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Evaluation of The Influence of an Aquaculture Basin on Water Resource Management Through The use of a Geographic Information System and The FREEWAT Modelling Tool: A Case Study in The El Tarf Region (Northeast Algeria)

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Abstract

The study area belongs to the Bouteldja plain in the northeast of Algeria that experiences a cold and rainy Mediterranean climate during winters alongside a hot and dry summer. As per the potentiometric map, the movement of groundwater is towards the east. During model development, a single-layer numerical model was created with the aid of the MODFLOW-2005 code and the FREEWAT modeling tool. Some GIS features were executed on the model in a steady-state condition through the hydrological year of 2020. MODFLOW Well (WEL) and MODFLOW Recharge (RCH) models were successively utilized to simulate groundwater extraction and recharge. Analysis of pumping test data indicates that the total contribution via the western boundary is lower than the term of extraction because of over-pumping. The simulation analyses of the water balance and groundwater recharge following the installation of the aquaculture basin, with or without pumping, demonstrate a reduction in hydraulic load in the area near the wells. As a result, the exploitation rate of these resources might amount to or even exceed their renewal rate. In conclusion, our work proposes a modeling approach to simulate the impact of an aquifer recharge management program by adding an aquaculture basin for a dual purpose: the development of fishery resources and agriculture in rural areas.

Keywords: *Aquaculture Basin; FREEWAT Modeling Tool; Wells Of Pumping; Groundwater; GIS*

1. Introduction

Life on Earth would not exist without water; a unique resource that cannot be replaced. Water is crucial in many regions of the world due to rapidly increasing demand, as well as the scarcity and degradation of available resources. This renewable natural resource, subject to the unchanging hydrological cycle of evaporation-precipitation, should guarantee conditions for development (2IE 2010). Unfortunately, the demand for water in the Southern Mediterranean region is expected to increase due to population growth, coastal urbanization, and the tourist attraction of coastal zones. With upcoming climate change, the situation is likely to worsen, exacerbating water scarcity and quality issues (Milano M 2009). It also has short and long-term impacts on surface and groundwater in this northern part of the African continent (Hamed et al 2018).

There are several factors that may explain the situation of hydrological stress in the eastern region of Algeria, including population growth, changes in water demand, and climate change... (Djaffar and Kettab 2015). The agricultural sector in this area depends primarily on groundwater, which is the most critical water source for rural communities. However, the exploitation of these resources has exceeded the capacity of the groundwater table due to the uncontrolled proliferation of surface wells. This situation has led to disturbances in the hydrodynamic functioning of the groundwater table, resulting in a continuous decline in its water level Smida et al 2006). As agricultural water demand includes irrigation water needed to support crop growth and water required directly for livestock, mainly drinking water, an aquaculture basin is being developed to reduce pressure on this water resource.

The purpose of this article is to provide a useful example of testing a conceptual and methodological model for integrated water resource management through the addition of an aquaculture pond, which serves a dual purpose: developing fisheries resources and agriculture in a rural area.

2. Materials And Methods

Geographic setting

Our research is conducted in the rural region of El Tarf province (northeast Algeria) along the W118 road, where three agricultural wells are located (Figure 1); the farmers' wells are constructed for irrigation purposes using groundwater (Chabour et al 2018).

The reason for choosing this study area is the insufficiency of local hydrological resources to meet the demand for irrigation water for agricultural production. Our work, therefore, aims to develop fisheries resources and agriculture in this study area.

Figure 1. Geographical location and zoom on the study area.

Climate characteristics

This region is subject to a Mediterranean climate, characterized by a strong interannual variability of precipitation and a marked alternation of seasons, with humid and cold winters and dry and hot summers **(Barcikowska et al 2020).** According to climatological studies by Boularouk et al (2018) in the basin of the Kebir-Est River, during the wet season it reaches a peak of more than 0.95 Hm^3 per year. Since groundwater recharge is mainly provided by precipitation, any change in the precipitation regime should have an impact on the groundwater resource (Drouiche et al 2019). The average annual rainfall varies between 594 mm and 817 mm, with an average annual temperature of 18°C and evapotranspiration ranging from 485 mm/year to 581 mm/year (Attoui et al 2012).

Geological and hydrogeological characteristics

The geology of the study area is part of the northeastern Algerian Tell geology, which extends from the Constantine region to the Algerian-Tunisian border. It is characterized by the Secondary (marls and calcareous marls), the Tertiary (formations, sandstones and clays) and the end of the Quaternary (alluvium) (Zaoui et al 2019).

