (P01 and P02) and injection (P03) wells (adapted from Paiva et al., 2017)

Figure 2. The area where the managed aquifer recharge pilot scheme is being installed - Pina, Recife, Brazil.

On-site, there is an injection well (P03, Figure 2) and a monitoring well (P02) located about 20 m away from each other. The monitoring well is used to monitor the impact of the recharge, the piezometer's natural behavior, and the tidal influence on the water table of the different aquifer layers. The multilevel injection well has depths of 135 and 126 m, and contains filter zones between 133-141 m and 166-170 m. The monitoring well has depths of 180 m and 113 m, and filters spaced between 145 and 147 m, 153 and 155 m, 167 and 169 m, and 175 and 177 m. All tubes are 2 inches in diameter and made of PVC. These measurements and the lithological profile performed during the construction of the multi-piezometer provide a good basis for understanding the project site from a hydrogeological perspective, which is important for pilot system design.

The RMR is a multilayered sedimentary aquifer system located in the estuarine area of the Capibaribe River and includes smaller rivers such as the Beberibe, Tejipió, Jordão, and Jiquiá. It also includes a mangrove ecosystem, a zone that developed due to tidal penetration into the estuarine area. The RMR was formed geologically by crystalline basement rocks and Meso-Cenozoic sediments from the coastal sedimentary basins of Paraíba and Pernambuco. Both basins are separated by the transverse structure of the Pernambuco Lineament with an east-west direction near UTM 9,105,000 South (Batista, 2015). The area of interest for this study is located in the Recife plain, south of the Pernambuco Lineament. The elevation of this plain is very low, from 1 to 10 m above sea level (Cary et al., 2015).

The pilot system is in its implementation phase. During the present project, it was not possible to conclude the complete installation of the necessary construction. There is already a multilevel well where the water will be injected. The other equipment in the system has already been designed but has not yet been installed due to problems in hiring the company. The ASR system will consist of a rainwater harvesting structure that will be installed on the school roof and a sand filter to pre-treat the injection water. After removing the fine particles, the rainwater will be stored in a reservoir next to the well. The previously treated rainwater will be infiltrated by gravity into the ASR well in the Cabo Superior confined aquifer, as shown in the diagram in Figure 3. The ASR well is a multilevel well and rainwater can later be recovered through the adjacent pipe. The preliminary studies for the installation of the pilot system consist of a test of water injection into the aquifer to know the water infiltration rate, the installation of a real-time monitoring system, which was installed to continuously monitor the levels of groundwater, in addition to the risk assessment of the system. These results will be detailed in the following chapters.

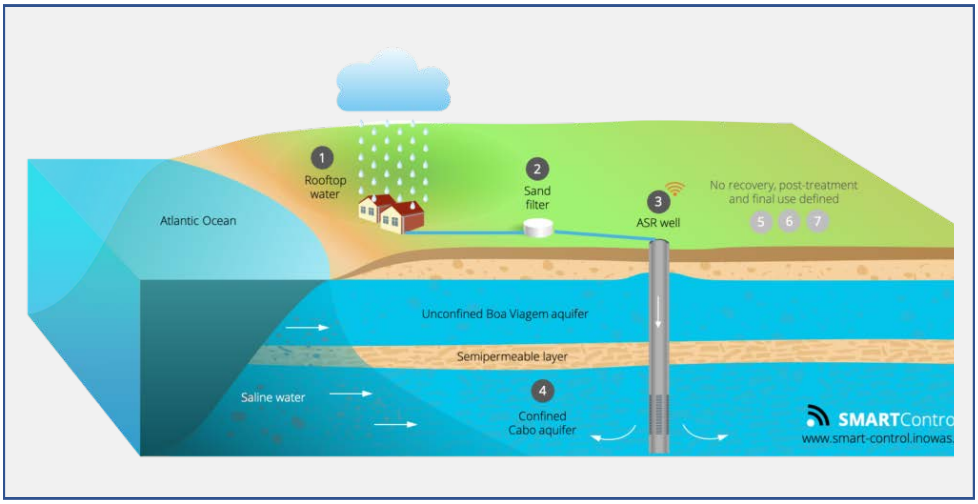

Figure 3. Schematic overview of the MAR components of the Landelino Rocha school, Recife, Brazil.

3 RESULTS

3.1 AQUIFER MONITORING

The aquifer monitoring uses manual and automatic sensors installed in 3 piezometers, through which it is possible to collect data on groundwater levels. The well P01 is located at the Yacht Club, well P02 is at the Landelino Rocha school and well P03 is also located at Landelino Rocha school (Figure 1).
The multilevel well of Brasília Teimosa, located in the Yacht Club (P01) has two tubes called deep P1, with 180 m depth, and shallow P1 with 110 m. The shallow P1 has a high salinity index, which caused damage to the sensor. Therefore, it was only possible to monitor during the 4 months, as shown in the following graph (Figure 4). The P1 deep well, also located in the Yacht Club, features monitoring from September 2017 until November 2019. Due to imposed social restrictions, more recent visits did not occur which included also the other monitoring wells. The variation of the static level was approximately 4 meters according to Figure 4.

