Natural Resources, 2023, 14, 205-214
https://www.scirp.org/journal/nr
ISSN Online: 2158-7086
ISSN Print: 2158-706X

Modelling of the Hydrogeological Behaviour of the Tassette Aquifer: Study of the Possibilities of Exploiting This Aquifer as an Alternative against the Limestone Problem in the Commune of Thies

Saidou Ndao[1,2]*, Famara Seydi Ba[1,2], Papa Babacar Diop Thioune[3], Diadioly Gassama[1,2]

[1]Laboratory of Science and Technology of Water and Environment (LaSTEE), Polytechnic School of Thies, Thies, Senegal
[2]UFR Sciences and Technologies, Iba Der THIAM University of Thies, Thies, Senegal
[3]Higher Institute of Agricultural and Rural Training ISFAR, Alioune DIOP University of Bambey, Bambey, Senegal
Email: *saidou.ndao@univ-thies.sn

How to cite this paper: Ndao, S., Ba, F.S., Thioune, P.B.D. and Gassama, D. (2023) Modelling of the Hydrogeological Behaviour of the Tassette Aquifer: Study of the Possibilities of Exploiting This Aquifer as an Alternative against the Limestone Problem in the Commune of Thies. *Natural Resources*, **14**, 205-214.
https://doi.org/10.4236/nr.2023.1410014

Received: August 18, 2023
Accepted: October 28, 2023
Published: October 31, 2023

Abstract

Senegal's drinking water supply comes on the one hand from groundwater and mainly from Maastrichtian and Paleocene aquifers. The Tassette area included in the Thies region has such potential that the Paleocene is currently exploited to cover a certain part of Dakar's important water needs. In addition, the city of Thies is itself confronted with the problems of limestone present in its drinking water and generally creating problems of scaling pipes. A water transfer is therefore a possible option to deal with this situation. This study will consist of modelling the Tassette aquifer to determine if it will cover Thies' water needs over a period of 20 years. To assess the responses of the groundwater to pumping at this level and the changes that may occur, a numerical hydrogeological model is necessary. In order to have a better overview of the area, boreholes and piezometric tests were carried out, highlighting the different characteristics of the aquifer and the water it contains. Based on these, the model was developed according to a mesh system and more precisely by discretization and simulation according to the finite difference method from the Visual Modflow Flex software. The results observed for this modelling show that the city of Thies cannot be supplied as a whole. This mining model also causes brackish water intrusion. On the other hand, the additional withdrawal of a certain quantity of water compared to the current situation does not have as great negative impacts and would still partially meet the expectations of this modelling.

Keywords

Modelling, Tassette, Hydrogeological Model, Aquifer, Aquifer

1. Introduction

Senegal is a country facing several problems in terms of its groundwater resources according to the different zones and regions. Indeed, Senegal's groundwater suffers from ills such as overexploitation, salinization, excess fluoride, limestone or iron, or anthropogenic pollution. Good management of these resources would therefore be necessary to ensure the improvement of the living conditions of populations and sustainable development [1] [2]. Thies, a city near Senegal's capital Dakar, whose drinking water is supplied mainly from the Maestrichtian aquifer, is particularly affected by the significant presence of limestone. When the water is thus rich in limestone, it is called hard water. The advantage of hard water is that it covers part of the Ca^{2+} and Mg^{2+} needs of man and it is more pleasant to drink, however, limescale deposits in pipes imply the reduction of diameters which can be the cause of system malfunction, a decrease in working pressure, energy and additional expenses due to the alteration of water transfer pipes [3] [4] [5].

In order to deal with this problem of hard water, transferring water from Tassette would be a good alternative. At this level, a battery of boreholes has been set up by the National Water Company of Senegal (SONES) and hydrogeological and geophysical studies as well as qualitative and quantitative monitoring are conducted by the Directorate of Water Resources Management and Planning (DGPRE). A more in-depth study aimed at feeding the city of Thies could be envisaged.

