Shahid Chamran University of Ahvaz

Irrigation Sciences and Engineering (JISE)
Vol. 48, No. 4, Winter 2026, p. 79-103
Journal homepage: https://jise.scu.ac.ir

Research Paper

Estimation of Transmissivity and Storage Coefficients in a Dual-Aquifer System Using Combined Field and Analytical Methods

Sheyda Mohammadi Fard[1], Jahangir Abedi-Koupai[2] and Saeid Eslamian[3]

1- Corresponding Author, PhD Student, Department of Water Engineeribg, College of Agriculture, Isfahan University of Technology (s.mohammadifard@ag.iut.ac.ir)*
2 - Department of Water Engineeribg, College of Agriculture, Isfahan University of Technology.
3- Department of Water Engineeribg, College of Agriculture, Isfahan University of Technology.

ARTICLE INFO

Artlcle history:
Received: 01 July 2025
Revised: 01 September 2025
Accepted: 22 September 2026
Available online: 04 January 2026

Keywords:
Aquifer, Groundwater, Transmissivity, Storage.

TO CITE THIS ARTICLE:
Mohammadifard, S., Abedi Koupai, J., Eslamian, S. 2026. 'Estimation of Transmissivity and Storage Coefficients in a Dual-Aquifer System Using Combined Field and Analytical Methods', *Irrigation Sciences and Engineering*, 48(4), pp. 79-103. doi: 10.22055/jise.2025.49895.2167

Abstract

This study investigates the hydrodynamic coefficients of the Kouhpayeh-Segzi (KSA) aquifer, a vital groundwater resource in Isfahan province in central Iran, located in an arid to semi-arid climate, where surface water is unreliable. The research addresses the increasing dependence on groundwater in the region, driven by population growth, agricultural expansion, and industrial development, which has led to over-extraction, groundwater table depletion, reduced well yields, and land subsidence. The main objective is to accurately estimate the parameters of hydrodynamic coefficients—transmissivity coefficient and storage —essential for sustainable groundwater management. Traditional pumping tests, although standard, are costly and limited by practical constraints, especially in deep or data-poor environments. To overcome these challenges, this study integrates multiple data sources, including grain-size distribution analysis, well drilling logs, geophysical surveys, and exploratory and observational well data. The approach involves re-analyzing pumping test data, determining alluvium thickness, bedrock elevation, and consequently preparing maps of the transmissivity and storage for the aquifer. The studied aquifer has two types of aquifers: confined and unconfined. The results show that the average values of hydrodynamic coefficients such as the transmissivity and storage of the KSA unconfined aquifer are estimated to be 960 m2/day and 3.9% and the transmissivity unconfined aquifer is estimated to be 914 m2/day, respectively. The findings emphasize the necessity of continuous monitoring, adaptive management, and the use of advanced analytical and geophysical techniques to ensure the long-term sustainability of groundwater resources in the KSA region.

Introduction

One of the essential needs for the growth and development of any country is water, which is not only necessary for the expansion of cities and industries but is also considered a key factor in agricultural development. On the other hand, groundwater resources are among the most important sources of water. The hydraulic study of aquifers is significant because it leads to better utilization of groundwater and, consequently, improved management of water resources. In arid and semi-arid regions, since rainfall occurs only during a short period of the year and evaporation and transpiration rates are high, surface water resources are not a reliable source for water supply. Therefore, in these areas, greater reliance is placed on groundwater resources.

Hydrodynamic coefficients of an aquifer (storage (S) and transmissivity (T)) are the most important hydrogeological information for describing the characteristics of any aquifer. The implementation of most projects

 DOI: 10.22055/jise.2025.49895.2167

and research plans in any aquifer depends on the availability of accurate and precise hydrodynamic coefficients. One of the methods to determine these parameters is conducting pumping tests, which are usually very costly and face many limitations, especially in arid regions due to increased drilling depth. Therefore, in recent years, efforts to find the fastest and most economical solutions to perform these tests in most areas have led to the development of various methods. These methods analyze existing data to obtain average values of aquifer coefficients.

The aim of this study is to estimate the hydrodynamic coefficients of the KSA aquifer in Isfahan province in the central part of Iran. Therefore, the objectives of this work are: i) Collecting drilling log data and extracting hydrodynamic coefficients from them ii) Collecting data from pump tests and analyzing them to extract the hydrodynamic coefficient iii) Combining the extracted data in the two above cases to draw maps of both the storage and transportability. Research questions: i) What are the values of hydrodynamic coefficients using the grain-size method? Ii) What values do the hydrodynamic coefficients include in the pumping test method?

There are various methods for measuring the hydrodynamic coefficients of an aquifer, including laboratory methods, groundwater modeling, pumping tests, use of tracers, geophysical methods, and experimental methods such as grain-size, balance. Due to the high cost of pumping tests to estimate hydrodynamic coefficients, the innovation in this study is to use available information and combine the results of two pumping test and grain-size methods to estimate the transportability and storage in the aquifer.

In this study, the inverse solution method was not used to estimate the hydrodynamic coefficients of the aquifer, but the results of this research can be used in the inverse solution method. Because the inverse solution method in estimating the hydrodynamic coefficients of the aquifer is a numerical and optimization method that is used to estimate important hydrodynamic parameters such as transmissivity, storage and hydraulic conductivity. This method is used when there is little direct data or simple analytical models are not suitable. In this method, first, using the equations governing groundwater flow, the behavior that the parameters are expected to have is simulated (Sahranavard et al., 2023). Then, by comparing the simulated model with the actual data (the results of the present study), the difference between the model and observations is defined as the objective function.

Ansarifar et al.(2019) study combines borehole data interpretation with an inverse solution method to estimate hydraulic conductivity (K) and specific yield (Sy) of the Bandar-e Gaz unconfined aquifer in Northern Iran, without pumping test data. A numerical model calibrated and validated over two 12-month periods demonstrates high accuracy using the Nash-Sutcliffe criterion. Results show that K and Sy values range from 5–15 and 0.024–0.036 m/day, respectively, with a spatial pattern decreasing from south to north, aligning with the sediment characteristics of the aquifer.

Pumping tests are one of the most reliable and common field methods for determining the hydraulic properties of aquifers, because this test reflects the hydraulic properties of a relatively large part of the aquifer (the part where the depression cone has formed). A well dewatering test or pumping test is performed to determine the hydraulic properties of an aquifer to study the groundwater status of an area or to determine the amount of dewatering and water level drop in a well. In a pumping test, the goal is to determine the storage and the transportability of the aquifer, and for this purpose, the presence of observation wells or piezometric wells at certain distances from the main well being tested is mandatory. This test is performed under stable and unstable conditions or in a stepwise manner (Lohman, 1972).

One of the methods that can be used to estimate a relatively good estimate of the hydrodynamic coefficients of an aquifer is to use the grain-size method. In this method, by obtaining the permeability coefficient and determining the thickness of the aquifer, the transportability can be calculated. Also, by

obtaining the effective porosity, an estimate of the aquifer storage can be obtained (Domenico and Schwartz, 1990).

Accurate estimation of aquifer parameters is essential for effective groundwater management, but traditional methods face challenges due to subjectivity and non-uniqueness. The proposed Weighted Joint Curve Method (WJCM), based on the Theis equation and optimization, provides unique and reliable parameter estimates by considering both pumping and recovery phases. Application of WJCM to real data demonstrates its efficiency, ease of implementation, and potential for improving groundwater evaluation and management (Li et al., 2025).

Pumping test data are inherently noisy, causing variability in aquifer parameter estimates when analyzed by traditional trial-and-error methods that often yield uncertain, non-unique results. Bashandy et al. (2024) in a study develops a FORTRAN-based tool employing the Markov Chain Monte Carlo (MCMC) algorithm with various likelihood functions to quantify uncertainty and identify the most probable aquifer parameters with high confidence. The tool's effectiveness is demonstrated through hypothetical and real cases, showing improved reliability over standard methods for confined and semi-confined aquifers.

Benson (2023) derives a convolutional solution for pumping tests accommodating any pumping history, improving computational efficiency by using the time derivative of the well function and enabling nonlinear well loss modeling. The method supports simultaneous use of data from multiple observation wells and provides MATLAB and Python codes for parameter optimization. Results highlight the importance of objective function construction and suggest Bayesian inversion for robust estimation of aquifer parameters due to non-uniqueness in step-drawdown test optimization.

Large-scale groundwater models face challenges in parameterization due to limited observational data and scale mismatches. Houben (2022) in research uses spectral analysis of groundwater level fluctuations to derive regional hydraulic parameters, demonstrating that specific aquifer locations can reveal representative parameters. Results show that robust parameter estimation requires long-term data and knowledge of aquifer length and measurement location, enabling effective bridging of scale gaps in groundwater modeling.

Groundwater plays a vital role in securing water resources and ecological stability in semi-arid regions. Li et al. (2019) in a study develops a three-layer hydrogeochemical zoning model for a typical semi-arid basin in western Jilin Province, revealing spatial hydrogeochemical evolution from recharge to discharge zones. The model integrates geological, hydrodynamic, and chemical characteristics, highlighting processes such as leaching, cation exchange, and evaporation that shape groundwater chemistry and elemental distribution.

Accurate hydrogeological parameter estimation is critical for groundwater management. Li and Qian introduced a global curve-fitting method combining pumping and recovery data, showing slightly higher but comparable results to traditional Hantush-Jacob methods, confirming its reliability (Li and Qian, 2012).

A study in China presents a closed-form analytical solution for constant-rate pumping in a confined aquifer affected by a rectangular waterproof curtain, using the image method and superposition principle. A straightforward approach for estimating hydraulic parameters is demonstrated with field data from Wuhan, China, showing good agreement between predicted and observed drawdowns. The solution and parameter estimation method are reliable and valuable for designing dewatering systems in deep excavation projects (Li et al., 2023a).

In another study in China develops a novel dimensionless analytical solution for variable-rate pumping tests using piecewise-constant approximations, addressing limitations of classical constant-rate models. The new type curve method estimates hydraulic conductivity and specific storage by matching observed

 DOI: 10.22055/jise.2025.49895.2167

drawdown data with curves dependent on dimensionless inflection time. Application to field data from Wuxi City, China, shows close agreement with PEST calibration and lithology-based validation, providing reliable aquifer parameter estimates (Li et al., 2023b).