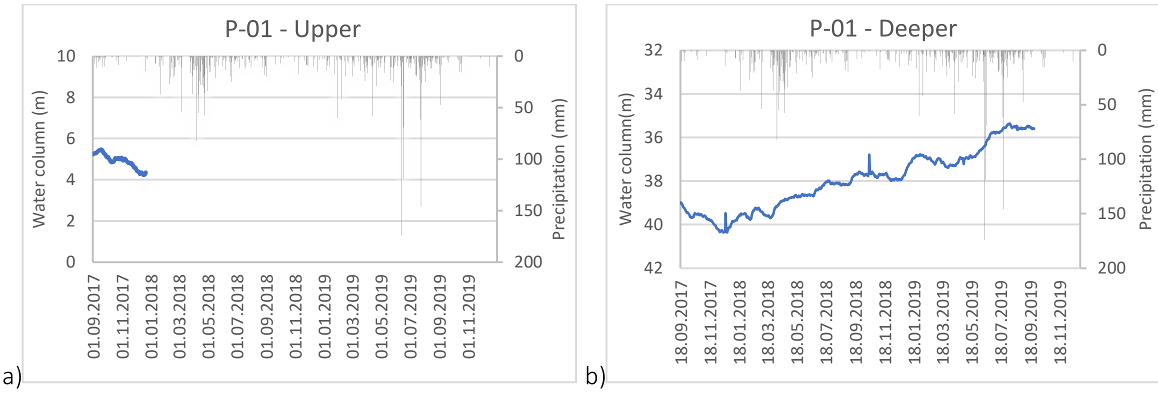

Figure 4. Graph of the water column at P01 from 09/01/17 to 11/01/19. a) shallow well, b) deep well

The same behavior was perceived in the multilevel well of the Landelino Rocha school, in Boa Viagem neighborhood. In 2017, lower precipitation values were recorded and consequently, there was a decrease in potentiometric levels during this period. In the following years, there were more rain events, increasing the water column.
In addition, the HIDROREC II (Costa et al. 2002) study proposed a restricted exploitation area called Exploitable Groundwater Zoning Map in the Metropolitan Region of Recife. The coastal strip, which encompasses the monitoring wells area, were obliged to restrict the number of new well drilling and reduce the flow by 30% or 50% depending on the aquifer. This may be one of the reasons that have resulted in a gradual increase in water level since 2018.
The following are the graphs of the water column of shallow P02 and deep P02 wells, located in Pina (Figure 5).

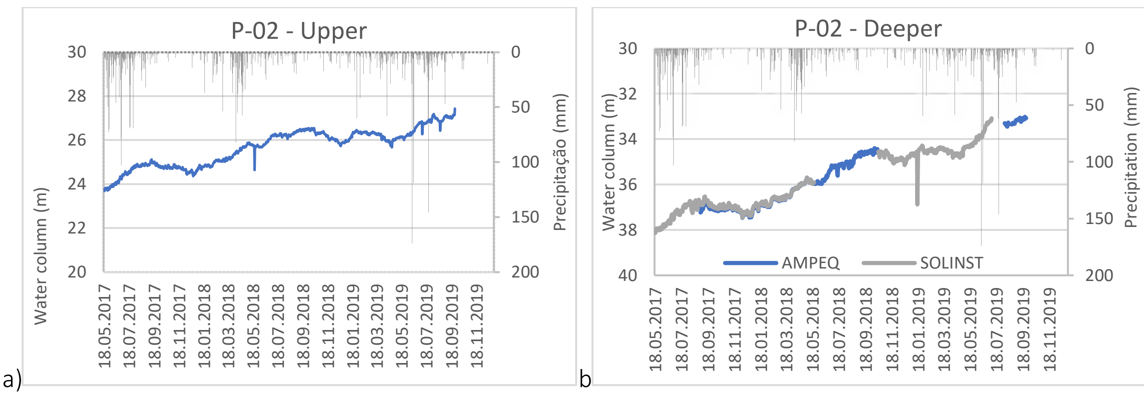

Figure 5. Graph of the water column at P02 from 09/01/17 to 11/01/19: a) shallow well, b) deep well

In the deep well of P02, two sensors measure the water level, Ampeq and Solinst. The idea is to make a comparison and analyze if the sensors are well-calibrated and performing correct measurements. In addition, if the sensor fails, the other continues to monitor and with this, no data is lost, as can be seen earlier in Figure 5. Finally, the electrical conductivity data collected in the P02 deep well of the Landelino Rocha School, are presented. With the increase in the level, seen in the previous graphs, there was a dilution of the water and a consequent decrease in salinity, as can be seen in Figure 6. The data show the influence of the tide, being perceived by the daily fluctuations of the data. Collected data present some failures.

