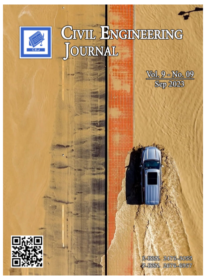
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 09, September, 2023



Assessing Artificial Recharge on Groundwater Quantity Using Wells Recharge

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Received 16 June 2023; Revised 07 August 2023; Accepted 13 August 2023; Published 01 September 2023

Abstract

In arid and semi-arid countries like Iraq, which suffer from water scarcity due to the effects of climate change and decreased surface water flow, groundwater is considered a vital source of irrigation water. This study is concerned with the influence of artificial recharge on the rehabilitation of the unconfined aquifer called Al-Dibdibba, located between the cities of Najaf and Kerbala in central Iraq around 31°550′ N and 32°450′ N and 43°300′ E and 44°300′ E. Due to excessive groundwater pumping rates for irrigation, this aquifer has suffered from groundwater decline and increased salinization during the previous 20 years. By establishing a conceptual model in the groundwater modeling system software (GMS), a numerical model was made to simulate groundwater flow. Artificial recharge using recycled water (tertiary treatment) from Kerbala's primary WWTP was carried out using 25 injection wells. The model was calibrated against historical and observed water level data for periods from 2016 to 2017. Three scenarios to predict how the aquifer would act with artificial recharge of 5%, 8%, and 10% from the total daily outflow of the WWTP in Kerbala (100000 m^3/day) were studied. The calibration model met the observed values of groundwater levels with R^2 = 0.989 for steady-state simulations and R^2 = 0.987 for transient simulations. In the final analysis of the simulation, the results show that the maximum predicted groundwater level was raised by the injection of treated water through 25 wells by 1.05 m for 5000 m3/day, 2 m for 8000 m^3/day, and 3 m for 10,000 m^3/day recharge pumping rates. In addition, if water were pumped into the aquifer, it might support the development of agricultural lands covering more than 93 km^2. So, artificial recharge can be considered one of the important solutions to adaptation to the effects of climate change and desertification in Iraq.

Keywords: Artificial Recharge; Groundwater; Dibdibba Aquifer; Treated Wastewater; GMS.

1. Introduction

Water is a necessary component for human survival and agricultural productivity. Protecting the drinking water supply and preventing water pollution are two of the day's most pressing issues. Accommodate a variety of needs in agriculture, industry, and other settings. Groundwater has emerged as one of the most precious resources in recent years. Groundwater is an ideal water supply because it is more stable over extended periods and across huge regions and is not as susceptible to seasonal and long-term variations. In the absence of any other water source, such as rivers or lakes, groundwater is frequently a viable option [1]. While surface water calls for the construction of infrastructure, the research and development of new water technologies, and significant financial investments, aquifer development is anticipated to respond to the rising needs gradually. Groundwater is frequently used for irrigation purposes in countries with dry or semiarid climates. Domestic water systems in certain Middle Eastern nations rely entirely on groundwater [2, 3]. Effective management of groundwater resources is crucial to keeping up with rising water demand. Several direct and

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http://dx.doi.org/10.28991/CEJ-2023-09-09-010

indirect factors are linked to how groundwater supplies are affected by climate change and global warming. The warming climate and shifting precipitation patterns will affect groundwater levels, recharge, discharge, and yearly storage. Because of the effects of climate change, plant transpiration and evaporation rates will shift, indicating more soil dryness, less natural groundwater recharge, and greater soil moisture losses [4, 5].

Groundwater supplies more than a third of humanity's total water consumption. More than half of the world's population relies on groundwater as their primary source of drinking water, and that number is much higher in rural areas [6, 7]. For optimal water exploitation and to maintain the strategic storage of these resources, groundwater basins were used because of the scarcity of available surface water resources and the deterioration of their quality [3]. Continual groundwater extraction from aquifers for all uses contributes to groundwater depletion in many parts of the world, making it crucial to estimate the physical parameters of water-bearing layers as part of groundwater research [8, 9]. Groundwater is frequently used as a secondary water source in countries with recurrent water stress and large aquifer systems. Overexploitation or chronic groundwater depletion can occur if groundwater abstraction exceeds groundwater recharge over large areas of land and for extended periods of time. In the last few years, water demand has increased in Iraq for agricultural and industrial activities. as a result of increasing numbers of people, as well as urbanization, industrialization, agricultural intensification, and changes in other lifestyle factors. Since the growing population's needs cannot be met by surface water, the use of groundwater has increased, which has contributed to its depletion [10-12].

Groundwater supplies can be increased by the use of artificial recharge systems, which are systems that involve the application of surface water to the ground or the injection of water into the ground. Artificial recharge can also be used to convert surface water into groundwater in areas where groundwater is historically preferred for drinking, to enhance water quality by soil-aquifer treatment or purification, to use aquifers as water conveyance systems, and to prevent saltwater intrusion or land subsidence. Water can be infiltrated into the ground or artificially recharged by creating basins, furrows, or ditches to collect or direct water over the soil surface [13]. It can be done even when freshwater supplies from more conventional means are limited. As an alternate supply, treated wastewater can be utilized for irrigation to meet agricultural water needs and for artificial recharge of aquifers to slow the depletion of groundwater. Many countries, such as the USA, Canada, the Netherlands, Mexico, France, Brazil, Qatar, Egypt, Saudi Arabia, China, Cyprus, and India, use such methods [14–19]. Artificial water recharge is one way to sustainably manage the decline of groundwater levels in nations like Iraq, which are located in arid regions [20–25]. Well-pumping and pond water filtration are the two most common methods of artificial recharge. Because evaporation is higher in these surface water ponds than in wells and because considerable volumes of raw water are lost, wells were employed to recharge the aquifer in this study [26–28].

The United Nations has identified Iraq as one of the Arab countries most vulnerable to the effects of climate change, and the country is now facing various environmental challenges. Water scarcity isn't the only problem climate change is causing in Iraq [29]. In recent years, the Republic of Iraq's water demand has risen due to the country's expanding population and growing economy [30]. The national water strategy prioritizes the reuse of treated wastewater from urban sources for agricultural irrigation and the artificial recharge of groundwater [31]. Putting surface water on or in the ground for infiltration and subsequent flow to aquifers is the goal of artificial recharge systems to increase groundwater supplies. To accomplish artificial recharge, basins, wells, furrows, and ditches are used to pond or channel water onto the soil surface [33, 32].

With groundwater being such a finicky and valuable resource, the idea of artificial groundwater recharge technology is gaining traction. Water quality indices may be affected by artificial recharge, which is useful since it provides an effective form of water storage that allows for better use of existing resources [34]. Many studies have shown that artificial recharge is possible when conventional fresh raw water sources are threatened with severe depletion [34]. Water shortages are a problem in Iraq, as the country has few unique water resources. It has serious problems on several fronts, including politics, the economy, the environment, and national security [35]. Sheng [35] primarily focuses on the Dibdibba aquifer in southern Iraq, which is not restricted by surface features. This aquifer has experienced groundwater loss and water salinization during the last 20 years due to high groundwater pumping rates for agricultural purposes. This serious threat has motivated many authors to study this problem through modeling. The paucity of artificial recharge studies in the region is unfortunate and may be attributable to the absence of processed water or other non-rainwater sources in the research area. Within the confines of the aquifer formation, in 2020, Kerbala established its first wastewater treatment plant (WWTP).