Tassette is part of the department of Thies. The distance separating it from the city is equal to about 20 km [6]. The water of the Tassette aquifer being of better quality than that present in Thies, this transfer could be done either completely, that is to say with cessation of the use of the Thies aquifer, or by a possible dilution of the water of the Thies aquifer by that coming from Tassette to lower the concentration of minerals such as limestone [7].

2. Methods and Materials

2.1. Geographical Location of the Study Area

The region of Thies, located in the west of Senegal at 14˚46' North - 16˚54' West, is limited to the east by Fatick and Diourbel, to the west by Dakar and the Atlantic Ocean, to the north by Louga and to the south by the Fatick region. It thus covers nearly 3.4% of the country's surface [8] [9]. **Figure 1** shows the location of the Tassette area.

2.2. Visual Modflow Flex Software Overview

Visual Modflow Flex is a software created by SCHLUMBERGER Water Services;

Figure 1. Location of the Tassette area.

It has an intuitive and easy-to-use interface that simulates groundwater flows, their quality, quantity, etc., thanks to a set of tools [10] [11] [12].

With this software, it is possible to choose between a conceptual model approach and a classical numerical model approach [13] [14] [15].

2.3. Estimated Water Needs of the City of Thies in 2037

For the estimation of the population Thiessoises by 2037 we start from the geometric method given by the following relation:

$$P_n = P_o \times (1 + T)^n \tag{1}$$

With

P_n = Future population

P_o = Current population

n = horizon

T = rate of increase

We will consider an increase rate of 2.5% [16].

Daily consumption is equivalent to:

$$C_j = P_n \times C_u \tag{2}$$

C_u = Unit consumption

2.4. Elaborating Model Input Parameters

1) Geologic of aquifere

At the study area level, three (3) electrical sounding sections were developed. Two (2) oriented from southwest to northeast (SW-NE) and one (1) approximately west to east (W-E). From these profiles, isobath maps of the roof and wall of the aquifer and isopaque maps of thicknesses were prepared.

2) Sampling

- ❖ The Paleocene globally is exploited by about 300 boreholes. In the area more specifically, we mainly note:
- ❖ The drilling of the Notto-Diosmone-Palmarin system which takes a total flow of 5500 m^3/d;

- ❖ Four (4) functional rural boreholes operating between 46 and 178 m^3/d, an average flow of 112 m^3/d;
- ❖ Seven (7) SONES boreholes used mainly for the supply of Dakar and taking overall a flow of nearly 15,000 m^3/d.

2.5. Model Calibration

For steady state, we determine the hydraulic conductivity at saturation of the zone. The calibration will thus be carried out from data such as operating rates, hydraulic conductivity, boundary conditions.

There are three conductivity zones to arrive at an acceptable calibration of the model: a conductivity zone equal to 7 × 10^{-1} m/s located in the northwest part, a second in the central part, around 4 × 10^{-4} m/s and in the southeast, the conductivity would be 3 × 10^{-5} m/s.

For each simulation scenario, we have entered in a table the flow rates used.

- Scenario 1

For this situation, it is considered the current AEP with the drilling already present in the area for a horizon of 20 years.

Seven (7) boreholes set up by SONES provide nearly 150 m^3/h each, or 3000 m^3/d; four (4) rural boreholes with flows between 46 and 178 m^3/d, or an average of about 112 m^3/d; NDP system drilling that exploits 5500 m^3/d.

Drilling information for this scenario is reported in **Table 1**.

- Scenario 2

In addition to the data from scenario 1, we consider in it an increase in the number of collection structures for the supply of the city of Thies by 2037.

Assuming that this increase in exploitation is carried out from a battery of five (5) boreholes dug in the central part of the model in order to avoid overexploitation in the southeastern and western parts and at the same time limit brackish water inflows.

Table 1. Location and operating rates of scenario 1 structures.