According to studies by Kherici and Messadi (1992), the hydrogeology of this study area is defined by a deep layer consisting of gravel, pebbles and sandy materials of Numidian origin, with interbeds of marls, all overlain by an argillaceous-limy layer which constitutes the roof of the confined aquifer.

Agri_aquacultural characteristics

One of the riches of the wilaya is undoubtedly its hydro-agricultural potential. The most important economic activity in the study zone, compared to industry, relies on the irrigation of groundwater, made up of relatively recent and shallow coastal aquifers that are actively recharged through precipitation (*Gayar 2021).* The most commonly produced agricultural products, in descending order, are vegetables, industrial crops such as tomatoes, fodder, and cereals.

Aquaculture is a strategic sector for meeting food needs and becoming an attractive and important component of rural livelihoods which, in small-scale production systems, provides high-quality animal proteins and essential fatty acids, vitamins, and minerals (Halwart 2005).

This region is characterized by agricultural and aquaculture activities; therefore, the intention to establish a freshwater fish farm. Moreover, being an agricultural zone par excellence, this aquaculture pond has a dual objective of developing fishery resources and agriculture, by using these nutrient-rich freshwater (salts and organic products) for irrigation of watermelon crops, for example; while ensuring water quality control.

The conceptual model

The studied area measures 900 m wide and 1260 m long, representing the hydraulic functioning of a studied aquifer system (Barthélemy and Seguin 2016). This area is located in the Bouteldja Plain (Figure 2), where several hydrogeological studies have been conducted (Gaud 1976;_Bounab et al 2017) showing that the plain is composed of gravels, pebbles, and sands of Numidian origin.

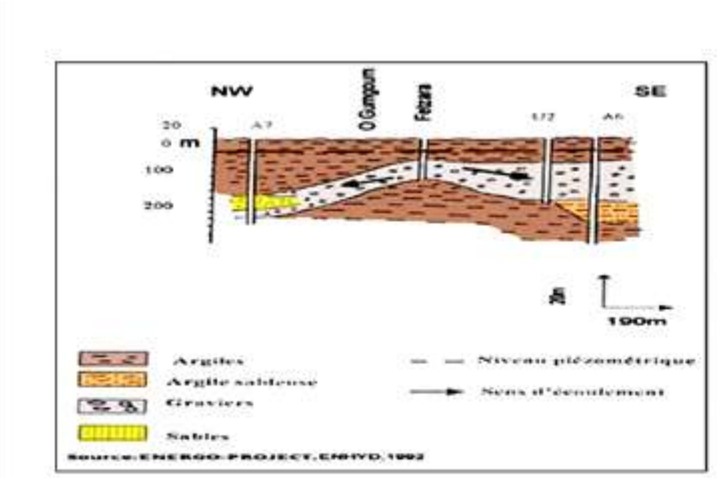

Figure 2. Hydrogeological section in the bouteldja plain (ENERGO - PROJEKT -E.N.H.Y.D 1992)

Hydraulic head measurements were taken during the 2020 hydrological year: one during high water in April and one during low water in September. These measurements were taken from well water levels, providing insight into the groundwater flow dynamics in the region (Figure 3). Analysis of the two piezometric maps revealed consistent findings and characteristics, which allowed for the interpretation of a single map that shows groundwater flow generally oriented from west to east.

Figure 3. Hydrodynamics of the groundwater flow system in the study area in **(A)** April 2020 and **(B)** September 2020.

Aquaculture pond

In Algeria, semi-intensive inland aquaculture currently revolves around two fish types: tilapia (Oreochromis niloticus) and African catfish (Clarias spp.). These fish species are not suited for farming at low temperatures, which limits their production to the warm months of the year.

The tilapia, a warm freshwater fish species, is an ideal fish to be grown in aquariums. As a cichlid species, it is capable of reproducing early, at just four months of age, and producing numerous offspring each time (Lazard 1984). Oreochromis niloticus, the African tilapia species, is successful in farming due to its resilience, fertility, and ease of growth. The farming of this species requires a closed-circuit system that ensures full control over the water temperature.

The basin is built on top of the groundwater system at the center of the facility and is fed with freshwater from a well. It is a square basin with a recharge rate of 2.10^{-7}m/s.