The degradation of the Euphrates and Tigris rivers, crucial to Iraq's agriculture and water supply, is one of the country's most pressing issues. Neither river begins its journey in Iraq, Turkey, or Iran. Iraq's agricultural output will continue to decline due to climate change and hydraulic projects like huge dams erected upstream on the Euphrates and Tigris rivers. The desertification issue will only get worse as a result of this. One of the most widely used groundwater modeling tools is MODFLOW. This popularity might be because the application works with most groundwater modeling problems. Using numerical modeling, researchers could estimate aquifer storage and execute groundwater recovery via exploratory simulations and scenario building. Groundwater flow models were used to enhance the suitability of the locations determined by geographic information system analysis (GIS).

This research used 3D calibrated numerical models built using the MODFLOW program and the GMS 10.7 software to assess the effect of artificial recharge by wells on the groundwater level behavior in an unconfined aquifer (Dibdibba). The major objective of this study is to calculate the magnitude and spatial extent of groundwater rise resulting from artificial recharge at selected wells. The rangeland around the Kerbala WWTP is being studied in this particular study. Throughout the artificial recharge era (from 2022 to 2030), sensitivity testing on the efficacy of artificial recharge is conducted using observation wells monitoring groundwater levels.

2. Materials and Methods

2.1. Research Field

Iraq is situated in a very arid region of the Middle East. Approximately between 31°550′ N and 32°450′ N and 43°300′ E and 44°300′ E, Figure 1 depicts the location of the research region (Dibdibba aquifer) in central Iraq. The Dibdibba aquifer is a shallow, unconfined aquifer completely refilled by rainwater. The cliffs of Tar Al-Sayyed and Tar Al-Najaf form the northern, western, southern, and southwestern boundaries, giving the region a total size of 1100 km^2. Both of which are located inside the cities of Kerbala and Najaf. Al-Razzaza Lake is an open-surface reservoir close to the aquifer's northern edge. Sediments from the Quaternary Period form the aquifer's eastern boundary. The Dibdibba aquifer is often regarded as Iraq's most significant water source. Groundwater extraction has increased because of the region's high rate of agricultural activity, which necessitates more water for irrigation. The hydraulic gradient value for the research area is between 0.0011 and 0.0005, and the movement of groundwater is predominantly north eastward, towards the Euphrates River, from the southwest.

The terrain is between 10 and 90 meters above sea level. Its temperature fluctuates from a low of 11 C in the winter to a high of 37.5 C in the summer. The average annual precipitation at the Kerbala weather station is 90 mm, while at the Najaf station, it's 112 mm. Between November and March, most of the year's precipitation occurs. June to September is the driest time of year. May and October saw sporadic and scant precipitation. The quantity and quality of groundwater have both declined since 2003. Water extraction has significantly impacted this region, especially in overexploited regions [36]. The growing use of irrigation in farming has been linked to soil erosion and fertilizer runoff, which enter the unconfined aquifer and contribute to groundwater salinization. This research looked at the potential of utilizing treated urban wastewater as an artificial recharge source to address the declining groundwater level and deteriorating water quality in the Dibdibba unconfined aquifer. It was chosen because of its closeness to the wastewater treatment facility and the large amount of this water (100,000 m^3/day).

2.2. Hydrogeological Characterization

Data gathering and processing are necessary to construct a model accurately representing natural conditions. Several wells inside the research region's analysis area are used to collect hydrogeological data, such as aquifer parameters. A limited number of locations provide data on the hydrogeological features of the modelled region, such as aquifer parameters. The Kriging technique was utilized to make regional-scale data predictions, allowing for approximating the required data. The study area's aquifer features were predicted based on the positions of a subset of production wells, as shown in Figure 1. These features significantly affect the precision with which artificial aquifer recharge may be estimated. When using a method like this, the soil's most salient characteristics largely determine the rate at which water percolates downward and infiltrates.

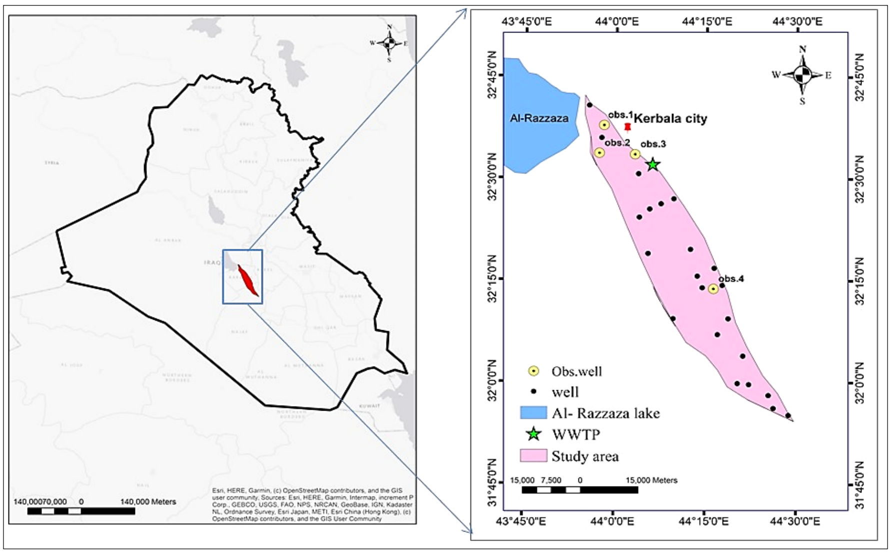


Figure 1. Location of the research area in Iraq and the Kerbala WWTP

Infiltration test data and deep well logs were used to determine the lithology formation depicted in Figure 2. Middle to late Eocene (Al-Dammam), late lower Miocene (Euphrates), middle Miocene (Fatha and Nfayil), upper Miocene (Injana), and upper Miocene-Pliocene (Dibdibba) strata make up the stratigraphic column of the study region. The Al-Dibdibba plateau, which is 1,100 km^2 in area, is the top of the primary unconfined aquifer that supplies the cities of Najaf and Kerbala. The aquifer is replenished by seasonal runoff, especially from the east and north-east, and by precipitation directly on the plateau [37]. Pebbly sandstone, sandstone, siltstone, claystone, secondary gypsum, and marl are the other main components of the Dibdibba formation. Between 45 and 60 meters is the formation's thickness. The Al-Dibdibba formation, the tallest exposed series, underlies the desert plain between Najaf and Kerbala. The Tar Al-Najaf and the Tar Al-Sayyed have peaks where this structure may be seen.

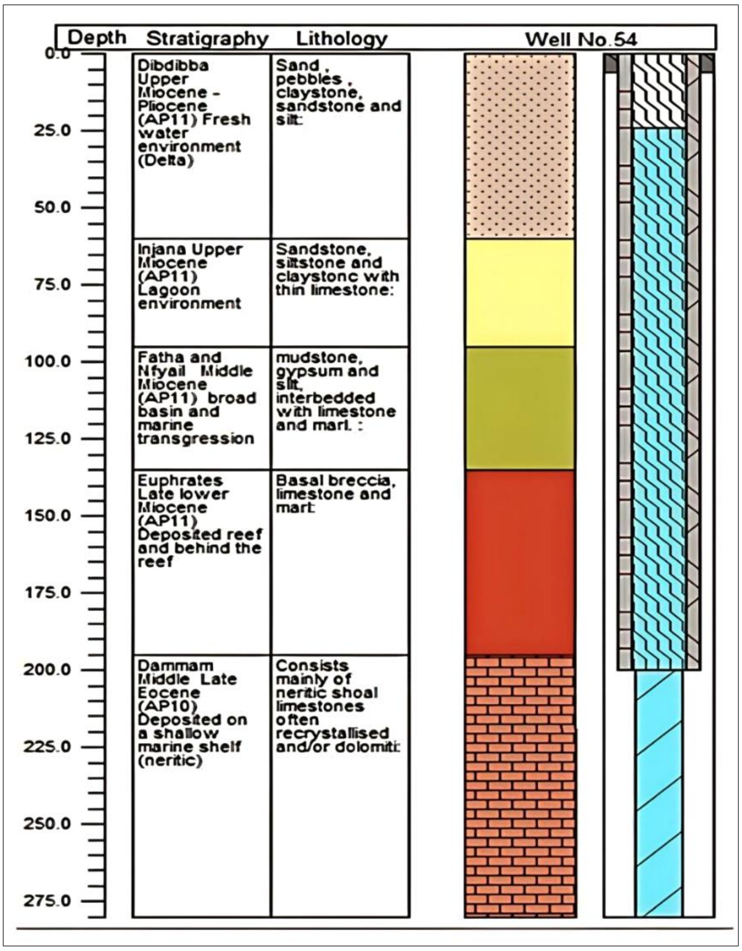


Figure 2. Formations in the research area, including their stratigraphy and lithology [37]