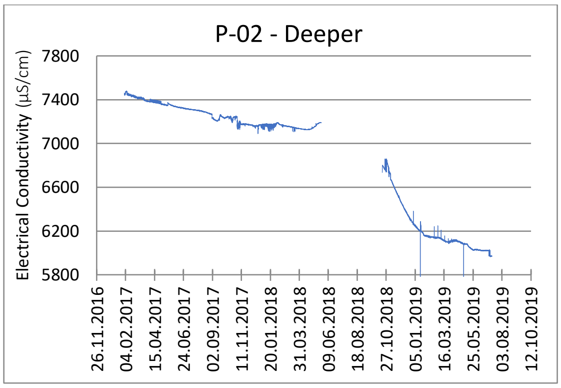

Figure 6. Graph of the Electrical Conductivity in the P02 - deeper from 18/08/16 to 01/12/19

3.2 INJECTION TEST

In January 2019, a recharge test was carried out to determine the recharge rate and to identify the behavior of the injected water in the Cabo aquifer. The test was carried out in well P03 at Landelino Rocha school. Successive injections were performed to analyze the water level drawdown in the well tube. The determination of the recharge rate was based on water level responses after filling the well with water (Figure 7)
The injection rate of the test decreased with the water volume, moving from 6.7L/min to 1.1L/min. Figure 8 shows the decrease in the recharge rate over time. After the injection of about 100 L, a constant recharge rate of about 1.2 L / min resulted, a value lower than expected, according to Silva et al. (2004). The result directly influences rain capture systems. A larger storage location will be necessary due to the slow injection. The test lasted 5 hours and could be infiltrated 360 L into the aquifer. It is recommended to perform one more test in a nearby well to compare with the results obtained in well P01.

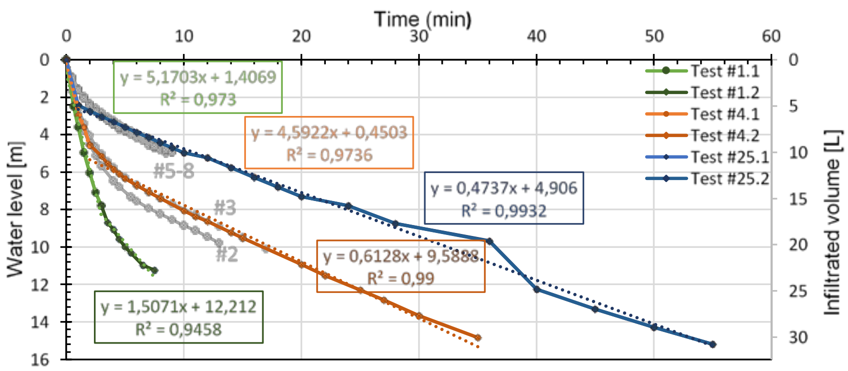

Figure 7. Variation in water level over time relative to the first seven injection series (Fernandes et al., 2019).

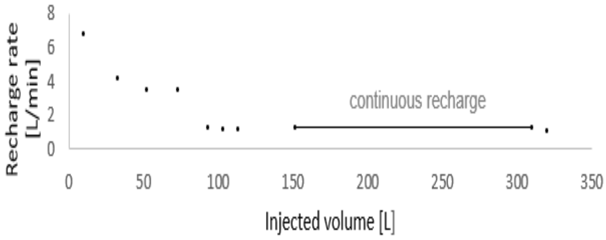

Figure 8. Variation in recharge rate over time in continuous refill test (Fernandes et al., 2019)

3.3 REAL-TIME MONITORING SYSTEM

The real-time monitoring system (RTMS) was installed on December 02, 2021. The system consists of sensors that measure the well water level and transmit the data to the system. RTMS records readings every 10 minutes. Data becomes available in the system as soon as they are sent online. The system sensors were acquired with funds by FACEPE. The installed system is produced and marketed by Ampeq (http://ampeq.ch/), a company specializing in the development of technologies for water monitoring. We chose to use this brand's system due to the efficient technical support, easy maintenance, and cheaper price compared to other market options in Recife. Access to data visualization does not require registration. Access to download data is done through user registration.
RTMS installation required level sensors, placed inside the wells named EPA 11, EPA 12 and EPA 13 (Figure 9).

Figure 9. Installation of the water level sensor inside the injection well (P03)

These level sensors are submerged inside the access tube of these wells. It is important to point out that such equipment is highly sensitive and generally has a useful life of fewer than two years, mainly due to accelerated degradation by contact with water of high salinity and proximity to the coast. This material, however, can be reconditioned, so that it continues to function. The maintenance of the system, therefore, needs adequate planning for its satisfactory functioning. These sensors are connected by cables to the RTMS. It was necessary to dig ditches for the passage of these cables. These cables need to be properly protected from direct sunlight and mechanical stresses that weaken their structure, causing them to break and interrupt data transmission. These cables were routed through the external walls of the Landelino Rocha school library, where the GSM system is located. In addition to the level sensors, a pluviograph is connected to the system. The equipment belongs to the

Water Resources Group (UFPE). Both cables are finally connected to the system (Figure 10) so that this data can be transmitted via the internet to the Ampeq system, to store such information and allow real-time access as soon as the system is accessed.