Data processing tools

For data processing, we chose the cartographic software: geographic information system (GIS), qgis 2.18.21 Las Palmas. We implemented the groundwater flow numerical model using the FREEWAT software (Rossetto et al 2015; DeFilippis et al 2017; Fogliaet al 2018; Cannata et al 2018; Harizi et al 2021). The FREEWAT modelling platform was developed as a plugin (De Filippis et al 2018) of the well-known, free, and open-source desktop GIS software (QGIS Development Team 2009). MODFLOW is one of the most widely used models worldwide for numerical simulation of groundwater flow in aquifers. The MODFLOW-2005 executable (Harbaugh 2005) must be downloaded only.

In our study, we also used Google Earth to better locate and calibrate our study area using the latest Google Earth satellite images and Surfer software (designed by Golden Software) to allow us to make digital elevation models (DEM) from field data collected by GPS.

The numerical model

The modelling area is defined by a horizontal grid consisting of 15 rows and 21 columns (315 cells) with a 60 m by 60 m resolution. The vertical discretization is composed of a permeable sand layer that represents the main hydro-stratigraphic unit, which is homogeneous and confined, and is 70 m thick. The hydraulic conductivity in the three Cartesian directions (Kx, Ky, and Kz) is 3.e-5 m/s. The model will be executed over four stress periods (SP), during which all defined conditions/constraints (such as wells and recharge) remain constant. The starting head (STRT), which represents the initial condition of the simulation, is 62 m. To implement the model, the necessary data files include a raster file (map.tif), a point shapefile with the well location (wells.shp), and a polygon shapefile with the location of the aquaculture pond (Aqua_pond.shp).

3. Results and Discussion

The simulation covers the year 2020 as a representative year, with 4 stress periods of 30 days each. The simulation, carried out in steady state, represents the average budget on an annual basis (Positano and Nannucci 2017) during which four periods have been defined as follows: no constraint has affected this system for one day: the storage term is zero and no flow occurs, and there is no recharge of the aquifer.

During model construction, certain MODFLOW packages were activated to simulate specific boundary conditions and source/sink terms (WELL / RCH pack). The second period lasted 30 days, during which three pumping wells penetrating the aquifer were activated, including agricultural wells for groundwater extraction. The withdrawal term due to the presence of the three wells (PUITS - OUT) is equal to the overall input through the west boundary (CONSTANT CHARGE - IN) at approximately 7.50 x10-2 m^3/s (6480 m^3/day), and the (IN - OUT) is lower, with pumped volumes greater than the inflow volumes (Figure 4).

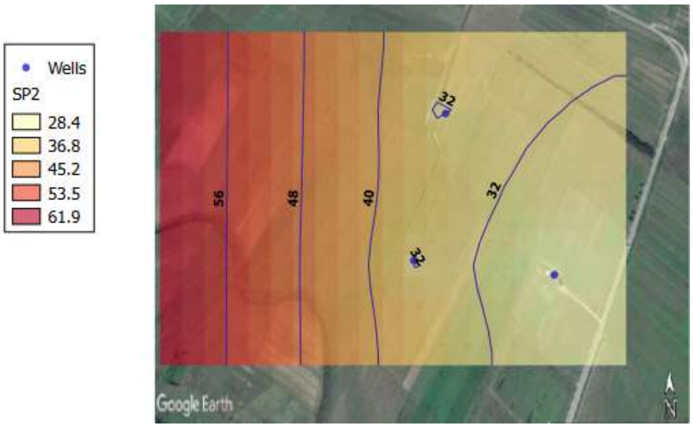

Figure 4. Simulated hydraulic head after pumping.

Furthermore, artificial recharge of aquifer systems is carried out through an aquaculture basin for aquifer recharge; and the impact of a managed aquifer recharge system (an aquaculture pond) on the overall water balance is defined using the MODFLOW Recharge (RCH) package to simulate distributed recharge to the groundwater system. A new flow term now enters the model balance after a month of pumping: the source term due to the presence of an aquaculture basin (recharge) without pumping. This term is equal to 4.32 x10-3 m^3/s, or approximately 373 m^3/day (Figure 5).

Figure 5. Simulated hydraulic head after implementation of the aquaculture pond.

Another model configuration, with both wells and aquaculture recharge active, (Figure 6) has a flow rate at the western limit estimated at around 7.06 x10-2 m^3/s (6108 m^3/day), which is lower than that observed during pumping alone; this justifies the overexploitation of these irrigation wells.