Nom	X_COORD	Y_COORD	Z (m)	Pumping rate (m^3/j)
Tassette F4 NDP	299,643	1,617,601	24.8	−5500
Sipane	299,095	1,615,207	16.35	−112
Tassette P1	299,918	1,616,339	20	−112
Tassette P12	299,346	1,614,823	19.476	−112
Tassette P2	298,990	1,616,856	25	−112
F1	292,022	1,620,523	50.24	−3000
F2	291,552	1,620,367	40.6	−3000
F3	291,456	1,619,876	39	−3000
F4	291,834	1,619,545	41.3	−3000
F5	292,306	1,619,703	42.6	−3000
F6	292,400	1,620,194	49	−3000
F7	291,928	1,620,034	42	−3000

The water needs of the city of Thies for 20 years having been estimated above at 37,000 m^3/d, providing this quantity of water would imply an operating rate of 370 m^3/h by boreholes, considering a pumping time of 20 hours, *i.e.* a daily volume of 7400 m^3 produced by each borehole (Table 2).

- Scenario 3

We start here from a contribution of part of the water needs of the city of Thies, still for the horizon of 20 years, for a possible dilution with the water currently used to reduce limestone concentrations. The captor field added to the previous scenario is retained. However, Thies' water requirements for scenario 3 being halved 18,500 m^3/d, operating flows would therefore return to 185 m^3/d for each structure. The pumping time considered to be 20 hours, the volume pumped at each borehole is therefore 3700 m^3/d (Table 3).

- Scenario 4

This scenario consists of covering nearly a third of the water needs of the inhabitants of the city of Thies. The Tassette aquifer does not have a very large capacity, and considering in this case that scenarios 2 and 3 do not provide good results and are therefore not able to meet the expectations of this modelling, this option would therefore, if the results are conclusive, be a plus both for the population concerned and for the quantitative and qualitative conservation of that groundwater.

Table 2. Location and operating flows of scenario 2 structures.

Nom	X_COORD	Y_COORD	Z (m)	Pumping rate (m^3/d)
Tassette F4 NDP	299,643	1,617,601	24.8	−5500
Sipane	299,095	1,615,207	16.35	−112
Tassette P1	299,918	1,616,339	20	−112
Tassette P12	299,346	1,614,823	19.476	−112
Tassette P2	298,990	1,616,856	25	−112
F1	292,022	1,620,523	50.24	−3000
F2	291,552	1,620,367	40.6	−3000
F3	291,456	1,619,876	39	−3000
F4	291,834	1,619,545	41.3	−3000
F5	292,306	1,619,703	42.6	−3000
F6	292,400	1,620,194	49	−3000
F7	291,928	1,620,034	42	−3000
F8	296,703	1,618,245	32.344	−7400
F9	297,186	1,618,229	34.079	−7400
F10	297,168	1,617,639	29.507	−7400
F11	296,882	1,617,907	34.758	−7400
F12	296,560	1,617,834	34.321	−7400

Table 3. Location and operating rates of scenario 3 structures.

Nom	X_COORD	Y_COORD	Z	Pumping rate (m^3/d)
Tassette F4 NDP	299,643	1,617,601	24.8	−5500
Sipane	299,095	1,615,207	16.35	−112
Tassette P1	299,918	1,616,339	20	−112
Tassette P12	299,346	1,614,823	19.476	−112
Tassette P2	298,990	1,616,856	25	−112
F1	292,022	1,620,523	50.24	−3000
F2	291,552	1,620,367	40.6	−3000
F3	291,456	1,619,876	39	−3000
F4	291,834	1,619,545	41.3	−3000
F5	292,306	1,619,703	42.6	−3000
F6	292,400	1,620,194	49	−3000
F7	291,928	1,620,034	42	−3000
F8	296,703	1,618,245	32.344	−3700
F9	297,186	1,618,229	34.079	−3700
F10	297,168	1,617,639	29.507	−3700
F11	296,882	1,617,907	34.758	−3700
F12	296,560	1,617,834	34.321	−3700

Indeed, in this scheme, we seek to provide nearly a third of the estimated needs for this population and for 20 years. We are therefore starting from a flow of 12,000 m^3 withdrawn per day, in addition to the current situation, that is to say scenario 1. This quantity divided between boreholes F8, F9, F10, F11 and F12 is equivalent to a flow rate of 2400 m^3/d per drilling, or 120 m^3/h per borehole for a daily pumping of 20 hours. Table 4 shows the flow rates sampled for this scenario.

