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Study of artificial recharge of Turonian aquifer (Tadla Bassin-Phosphate Plateau-Downstream Tassaout)

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Abstract. The Turonian aquifer of the Tadla basin-Phosphate Plateau-Tassaout downstream, is currently experiencing a significant decrease in its hydraulic capacities, due to the combination of intensive exploitation and the shortage of beneficial precipitation. To remedy this problem, we proposed various possible scenarios for artificially recharging the aquifer, namely: Exploitation of dams, The use of wastewater treatment plants, The creation of infiltration thresholds along wadis upstream of the aquifer; based on hydrological/hydrogeological, geological, and climatological studies, in order to better adapt the development scenarios to the aquifer under study and its functioning. As for the volume of water needed for recharge depends on the objective of artificial recharge: either maintain the piezometric level of the previous year, or raise the piezometric level to a given level. The methodology adopted would constitute a working and exploitation methodology that could be transposed to other aquifers with similar characteristics.

Introduction

The practice of artificially replenishing underground water sources has a long history, spanning many centuries. Early methods were typically straightforward, involving the construction of barriers to hold surface water and allow it to seep into the ground and underground water reserves. These techniques were often used for watering agricultural land in dry regions(water reservoir in the Tadla region. However, it has experienced substantial declines in water levels. From 1986 to 2015, the groundwater level dropped by over 25 meters at monitoring point 1525/36, and a 30-meter reduction was observed at monitoring point 1547/37 during the same period. This decline is primarily attributed to water extraction for drinking and irrigation, as reported by the Oum ER RBIA Water Basin Agency (ABHOER). Currently, around half of the aquifer's area sees its level drop by at least 1 meter annually, with certain considerable sections experiencing annual declines of 2 meters or more [2].

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These reductions are largely due to reduced precipitation and increased water extraction [3,4].A key aim of research into artificial recharge is to demonstrate how underground water storage areas can help manage floodwaters or surplus irrigation supplies. During periods of heavy rainfall, these temporary water surpluses could be utilized by encouraging them to seep into the ground below, thereby employing the natural storage capabilities of underground water-bearing layers.

Methodology

The capacity of the Turonian aquifer to be artificially recharged, like all aquifers, depends on a number of criteria, namely: geology, hydrology, hydrogeology, climatology, and (t of this study, three permeability tests were carried out in 2023 in the artificial recharge area (phosphate plateau) in different formations (Turonian, Senonian, Visean) using a double-ring infiltrometer to assess surface infiltration in order to select sites favorable for artificial recharge in comparison with existing transmissivity data.

Results

The extensive Tadla-Plateau des phosphates-Tassaout downstream hydrogeological basin is named for its three main geographical components, which are intrinsically linked both geologically and hydrogeologically. It encompasses four provinces: Beni Mellal, Fqih Ben Salah, Khouribga, and Settat. Its boundaries, precisely mapped, indicate it spans an area of sediments dating from the Cretaceous to the Miocene-Pliocene-Quaternary periods. The Oued approximately 11,000 km² [5]. The basin includes the following three primary entities:
-The phosphate plateau, situated in the north, is a plateau that gradually inclines southeastward, featuring a succession of tiered platforms significantly altered by erosion;
-The Tadla plain, located in the south, is characterized by an expansive depression filled with Oum Er Rbia river bisects it into two subdivisions: Beni Amir to the north and Beni (assaout downstream, found in the basin's southwest, forms a geological and hydrogeological extension of the Tadla plain.