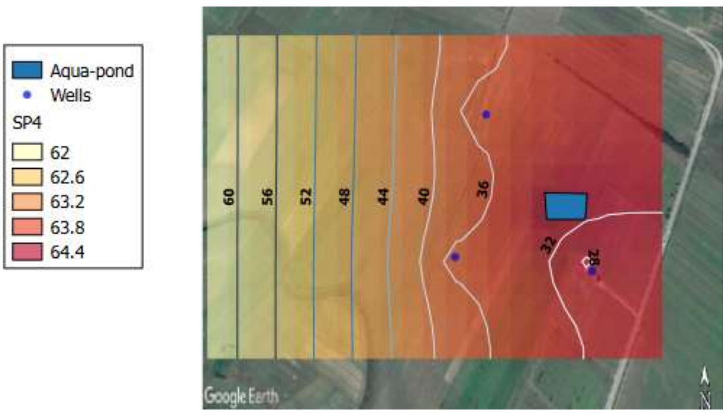

Figure 6. Simulated hydraulic head after pumping and aquifer recharge.

Table 1 displays the culmination of the underground water evaluation, after the fourth period of stress: RECHARGE - IN (4.32 x10^{-3} m^3/s = 373.25 m^3/day) and PUITS - OUT (7.50 x10^{-2} m^3/s = 6480 m^3/day); and the ratio (IN - OUT) = -1.45 x10^{-6}. The withdrawal of water through pumping was computed to reach 395,280 m3/day.

Table 1. Model groundwater balance after three months of simulation.

	Inflow	Outflow
Constant head	384076	11194
Wells	-	395280
Aqua pond (RCH)	22394	-
Total	406470	406474

Figure 7 figures the impact of the aquaculture basin, especially by means of elevation comparison at the location of the wells; allowing a height difference estimation from west to east of 1.53 m, then 1.61 m and ending at 2.25 m.

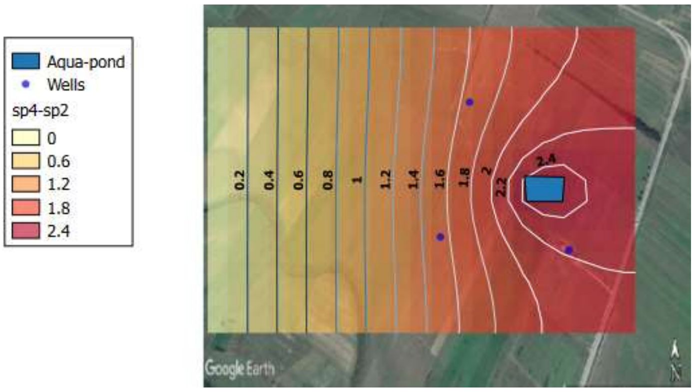

Figure 7. Difference between simulated hydraulic loads after pumping add aquifer recharge.

4. Conclusion

The simulations conducted on the analyzed case study produce several results:

Firstly, the interpretation of the pumping tests data showed that the overall contribution through the western limit (CONSTANT HEAD - IN) is lower than the well extraction (WELLS - OUT) due to excessive pumping. Both RECHARGE - IN and WELLS - OUT terms are involved in the groundwater balance after three months; their values are respectively 4.32×10-3 m^3/s (373.25 m3/day) and 7.50×10-2 m^3/s (6480 m^3/day).

The results also indicate that the exploitation rate of these resources can approach or exceed their replenishment rate. In this context, our study endeavors to provide an exemplary test of a conceptual and methodological model for integrated water resources management.

Moreover, the integration of aquaculture into larger agricultural systems has been advocated as a way to increase food production, preserve the environment, and ensure food security:

- Animal manure usage as fertilizer for ponds
- Crop by-products utilization as supplementary food for fish
- Pond sediment use as land fertilizer for crops and aquaculture wastewater use for crop irrigation.

Lastly, water quality is a critical factor in any farming system. Hence, it is highly necessary to ascertain water availability and quality before investing in a production system.

Authors' contributions

HG: Conceptualization, Methodology, Formal analysis, Software Data curation, Writing – Original draft preparation. **SL:** Conceptualization, Methodology, Formal analysis, Software Data curation. **FM:** supervision. **HG, SL and FM:** final review and approval for submission.

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Ethical Approval

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Competing interests

The authors declare no competing interests

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