3. Results and Discussions

This part is particularly devoted to the different results obtained for this modeling, we will first estimate the drinking water needs of the inhabitants of the city of Thies and this result will make it possible to evaluate the behavior of the aquifer in cases where these quantities are taken.

The principle of the model and calibration will help to better understand the processes by which the results obtained are generated in Visual Modflow Flex.

To meet the demand of the city of Thies in a horizon of twenty (20) years, the necessary water production should be about 37,000 m^3 per day for a population of 552,709 inhabitants.

At this level, the simulation results indicate an evolution of the piezometric surface almost identical to steady-state piezometrics.

Table 4. Location and operating rates of the works in the scenario.

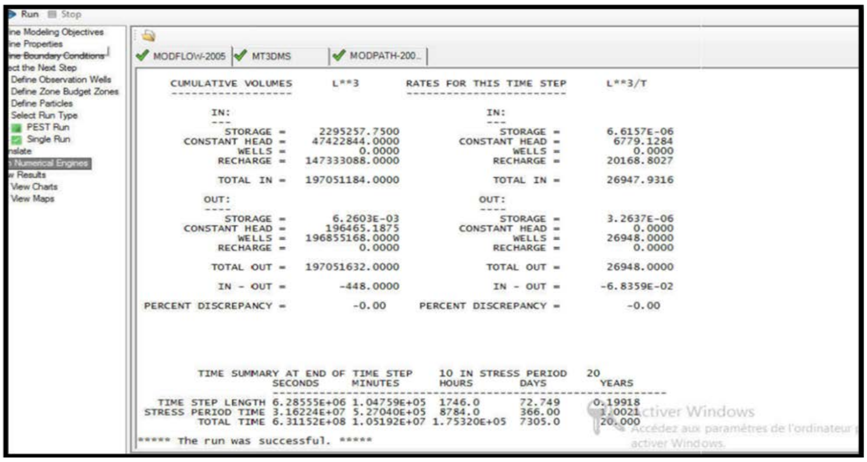
Nom	X_COORD	Y_COORD	Z (m)	Pumping rate (m^3/d)
Tassette F4 NDP	299,643	1,617,601	24.8	−5500
Sipane	299,095	1,615,207	16.35	−112
Tassette P1	299,918	1,616,339	20	−112
Tassette P12	299,346	1,614,823	19.476	−112
Tassette P2	298,990	1,616,856	25	−112
F1	292,022	1,620,523	50.24	−3000
F2	291,552	1,620,367	40.6	−3000
F3	291,456	1,619,876	39	−3000
F4	291,834	1,619,545	41.3	−3000
F5	292,306	1,619,703	42.6	−3000
F6	292,400	1,620,194	49	−3000
F7	291,928	1,620,034	42	−3000
F8	296,703	1,618,245	32.344	−2400
F9	297,186	1,618,229	34.079	−2400
F10	297,168	1,617,639	29.507	−2400
F11	296,882	1,617,907	34.758	−2400
F12	296,560	1,617,834	34.321	−2400

The loads in the different structures retain substantially the same values in the first periods. But a rather small discount would be observed at the end of the 20 years of project. This variation is mainly due to the pumping of large flows around the battery of the 7 boreholes of the SONES. The balance of inputs and outputs during the simulation is estimated according to 10 Time Step steps of 20 stress periods each. Figure 2 shows the balance of model inputs and outputs for scenario 1 to 2037.

The simulation results for this situation show a very significant variation in piezometrics even altering the saturation of the water table in places with loads of about −24 m. Figure 3 shows the balance of water inflows and outflows in the area.