Figure 10. Internet data transmission device

Data can be accessed through the following addresses:

- To visualize the level data (Figure 11): http://ampeq.net/graf/est_landelino.php and http://ampeq.net/graf/est_mini_landelino.php;
- To view the rain gauge data (Figure 12): http://ampeq.net/chuva/landelino_chuva.php
- To download data (login and password required): http://ampeq.ch/en/usuario.php

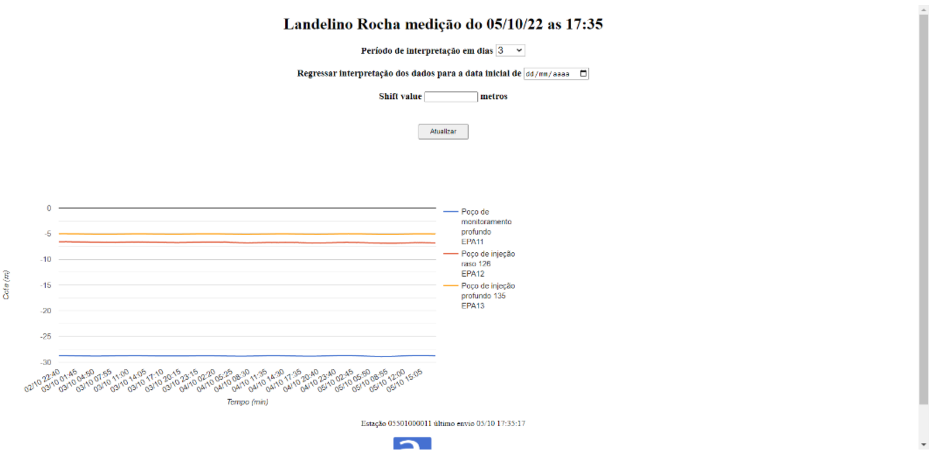

Figure 11. Screenshot of the real-time level data visualization of the 3 monitoring wells (Apeq website).

The level data can be observed in real-time by the Ampeq address and over the observed time, the difference between the levels of the EPA 11, EPA 12, and EPA 13 wells are noted.

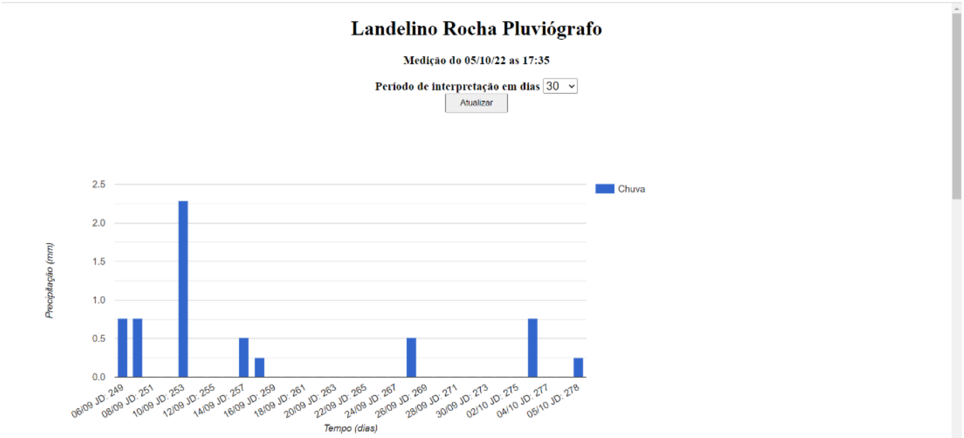

Figure 12. Visualization of rain data in real-time on the monitored rain gauge (Ampeq website).

The rain gauge can also be accessed via Ampeq's address, showing the accumulated rainfall events that have occurred over time and thus making an observation of its influence on the water level in the aquifer. This information provides the necessary support for the study area to be integrated into the SMART-Control project. With the installation of the RTMS at the Landelino Rocha school, the pilot study site in the city of Recife interconnected these data so that they can be used on the INOWAS platform (https://inowas.com/). It is a tool developed as an open-access web service with powerful server features to ensure a comfortable modeling experience and reliable simulations. The data monitored are sent to the INOWAS platform and are available in the T10 tool - Real-time Monitoring (Figure 13).

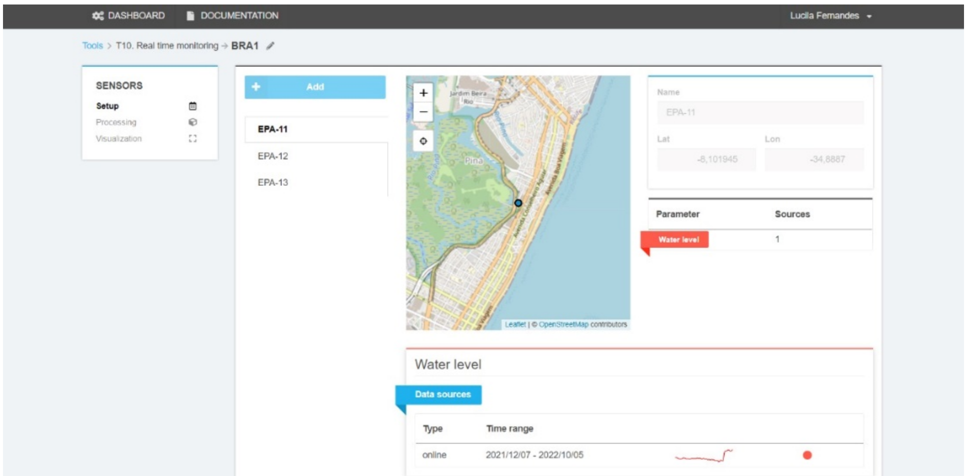

Figure 13. INOWAS T10 Tool - Real-time monitoring (INOWAS platform)

This tool encompasses a web-based monitoring system developed to integrate time series data into the INOWAS platform. Real-time sensors can be connected to the platform, such as those installed at the Landelino Rocha school by Ampeq, where time series data can be uploaded. Data can be viewed, processed, downloaded and prepared for later use. The next figures show the monitoring tool of the INOWAS platform using data from EPA 11 (Figure 14), EPA 12 (Figure 15), and EPA 13 (Figure 16) wells.