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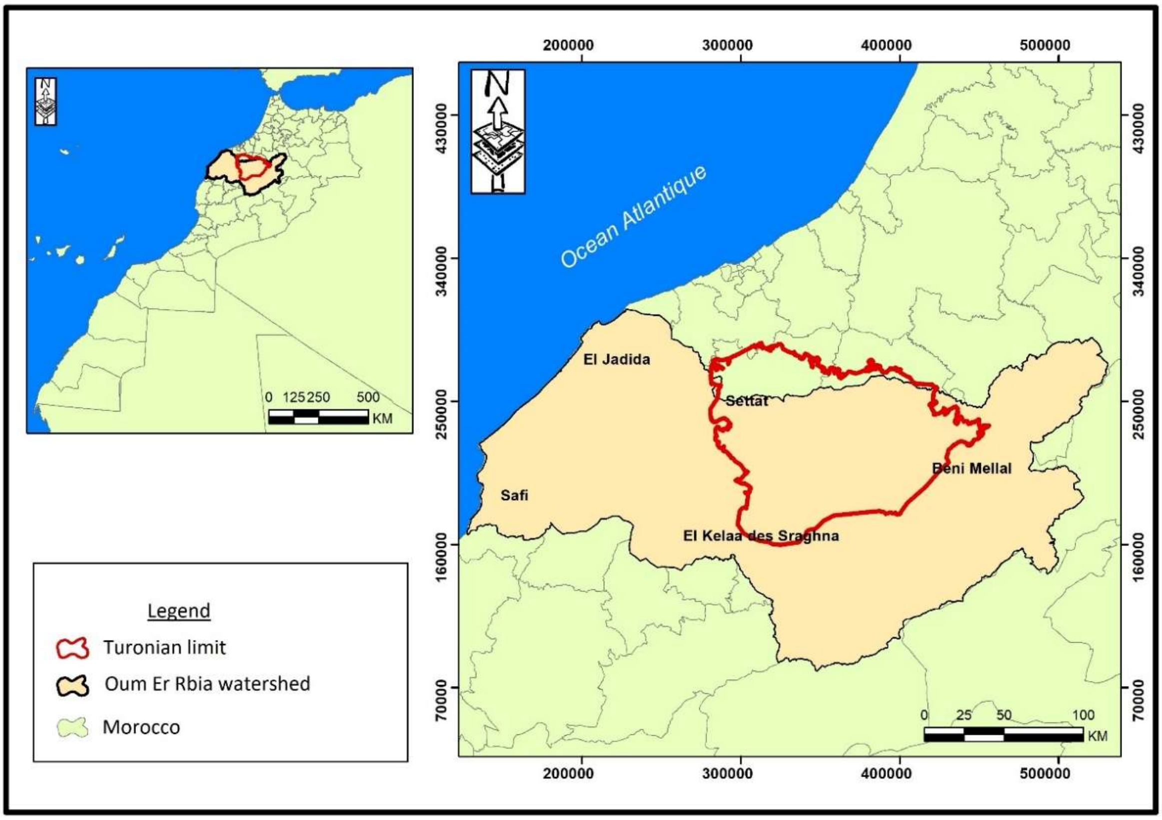

Figure 1 : Geographical location of the Turonian aquifer

The region under investigation experiences a temperate, semi-arid climate, characterized by hot, dry summers and cold winters. An analysis of average monthly rainfall indicates a wet season occurring between October and April, followed by a dry period from May to September.

The Oum Er Rbia River is the principal waterway in the study area. It originates in the mountains at the southwestern edge of the High Atlas and traverses the Tadla region for approximately 160 kilometers, thereby hydrologically separating the plain into two uneven portions [5].

The river system on the right bank is not extensively developed. It comprises smaller watercourses whose flow is mainly diverted for local irrigation, thus only reaching the Oum Er Rbia during times of significant flooding.

In contrast, the drainage network on the left bank is more extensive. It includes the following watercourses: Oued Derna, Oued El Abid, and Oued Tessaout.