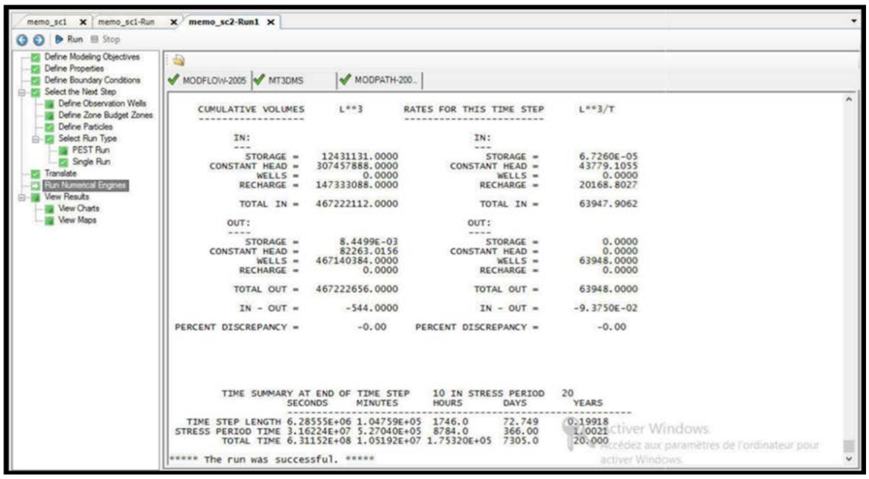
For this scenario, we find that the decrease in the potential withdrawal to supply the city of Thies gives less extreme results compared to the second situation. Indeed, the simulation with the same process and the same calibration data as the previous one reveals a piezometric surface remaining above the level of the roof of the aquifer. Figure 4 shows Balance of model inputs and outputs for scenario 3 to 2037.

Regarding this option, the charges are negative in places and mainly towards the center where the catchment field for Thies is located. They remain positive towards the East up to nearly 4 meters. Figure 5 shows Balance of model inputs and outputs for scenario 4 to 2037.



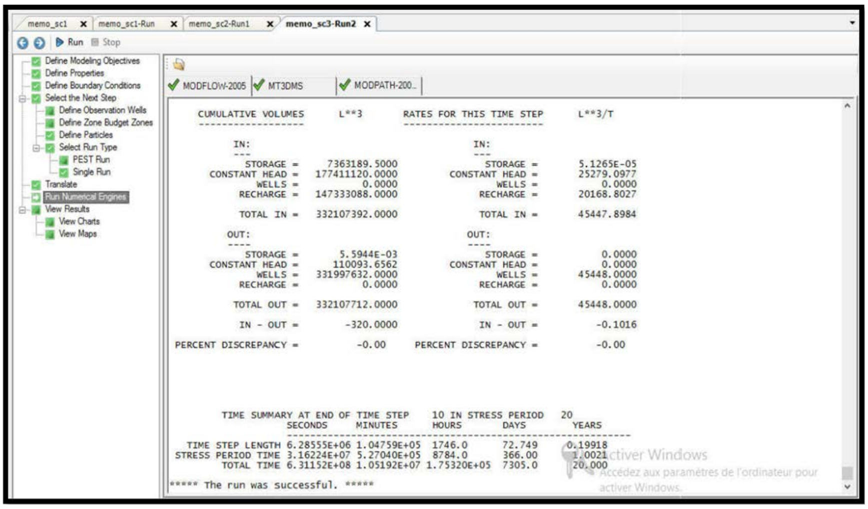
```
    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                     IN:
          ---                                     ---
             STORAGE =     2295257.7500              STORAGE =       6.6157E-06
       CONSTANT HEAD =    47422844.0000        CONSTANT HEAD =        6779.1284
               WELLS =           0.0000                WELLS =           0.0000
            RECHARGE =   147333088.0000             RECHARGE =       20168.8027

            TOTAL IN =   197051184.0000             TOTAL IN =       26947.9316

         OUT:                                    OUT:
         ----                                    ----
             STORAGE =       6.2603E-03              STORAGE =       3.2637E-06
       CONSTANT HEAD =      196465.1875        CONSTANT HEAD =           0.0000
               WELLS =   196855168.0000                WELLS =       26948.0000
            RECHARGE =           0.0000             RECHARGE =           0.0000

           TOTAL OUT =   197051632.0000            TOTAL OUT =       26948.0000

            IN - OUT =        -448.0000             IN - OUT =      -6.8359E-02

 PERCENT DISCREPANCY =            -0.00     PERCENT DISCREPANCY =           -0.00



      TIME SUMMARY AT END OF TIME STEP    10 IN STRESS PERIOD   20
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 6.28555E+06 1.04759E+05  1746.0      72.749     0.19918
 STRESS PERIOD TIME 3.16224E+07 5.27040E+05  8784.0      366.00      1.0021
         TOTAL TIME 6.31152E+08 1.05192E+07 1.75320E+05  7305.0     20.000
***** The run was successful. *****
```