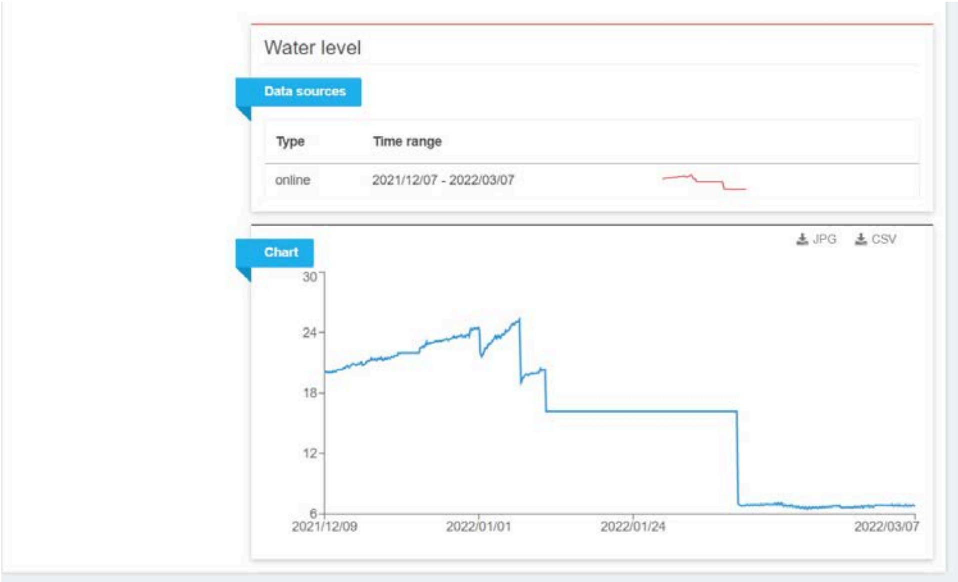

Figure 14. EPA 11 well (Lower monitoring tube (P02))

The EPA 11 well sensor stopped working and required maintenance by Ampeq technical support. It can be observed that during the period, no level variation was recorded and the sensor maintenance was subsequently carried out.

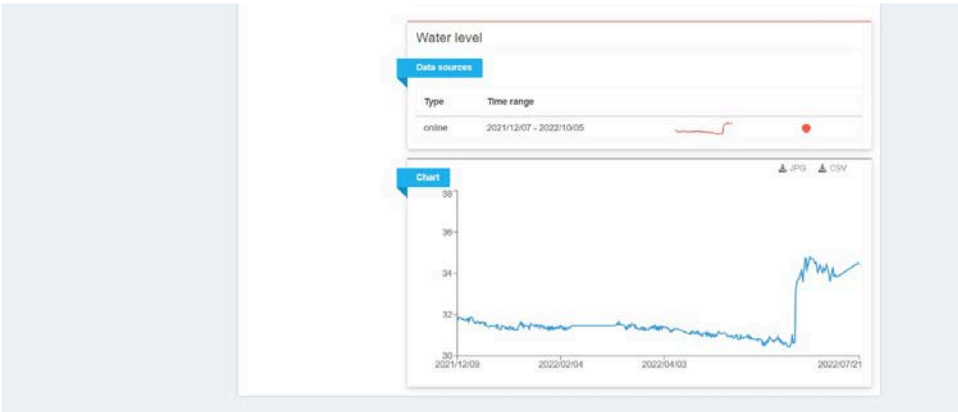

Figure 15. EPA 12 well (Upper Injection tube (P03))

During the recording made in this sensor, its maintenance was carried out in the EPA 12 well (component replacement and installation of additional weight to avoid sensor fluctuation) and thus, record more reliable information.