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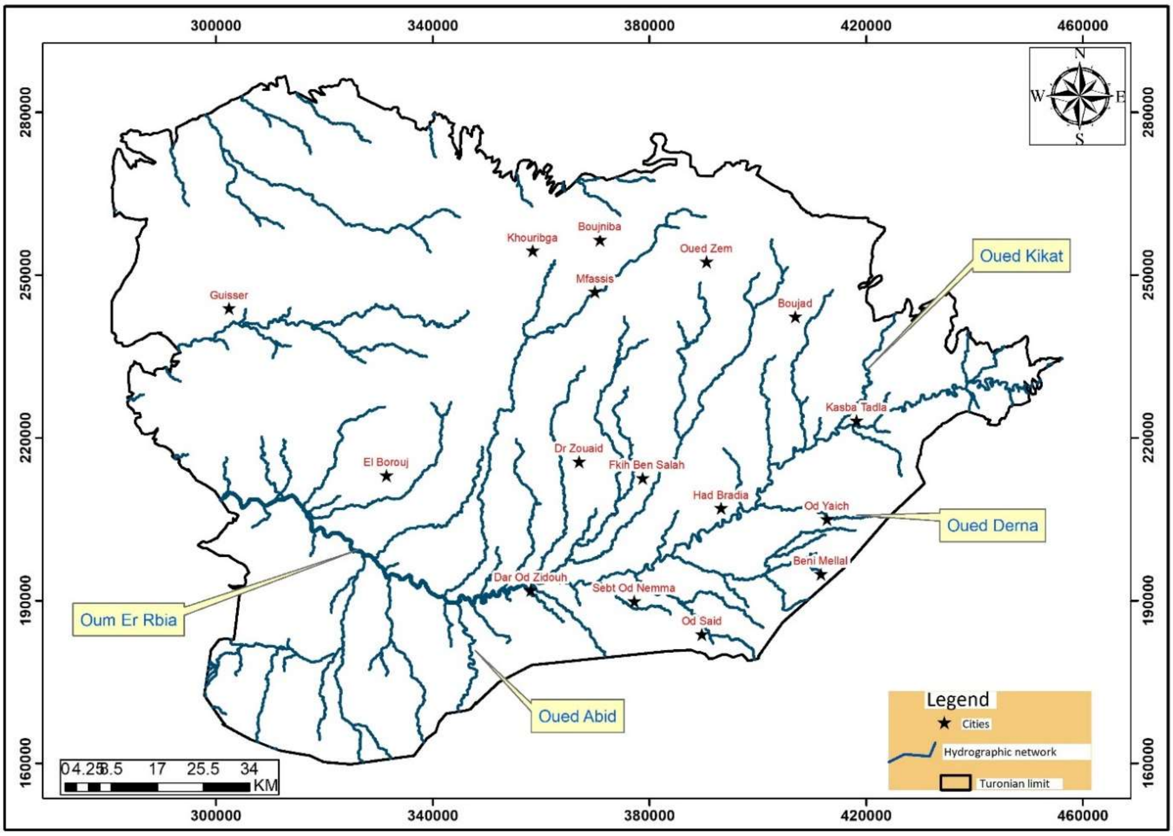

Figure 2: Hydrographic network of the Turonian aquifer

The Turonian layer is visible all around the Phosphate Plateau, from Oued Oum Er Rbia, near Zaouiat Ech Cheïkh, in the east, to the Mzizoua anticline in the west. This stratigraphic group is characterized by various types of carbonate rocks related to the conditions of deposition: clayey-carbonate dolomitic rocks, sometimes slightly evaporitic, are typical of the transgressive Cenomanian [5]. Uniform carbonate facies covering the entire territory are characteristic of the Upper Cenomanian and Lower Turonian. To the east, at Kasbat Tadla and in the Atlas unit of Beni Mellal, 10-meter-thick limestone deposits extend across the Tadla basin from east to west. They represent a particularly important facies from a hydrogeological point of view. Due to their initial porosity, these formations promote the development of dolomitic formations whose effects extend widely to Cenomanian and Senonian carbonates. The dolomitized body acquires a very large volume in the form of a spindle-shaped body and significant secondary porosity; it constitutes the major aquifer of the Tadla basin.