2.3. Groundwater Flow Simulation

A conceptual model was built so that the numerical modelling might achieve its goals. The conceptual model simplifies and idealizes the underlying problem and comprises a spatial arrangement of hydrogeological and geological components. The type of boundaries, where they are located, and the aquifer parameters' values all play a consistently acceptable role. Hydrogeological conditions in the research region must be described in detail before the groundwater flow model is implemented in terms of both the concept and implementation of a well-calibrated model. In this investigation, using a geostatistical method (Kriging), we extrapolated information about groundwater levels and other aquifer properties, such as hydraulic conductivity and the extent of the unconfined aquifer. These parameters are critical inputs for the GMS simulation software's MODFLOW module. Figure 3 illustrates the flow chart of the current study methodology and steps.

2.3.1. Zone Division

Each homogenous zone requires its own independent hydraulic conductivity and recharge rate calculation. The geographically distinct values are necessary for groundwater modeling research [38]. Therefore, the research area is divided into one recharge zone based on geology and aquifer parameters and eight hydraulic conductivity zones based on the results of pumping experiments on fifteen wells. The names and locations of these regions are shown in Figure 4.

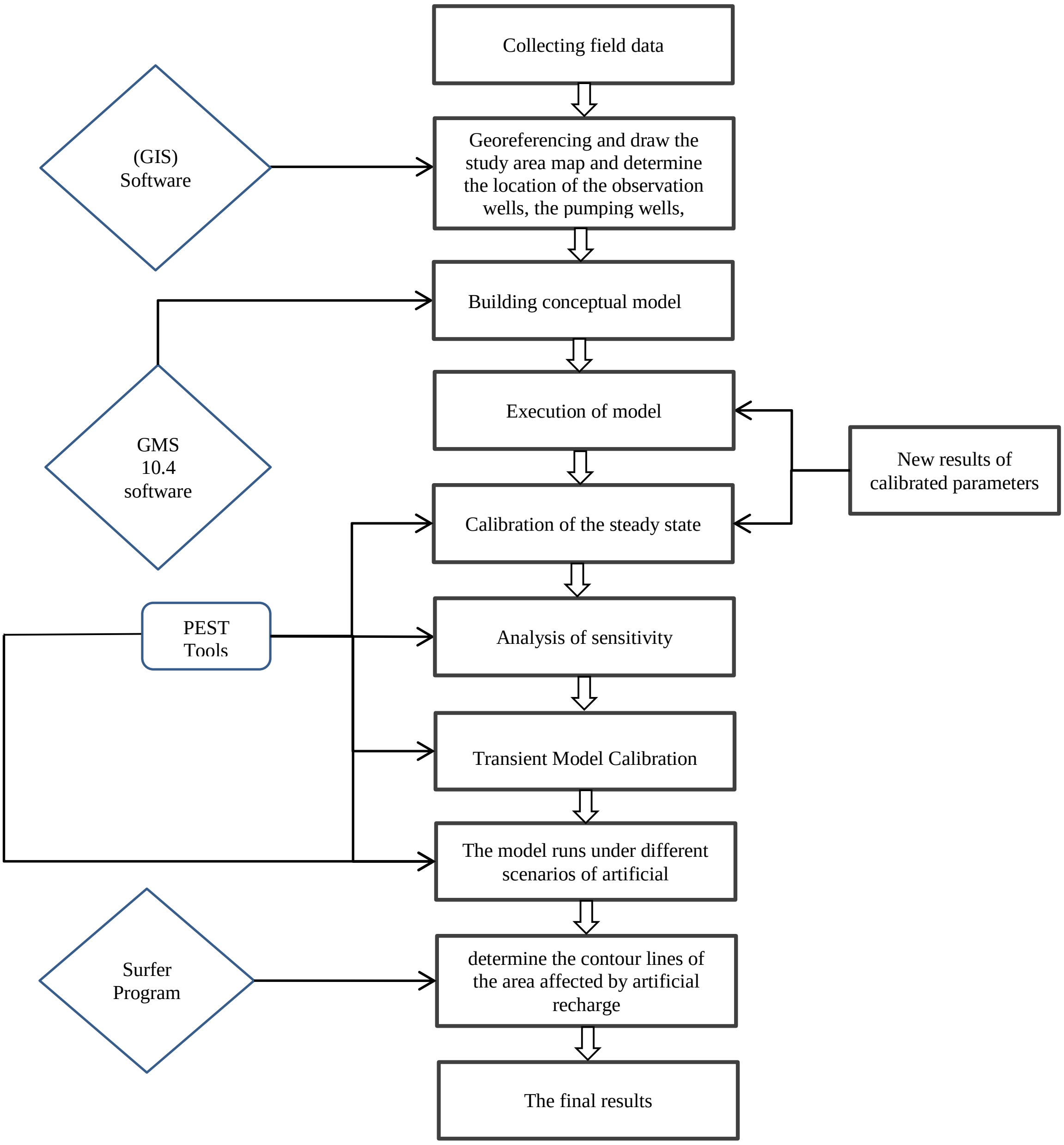


Figure 3. Flow chart of the proposed workflow methodology

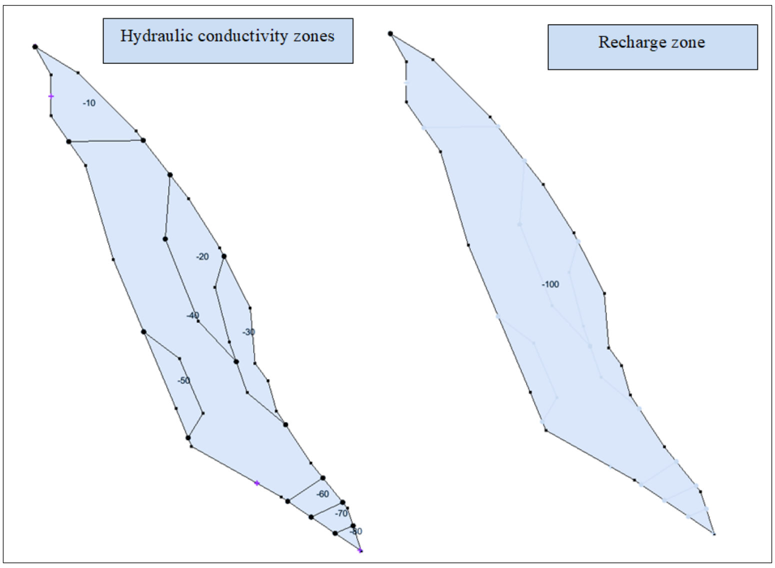


Figure 4. Dibdibba aquifer's hydraulic conductivity and recharge zones

2.3.2. Grid Design

1100 km^2 is the total area of the model's domain. The number of functional cells in the model grid is 3600. Row and column (x, y) cell width distances are fixed at 500 meters (Figure 5). Multiple simulations were run to determine the best grid size for the model. The model area was laid out on a horizontal grid in two dimensions, and it was shown in the vertical plane as an unconfined layer. Based on a topographic contour map of the area, the aquifer's upper elevation values were calculated, as was the low aquifer elevation, which was calculated by subtracting the highest points from the formation depth. The geological formation was estimated to be around 40 meters deep on average. Since MODFLOW is a part of GMS, we have to utilize m.a.s.l. (meters above sea level) to define the topography as a separate layer. As a result, the same units were used to produce all the remaining layers of the input and output contour maps.