In this study, hydrodynamic coefficients of aquifer layers were estimated using grain-size distribution curves, observation well logs, exploratory and production wells, geophysical studies, and pumping tests. The work steps are summarized in the flowchart of Figure (1).

The present research was conducted to achieve the following objectives:

- Collecting pumping test data
- Reviewing and reanalyzing conducted pumping tests to refine the coefficients and verify the accuracy of the data
- Determining the thickness of alluvium and the bedrock elevation based on existing data (including geophysical information, borehole logs, and production and exploratory wells that have reached the bedrock)
- Preparing transmissivity (T) curves and storage maps.

Materials and Methods

Study Area

Isfahan Province is located within the arid and semi-arid regions of Iran. Moreover, the timing and location of precipitation in this province do not align with water demand. Most cities in Isfahan Province are situated in areas with limited access to surface water resources; therefore, they primarily rely on groundwater. The presence of numerous deep and semi-deep wells in the aquifers and Qantas in these cities supports this claim. Given these conditions and technological advancements, groundwater exploitation has significantly increased over the past few decades. This has resulted in an imbalance between recharge and withdrawal, leading to a negative groundwater balance and adverse consequences such as declining water table levels, reduced well yields, well displacement and collapse, increased pumping costs due to greater depths, irreversible aquifer volume reduction, and compaction of the aquifer system. These effects cause decreases in transmissivity, storage, and land subsidence. To prevent further quantitative and qualitative decline, proper management of groundwater resources must be seriously considered as a fundamental principle in the planning of Isfahan Province by authorities and stakeholders. The present study was conducted in the KSA area located in the center of Isfahan Province.

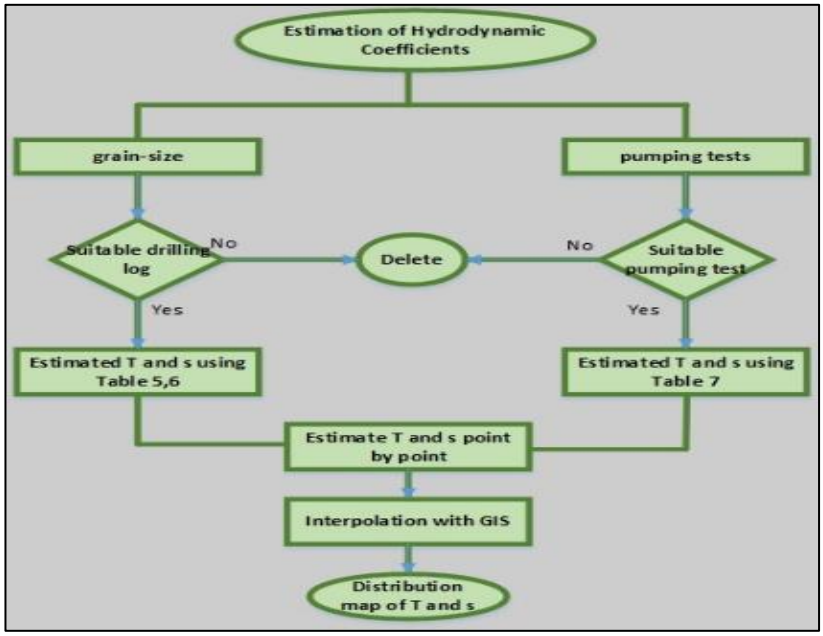


Fig. 1- Flowchart for work steps

Kouhpayeh-Segzi (KSA) Study Area

The KSA study area is one of the main sub-basins of the Gavkhouni watershed in Iran, located in the eastern part of this watershed, covering an area of approximately 6,678 square kilometers. It extends between longitudes 51°34' to 53°1' east and latitudes 32°11' to 33°13' north. Figure (2) shows the Gavkhouni watershed and the KSA study area in relation to Isfahan Province. Additionally, Table (1) provides detailed information about the KSA.

Groundwater Characteristics in the KSA Study Area

Initially, the topography of the KSA study area was examined, as shown in Figure (3). Based on the topographic maps, the elevations and the inflow and outflow points of the aquifers can be identified. As observed, the northern parts of the study area have the highest elevations, which gradually decrease towards the center and east of the area.

For better visualization, Figure (4) presents the KSA study area in Isfahan Province overlaid on a satellite image. This clear image allows the identification of various landforms such as mountains, agricultural lands, rivers, and so on. Understanding the location of these features around the studied aquifers significantly aids in determining the inflow and outflow zones of the aquifers under study.

Further, the characteristics of the KSA study area are analyzed including aquifer discharge and withdrawal, groundwater depth, groundwater level, fluctuations of the groundwater surface, aquifer thickness, saturated thickness, and aquifer storage. Using statistical data, the amount of discharge in the KSA study area through springs, Qantas, and wells is presented in Table (2).

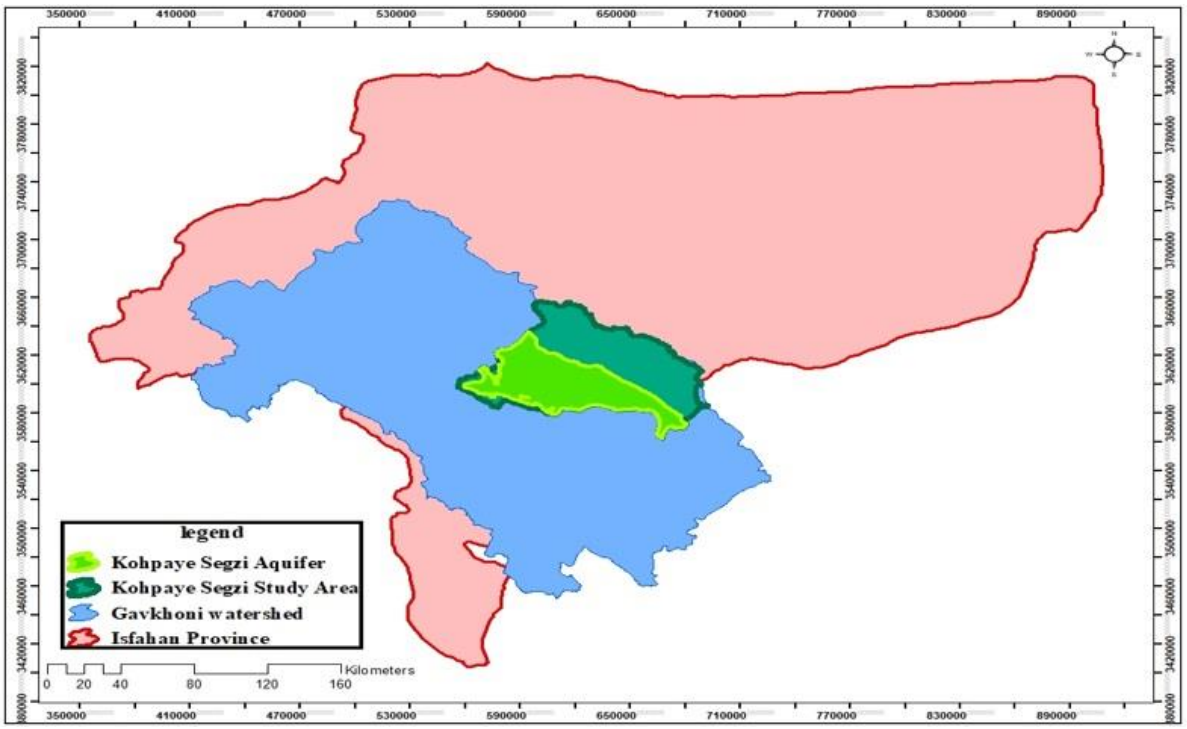


Fig. 2- The Gavkhouni basin and the KSA study area in Isfahan Province

Table 1- Detailed information about the KSA area

Watershed Basin	Sub-basin	Study Area (km^2)	Plain Area (km^2)	Aquifer Area (km^2)
Gavkhouni	Kouhpayeh-Segzi	6422	4978.3	2940