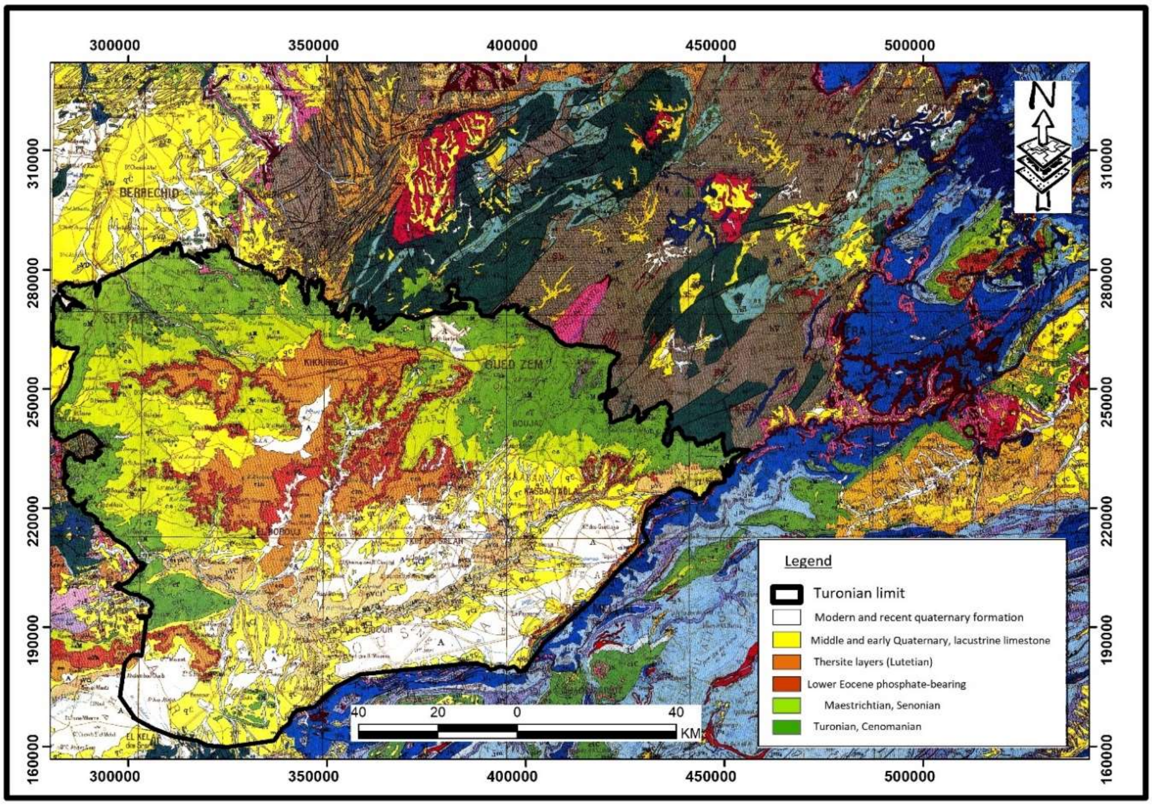

Figure 3: Geological map of the Turonian aquifer (Excerpt from the geological map of Morocco 1/500,000)

The Tadla-Phosphate Plateau-Tassaout downstream hydrogeological basin features an extensive multi-layered groundwater system. Comprising, from top to bottom, several distinct layers, these include the Miocene-Pliocene-Quaternary complex, the Eocene aquifer, the Senonian aquifer, the Turonian aquifer, and the weathered Primary aquifer [5,6,7].

The Turonian aquifer, which spans an area of 11,000 km², is an intricate groundwater body divided into three distinct zones [5,8]:

Zone 1: Situated north of the Tadla plain (encompassing Fkih Ben Saleh and El Borouj), this area features a confined aquifer that moves through extensively fractured and faulted limestone.

Zone 2: Situated on the phosphate plateau, this area contains an unconfined aquifer within comparatively thin and moderately fractured limestone.

Zone 3: Positioned to the south of the Tadla plain, this region features a confined aquifer that primarily moves through marl-limestone formations.