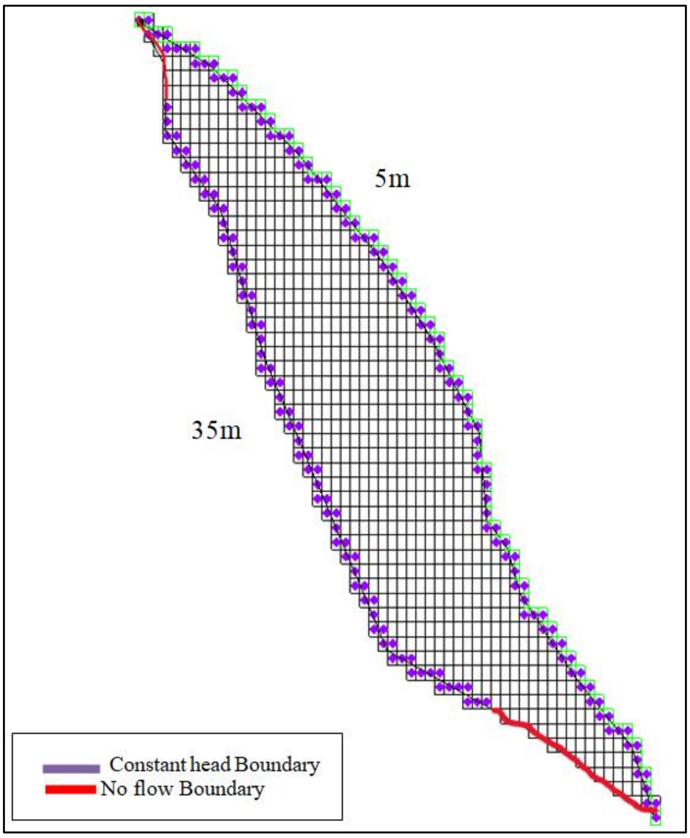


Figure 5. The research area's grid and flow model boundaries

2.3.3. Recharge Estimation

The study region's primary recharge source is rainwater seeping through a permeable medium. The modeling procedure uses the recharge value as a stand-in for the first attempt at estimating recharge. Calibrated recharges will be utilized instead of field recharges since field recharge values are difficult to determine. The geographical distribution of the calibrated recharge was determined using a water balance study and then fine-tuned until a satisfactory match was found between the estimated and measured heads. A significant portion of the system discharge is made up of groundwater extracted by wells for use in irrigating the region under investigation. The Dibdibba aquifer now has over 3,000 operational wells. There has been a significant decline in operating wells over the past few years, with the General Commission of Groundwater estimating that just 500–750 wells remain active in the research area. Average pumping rates are 25–30 m^3/h, and typical well depths are between 20 and 90 m. There is a wide range of possible well-specific capacities, from 5 m^2/h to 220 m^2 /h [39]. The total yearly abstraction from the Dibdibba aquifer was computed based on the withdrawal rate of pumps and the average number of hours the pumps were in use.

$$\text{Total abstraction} = (\text{pumping rate l/s} \times \text{operation time h/day} \times \text{days of operation per year}) \times \text{number of wells used} /365$$

Assuming a daily running time of 6–8 hours, an average discharge of 8 L/s, and 145 operating days per year, the annual pumping rate is 11,500 m^3/day. Due to a lack of field data, we utilized these approximated values as input for the simulation mode.

3. Results and Discussion

The numerical model can be utilized for groundwater management once calibrated and validated to ensure consistency with actual aquifer conditions. An unconfined aquifer lies under the Al-Dibdibba region, and we use a calibrated numerical model to examine the effect of wells on groundwater levels in this aquifer. Thus, building and validating a reliable simulation model to achieve the study's goals was crucial. The simulation model measured the impact of artificially recharging the wells through several hypothetical scenarios.

3.1. Steady-State Model Calibration and Validation

Regular comparisons of observed values from the field to those estimated by the model might be utilized for calibration and validation in GMS, thanks to the observation coverage. As well as the observed values, a 95% confidence interval, and a 0.5 m interval were also recorded. Calibration targets are shown as a consequence of the calibration procedure (Figure 6). The measured value is just in the middle of the goal. The calibration target has two ends, one at the observed value plus the interval and the other at the observed value minus the interval.

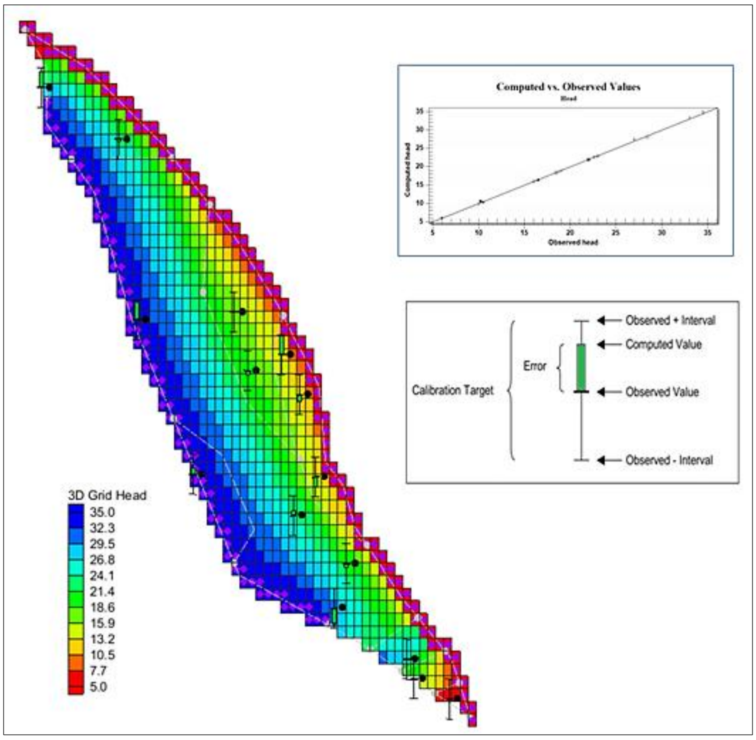


Figure 6. The steady-state calibration of the Dibdibba aquifer led to a contour map showing the simulated groundwater level in meters above sea level (m.a.s.l)

A whole bar represents the mistake, with green indicating that the number is acceptable. A yellow bar indicates an error of less than 0.5 meters; a red bar indicates an error of more than 1 meter. The goal is to get the colored bar to zero, representing the mistake. In order to calibrate and verify the numerical model for steady-state situations, data from just 15 recorded wells were utilized to measure groundwater levels. These 15 wells were chosen to be representative of the whole research area, which greatly streamlined the calibration procedure (which was automatically completed via the PEST features included within the GMS program). Figure 6 displays the final contour map of the simulated water heads in the aquifer. 11 of the 15 calibration targets in the model have green bars, and the other water heads have values that are very close to the observed values. This is a vast improvement over the first solution and indicates that the excellent, calculated solution matched the field-measured values.

The calibrated fit was visualized as a scatter plot (Figure 6) between the observed and simulated water heads. The goodness of fit, often known as the coefficient of determination (R^2), is calculated. The R^2 value of 0.989 in the scatter plot indicates a very good fit. Table 1 also displays an error analysis. When comparing observed and calculated heads, the mean error (ME) was found to be negligible (-0.145). The root mean squared error (RMSE) and mean absolute error (MAE) values were both small, indicating that the conceptual model and all data utilized to construct it are sufficiently reliable for groundwater flow prediction.