 DOI: 10.22055/jise.2025.49895.2167

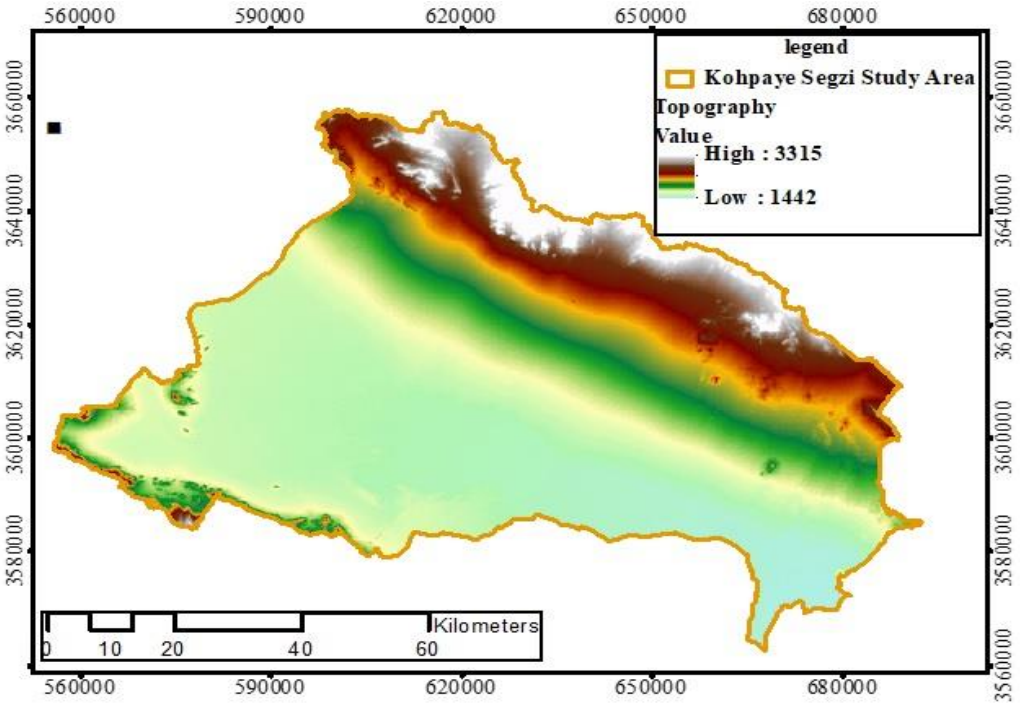


Fig. 3- Topographic map of the KSA area

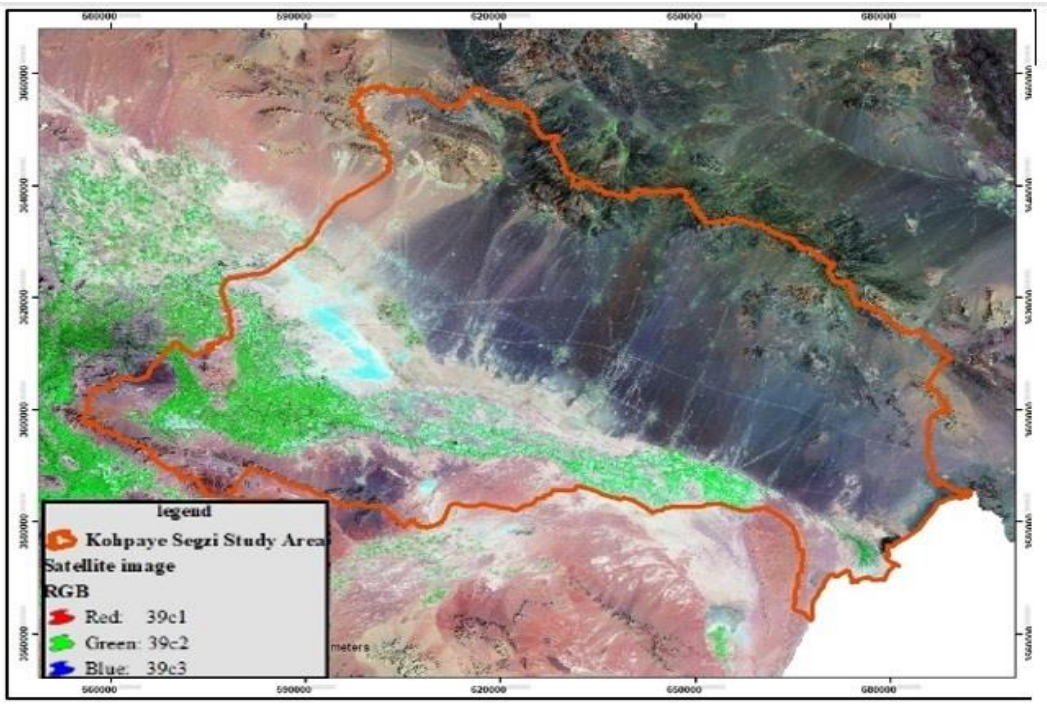


Fig. 4- Satellite image of the KSA area

Table 2- Information on the discharge annual rate of the KSA aquifer

Number of Springs	Number of Qanats	Number of Wells	Total Discharge (million cubic meters)
127	263	18,094	194.58

Table 3- Number of discharge wells by depth in the KSA Area

Depth (meters)	Number
1-45	18969
45-90	1136
90-135	377
135-180	125
180-225	310
225-270	137
270-315	65
315-360	16
360-405	11
405-450	1

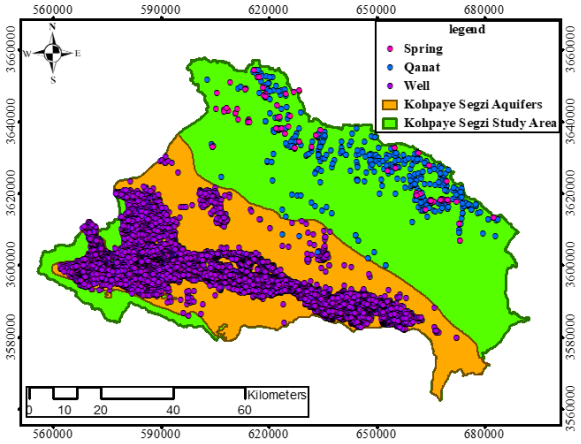


Fig. 5- Distribution of discharge Wells, springs, and Qanats in the KSA Area

The depth of the majority of discharge wells within the KSA study area ranges between 20 and 100 meters. Table (3) presents the number of discharge wells categorized by their depth. Additionally, between the years 1991 and 2011, there was a significant increase in the number of drilled wells. This increase has led to a substantial rise in groundwater extraction during this 20-year period, causing a sharp decline in the groundwater level within KSA study area. The drilling of discharge wells plays a crucial role in the direct utilization of groundwater, especially for agricultural water supply in this region. Figure (5) illustrates the spatial distribution of 21,138 discharge wells drilled throughout the KSA study area.

One of the main causes of groundwater level decline is the excessive drilling of numerous wells in the alluvial aquifer and the consequent over-extraction beyond the aquifer's capacity. This overexploitation results in reservoir depletion and further groundwater level reduction in the coming years. Effective groundwater resource management requires a comprehensive assessment of the aquifer's storage capacity relative to the inflows from various sources. Based on the capacity of each aquifer, regulated permits for groundwater withdrawal should be issued to maintain groundwater levels in a balanced state and to prevent adverse phenomena such as land subsidence.

 DOI: 10.22055/jise.2025.49895.2167

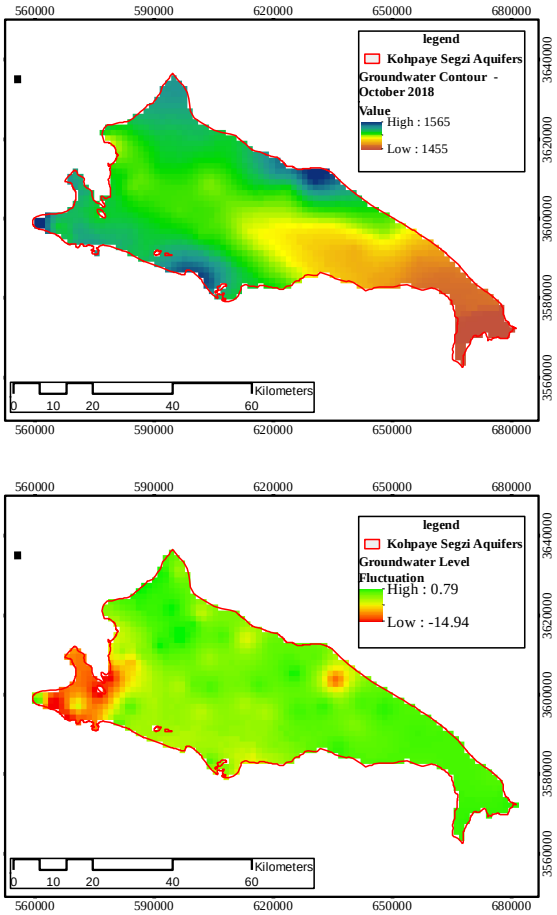


Fig. 6- Groundwater level fluctuation map comparing October 2008 to October 2018

Figure (5) shows the spatial distribution of Qanats and springs within the KSA study area. As observed in the figure, the concentration of springs and Qanats is primarily located in the northern and northwestern parts of the study area.

To analyze and identify the inflow and outflow patterns in the KSA aquifer, groundwater level contour maps were drawn for the month of October in the years 2008 and 2018. These maps were also used to delineate groundwater level fluctuations. Figure (6) presents the groundwater contour map for the KSA aquifer based on data from October 2018. According to the map legend, the highest groundwater levels correspond to the recharge areas of the aquifer, including the western regions (southwest, northwest, and west). The area around Isfahan city shows comparatively thinner saturated thickness than other parts of the study area. During the preparation of the groundwater contour map, piezometer well hydrographs from various aquifers were reviewed wherever necessary to verify the accuracy and reliability of the groundwater level data.

To examine groundwater level changes and to draw fluctuation maps, data from the monitoring network of the KSA aquifer for October 2008 and October 2018 were used. The groundwater level fluctuation map between October 2008 and October 2018 is shown in Figure (7). It is observed that the greatest fluctuations in groundwater levels during the ten-year period under study occurred in the western part of the aquifer, which contains a large number of wells and agricultural lands. This area also includes the regions surrounding the Zayandehrud River.

Using geophysical studies conducted across the KSA study area and well log data from exploratory and discharge wells that have

reached the bedrock, the aquifer thickness maps shown in Figures (8 and 9) were prepared for the entire aquifer. The number of exploratory wells within the KSA aquifer is presented in Table (4).

The aquifer thickness in the KSA ranges from approximately 20 meters up to 400 meters in the southern and central parts of the aquifer. The maximum and minimum bedrock elevations observed across the aquifer are 1632 meters and 1057 meters, respectively.

In the previous sections, the groundwater equipotential map based on data from the groundwater monitoring network for October 2018 and the aquifer thickness map were prepared. By combining the groundwater equipotential map and the aquifer thickness map, the saturated thickness map of the aquifer was extracted. This map is presented in Figure (9) for the KSA aquifer.