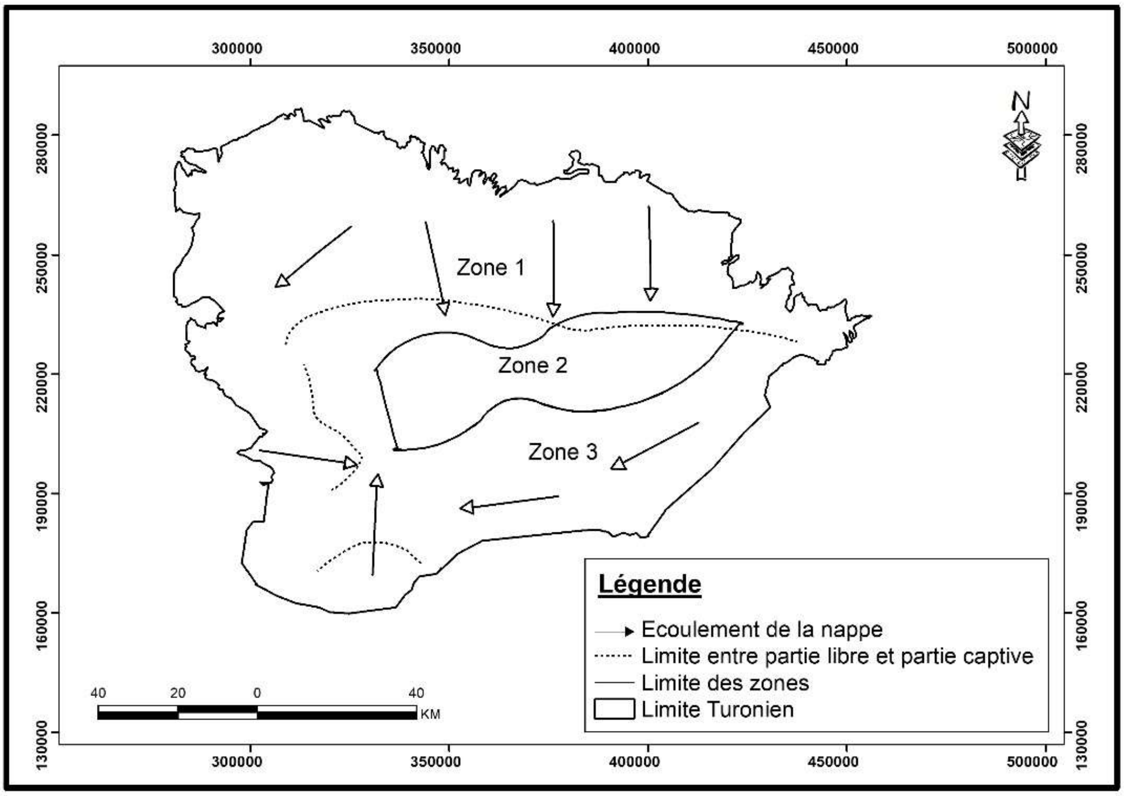

Figure 4: Diagram of the hydrodynamic functioning of the Turonian aquifer (BOUKDIR, 2007)

In terms of permeability, permeability tests show that the Turonian and Senonian are permeable formations, while the Visean is an impermeable formation. Three hydrodynamic zones can be identified based on transmissivity: areas with low transmissivity (10^{-6} to 10^{-3} m^2/s) correspond to low-yield sectors, while intermediate transmissivity (10^{-4} to 10^{-2} m^2/s) increases from south to north with the transition from an unconfined to a confined aquifer, high transmissivity ($>10^{-3}$ m^2/s) is found mainly between Kasba Tadla and Fkih Ben Salah and is linked to the good fissured permeability of the Turonian aquifer.[5]