Table 1. Statistical indexes of the steady state calibration

Evaluation Criteria	Symbol	Index value
Mean error (m)	ME	-0.145
Mean absolute error (m)	MAE	0.690
Root means square error (m)	RMSE	0.954

Equations 1 to 3 explain the calculation mechanism for each of the ME, MAE, and RMSE.

$$\text{ME} = \frac{\textit{Sum of all error values}}{\textit{Number of records}} \tag{1}$$

$$MAE = \frac{100}{N} \sum_{i=1}^{N} \left| R_{mearured} - R_{Exp.} \right| \tag{2}$$

$$\text{R}MSE = 100 \times \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{R_{measured} - R_{Exp.}}{R_{measured}} \right)^2} \tag{3}$$

3.2. Transient Model Validation

Groundwater levels are modelled as a function of time in the transient problem. The transient-state simulation employed the steady-state simulated aquifer heads as the beginning heads. The measured heads were used as the primary reference points for this run's calibration. To conform to the data, the stress period step size was increased on a monthly basis. Sy values were previously determined through pumping tests in the literature, with results ranging from 0.001 to 0.05 [40].

Transient data from several sources, such as observation of water levels, pumping well data, and recharging data, must be managed to construct a transient simulation. This kind of data organization and formatting might be tedious. Conditions of rapid recharging and rapid pumping will be simulated. The results of numerical models depend heavily on their spatial and temporal resolution, and choosing a simulation time stage is a crucial part of transient model development [40]. Similar to the steady-state model, the boundary conditions were kept constant. When recruiting the first group of wells, the steady-state model was applied.

The model was fine-tuned using data collected over around two years, from January 2016 through December 2017. Measured data was used to split the simulation time into eight stress periods of varying lengths. Furthermore, the local consumption data assesses the relevant discharge rates. The equivalent groundwater levels recorded from four control wells were used in calibration and validation operations (Figure 1). These wells were placed in roughly representative areas, particularly in the region around the Kerbala WWTP (Obs. 1–3). For this study, the primary variable adjusted in a transient calibration is the specific yield for an unconfined aquifer. Trial and error adjusted specific yield parameters during the transient state calibration procedure until a satisfactory match was found between the observed and calculated heads (Figure 7). Table 2 displays the results of the validation of the groundwater flow model using the MAE and RMS error throughout the stress period. In most time intervals, the RMS variation is less than 1 m, proving the simulation is accurate.

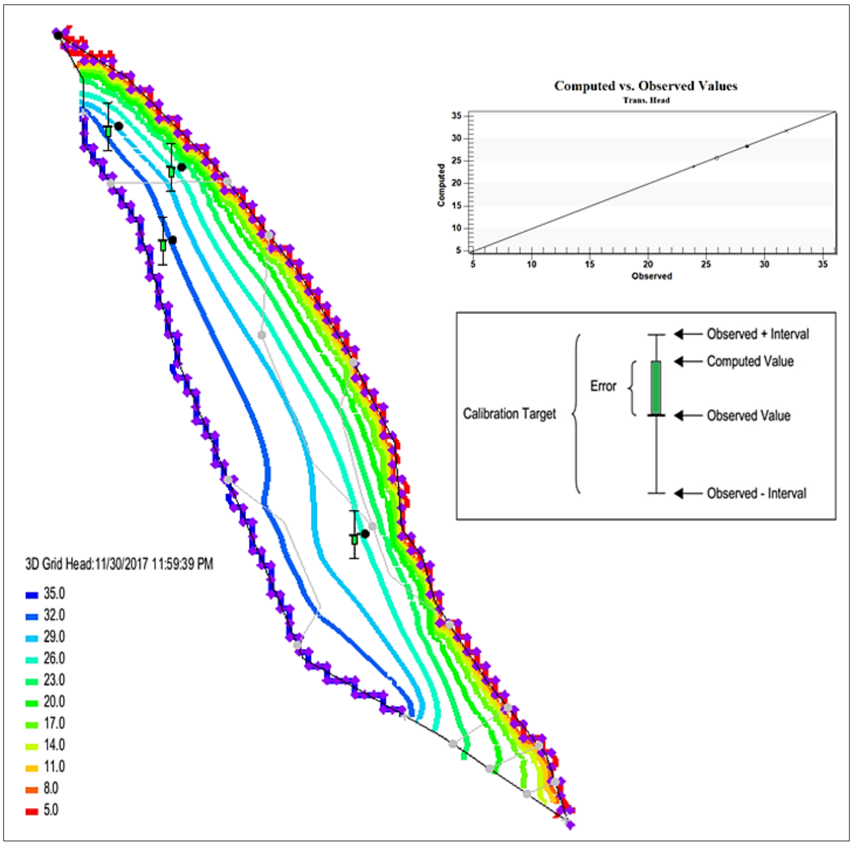


Figure 7. Verification in four observation wells over the transient period of 2016–2017

Table 2. Summary of the transient calibration errors

Evaluation Criteria	Symbol	Error value
Mean error (m)	ME	-0.34596
Mean absolute error (m)	MAE	0.702224
Root mean square error (m)	RMSE	0.837988

Hydrographs were calibrated from January 2016 through December 2017 to measure the calibrated transient model's performance. Despite a few cases where the modelled heads deviated from those observed, the projected head hydrograph exhibited a close agreement with the measured values. The monitoring data consistently demonstrates a downward trend in elevation over the analyzed periods. These assessments indicated that the model was accurate. The transient simulation showed the model to be highly accurate in predicting the observed water head in the Obs. wells. Figure 8 shows that the simulation model results consistently overstate the actual value for observation well no. 3 (Obs.3). During the validation time, groundwater levels were recorded but were within acceptable parameters (green targets). This agrees with calibrating recharge, hydraulic conductivity, and Specific yield results. A transient scatter plot of measured values against simulated aquifer heads was used to assess the performance of the transient model. The coefficient of determination, R^2, for this scatter plot is 0.997.