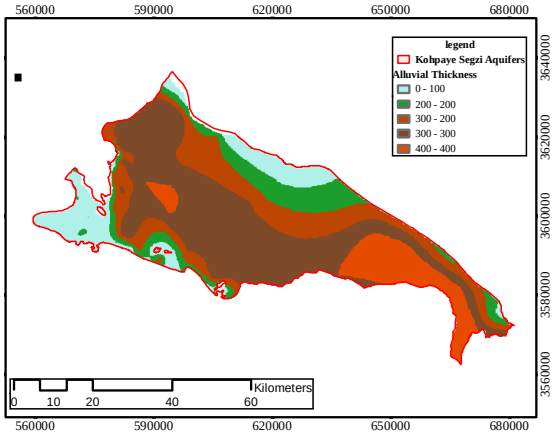


Fig. 7- Alluvial thickness map

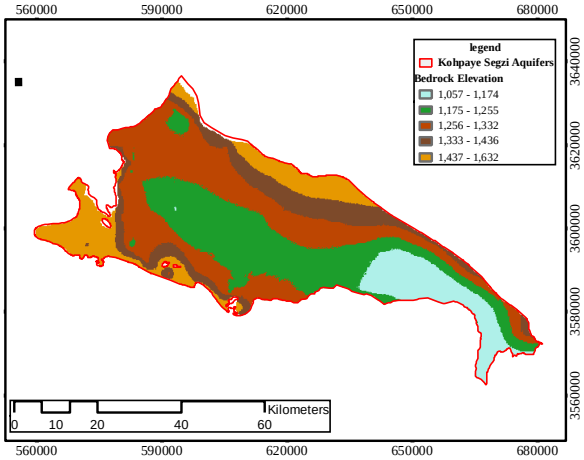


Fig. 8- Bedrock elevation map

Table 4- The Exploratory Wells' data in the KSA Aquifer

Number of Exploratory Wells	Exploratory Drilling Depth in Alluvium (m)	Number of Observation Wells Adjacent to Exploratory Wells in Alluvium	Observation Well Depth in Alluvium (m)
6	422	2	1883

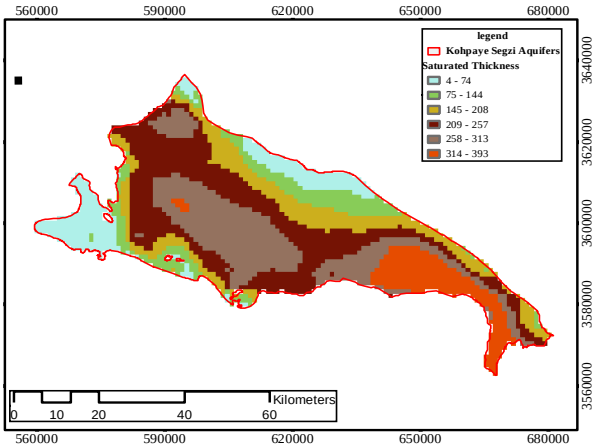


Fig. 9- Saturated thickness map October 2018

 DOI: 10.22055/jise.2025.49895.2167

Conventional Pumping Test Methods

Pumping tests remain the gold standard for determining hydrodynamic parameters like transmissivity and storativity. The Theis (1935) analytical solution forms the foundation:

$S=W(u)Q/4\pi T$ (1)

$u=(r^2 S)/4Tt$ (2)

Here:

s = drawdown (length)

Q = pumping rate (volume per time)

T = transmissivity of the aquifer (length squared per time)

S = storativity (dimensionless)

r = radial distance from the pumping well (length)

t = time since pumping started (time)

W(u) = Theis well function, subsequent developments include:

Type-curve matching (Theis, 1935) for early-time data analysis

Cooper-Jacob approximation (1946) for late-time pumping conditions

Neuman's method (1975) for unconfined aquifers incorporating vertical hydraulic conductivity

Borehole Logging and Single-Well Techniques

Recent studies emphasize cost-effective alternatives:

Single-well tests (Hvorslev, 1951; Batu, 1998):

Analyze slug test recovery data using Bouwer-Rice (1976) equations

Borehole geophysical logging:

- Flowmeter logs (Molz et al., 1989) quantify vertical flow variations
- Thermal and resistivity logs infer hydraulic conductivity profiles (Paillet, 2000)
- Acoustic televiewer data enhances fracture network characterization (Williams et al., 2002)

Comparative Studies and Modern Advancements:

Pumping test limitations: High costs and multi-day durations in low-T aquifers (Kruseman and de Ridder, 1990)

Validation studies:

- Quinn et al.(2015) showed <15% discrepancy between pumping tests and combined FLUTe™ liner/flowmeter logging
- Mace (2001) achieved T estimates within 1 order-of-magnitude using pulsed neutron logging

Numerical modeling integration:

- Inverse modeling packages (e.g., MODFLOW-USG, AQTESOLV) resolve heterogeneous parameters
- Machine learning approaches (Xie et al., 2022) reduce interpretation subjectivity

Due to the lack of sufficient data and information related to pumping tests in the study units and their inadequate spatial distribution, this study utilized drilling logs from exploratory, observation, and discharge wells drilled to bedrock, collected from county water authorities and related files, to complete and cover the entire plain area. It is noteworthy that the well logs were prepared based on the theoretical description of the drilled soil. The well drilling logs were obtained from the Isfahan Regional Water Company. Nevertheless, efforts were made to use well logs with higher accuracy, and by referring to grain-size distribution tables Tables (5 and 6), estimates of permeability coefficient (k) and effective porosity. Another important use of the drilling logs was to determine the thickness of the alluvium and the saturated layer.

Since some areas lacked geophysical studies or the geophysical tests were conducted with closely spaced transmitting electrodes that prevented accurate determination of alluvial thickness, drilling logs were used to identify the bedrock and alluvial thickness. Subsequently, based on groundwater equipotential maps drawn from observation well data, the thickness of the saturated layer was determined.

After preparing a thickness map in the KSA aquifer and estimating the permeability coefficient in each of the logs under study using the following equation, the transportability is calculated for each log under study.

$T=k*b$ (3)

In the above equation: T is the transportability, k is the permeability coefficient, and b is the thickness of the aquifer.

Table 5- Permeability values in various alluvial sediments

Row	*Sediment Type*	*Permeability (m/d)*	*Group*
1	Clay	0.001–0.1	K1
2	Silt – fine sand, silt and clay	1–2	K2
3	Mixture of fine sand, coarse sand and clay	5	K3
4	Clayey fine sand – homogeneous very fine sand – clay, sand and gravel	7	K4
5	Clayey fine sand – mixture of sand, clay and gravel – sandy clay and sand	10	K5
6	Mixture of fine, medium sand and some clay – mixture of clayey sand and some gravel – mixture of very fine sand and some gravel	12	K6
7	Homogeneous fine sand – mixture of sand, sandy clay and gravel – very fine sand, sandy clay, some gravel and pebbles	15	K7
8	Mixture of fine, medium and coarse sand – mixture of fine gravel, sand and sandy clay	20	K8
9	Mixture of fine and medium sand – mixture of fine gravel, sand, pebbles and clay	25	K9
10	Homogeneous medium sand – mixture of pebbles, fine, medium gravel, clay and fine sand	30	K10
11	Mixture of fine and coarse sand with some gravel	35	K11
12	Mixture of medium, coarse sand and some gravel – mixture of pebbles, sand, clay and sandy gravel with some gravel	40	K12
13	Homogeneous coarse sand – mixture of pebbles, gravel and clayey sand	50	K13
14	Mixture of sand and gravel – mixture of medium and coarse sand, gravel and pebbles	60	K14
15	Mixture of pebbles, fine, medium gravel and sand	70	K15
16	Homogeneous fine gravel – mixture of pebbles and medium and fine gravel	90	K16
17	Clay and medium sand	110	K17
18	Homogeneous coarse gravel (in terms of size)	120	K18
19	Homogeneous pebbles	130	K19

Reference: Kruseman and Ridder, 1990

Table 6- Effective Porosity Values in Various Alluvial Sediments

Row	*Sediment Type*	*Effective Porosity (%)*	*Group*
1	Clay	2	m1
2	Sandy clay – sandy silt – clay and fine sand – silt	4	m2
3	Medium sandy clay	6	m3
4	Compacted sand – coarse sand and clay – clayey sand – clay, sand and gravel – very fine sand with some gravel – fine compacted gravel, clay	8	m4
5	Pebbles, gravel, sand and some clay – sandy clay and gravel – fine sand, sandy clay, some gravel and pebbles	10	m5
6	Gravel, sand and pebbles	12	m6
7	Sand and pebbles – gravel and pebbles – fine sand	15	m7
8	Medium sand – coarse sand – fine gravel – gravel and sand	20	m8
9	Gravel and pebbles	22	m9

Reference:Batu, 1998

A pumping test is a widely used method to evaluate the hydraulic properties of an aquifer, including its specific yield, transmissivity, and storativity. During the test, groundwater is pumped from a well at a controlled, usually constant rate, while water level drawdowns are measured in the pumping well and nearby observation wells. This process creates a cone of depression around the pumping well, reflecting the aquifer's response to pumping. The drawdown data collected over time allow for the estimation of aquifer parameters by applying analytical or numerical models based on Darcy's law and groundwater flow principles (Singh and Tripura, 2022). How does Figure (11) classify soil textures and show the relationship between grain-size and specific yield.

One important application of pumping tests is the determination of specific yield, which represents the volume of water an aquifer releases from storage per unit decline in the water table. This can be estimated by comparing the volume of water discharged during the test with the volume of dewatered material in the cone of depression. The method involves calculating the volume of the saturated zone that has been drained and relating it to the total pumped volume (Remson and Lang, 1955, Ramsahoye and Lang, 1961). Although the calculation can be complex due to the slow convergence of series solutions, simplified approaches and type-curve methods have been developed to facilitate practical estimation (Gong et al., 2021).

Pumping tests typically last from several hours to days, depending on the aquifer characteristics and the objectives of the test. They provide valuable information not only on specific yield but also on aquifer transmissivity, heterogeneity, and boundary conditions. Moreover, the recovery phase after pumping stops is crucial for verifying the test results and refining parameter estimates (Ramsahoye and Lang, 1961).

Despite their usefulness, pumping tests have limitations, such as assumptions of homogeneous aquifers, no recharge during testing, and idealized boundary conditions. Therefore, combining pumping test results with other methods like grain-size analysis or soil moisture measurements can improve the reliability of specific yield estimates and groundwater resource assessments.

Overall, pumping tests remain a fundamental tool in hydrogeology for characterizing aquifer properties essential for groundwater management and sustainable water supply planning. The different methods of pumping test analysis are listed in Table (7).