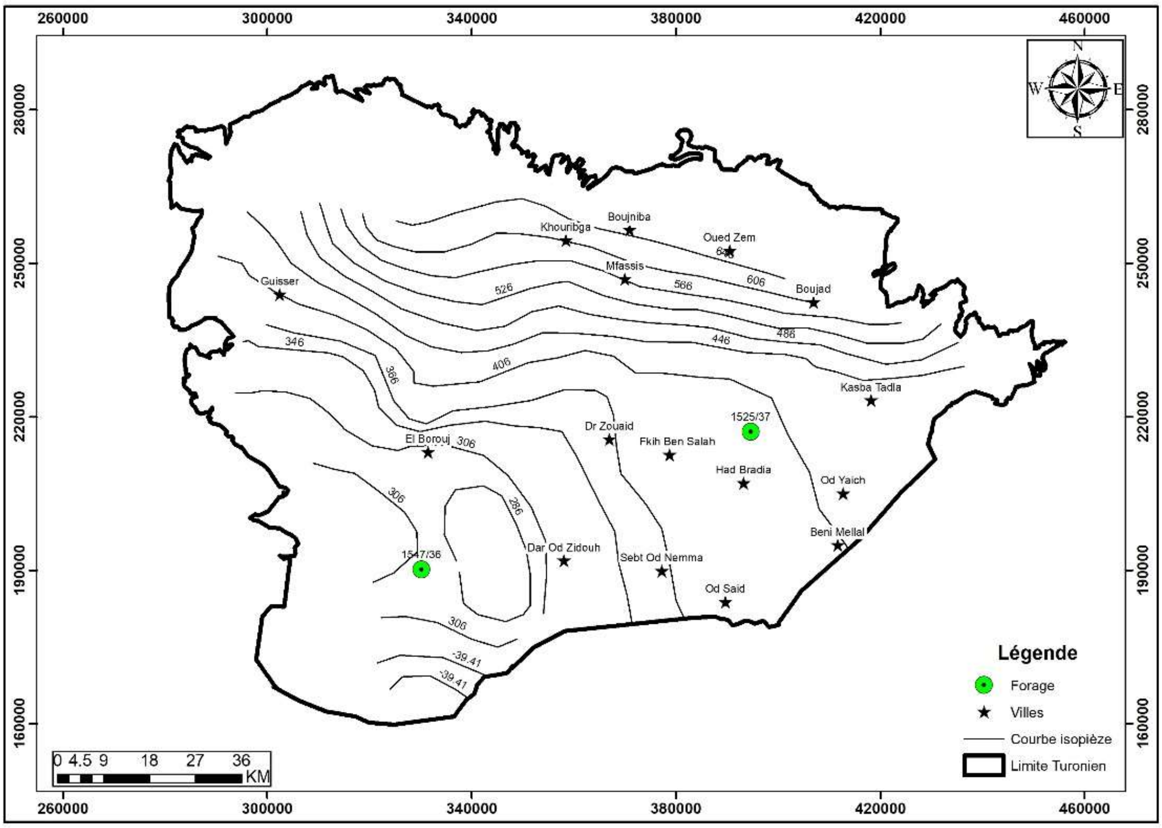

Figure 5: Piezometric map of the Turonian aquifer 2022

Scenarios

Artificial recharge of the Turonian aquifer is carried out on the phosphate plateau, particularly within the Senonian and Turonian formations (fissured limestone), which are permeable areas with good transmissivity. For more effective artificial recharge of the Turonian aquifer, several development plans are possible, as described below:

Exploitation of dams: The choice of the appropriate type of dam for artificial aquifer recharge depends on several factors, including local hydrogeological characteristics, recharge objectives, environmental constraints, and available resources. Types of dams that may be suitable for artificial recharge include: retention dams, embankment dams, underground dams, rockfill dams, and gabion dams.As part of the artificial recharge of the Turonian aquifer, studies were conducted on a watershed located in the artificial recharge zone known as the Kikat watershed. As its name suggests, it is named after the main watercourse, Oued Kikat, a tributary of Oued Oum Er Rabia, whose outlet is the dam site located between Ait Dahame and Béni Zrantel. In this context, according to the field study, the most appropriate type of dam is an embankment dam. This dam will allow the Turonian aquifer to be recharged by infiltration through fissured limestone (Senonian and Turonian).

The use of wastewater treatment plants: Artificial aquifer recharge using a wastewater treatment plant is a commonly used method for reusing treated wastewater to recharge groundwater. The general steps in this process are as follows: Wastewater collection and treatment - Advanced treatment - Storage of treated wastewater - Injection/infiltration of treated wastewater into the aquifer - Monitoring and evaluation.This study focused on wastewater treatment plants located in the phosphate plateau, namely those in Boujaad, Oued Zem, and OCP. The recommended recharge system is the infiltration basin, as it improves the quality of the treated water before it reaches the groundwater and is also more economical than the injection system.

The creation of infiltration thresholds along wadis upstream of the aquifer: Artificial recharge of an aquifer using thresholds involves creating a solid structure or transverse dam in watercourses to retain water and allow it to flow into the aquifer. The general steps in this process are as follows: Hydrogeological studies - Selection of the weir location - Weir design - Weir construction - Flow adjustment - Monitoring and evaluation.
Above are a few wadis that could be used for artificial recharge of the Turonian aquifer through the integration of infiltration weirs: Oued Guerroum, Oued Srirou, Wad Qicher, Oued Sidi Boubker.