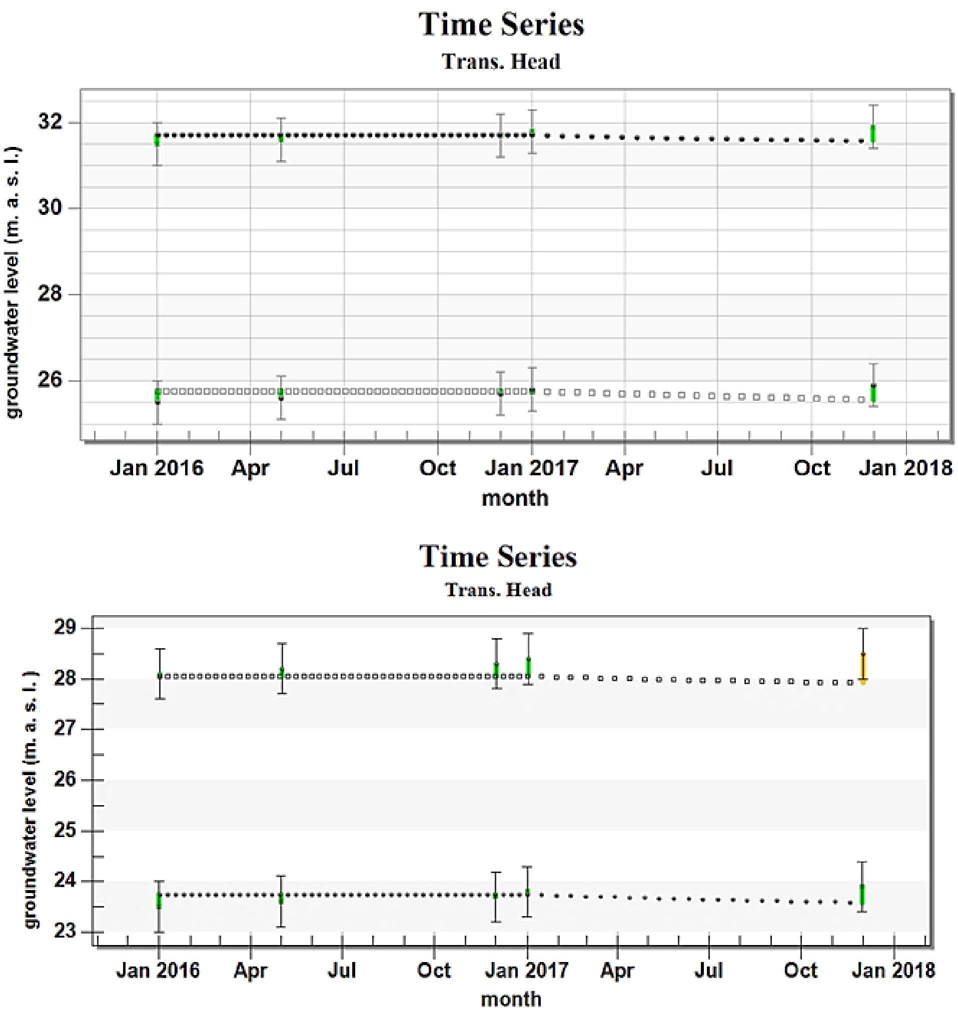


Figure 8. Verification in four observation wells over the transient period of 2016–2017

3.3. Assessment of Artificial Recharge

The predicted effect of artificial recharge by wells on groundwater elevation around the Kerbala WWTP was assessed using calibrated models. Between 2016 and 2030, various scenarios were implemented that accounted for natural recharge, artificial recharge, and the rate at which pumps withdrew groundwater. In order to achieve this, four simulation models (SIM1, SIM2, SIM3, and SIM4) were used to run computations over the predicted occurrence (2016–2030). All boundary conditions in SIM1 were maintained at the beginning of the simulation, with the 2016 extraction and natural recharge rates assumed to continue without change and the artificial recharge rate at the WWTP disregarded. By 2030 (in this hypothetical future), groundwater levels are expected to have dropped by over 2.7 meters in some areas and by 1.7 meters near the Kerbala WWTP (Figure 9). The expected decrease in groundwater levels is highly sensitive to the assumptions about the extraction values estimated by Equation (1) (11,000 m^3/day) because of the scarcity of observation data.

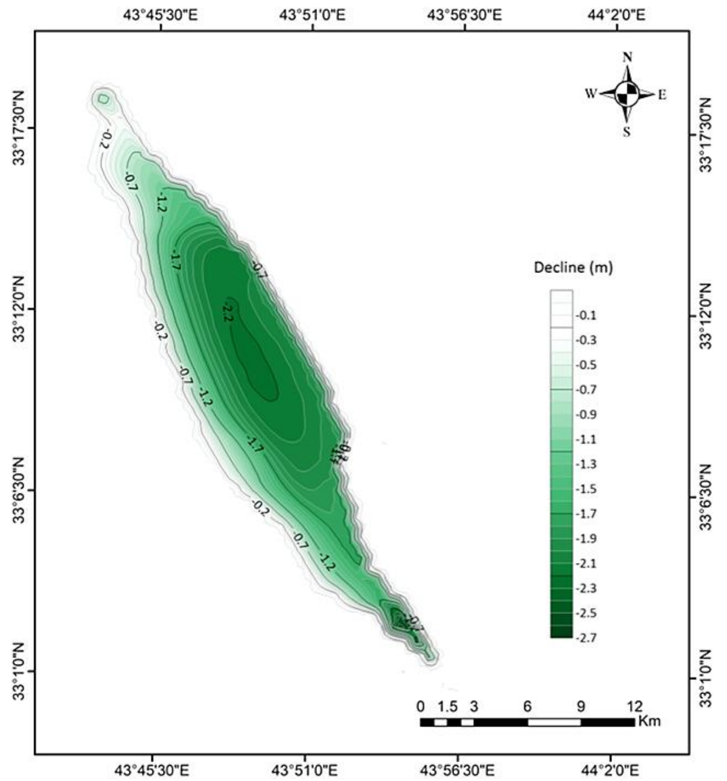


Figure 9. Groundwater levels are predicted to drop in the study region without recharge

Using the same initial conditions as SIM1, SIM2 injected a 5000 m^3/day recharge flow into 25 randomly selected recharge wells. These recharge wells were strategically placed all throughout the area surrounding the treatment facility to maximize efficiency and economy. By comparing the predicted groundwater level in 2030 using SIM1 and SIM2, it was found that an artificial recharge pumping rate of 5000 m^3/day would be sufficient to raise the groundwater level by close to 1.3 m (maximum). Under recharge conditions, the region around the WWTP site would be impacted by a groundwater level rise of up to 1.05 meters, with an approximate area of 15.77 km²; at the lowest possible increase of 0.35 meters, the affected area would be 76.81 km², as shown in Figure 10. In another hypothetical scenario (SIM3), the output from the WWTP was increased by 8% (or 8,000 m^3/day), and this extra water was used to recharge the aquifer groundwater table artificially.

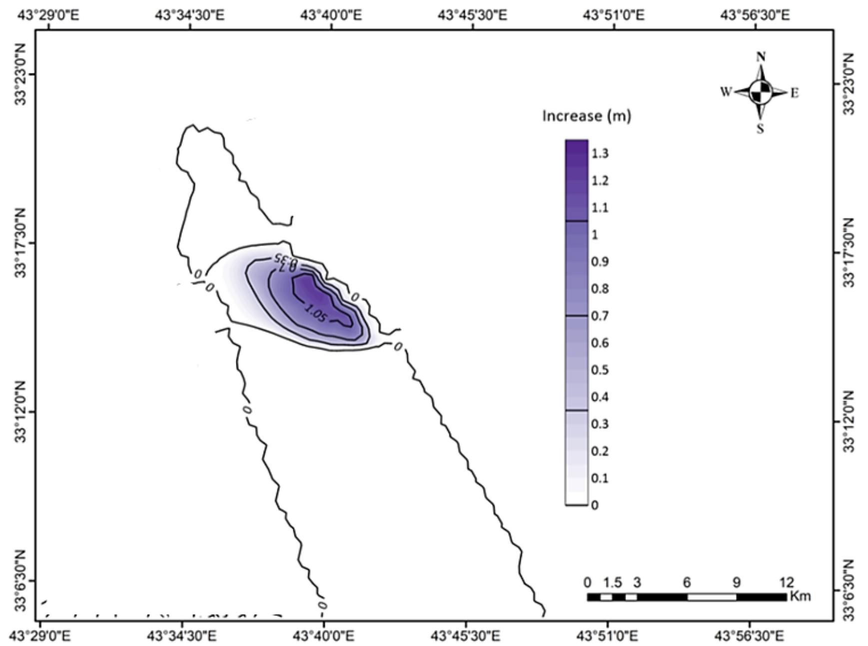


Figure 10. Differential rises in groundwater levels between SIM2 and SIM1 as a result of artificial recharge in 2030

There was a greater effect on the groundwater level as a result of the rise. There was a maximum increase in groundwater levels of 2 meters with an area of 26.077 km². The impacted area grew by 1 meter, reaching 74.12 km² (Figure 11).