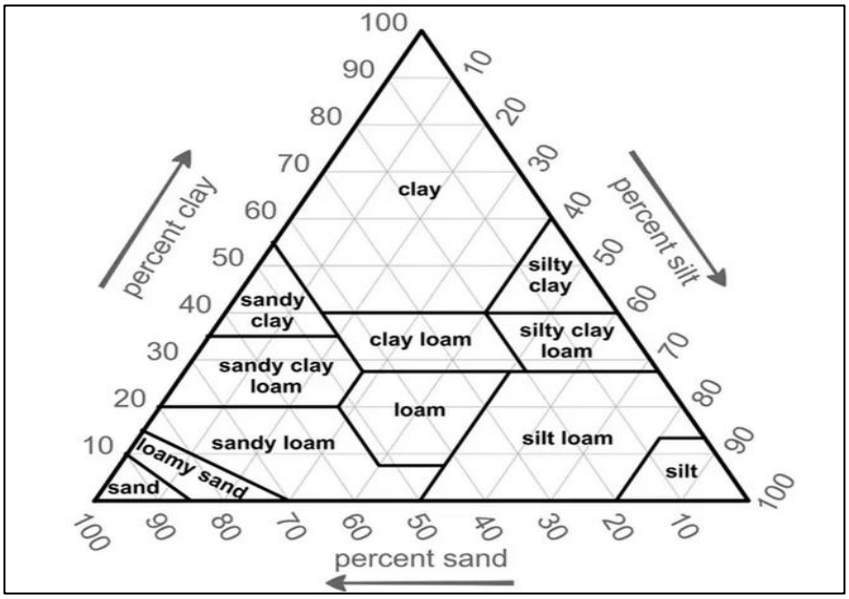


Fig. 10- Relationship between Grain-Size and Specific Yield (Soil Survey Staff, 1993)

Table 4-Pumping test analysis methods

Description	Pumping Test Analyses
A generalized graphical method for evaluating formation constants and summarizing well field History. (Cooper Jacob Straight Line Method)	Cooper and Jacob, 1946
Constant discharge from a fully penetrating well in a nonleaky aquifer	Theis, 1935
Constant discharge from a fully penetrating well in a nonleaky aquifer	Theis, 1935 (Unconfined)
Recovery test after constant discharge from a fully penetrating well in a nonleaky aquifer	Theis, 1946 (Recovery)
Constant discharge from a partially penetrating well in a nonleaky aquifer	Hantush, 1961
Constant discharge from a fully penetrating well of finite diameter in a nonleaky aquifer	Papadopulos and Cooper, 1967
Constant discharge from a well in a leaky aquifer with storage of water in the confining beds	Hantush, 1960
Constant discharge from a fully penetrating well in a leaky aquifer	Hantush and Jacob, 1955
Constant discharge from a partially penetrating well in a leaky aquifer	Hantush, 1964
Theory of flow in unconfined aquifers considering delayed response of the water table	Neuman, 1972
Effects of partial penetration on flow in unconfined aquifers considering delayed aquifer response	Neuman, 1974
Double-Porosity Models for a Fissured Groundwater Reservoir with Fracture Skin	Moench, 1984
Transient Flow to a Large-Diameter Well in an Aquifer with Storative Semi Confining Layers	Moench, 1985
Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer	Moench, 1997

Dana and Jwan, (2016)

Results and Discussion

The minimum thickness of the saturated zone in the piedmont aquifer is 10 meters, with the lowest thickness observed in the southwestern and northern parts of the aquifer. Moving toward the central areas of the aquifer, the thickness of the saturated layer increases. The maximum and average thicknesses of the saturated zone are 392 meters and 224 meters, respectively. The aquifer in this area has two aquifers: confined and unconfined aquifer.

Drilling logs of exploratory, observational, and discharge wells have been analyzed using the grain-size distribution method. In each of the examined logs, the thickness of the first aquifer, the thickness of the impermeable layer between the two aquifers, and the thickness of the confined aquifer must first be determined. In the next step, based on the characteristics and composition of the materials in the unconfined and confined aquifers, the hydraulic conductivity is estimated using reference tables and charts.

Once the thickness of each layer and the estimated hydraulic conductivity for each layer are known, the transmissivities are calculated separately for the first (unconfined) and second (confined) aquifers. Moreover, by identifying the grain-size distribution in the drilling logs, the storage can also be determined using reference charts and tables. However, it should be noted that the storage estimated by the grain-size method is only applicable for the unconfined aquifer, and its estimation for the confined layer using this method is not valid. Confined aquifers have different hydraulic characteristics than unconfined aquifers. The grain-size method doesn't directly account for the compressibility of water and the aquifer matrix, which are the dominant factors in confined aquifer storage. Therefore, using this method for confined aquifers can lead to inaccurate and misleading results.

Figure (12) shows the KSA area with the boundary between the unconfined and confined aquifers. The results obtained from the grain-size analysis method, although

 DOI: 10.22055/jise.2025.49895.2167

potentially subject to significant errors due to the theoretical nature of well drilling logs, the inaccuracy in the percentages of soil components, and the unknown physical condition of the soil at depth (such as compaction), have greatly contributed to determining hydrodynamic coefficients when combined with other methods. In other words, from an engineering judgment perspective, comparing the coefficients derived from this method with those from areas where coefficients are known (based on pumping test results in exploratory wells and their comparison with grain-size analysis results from the drilling logs of these wells) has yielded acceptable outcomes. Moreover, the well yields have largely corresponded with the obtained coefficients.

Based on this, out of a total of 65 drilling logs from exploratory, observational, and discharge wells in the second case, 55 logs were selected for examination and analysis using the grain-size distribution method. Additionally, Figure (12) shows the location of the 55 drilling logs under study in relation to the aquifer boundary and the study area.

The estimated hydrodynamic coefficients using the grain-size distribution method have been determined for the drilling logs under study for both aquifers. According to the results obtained, the transmissivity for both aquifers and the storage only for the first (unconfined) aquifer at the water table have been estimated through interpolation methods. In the section “Expansion of Transmissivity”, the section “Interpolation techniques used in GIS” explains the use of different interpolation methods in GIS software as examples. The selection of the best interpolation method is made using aquifer characteristics such as aquifer thickness and annual discharge rate in different areas. It should be noted that the selection of the best method is subject to uncertainty due to limited information. The results, presented in Table (8), show that the minimum, average, and maximum storage at the first aquifer’s water table are estimated to be 2%, 4.6%, and 10%, respectively.

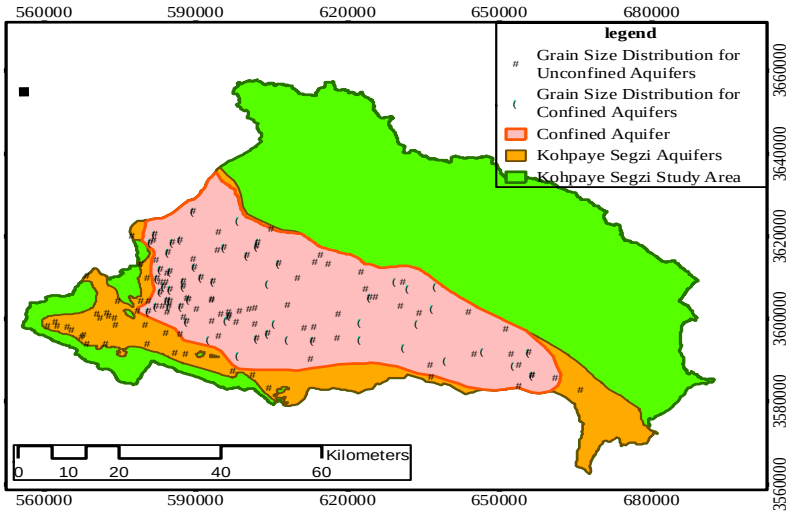


Fig. 11- Location of the grain-size distribution network for unconfined and confined aquifers

Table 5- Results of transmissivity and storage at the KSA Aquifer water table

Row		Transmissivity Coefficient (m²/day)			Specific Coefficient (%)		
		Minimum	Average	maximum	Minimum	Average	maximum
1	Unconfined Aquifer	80	313.1	1237	2	4.6	10
2	Confined Aquifer	177	845	1704	-	-	-

Storativity (*S*) is a dimensionless measure of the volume of water that will be discharged from an aquifer per unit area of the aquifer and per unit reduction in hydraulic head. For a confined aquifer, storativity results only from the rock and fluid compressibilities and is typically very small ($\sim 10^{-4}$–10^{-5}). For an unconfined aquifer, the small effect of rock and fluid compressibilities is generally neglected, and *S* is equal to the specific yield (S_y), which is defined as the volume of water that will drain under the force of gravity from unit bulk volume of the aquifer. This will be equal to the effective porosity, minus the fractional volume of water retained under gravity drainage by capillary forces (Rackley, 2017).

According to the definitions of storativity and specific yield, the values of storativity coefficients in a confined aquifer using the grain-size method are not valid. Thus, in the present study, only the specific yield in the unconfined has been calculated using the grain-size method. In order to estimate the storativity in the confined aquifer, the pumping test method should be used. The results of two pumping tests are given below. It can be seen that out of the two tests conducted, only test number 2 penetrated the confined layer. However, due to lack of information, the storativity in the confined layer cannot be estimated

Furthermore, the minimum, average, and maximum transmissivity for the first and second aquifers are calculated as 80, 313, and 1237 m²/day, and 177, 845, and 1704 m²/day, respectively.

In Figure (13), the transmissivity map for the second (confined) aquifer is depicted according to the boundary of the second aquifer. Additionally, Figure (14) shows the transmissivity map for the first (unconfined) aquifer derived from the grain-size distribution method, considering the boundary of the first aquifer, which corresponds to the overall boundary of the KSA aquifer.

Two pumping tests have been conducted in the KSA aquifer based on the investigations carried out. As a sample, the analysis of the pumping test using the methods presented in the Materials and Methods section for one of the pumping tests (Well No. 1) is described below. Other pumping tests have also been examined in the same manner, and the final results are presented at the end. Figure (15) shows the locations of two pumping tests conducted in the aquifer. Both tests are located almost near the boundaries of the confined layer.