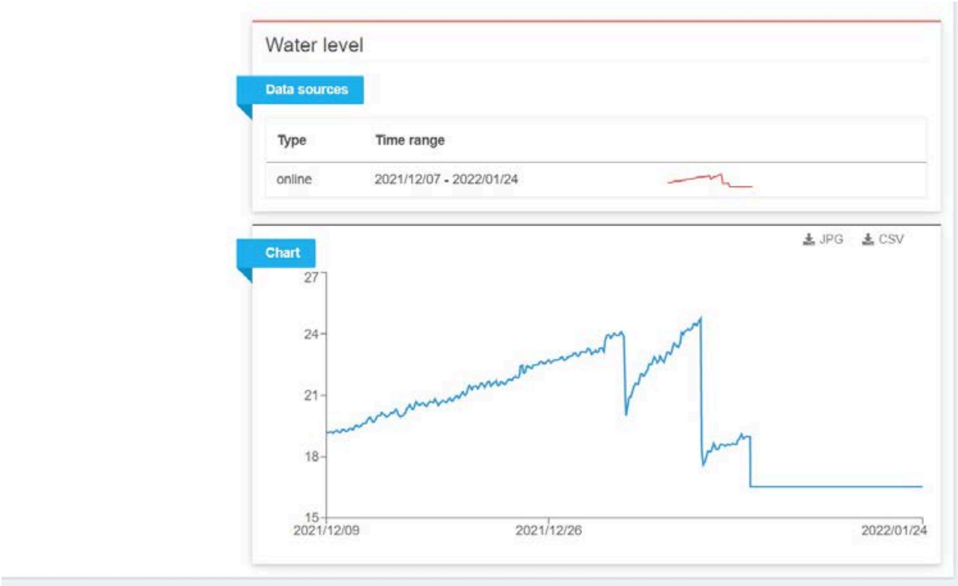

Figure 16. EPA13 well (Lower injection tube (P03))

As with the EPA 12 well, sensor maintenance was carried out in the EPA 13 well (component replacement and installation of additional weight to avoid sensor fluctuation) and also to record more reliable information.

3.4 RISK ANALYSIS

The planning of a managed aquifer recharge system includes a risk assessment before its implementation. For the pilot system located at the Landelino Rocha school in Recife, a risk assessment was carried out in light of the Australian guidelines for water recycling (NRMMC; EPHC; NHMRC, 2009). Given the scale of the scheme, only an initial risk assessment was recommended. The initial assessment has two objectives: it allows for assessing the apparent feasibility and degree of difficulty of the MAR project. In addition, it reveals uncertainties or the need for more information to carry out a risk assessment of health and the environment. The guidelines apply to all water sources, including recycled water, stormwater, treated drinking water, and natural water. They analyze changes in water quality in aquifers, based on scientific evidence. The guidelines recommend a prudent step-by-step approach to any project where uncertainties need to be resolved. As a result, human health and the environment remain protected.

Water supply quality and the risk of clogging

Previous tests showed good results for Total Nitrogen TKN=2.21 mg/L values, indicating a low risk of clogging. However, the results for turbidity showed a concentration of 12 NTU. The literature recommends using water with values between 0.1 and 3 NTU (Guttman and Negev, 2015). It should be considered that only one rainfall event has been evaluated, so exact statements can only be made after a more comprehensive study. OCD concentration has not yet been measured. A sand filter is being designed for pretreatment and preliminary testing will be done to investigate the effectiveness of the treatment. Further investigations are necessary because in the initial evaluation only turbidity and total nitrogen were investigated.

Groundwater salinity and recovery efficiency

At the site of the ASR pilot system, the groundwater of the lower cable aquifer presented mean Electrical conductivity (EC) values of 7400 µS/cm (Paiva et al., 2017). Samples collected in January 2019 showed slightly lower EC values of 6000 µS/cm, which still indicate brackish conditions (1500–15000 µS/cm). However, the EC measured at the project site is relatively high compared to the measured mean values of the Cape aquifer: 1246 µS/cm, n = 40 (Cary et al., 2015), 975 µS/cm (Coelho et al., 2018) and 926 µS/cm (Oliveira et al., 2017). The limit value given as the freshwater standard is 500 µS/cm, and therefore the EC values of ambient groundwater exceed the limit. The efficiency of the recovery will be analyzed with the EC values of the installed sensors. Three sensors will be needed. The first is to measure the EC of the water in the reservoir, another sensor to measure the EC value in the injection tube, and the third in the recovery tube. With these values, a salinity profile of the aquifer can be constructed. These are recommendations for future studies.

Aquifer capacity and groundwater levels

References do not mention fractures in the Cape aquifer, but a high clay content is reported. The Cabo aquifer is described as being heterogeneous, presenting fine clay intercalations, especially in the upper Cabo aquifer. Investigations are needed to assess the potential consequences of clay layers during refill and recovery. The hydraulic gradient can be analyzed by installing one sensor in the injection well and another sensor in a monitoring well, which is about 20 meters away. Hydraulic load values will be used to determine hydraulic gradients in the aquifer.

Conclusions

The Landelino Rocha school ASR system is being developed and studied as a pilot site to assess the feasibility of the technology. As it is a pilot scale scheme and has a high quality of the injected water, this initial assessment was considered adequate to assess the risks to human health and the environment at this stage of development. The assessment showed that the risks of aquifer pollution are low, as the risks of pollution of the reclaimed water are also considered low. There would be a high risk of clogging if no pre-treatment solution was provided. However, after installing the sand filter, it is necessary to assess the residual risk of the phenomenon. There is likely to be a low risk of impacts to user ecosystems and also a low risk of waterlogging or excessive groundwater level height. In addition, a low risk of dissolution of the aquifer matrix is expected, since the aquifer is not karst or composed of fractured rocks.
The biggest challenges for system development are operational. The assessment revealed a need to better understand aquifer characteristics to assess system efficiency. In addition, aquifer and water source water quality samples need to be analyzed more frequently. For more information on the initial risk assessment see the SMART-Control Deliverable 2.1 (Sprenger et al., 2019).