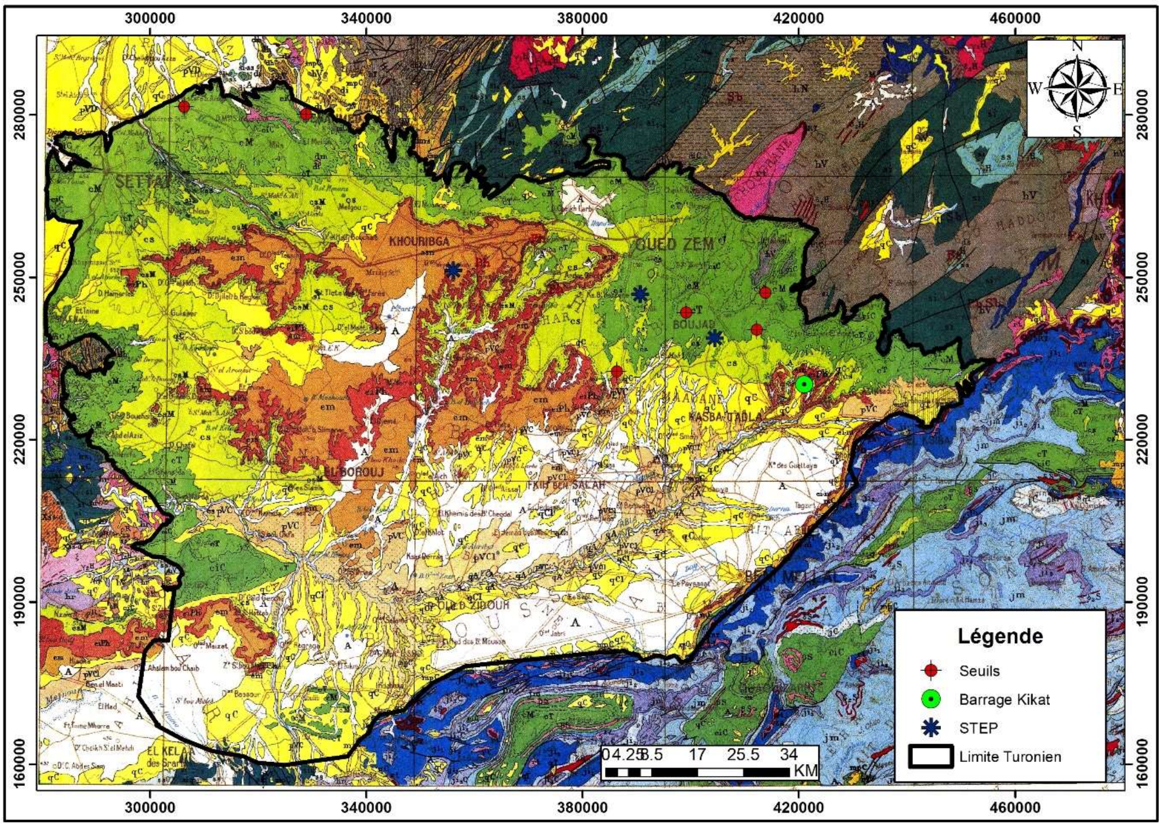

Figure 6: Potential areas for implementation of artificial recharge scenarios for the Turonian aquifer

Water balance

In the phosphate plateau, runoff (R) is considered negligible and the balance is written as [5]: Ie= P – ETR
Ie: effective infiltration per year
P: average annual precipitation (206.3mm);
ETR: actual evapotranspiration (185.3 mm)
This balance shows that the effective recharge of the Turonian aquifer is around 20 mm/year [5]. This recharge occurs in areas where the fissured Turonian limestone outcrops, mainly to the east of the phosphate plateau.
Below is a summary table estimating the recharge water volume for each scenario according to ONEE and ABH data:

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Table 1: Estimating the recharge water volume

Scenarios	Available water volume (m^3/year)	Potential recharge (m^3/year)	Comments
Exploitation of dam as the Kikat watershed	870890000	87089000	Optimized infiltration zones
Wastewater treatment plants of Boujaad	2000000	1 800 000	10% losses or inefficiency

Site selection matrix

General principle

Each criterion receives :

a Si score between 1 (unfavorable) and 5 (very favorable),

a Pi weighting expressed as a percentage according to its importance.

$$\mathbf{SG} = \sum_{i=1}^{n} \left(\mathbf{Pi} / \mathbf{100} \times \mathbf{Si} \right)$$

Table 2: Scenarios Selection Matrix

Sites	Transmissivity	Infiltration	Water Availability	Land ownership	Environmental Constraints	Global Score
SitesA	4	5	4	3	4	4.1
SitesB	4	5	2	2	2	3.35
SitesC	4	5	3	1	3	3.50

Grading scale

Each site is rated on a scale of 1 (unfavorable) to 5 (very favorable) for each criterion.

The weighting of the criteria is as follows: Transmissivity (30%); Infiltration (25%); Water availability (20%); Land ownership (15%); Environmental constraints (10%)

The overall score is calculated as a weighted sum.

Sites A, B, and C correspond respectively to the following scenarios: Operation of dams, Use of wastewater treatment plants, and Creation of infiltration thresholds along the wadis upstream of the water table.

Discussion

The data used comes from different periods: climatological (1986–2023), piezometric levels (2006–2023), and permeability tests carried out in 2023. This temporal disparity is explicitly indicated and discussed. The tests conducted in 2023 are considered representative of current hydrological conditions, although analyses incorporating climate projections are necessary to assess the long-term feasibility of recharge.

At the end of this study, we examined possible scenarios for artificially recharging the Turonian aquifer based on the following two main criteria : reasonable cost and rapid implementation. It is possible to use other dams and wadis than those demonstrated previously, provided that they are located in the limestone zone of the Turonian aquifer. However, cost data are not available at this stage; a specific economic study will be necessary to assess the financial viability of the project.

It should be noted that the different development scenarios proposed in this study have already been used in different countries, thus illustrating their efficiencies in the context of artificial recharge of aquifers [9,10,11,12,13,14].