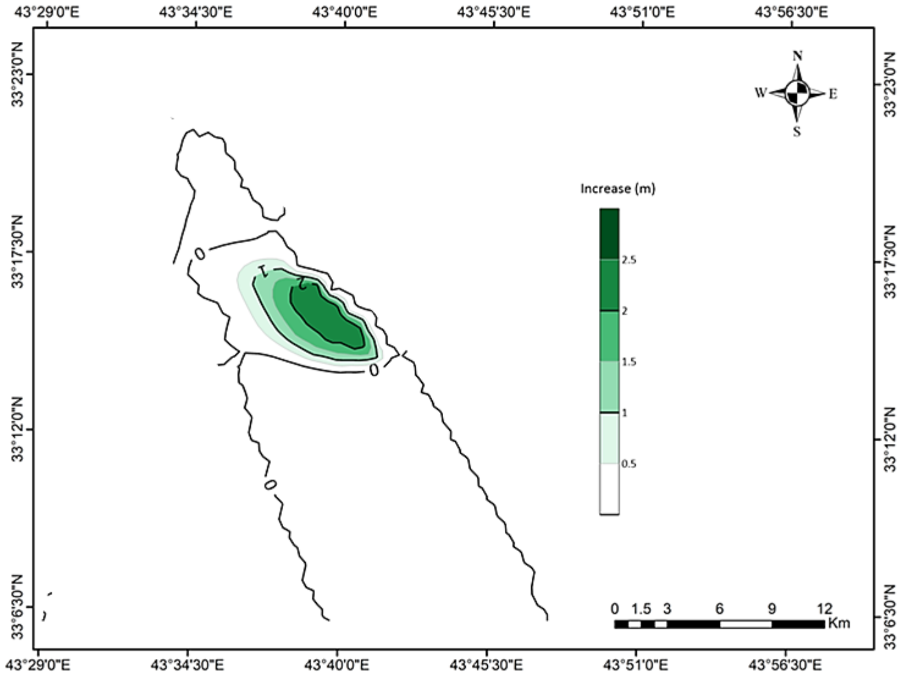


Figure 11. The 2030 effect of artificial recharge: SIM3 and SIM1 groundwater elevation rises are different

The fourth and final scenario, SIM4, involved using an artificial recharge rate for the aquifer groundwater table equal to 10% of the WWTP discharge (10,000 m^3/day). Maximum groundwater level rise was 3 meters across an area of 11.123 km². The area impacted positively increased by 1 meter with an area 93.081 km² (Figure 12).

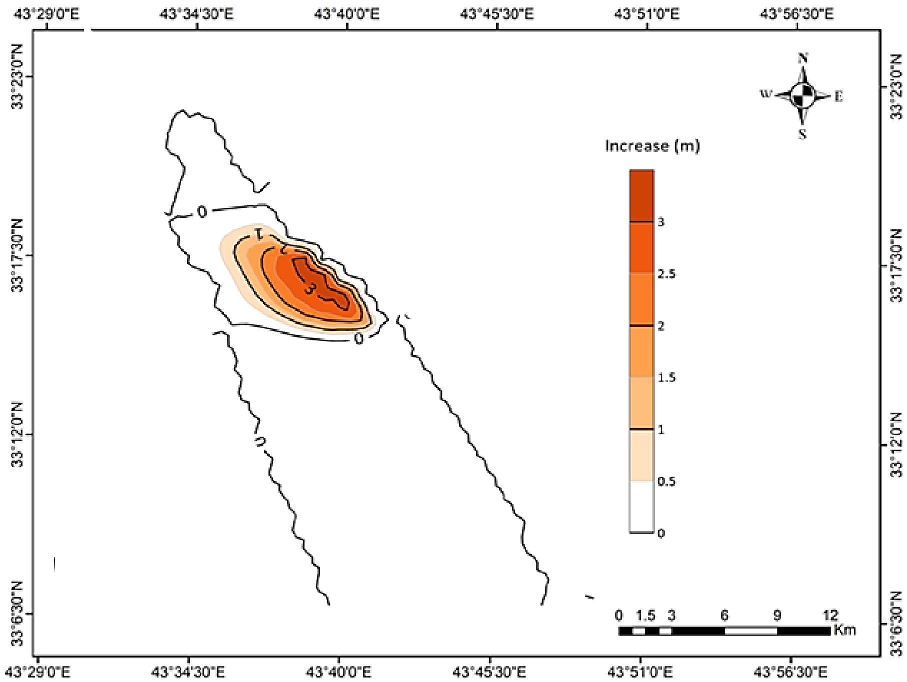
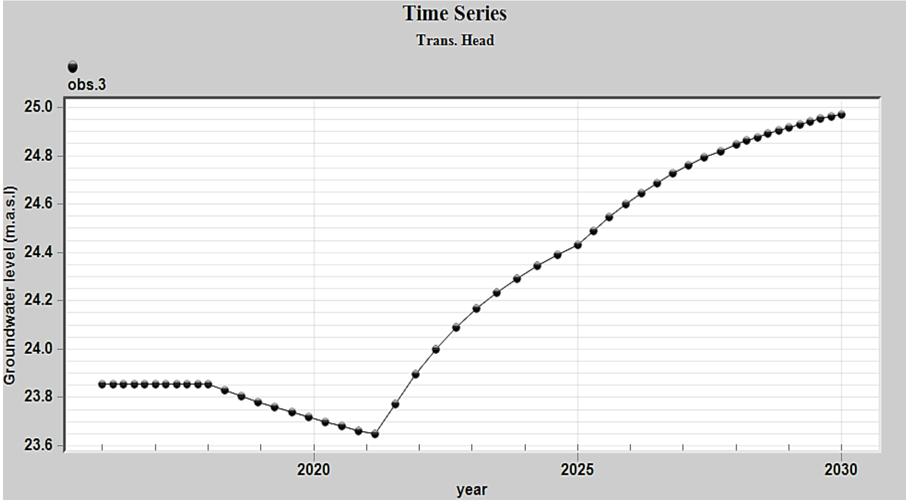


Figure 12. Impact of artificial recharge in 2030: differences in groundwater elevation increases between SIM4—SIM1

Results were compared to those from the observation well (Obs.3) located near the artificial recharge site for an understanding of the groundwater level's temporal evolution, as shown in Figure 1. Artificial recharge would cause an increase in groundwater levels close to the observation well 3 (Obs.3), as seen in Figure 13.



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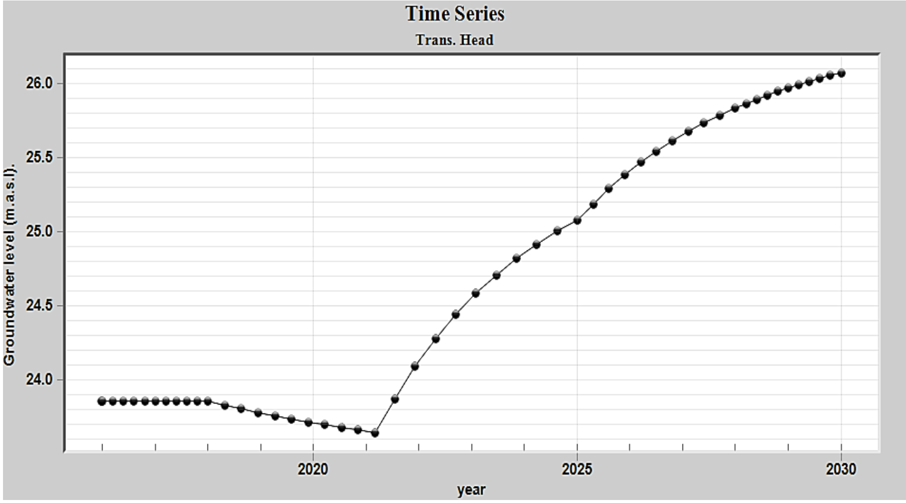