4 DISSEMINATION OF THE RESEARCH

Project website:

Information about research propagation, involved partners, project progress, and results can be accessed at the following website: https://smart-control.inowas.com/

Articles published in journals:

Shubo, T.; Fernandes, L.; Montenegro, S.G. An Overview of Managed Aquifer Recharge in Brazil. Water, v. 12, p. 1072, 2020.

Articles published in congress's annals:

Fernandes, L.; Conrad, A.; Montenegro, S.M.G. de; Paiva, A. L. R. de; Castro, M.A.R.A. Application and evaluation of an advanced aquifer storage and recovery pilot system in Recife, Brazil. In: 10th International Symposium on Managed Aquifer Recharge, 2019, Madrid. 10th International Symposium on Managed Aquifer Recharge, 2019.

Glass, J.; Stefan, C.; Sprenger, C.; Chakrabarti, R.; Montenegro, S.; Almeida, C.; Papanastasiou, P.; Marinos, S.; Maréchal, J.; Schneider, T.; Duzan, A. and Picot-Colbeaux, G. Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge applications: project outlook. In: 10th International Symposium on Managed Aquifer Recharge, 2019, Madrid. 10th International Symposium on Managed Aquifer Recharge, 2019.

Albuquerque, C.G.; Montenegro, S.M.G.L.; Paiva, A. L. R. de; Fernandes, L.A.; Gusmão, A.C.V.E.L. Proposal for mapping groundwater-dependent ecosystems in the Metropolitan Region of Recife. In: XXIII Brazilian Symposium on Water Resources, 2019, Foz do Iguaçu. XXIII Brazilian Symposium on Water Resources, 2019.

Ongoing searches:

Doctoral thesis: Lucila Fernandes - in progress. Title: Planning and implementation of a pilot system of managed aquifer recharge in the Metropolitan Region of Recife. Advisor: Profa. Dr. Suzana Maria Gico Lima Montenegro.

Doctoral thesis: Cleber Albuquerque - in progress. Title: Mapping of ecosystems dependent on groundwater for water resource management in the Metropolitan Region of Recife. Advisor: Profa. Dr. Suzana Maria Gico Lima Montenegro.

Completed searches:

Scientific initiation: Maria de Andrade - Completed. Title: Implementation of aquifer artificial recharge technique as a strategy for water resources management in the Metropolitan Region of Recife - PE. Advisor: Profa. Dr. Suzana Maria Gico Lima Montenegro.

Participation in events:

International Symposium on Managed Aquifer Recharge (ISMAR10). 2019. (Congress).

Training course:

In December 2021, an online training to MAR managers and technical operators was held. The main objective was to capacitate stakeholders from Recife and João Pessoa on how the risks associated with MAR installations can be reduced and controlled using the SMART-Control real-time monitoring and control system. More detailed information can be found at SMART-Control Deliverable 6.2 (https://smart-control.inowas.com/deliverables/)

5 CONCLUSIONS AND OUTLOOK

The SMART-Control project faced difficulties as a consequence of the restrictions caused by the Covid-19 pandemic, interrupting the execution of some activities. It was not possible to completely install the Aquifer Storage and Recovery (ASR) pilot system in the Landelino Rocha school, in the Pina neighborhood. The installation of the rainwater harvesting project, which is part of the pilot system, was also affected. All these activities have to be implemented in future projects. However, this project contributed to the advancement of the managed recharge of aquifers, intending to increase water availability in urban areas, preventing saltwater intrusion into coastal aquifers, and reducing extreme weather events.

Also due to social isolation, in-person events scheduled for the project were adapted to the remote format, to continue the research activities and discuss the use of tools to favor the management of water resources. The pilot project at the Landelino Rocha school together with the RTMS tool favors the accessibility of this information for the actors involved in the use of groundwater resources and with that the consequent better social acceptance of water reuse methods, demonstrating their suitability as adaptation measures against climate change.

As next steps, it is planned to advance in the modeling of the aquifer where the managed aquifer recharge is being implemented, using the data previously collected from the monitoring system and the injection tests.

6 REFERENCES

Batista, J. C. (2015) Superexplotação de águas subterrâneas, o caso de Recife. Tese. Universidade de São Paulo.

Bertrand, G.; Hirata, R.; Pauwels, H.; Cary, L.; Petelet-Giraud, E.; Chatton, E. et al. (2016): Groundwater contamination in coastal urban areas: Anthropogenic pressure and natural attenuation processes. Example of Recife (PE State, NE Brazil). In: Journal of contaminant hydrology 192, S. 165–180. DOI: 10.1016/j.jconhyd.2016.07.008.

Cabral, J. J. S. P.; Farias, V. P.; Sobral, M. do C.; Paiva, A. L. R. de; Santos, R. B. (2008): Groundwater management in Recife. In: Water International 33 (1), S. 86–99. DOI: 10.1080/02508060801927648.

Cary, L., Petelet-Giraud, E., Bertrand, G., Kloppmann, W., Aquilina, L., Martins, V., Hirata, R., Montenegro, S.M.G.L., Pauwels, H., Chatton, E., Franzen, M., Aurouet, A., Lasseur, E., PicotColbeaux, G. and Guerrot, C. (2015). Origins and processes of groundwater salinization in the urban coastal aquifers of Recife (Pernambuco, Brazil): a multi-isotope approach. Science of the Total Environment, v. 530–531, p. 411–429, 2015.