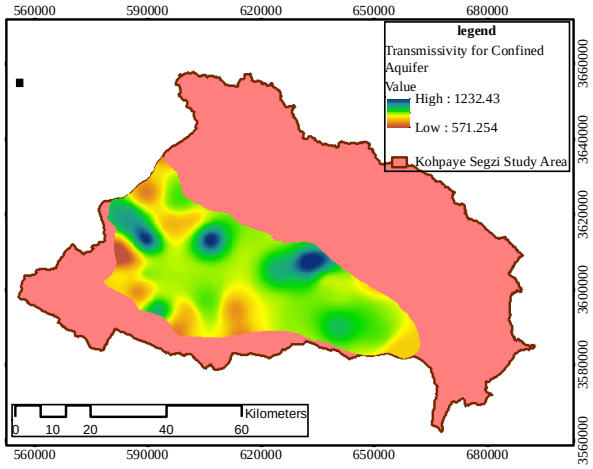


Fig. 12- Transmissivity map of the confined aquifer based on the grain-size distribution method

 DOI: 10.22055/jise.2025.49895.2167

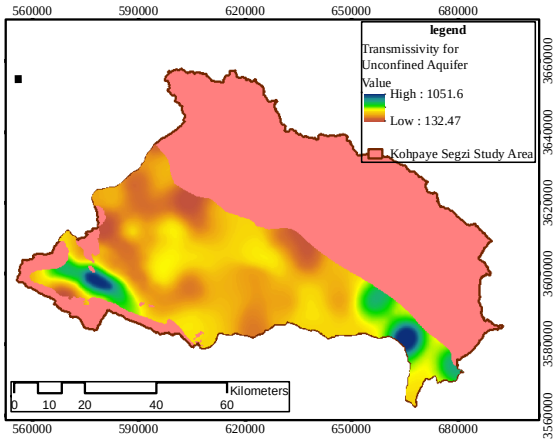


Fig. 13- Transmissivity map of the unconfined aquifer based on the grain-size distribution method

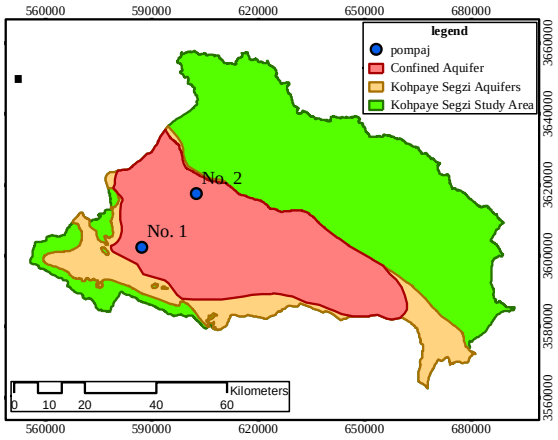


Fig. 14- Location of pumping tests relative to the KSA aquifer

Analysis of Pumping Test for Well No. 1

The pumping test for Well No. 1 was conducted in 1992 under constant rate conditions (a constant discharge of 1.25 liters per second). The depths of the pumping well and the piezometer were 52 meters and 50 meters, respectively, and the distance between the piezometer and the pumping well was 19 meters. It should be noted that since the pumping and piezometer wells used in this test do not penetrate the entire aquifer—considering that the aquifer thickness at this location is 250 meters—the hydrodynamic parameters of the pumping test need to be evaluated under both unconfined and leaky aquifer conditions for the partially penetrating well. The transmissivity (T) and storage (S) parameters were calculated using the AquiferWin32 software.

Finally, for two reasons, the results of this experiment do not provide a proper estimate of the hydrodynamic coefficients of the aquifer. The first reason is that the well was not drilled through the entire thickness of the aquifer and is not representative of the characteristics of the entire thickness of the aquifer. The other reason is the time of the experiment, which was conducted about 33 years ago, and the groundwater level in this aquifer has decreased significantly in recent years. Therefore, given that the well is located in the first layer (unconfined), the estimation of the hydrodynamic coefficients in this experiment is valid for the first layer. The results of the analysis of pumping test No. 1 using different methods are shown in Figures (16 to 19). Considering the characteristics of the tested well, the best results for estimating hydrodynamic coefficients occurred in the Hantush (leak confined partial penetration) method (Figure 21).

The well depth and aquifer thickness in the second experiment are 165 and 210 meters respectively. In this experiment, the pumping well is not drilled throughout the entire thickness of the aquifer, therefore, the estimated hydrodynamic coefficients in this experiment are slightly lower than reality. The difference between this experiment and experiment number one is that in this experiment, the pumping well is located in the second layer (confined) and the results of the hydrodynamic coefficients represent the characteristics of the confined layer. The characteristics of the two pumping experiments along with the results are shown in Table (9).

Table 6- Specifications and results of pumping tests

Thickness (m)	Q (l/s)	S (%)	T (m^2/day)	Depth (m)	zone	Y	X	Name
250	1.25	0.5	180	52	39	3602250	587250	No. 1
210	15.2	0.9	345	165	39	3617480	602588	No. 2

Table 7- Results of the pumping tests in the KSA aquifer

Hantush (leak confined partial penetration)		Hantush		Neuman		Recovery	Cooper Jacob		Theis		
T	S_c	T	S_c	T	S_y	T	T	S_c	T	S_c	
180	0.005	39	0.0004	34	0.0004	40	43	0.0003	43	0.0003	No. 1
345.6	0.009	139.2	0.004	75.4	0.016	300.8	192.9	0.002	153.5	0.003	No. 2

Skin effect and partial penetration significantly influence transmissivity estimates by altering the hydraulic conductivity near the well, thus affecting the drawdown behavior during pumping tests. Positive skin reduces effective permeability near the well, causing delayed flow response, while partial penetration limits the vertical extent of flow, both leading to transmissivity variations between methods. These effects must be considered for accurate interpretation (Pasandi et al., 2007).

Table (10) shows the results of the pumping test analysis using the Theis, Cooper and Jacob, Theis Recovery, Neuman, Hantush and Hantush (leak confined partial penetration) methods for the two wells shown in Figure (15). Also, in Figures (16 to 21), the results of the pumping test analysis for pumping test No. 1 are given as an example, and for pumping test No. 2, only the values of the results are included in Table (10). According to the above explanation about the characteristics of the tests performed, among the analyses performed, because the mentioned wells were not drilled throughout the entire thickness of the aquifer, the best analysis is to use the Hantush (leak confined partial penetration) method.

Pumping tests are among the most expensive methods for estimating hydrodynamic coefficients. Because in this method, two wells must first be drilled. One well is used as a pumping well whose depth is equal to the thickness of the aquifer, and the other well is used to record water level information during and after the test. In the KSA aquifer, only two pumping tests have correct information for analyzing the test and estimating hydrodynamic coefficients. Thus, the number and dispersion of pumping tests in the 2940 km^2 aquifer are very small. One of the main limitations of this study is the lack of an appropriate number of pumping tests and their dispersion across the KSA aquifer. This makes the grain-size method have the greatest impact on the estimation of hydrodynamic coefficients, which causes uncertainty in the estimation of coefficients.

Expansion of Hydrodynamic Coefficients by Integrating Results from Grain-size and Pumping Tests

Expansion of Transmissivity

The information used to draw the transmissivity map includes transmissivity values obtained from grain-size and pumping test methods, expansion of transmissivity using geophysical mapping techniques, well discharge distribution maps, and drainage network maps. The significance of each of these data sets is incorporated as different layers within GIS software. As mentioned in the previous sections, the dispersion of information in the grain-size method is much better than the pumping test method. However, in areas where pumping tests have not been conducted, only the results of the grain-size method have been used. In areas where pumping tests are available, the results of both methods have been combined and refined. Finally, using the data imported into the

 DOI: 10.22055/jise.2025.49895.2167

software, the priority of utilizing these data, various interpolation methods within the GIS software, and engineering judgment were applied to prepare the transmissivity map, which is shown in Figure (22).

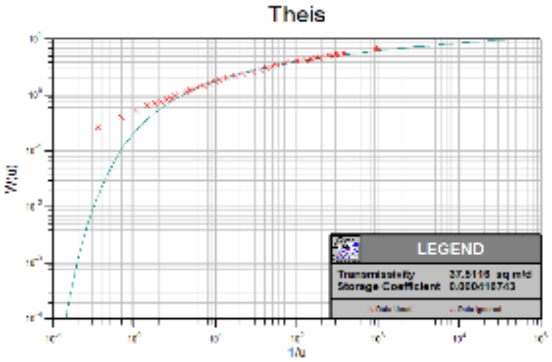


Fig. 15- Estimation of the storage and transmissivity of Pumping Well No. 1 using the Theis method

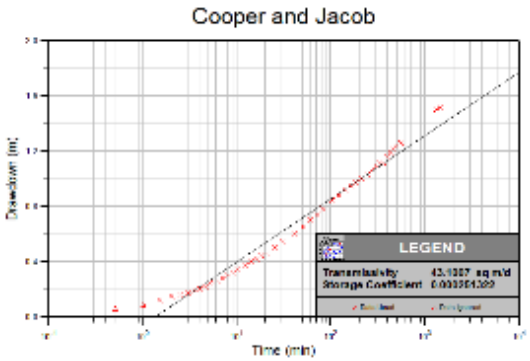


Fig. 16- Estimation of the storage and transmissivity of Pumping Well No. 1 using the Cooper-Jacob method

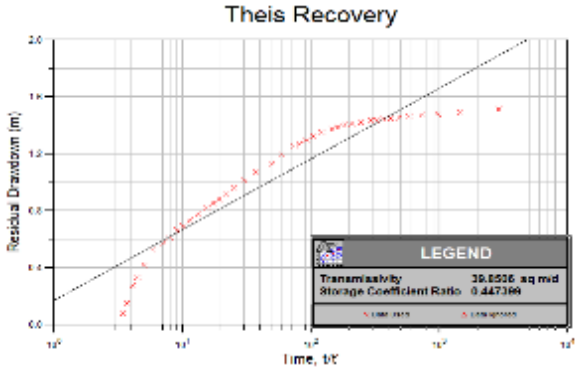


Fig. 17- Estimation of the transmissivity of Pumping Well No. 1 using the Thiem recovery method

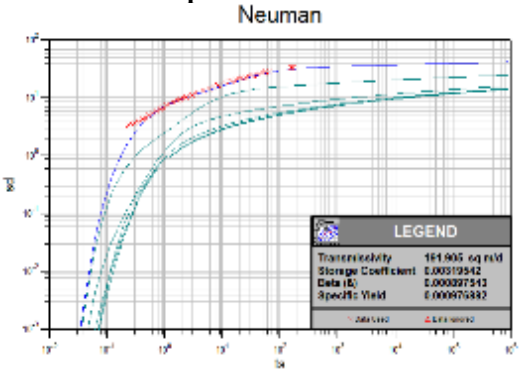


Fig. 18- Estimation of the storage and transmissivity of Pumping Well No. 1 using the Neuman method