Figure 2. Assessment of model inputs and outputs for scenario 1 to 2037.



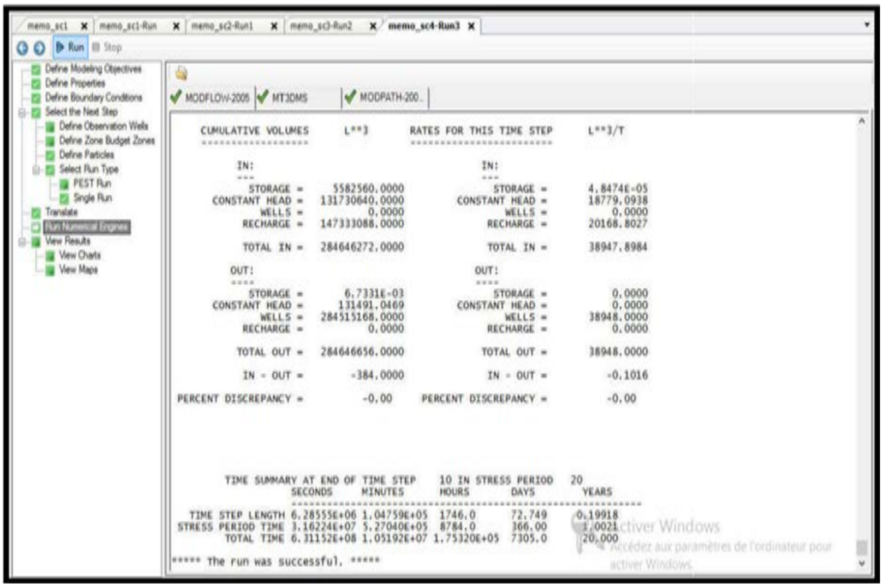
```
    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                     IN:
          ---                                     ---
             STORAGE =    12431131.0000              STORAGE =       6.7260E-05
       CONSTANT HEAD =   307457888.0000        CONSTANT HEAD =       43779.1055
               WELLS =           0.0000                WELLS =           0.0000
            RECHARGE =   147333088.0000             RECHARGE =       20168.8027

            TOTAL IN =   467222112.0000             TOTAL IN =       63947.9062

         OUT:                                    OUT:
         ----                                    ----
             STORAGE =       8.4499E-03              STORAGE =           0.0000
       CONSTANT HEAD =       82263.0156        CONSTANT HEAD =           0.0000
               WELLS =   467140384.0000                WELLS =       63948.0000
            RECHARGE =           0.0000             RECHARGE =           0.0000

           TOTAL OUT =   467222656.0000            TOTAL OUT =       63948.0000

            IN - OUT =        -544.0000             IN - OUT =      -9.3750E-02

 PERCENT DISCREPANCY =            -0.00     PERCENT DISCREPANCY =           -0.00



      TIME SUMMARY AT END OF TIME STEP    10 IN STRESS PERIOD   20
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 6.28555E+06 1.04759E+05  1746.0      72.749     0.19918
 STRESS PERIOD TIME 3.16224E+07 5.27040E+05  8784.0      366.00      1.0021
         TOTAL TIME 6.31152E+08 1.05192E+07 1.75320E+05  7305.0     20.000
***** The run was successful. *****
```