Coelho, V. H. R.; Bertrand, G. F.; Montenegro, S. M. G. L.; Paiva, A. L. R.; Almeida, C. N.; Galvão, C. O.; Barbosa, L. R.; Batista, L. F. D. R; Ferreira, E. L. G. A. (2018). Piezometric level and electrical conductivity spatiotemporal monitoring as an instrument to design further managed aquifer recharge strategies in a complex estuarial system under anthropogenic pressure. Journal of Environmental Management 209, 426–439.

Costa, W. D., Costa, H. F., Ferreira, C. A., Morais, J. F. S, Villa Verde, E. R., Costa, L. B. (2002). Estudo Hidrogeológico de Recife- Olinda- Camaragibe- Jaboatão dos Guararapes- HIDROREC II. SRH- PE. Recife, 150p.

Fernandes, L. A.; Conrad, A.; Montenegro, S.; Paiva, A.; Castro, M. (2019). Conceptualisation of an advanced aquifer storage and recovery pilot system in Recife, Brazil. Proceedings of ISMAR10, Madrid, Espanha.

Guttman, J. and Negev, I. (2015). Design of new injection wells for injecting surplus desalinated water into the aquifer. Water Quality Workshop, Algarve, Portugal.

IBGE (2018): Dados censitários. Instituto Brasileiro de Geografia e Estatística. Disponível em <www.ibge.gov.br>, acesso em: 05 de dez. de 2022.

Luna, R. M. R. de; Garnés, S. J. A.; Cabral, J. J. S. P.; Santos, S. M. (2017): Groundwater overexploitation and soil subsidence monitoring on Recife plain (Brazil). In: Nat Hazards 86 (3), S. 1363–1376. DOI: 10.1007/s11069-017-2749-y.

NRMMC-EPHC-AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health Health and Environmental Risks: Phase 1. NRMMC-EPHC-AHMC, Australia. Guttman, J. and Negev, I. (2015). Design of new injection wells for injecting surplus desalinated water into the aquifer. Water Quality Workshop, Algarve, Portugal.

Oliveira, M. M.; Leitao, T. E.; Martins, T.; Costa, W. D.; Ferreira, J. P. L. (2017). Estudos sobre a disponibilidade e vulnerabilidade dos recursos hídricos subterrâneos da região metropolitana do Recife, SILUSBA. Relatório da atividade 10. Paiva, A. L. R. D.; Bertrand, G. F.; Ferreira, E. L. G. A.; Monteiro, R. V. A.; Coelho, V. H. R; Montenegro, S.M.G.L. (2017). Comportamento hidrodinâmico em aquíferos costeiros da cidade sob influência da maré: Implicações pela gestão dos recursos hídricos em Recife (PE). XXII Simpósio Brasileiro de Recursos Hídricos.

Paiva, A; Bertrand, G; Ferreira, E; Monteiro, R; Coelho, V; Montenegro, S. (2017). Comportamento hidrodinâmico em aquíferos costeiros da cidade sob influência da maré: implicações pela gestão dos recursos hídricos em Recife (PE). XXII Simpósio Brasileiro de Recursos Hídricos, Florianópolis, Brasil.

Petelet-Giraud, E.; Cary, L.; Cary, P.; Bertrand, G.; Giglio-Jacquemot, A.; Hirata, R. et al. (2018): Multi-layered water resources, management, and uses under the impacts of global changes in a southern coastal metropolis: When will it be already too late? Crossed analysis in Recife, NE Brazil. In: The Science of the total environment 618, S. 645–657. DOI: 10.1016/j.scitotenv.2017.07.228.

Silva, G. E. S.; Montenegro, S. M. G. L.; Montenegro, A. A. A.; Costa, L. M.; Cavalcanti, G. L.; Moura, A. E. S. S. (2004). Avaliação do potencial da recarga artificial através de águas pluviais para recuperação da potenciometria de aquífero costeiro na planície do Recife-PE (brasil). Águas Subterrâneas, [S. l.], n. 1, 2004. Disponível em: https://aguassubterraneas.abas.org/asubterraneas/article/view/23360. Acesso em: 5 out. 2022.

Silva Junior, M. A. B.; Silva, S. R.; Cabral, J. J. S. P. (2017): Compensatory alternatives for flooding control in urban areas with tidal influence in Recife - PE. In: *RBRH* 22 (0), S. 207. DOI: 10.1590/2318-0331.011716040.

Sprenger, C., Panagiotou, K., Fernandes, L., Duzan, A., Baptista, V., Glass, J., 2019. SMART-Control Deliverable D2.1: Matrix of risks and remediation measures - Risks and remediation measures at different stages of MAR site development. https://doi.org/10.13140/RG.2.2.19884.39040

Zuurbier, K. G.; Zaadnoordijk, W. J.; Stuyfzand, P. J. (2014): How multiple partially penetrating wells improve the freshwater recovery of coastal aquifer storage and recovery (ASR) systems: A field and modeling study. In: Journal of Hydrology 509, S. 430–441. DOI: 10.1016/j.jhydrol.2013.11.057.