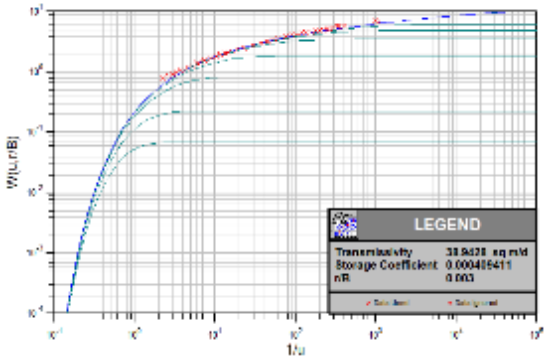


Fig. 19- Estimation of the storage and transmissivity of Pumping Well No. 1 using the Hantush method

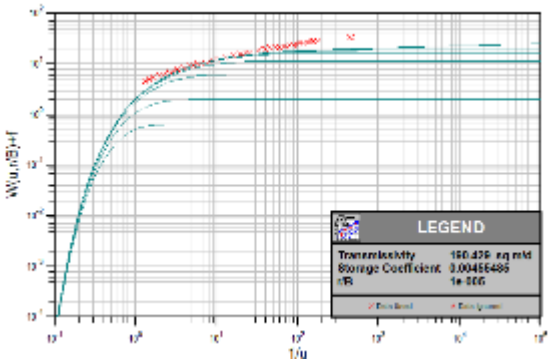


Fig. 20- Estimation of the storage and transmissivity of Pumping Well No. 1 using the Hantush (leak confined partial penetration) method

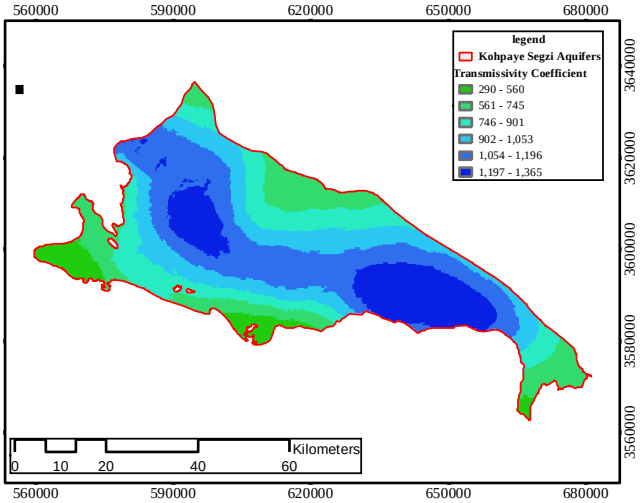


Fig. 21- Distribution map of transmissivity (Unconfined Aquifer)

Table 8- Values of error evaluation criteria for each interpolation method

Row	Error evaluation method	Interpolation method							
		IDW	GPI	RBF	LPI	OK	SK	UK	EBK
1	MARE	0.04	0.53	0.09	0.15	0.12	0.14	0.35	0.13
2	RMSE	45.92	293.86	81.01	120.78	80.19	91.08	190.53	86.81
3	R	0.99	0.5	0.96	0.92	0.96	0.95	0.79	0.96

Interpolation techniques used in GIS

This section explains the steps for selecting the best interpolation method in GIS software for mapping the transportability. For this purpose, the Geostatistical Analyst tool in ARCGIS software was used to apply deterministic and geostatistical methods for interpolation. The methods used include eight methods: IDW, GPI, RBF, LPI, OK, SK, UK, and EBK. The selection of the best interpolation method was based on cross-evaluation criteria and estimation errors such as MARE, RMSE, and R.

The choice of interpolation method depends primarily on the nature of the variable and its spatial variations. Although it is influenced by other factors, it is very difficult to provide a correct and general rule for choosing a method. Among the methods used, the UK, GPI and RBF methods have a weaker distribution of the transportability than the other methods, because in the eastern and border areas of the watershed, high values for the coefficient have been estimated, which is inconsistent with the reality of the region. The changes in the transmission in the OK, SK, EBK, IDW and LPI methods have greater suitability with the characteristics of the study area. However, to achieve the best method, the three UK, GPI and RBF methods are eliminated at this stage and the best interpolation method must be selected from the five OK, SK, EBK, IDW and LPI methods.

In the next step, based on selected points from the available data, the values of error criteria were used to evaluate the interpolation methods. In this study, three validation methods for each of the deterministic and geostatistical interpolation methods were evaluated and investigated to achieve this goal. The results obtained in Table (11) show that the lower the estimated errors and the higher the data correlation, the more suitable the interpolation method is for preparing the transportability zoning maps. Therefore, considering the error evaluation criteria, the best interpolation method is the inverse distance weighting (IDW) method.

To realistically estimate maps generated from interpolation, it is essential to provide an uncertainty estimate for these maps. Uncertainty estimation refers to the process of

 DOI: 10.22055/jise.2025.49895.2167

quantifying the degree of doubt associated with the results. This process typically involves identifying various sources of error and conducting statistical analyses. The goal of uncertainty estimation is to provide a range of possible values within which the model outputs are likely to lie with a high probability. This aids decision-makers in considering the confidence level of the results and making better-informed decisions. One of the simplest methods to assess uncertainty involves using statistical metrics such as the MARE (Beven, 2001). In this study, the MARE statistic was employed to estimate the uncertainty of the generated maps. Therefore, the uncertainty in the transmissivity maps is estimated to be ±0.04 (±4%).

To draw other maps using the interpolation method in GIS software, the above steps were performed similarly to select the best interpolation method.

The map of the KSA aquifer indicates that the highest values of this coefficient occur along and around the Zayandehrud River. Despite the considerable thickness of the aquifer in the northern boundaries and areas adjacent to the Gavkhouni wetland, the significant increase in clay and silt content in the grain-size distribution of the sediments indicates a low transmissivity in these regions.

Based on the final results, the average, minimum, and maximum values of the transmissivity in unconfined aquifer are 961, 290, and 1364 square meters per day (Figure 22) and the average, minimum, and maximum values of the transmissivity in confined aquifer are 914, 571, and 1232 square meters per day Figure (23), respectively.

Expansion of Storage

To prepare an integrated map of the storage across the KSA aquifer, various data obtained from grain-size analysis and pumping test interpretations were first imported into GIS software. According to the groundwater flow equations under steady-state and transient conditions presented below, in steady-state conditions (related to the first equation), hydraulic conductivity and ultimately transmissivity can be calculated by knowing the saturated thickness of the aquifer. However, to calculate the storage, a time series of available data is required, in which case the second equation describing transient flow conditions is used.

1. Steady-State Flow Equation (Fetter, 2001):

$$\left[K_x \frac{\partial h}{\partial x}\right] + \left[K_y \frac{\partial h}{\partial y}\right] + \left[K_z \frac{\partial h}{\partial z}\right] = 0 \quad (4)$$

2. Transient Flow Equation (Todd, 1980):

$$\left[K_x \frac{\partial h}{\partial x}\right] + \left[K_y \frac{\partial h}{\partial y}\right] + \left[K_z \frac{\partial h}{\partial z}\right] = S_y \frac{\partial h}{\partial t} \quad (5)$$

To prepare an integrated map of the storage across the KSA aquifer, various data obtained from grain-size analysis and pumping test interpretations were first imported into GIS software. One useful dataset aiding the creation of the integrated storage map is the fluctuations observed in piezometer wells within the aquifer.

Initially, based on the available statistical period from the provincial piezometer monitoring network, a hydrological year with complete data was selected. Then, for the selected year, the groundwater level for each well was considered on a monthly basis. Using the groundwater level data for the 12 months of the selected hydrological year for each piezometer, the annual standard deviation of groundwater levels was estimated for each well. The standard deviation values of groundwater levels have been used as a qualitative guide to draw an integrated map of the storage.

Based on the calculated standard deviation for each piezometer, a map of the groundwater level standard deviation for the piezometers in the selected year was drawn. It is worth noting that the groundwater level standard deviation

map can only be used to estimate the storage if the aquifer is in a state of equilibrium.

In such conditions, areas with low groundwater level fluctuations correspond to higher storage values, while areas with high fluctuations in groundwater levels correspond to lower storage values.

Finally, based on the estimated data and the aforementioned explanations, by directly using the storage values estimated from both grain-size analysis and pumping tests, as well as expanding this coefficient using the aforementioned maps in areas lacking direct storage estimates, an integrated storage map for the KSA aquifer was prepared and is shown in Figure (24). Changes in the storage in the KSA aquifer varies between 1.3% and 9.3%, with an average value of 3.9%.

As mentioned in the previous sections, the storage coefficient in a confined aquifer cannot be calculated using the grain-size method, and more pump tests must be conducted within the aquifer to estimate the storage coefficient of the confined layer.

Studies conducted in recent years show that the two methods of pumping tests and grain-size are capable of accurately estimating the hydrodynamic coefficients of an aquifer. Most studies that have dealt with groundwater modeling have used the results and analysis of pumping tests to obtain real information and have examined the efficiency of their model using the results of pumping tests (Li et al., 2025; Muauz et al., 2024; Singh and Tripura, 2022). Hydrodynamic coefficients estimated from pumping test analysis have very high acceptability in confined and unconfined aquifers (Bashandy et al., 2024).

Houben et al. (2022) used the drilling logs of observation wells to estimate and identify aquifer layers for groundwater modeling. The above-mentioned studies are among the studies that used the pumping test or grain-size method to estimate the initial and actual transportability and storage in the aquifer.

In the present study, both pumping test and grain-size methods were used to estimate the transportability and storage in the KSA aquifer in Isfahan province, Iran. Finally, the maximum, minimum, and average values of hydrodynamic, such as the transmissivity and storage of the KSA aquifer, are described in Table (12).