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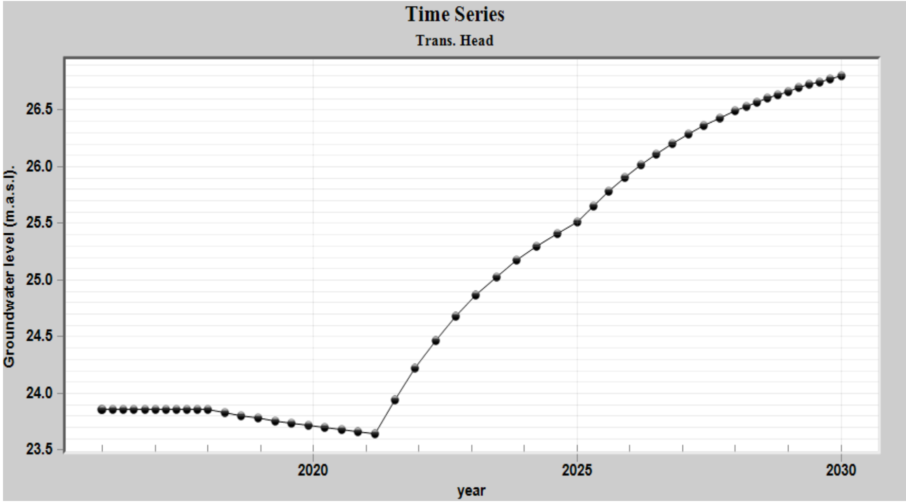

c. Groundwater level variations in observation well No.3 (Obs.3)

Figure 13. (a) SIM2 with 5000 m^3/day and (b) SIM3 with 8,000 m^3/day, (c) SIM4 with 10,000 m^3/day for period (2022 to 2030)

3.4. Sensitivity Analysis

One way to show how crucial the data is for parameter estimates is via sensitivity analysis. Since the computed parameter may have a greater impact throughout the simulation duration, the most sensitive observation may be affected [41]. Using parameter sensitivity, one may identify which parameters are more influential and have the least impact on the developed model's prediction outputs [42]. Each input parameter was subjected to a sensitivity analysis once the

PEST iterations were completed. The findings of the analysis of hydraulic conductivity and natural recharge for all of the research zones are shown in Figure 14. Hydraulic conductivity changes have a smaller effect on the model than natural recharge differences. The biggest zone's (RCH-100) natural recharge influences groundwater level estimates more than any other input component. For regions (HK-10, HK-50, and HK-80), hydraulic conductivity parameters had the smallest impact on the simulation model results. This tendency may arise from the fact that RCH-100 represents a somewhat large region compared to the other regions of parameters. Predictions for steady-state calibration may be affected by the geographic variability of parameters. Transient modeling reveals sensitivity owing to slow-responding increases and decreases in specific yield. By doing this analysis, it can be determined which model parameters are most and least influential. Because of this, future research can ignore changing non-sensitive factors while focusing on the highly sensitive parameters in the simulation model.

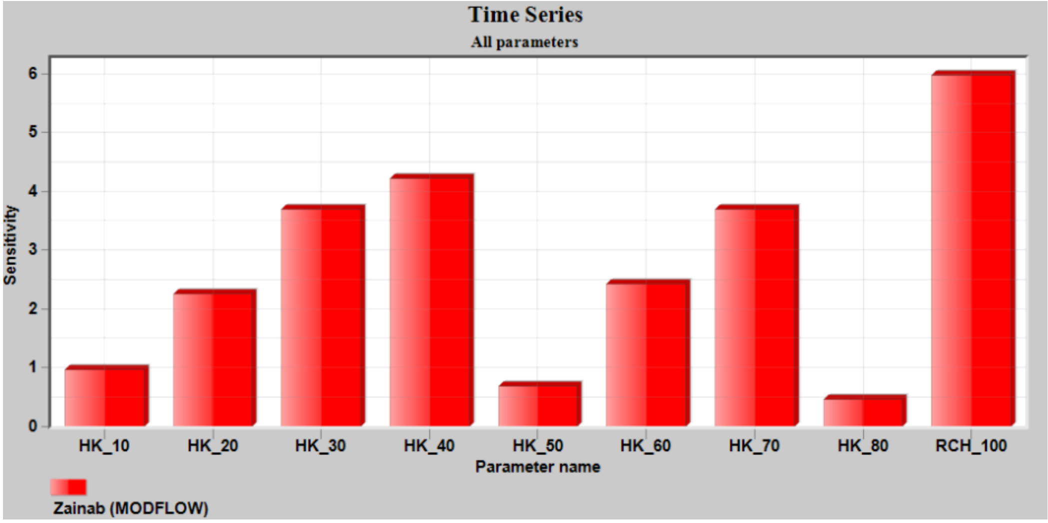

Figure 14. Sensitivity of parameters for study area

4. Conclusions

The sustainability of groundwater aquifers can be ensured, in part, through artificial recharge. While artificial recharge is crucial for several reasons, including water resource supply, rising water levels, land rebound, and creating agricultural land, it also provides a cheap energy source for the manufacturing sector. Sustainable resource management is threatened by issues related to the inefficiency of current storage methods and the lack of control over the rates at which groundwater is recharged and used. This research aimed to find out what would happen to the Dibdibba unconfined aquifer if part of the treated water from the Kerbala WWTP was reused. Groundwater modeling software (GMS 10.7) was used to simulate the impact of artificial recharge on groundwater quantity in the Dibdibba unconfined aquifer. The PEST tool was used to fine-tune the correctness of the constructed models automatically. Groundwater levels predicted by the steady-state and transient models in 2016 and 2017 were in line with observations. Sensitivity analyses of the models in 2016 and 2017 were performed to determine their level of robustness. Both the recharge and hydraulic conductivity parameters were shown to be sensitive to change, with the recharge parameter having a significantly larger effect on the model. Four scenarios were used in the period from 2016 to 2030, the first of which included the application of natural conditions without artificial recharge, and three of them used artificial recharge by wells (5000, 8000, and 10000 m^3/day) for Eight years from 2022 to 2030.

The results are: In the first scenario, the absence of rain and the ongoing extraction of water cause the water level to drop to a depth of 1.25 meters across most of the area. with an average annual drop of about 16.77 cm in Observation Well 3 (Obs.3). In the second scenario, after artificial recharge with 5000 m^3/day, the water level in the observation well (obs.3) increased at an average annual increase of 17.5 cm, for a total of approximately 1.4 meters throughout the recharge period. Over 15.777 square kilometers were impacted by the highest level, which was greater than 1 meter. In the third scenario, following artificial recharge of 8000 m^3/day, the water level in the observation well (obs. 3) increased by an average of 31.25 cm each year, for a total of almost 2.5 meters. The highest level was above 2 meters and affected an area of 26.077 square kilometers. In the fourth scenario, the water level in the observation well (obs. 3) increased by an average of 41.25 cm each year, for a total of almost 3.3 meters, after artificial recharge of 10000 m^3/day. The greatest level affected a region of 11.123 square kilometers and was more than 3 meters. The results indicate that in eight years of artificial recharge, it will lead to a minimum recovery of the water table of up to 50 cm over a recovery area of approximately 85 square kilometers. Therefore, the use of an artificial recharge site well increases the amount of groundwater, which can be used to irrigate crops during dry seasons and can also contribute to improving the quality of groundwater.

5. Declarations

5.1. Author Contributions

Conceptualization, W.H. and Z.G.; methodology, W.H.; software, Z.G.; validation, W.H. and Z.G.; formal analysis, Z.G.; investigation, W.H.; resources, W.H.; data curation, Z.G.; writing—original draft preparation, Z.G.; writing—review and editing, W.H.; visualization, Z.G.; supervision, W.H.; project administration, W.H.; funding acquisition, W.H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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