Figure 3. Assessment of model inputs and outputs for scenario 2 to 2037.



```
    CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
    ------------------                 ------------------------

          IN:                                     IN:
          ---                                     ---
             STORAGE =     7363189.5000              STORAGE =       5.1265E-05
       CONSTANT HEAD =   177411120.0000        CONSTANT HEAD =       25279.0977
               WELLS =           0.0000                WELLS =           0.0000
            RECHARGE =   147333088.0000             RECHARGE =       20168.8027

            TOTAL IN =   332107392.0000             TOTAL IN =       45447.8984

         OUT:                                    OUT:
         ----                                    ----
             STORAGE =       5.5944E-03              STORAGE =           0.0000
       CONSTANT HEAD =      110093.6562        CONSTANT HEAD =           0.0000
               WELLS =   331997632.0000                WELLS =       45448.0000
            RECHARGE =           0.0000             RECHARGE =           0.0000

           TOTAL OUT =   332107712.0000            TOTAL OUT =       45448.0000

            IN - OUT =        -320.0000             IN - OUT =          -0.1016

 PERCENT DISCREPANCY =            -0.00     PERCENT DISCREPANCY =           -0.00



      TIME SUMMARY AT END OF TIME STEP    10 IN STRESS PERIOD   20
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 6.28555E+06 1.04759E+05  1746.0      72.749     0.19918
 STRESS PERIOD TIME 3.16224E+07 5.27040E+05  8784.0      366.00      1.0021
         TOTAL TIME 6.31152E+08 1.05192E+07 1.75320E+05  7305.0     20.000
***** The run was successful. *****
```

Figure 4. Assessment of model inputs and outputs for scenario 3 to 2037.



```
  CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
  ------------------                 ------------------------

        IN:                                     IN:
        ---                                     ---
             STORAGE =     5582560.0000              STORAGE =      4.8474E-05
       CONSTANT HEAD =   131730640.0000        CONSTANT HEAD =      18779.0938
               WELLS =           0.0000                WELLS =          0.0000
            RECHARGE =   147333088.0000             RECHARGE =      20168.8027

            TOTAL IN =   284646272.0000             TOTAL IN =      38947.8984

       OUT:                                    OUT:
       ----                                    ----
             STORAGE =       6.7331E-03              STORAGE =          0.0000
       CONSTANT HEAD =      131491.0469        CONSTANT HEAD =          0.0000
               WELLS =   284515168.0000                WELLS =      38948.0000
            RECHARGE =           0.0000             RECHARGE =          0.0000

           TOTAL OUT =   284646656.0000            TOTAL OUT =      38948.0000

            IN - OUT =        -384.0000             IN - OUT =         -0.1016

 PERCENT DISCREPANCY =           -0.00   PERCENT DISCREPANCY =           -0.00




         TIME SUMMARY AT END OF TIME STEP   10 IN STRESS PERIOD   20
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 6.28555E+06 1.04759E+05  1746.0      72.749     0.19918
 STRESS PERIOD TIME 3.16224E+07 5.27040E+05  8784.0      366.00     1.0021
         TOTAL TIME 6.31152E+08 1.05192E+07 1.75320E+05  7305.0     20.000
***** The run was successful. *****
```

Figure 5. Assessment of model inputs and outputs for scenario 4 to 2037.

4. Conclusions

Groundwater quality is the most cost-effective way to supply households that are not served by public or private distribution systems, such as rural villages, and could serve as a catalyst for economic growth by increasing irrigated land and improving crop yields and crop diversity.

In short, the collection and exploitation of the various data related to the Paleocene aquifer, and more particularly in the Tassette area and its surroundings, made it possible to propose a general presentation of the area and its characteristics. As the Tassette area is indicated by several studies as part of the favourable potential for water transfers, it is therefore necessary to establish a model for the efficient and effective exploitation of this resource. In this sense, different scenarios were proposed and simulated during this work in order to deduce their effect on the water table, its capacity and its piezometric load. The results of this step were rather conclusive in terms of the almost unchanged piezometric surface.