The amount of water needed for artificial recharge of the aquifer depends on the purpose of the recharge:

- It may be to maintain the piezometric level of the previous year, in other words, the amount of water extracted from the aquifer each year should be equivalent to the amount of water introduced or infiltrated, depending on the type of equipment used;
- It may be to raise the piezometric level to a specific level, which involves considering the surface area of the aquifer in square meters and the desired height of the piezometric level in meters.

It is necessary to examine the quality of the available water and its fluctuations. It must be free of any pollution that could affect the quality of the reservoir, in particular toxic substances that cannot be removed by natural filtration. In addition, the water introduced must be chemically compatible with that of the reservoir. In the deep Turonian aquifer, natural groundwater generally has a moderate to high mineral content. It is mainly composed of calcium bicarbonates, sometimes mixed with magnesium, and may locally evolve towards compositions richer in chlorides or sulfates, depending on the nature of the rocks traversed and the duration of their underground circulation. Conversely, the waters that can feed this aquifer (such as surface water or treated wastewater) are characterized by more fluctuating salinity. They are often more concentrated in sodium and chlorides and contain increased levels of organic matter, nitrates, and man-made pollutants. This contrast in the chemical composition of the water is likely to cause unbalanced geochemical reactions as it passes through the soil, such as ion exchange, the formation of carbonate deposits, or a temporary increase in salt concentration. It is therefore essential to closely monitor major ions, electrical conductivity, and pollution indicators in order to preserve the quality of Turonian waters.

The main problem with recharge systems is the clogging of infiltration surfaces, which leads to low infiltration rates. Clogging is caused by physical, biological, and chemical processes [11]. Artificial recharge of the Turonian aquifer in the Tadla must be managed flexibly to ensure its effectiveness and preserve the quality of the groundwater. Water is injected at a regulated flow rate, alternating between periods of water supply and periods of rest, and targeting areas where water can penetrate the soil more easily. Monitoring is based on hydrodynamic and hydrochemical indicators, including changes in infiltration rates, piezometric levels, electrical conductivity, nitrates, and turbidity. A significant decrease in

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infiltration or deterioration in water quality is a warning sign. In the event of clogging or contamination, infiltration rates are reduced or temporarily halted, and corrective measures are implemented (basin rest, cleaning, pre-treatment improvement). The system is gradually brought back into service, accompanied by increased monitoring, until normal conditions are restored

Desilting injection wells and chemically destroying silting materials are conventional methods used at water collection stations. Along with piston pumping, desilting by pumping is the most frequently used process [11].

Conclusion and Outlook

This research focused on analyzing the artificial recharge of the Turonian aquifer in the Tadla basin, which is the most productive deep aquifer in this region and is used for drinking water supply and irrigation. This aquifer has shown a significant decrease in piezometric levels over the years. In this context, we drew on existing studies on the hydrogeological functioning of this aquifer in order to propose development scenarios to improve adaptation to artificial recharge.
With the aim of artificially recharging the Turonian aquifer, we proposed three development scenarios based on natural recharge areas, i.e., at the level of fractured limestone.
The volume of water required for artificial recharge of the aquifer depends on the objective of the recharge: either to maintain the piezometric level or to increase it to a specific level.

The ideal period for artificial recharge depends on several factors: the rainy season, the region's water balance, and seasonal constraints. In the case of the Turonian aquifer, the appropriate period for artificial recharge is between April and May.

The monitoring system relies on a limited network of piezometers and monitoring wells, strategically installed to assess the hydrological and qualitative effects of artificial recharge[15]. The network includes at least one monitoring point located upstream of the recharge area, serving as a reference for the initial state of the aquifer, as well as one or two measuring points in close proximity to the recharge area in order to quickly detect the consequences of infiltration. Piezometers positioned downstream, in the direction of groundwater flow, are used to monitor the propagation of the recharge signal and any changes in groundwater quality. When conditions permit, multi-level wells are recommended in order to distinguish vertical transfers and determine transit times within the aquifer. These piezometers are used for regular monitoring of groundwater levels, the physical and chemical characteristics of the water (such as salts, chlorides, sulfates, etc.) and, where applicable, microbiological indicators. They thus form the basis of the artificial recharge monitoring system.
In conclusion, we can say that the methodology used could serve as a working and operational model applicable to other aquifer areas with similar characteristics.
It should be noted that for the successful implementation of artificial recharge of an aquifer, it must be preceded by a comparative assessment of the effects of AR using simulation models. Hydrodynamic simulations using mathematical models are designed to compare the effects of artificial recharge in terms of rising water levels and the area of influence.

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