It will especially be necessary to carry out regular maintenance of the supply networks and avoid high temperatures at the level of the appliances such as hot water ducts, water heaters, washing machines, etc., leading to the precipitation of limescale and the formation of scale. In addition, including the Maastrichtian in this same Tassette area would perhaps make it possible to have a modeling with better results because it has greater potential.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Faye, C. Water Resources Management in Africa: Data Availability Issues and Un-

certainties Associated with Hydrological Measurements in Senegal.

[2] Faye, M.M. (2005) Senegal Agricultural Market Development Program.

[3] DiakhatÉ, F. (2022) Mining Resources and Local Development: The Case of the Commune of Chérif Lô (Thies Region).

[4] Diop, M. (2021) Problem of Access to Drinking Water in Urban Areas: The Case of the Commune of the Cleaned Plots of Dakar.

[5] Laissard, G. (1984) Water for Your Health: Practical Manual for Hydrotherapy and Balneotherapy. FeniXX.

[6] SY, B.A., Kola, E., Magrin, G., *et al.* Tropicale (IGT) of the University. Felix Houphouët-Boigny, Cote d'Ivoire-Dr. Ibrahima MBAYE (Geographer), Associate Professor, Assane SECK University, Ziguinchor (Senegal)-Dr. Tidiane SANE (Geographer), Associate Professor, Assane SECK University, Ziguinchor (Senegal)-Dr Irène KASSI-DJODJO, (Geographer), Associate Professor, Institute of Tropical Geography (IGT).

[7] Diédhiou, A., LO, M.L., Thioune, P.B.D., *et al.* (2018) Modelling of Water Erosion of Cultivated and Uncultivated Soils on the Thies Plateau (Senegal). *International Journal of Innovation and Applied Studies*, **25**, 210-221.

[8] Mainguet, M. (1999) Aridity: Droughts and Human Development. Springer Science & Business Media, Berlin. https://doi.org/10.1007/978-3-662-03906-9

[9] Ly, C., Fall, B., Camara, B., *et al.* (1998) Urban Horse-Drawn Transport in Senegal-Situation and Economic Importance in the City of Thies. *Journal of Livestock and Veterinary Medicine of Tropical Countries*, **51**, 165-172. https://doi.org/10.19182/remvt.9643

[10] Martos-Rosillo, S., Guardiola-Albert, C. and Marín-Lechado, C. (2015) Hydrogeological Characterization and Evaluation of the Recharge of a High Mountain Aquifer Developed in Hard Rocks, Bérchules River Basin, Sierra Nevada, Granada. Water in Andalusia. Water: Key Environmental and Socio-Economic Issues. IGME, Madrid, 623-634.

[11] López Ramírez, S.E., *et al.* (2015) Update of the Numerical Model of the Morroa Aquifer Using Visual Modflow Flex.

[12] Cisneros Zamora, G.Z. (2019) Groundwater Flow Model of the Laguna de Hormigas Aquifer, Chihuahua, Mexico. Ph.D. Thesis, Autonomous University of Chihuahua, Chihuahua.

[13] Mouakoumbat, N.J.L., Gampio, U.M., Nkaya, G.M., *et al.* (2022) Hydrogeological Characterization and Approach to a Conceptual Model of the Aquifer of the Cuvette Basin, Republic of Congo. *International Journal of Geosciences*, **13**, 997-1023. https://doi.org/10.4236/ijg.2022.1311051

[14] Gossel, W. (2013) GIS-MODFLOW: A Small OpenSource Tool to Connect GIS Data with MODFLOW. *Grundwasser*, **18**, 99-102. https://doi.org/10.1007/s00767-012-0218-9

[15] Khalil, K., Khan, Q. and Mohamed, M. (2022) Modeling Aquifer Storage and Recovery in the Eastern District of the United Arab Emirates Using MODFLOW. *Scientific Reports*, **12**, Article No. 17537. https://doi.org/10.1038/s41598-022-20470-7

[16] Diop, T. (1990) Population and Cities Senegal: Demographic Growth. *Africa Development/Afrique et Développement*, 33-43.