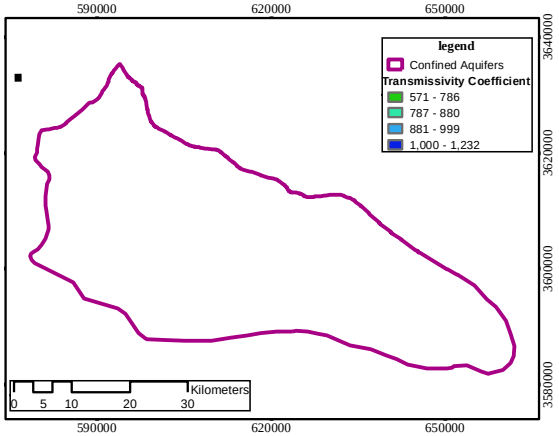


Fig. 22- Distribution map of transmissivity (confined Aquifer)

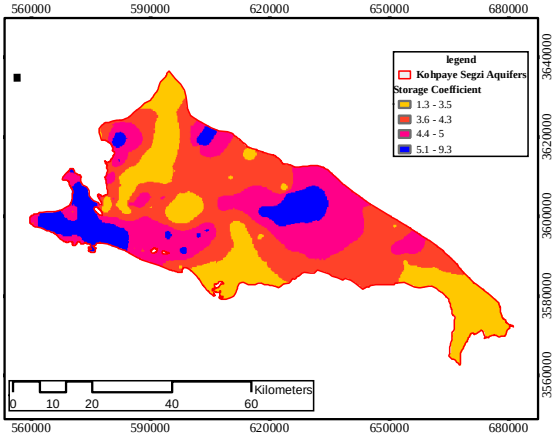


Fig. 23- Distribution map of storage (Unconfined Aquifer)

Table 9- Final values of hydrodynamic coefficients

Row		*Transmissivity Coefficient (m²/day)*			*Storage Coefficient (%)*		
		Minimum	Average	maximum	Minimum	Average	maximum
1	Unconfined Aquifer	290	1364	961	1.3	9.3	3.9
2	Confined Aquifer	571	1232	914	-	-	-

 DOI: 10.22055/jise.2025.49895.2167

Conclusions

- Based on the conducted investigations, the greatest saturated layer thickness is approximately 390 meters near the Gavkhouni wetland, while the smallest saturated thickness in the KSA aquifer occurs in the mountainous slopes near the city of Isfahan, estimated at about 10 meters.
- In total, 206 well logs were collected across the studied aquifers, of which approximately 186 logs were deemed suitable for estimating hydrodynamic coefficients.
- In the grain-size analysis method, by examining the drilling logs of exploratory, observational, and production wells, the suitability of each log was first evaluated using parameters such as geological maps, the drainage network of production wells, groundwater flow lines, and groundwater level contours. Subsequently, based on charts and tables from references, hydraulic conductivity and storage values were estimated.
- The Results obtained from the analysis of pumping tests in perfectly permeable wells or wells assumed to be perfectly permeable show that the storage values in most of the cases analyzed indicate that the Hantush (leak confined partial penetration) method provides more reliable storage estimates compared to the Theis, Cooper-Jacob, and Neuman methods.
- According to the final studies, the average storage in the KSA aquifer is estimated at 3.9%, the average alluvial thickness is 200 meters, and the average transmissivity of the aquifer is estimated at 960 square meters per day.

The methods used in this study are pumping test and grain-size to estimate hydrodynamic coefficients in the KSA aquifer. It is necessary to consider uncertainty in estimating the transferability and storage. However, in this study, computational errors have been minimized. In the grain-size method, well drilling logs that have been prepared with high accuracy and quality have been used. The number of pumping tests is limited due to the aquifer area. Also, an attempt has been made to select the best interpolation method for extracting transportability and storage maps using error evaluation criteria.

Recommendations

Given the importance of the hydrodynamic coefficients of the aquifer, it is necessary to conduct various studies in the future to increase the accuracy of the calculations. Given that pumping tests are expensive, in order to achieve better results in the analysis of pumping tests, it is recommended to improve the quality of pumping tests. Before performing a constant-speed pumping test, a step test should be performed in the pumping well for 24 hours and the drop in the same pumping well should be recorded in order to obtain well information. After calculating the well specifications, including efficiency, critical flow rate, maximum allowable flow rate, critical drop, etc., pumping should not be performed in the well for 24 hours until the water level returns to the initial level. Then, in the next step, a constant-flow pumping test can be performed and the drop in the piezometer well can be measured.

In order to increase the accuracy of estimating hydrodynamic coefficients by the grain-size method, it is recommended that when drilling any new well, whether exploratory, observational, or operational, the well drilling supervisor prepares disturbed or undisturbed samples during drilling and takes the said samples to the geophysical laboratory to accurately determine the amount and percentage of different particles in the composition of the sample taken. Also, in this regard, a grain-size curve can be prepared for the samples under test. In this case, a drilling log can be prepared with much higher accuracy than in the past.

In future studies, it is suggested that the results of the present study be used as baseline information to develop and calibrate a numerical groundwater flow model in the KSA aquifer. This will provide a powerful tool for sustainable water management in the study basin.

Acknowledgment

This research has no acknowledgments.

Conflict of Interest

The authors declared no potential conflicts of interest concerning the research, authorship, and publication of this article**.** Confirmation.

Funding

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

Data Availability Statements

Data Availability Statement: All information and results are presented in the text of the article.

Authors' contribution

First Author: Sheyda Mohammadi Fard, Data analysis.

Second Author: Jahangir Abedi-Koupai Results and Discussion.

Third Author: Saeid Eslamian, Article writing.

References

1- Ansarifar, M., Salarijazi, M., Ghorbani, K. and Kaboli, A., 2019. Spatial estimation of aquifer's hydraulic parameters by a combination of borehole data and inverse solution. *Bulletin of Engineering Geology and the Environment*. DOI:10.1007/s10064-019-01616-w

2- Batu, V., 1998. *Aquifer Hydraulics: A Comprehensive Guide to Hydrogeologic Data Analysis*. Wiley, New York.

3- Bashandy, A.M., Bekhit, H.M. and Radwan, H.G., 2024. Uncertainty assessment of aquifer hydraulic parameters from pumping test data. *Appl Water Sci, 14(84).* DOI: 10.1007/s13201-024-02134-1

4- Benson, D.A., 2023. Automated Estimation of Aquifer Parameters from Arbitrary-Rate Pumping Tests in Python and MATLAB. *Groundwater, 62 (2),* pp. 285-294. DOI: 10.1111/gwat.13338

5- Beven, K., 2001. *Rainfall-Runoff Modelling: The Primer*. Wiley.

6- Bouwer, H. and Rice, R.C., 1976. Slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resources Research, 12(3),* pp.423–42.

7- Cooper, H.H. and Jacob, C.E., 1946. A generalized graphical method for evaluating formation constants and summarizing well-field history. *Trans. Am. Geophys. Union, 27, 526-534.*

8- Dana, K. M. and Jwan, S. M., 2016. Performing Pumping Test Data Analysis Applying Cooper-Jacob's Method for Estimating of the Aquifer Parameters. *Mathematical Modelling in Civil Engineering, 12(1),* pp.9-20. DOI: 10.1515/mmce-2016-000

9- Domenico, P.A. and Schwartz, F.W., 1990**.** *Physical and Chemical Hydrog*eology. Wiley.

10- Fetter, C.W., 2001. *Applied Hydrogeology* (4th ed.). Prentice Hall. ISBN: 978-0130882394.

11- Gong, C., Zhang, Z., Wang, W., Duan, L. and Wang, Z., 2021. An assessment of different methods to determine specific yield for estimating groundwater recharge using lysimeters. *Science of The Total Environment, 788,* pp.147799. DOI: 10.1016/j.scitotenv.2021.147799

12- Houben, T., Pujades, E., Kalbacher, T., Dietrich, P. and Attinger, S., 2022. From Dynamic Groundwater Level Measurements to Regional Aquifer Parameters— Assessing the Power of Spectral Analysis. *Water Resources Research, 58, pp.* DOI: 10.1029/2021WR031289

13- Hvorslev, M.J., 1951. Time lag and soil permeability in groundwater observations. Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, Bulletin 36.

14- Kruseman, G. P. and de Ridder, N.A., 1990. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

15- Li, M., Wang, H., Gu, H. and Chi, B., 2025. Weighted joint curve inversion of aquifer parameters in pumping tests with multiple observation wells. *Desalination and Water Treatment*. *321, 101040.* DOI:10.1016/j.dwt.2025.101040

16- Li, M., Liang, X., Xiao, C., Cao, Y. and Hu, S., 2019. Hadrochemical Evolution of Groundwater in a Typical Semi-Arid Groundwater Storage Basin Using a Zoning Model. *Water, 11, 1334*. DOI: 10.3390/w11071334

17- Li, P. and Qian, H., 2012. Global curve-fitting for determining the hydrogeological parameters of leaky confined aquifers by transient flow pumping test. *Arab J Geosci, 6*, pp.2745‑2753. DOI: 10.1007/s12517-012-0567-9

18- Li, Y., Xie, W., Wang, H., Peng, B., Xiong, F. and Zhu, C., 2023a. Hydrogeological Parameter Estimation of Confined Aquifer within a Rectangular Shaped Drop Waterproof Curtain. *Water, 15, 356.* doi: DOI: 10.3390/w15020356

19- Li, Y., Zhou, Z., Zhuang, C. and Dou, Z., 2023b. Estimating Hydraulic Parameters of Aquifers Using Type Curve Analysis of Pumping Tests with Piecewise-Constant Rates. *Water, 15(9),* pp.1661. DOI: https://doi.org/10.3390/w15091661

20- Lohman, S.W., 1972**.** *Ground-Water Hydrauli***cs**. U.S. Geological Survey Professional. pp 708.

21- Mace, R.E., 2001. *Estimating transmissivity using specific-capacity data.* Geological Circular 01-2Affiliation: Bureau of Economic Geology, The University of Texas at Austin.

22- Molz, F.J., Melville, J.G. and Johnson, M.M., 1989. Using flowmeter logs to quantify vertical flow variations in wells. *GroundWater, 27(5),* pp.631–638.

23- Muauz, A., Behailu, B. and Bediru, H., 2024. Application of surface geophysical investigations and pumping test data analysis for better characterization of aquifer hydraulic parameters, Upper Awash Sub-Basin, Central Ethiopia. *Journal of Hydrology: Regional Studies, 55, 101933*. DOI: https://doi.org/10.1016/j.ejrh.2024.101933

24- Neuman, S.P., 1975. Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response. *Water Resources Research, 11(2),* pp.329-342.

25- Paillet, F. L., 2000. Hydraulic conductivity estimation from borehole flow and thermal logs. *Ground Water, 38(6),* pp.885–894.

26- Pasandi, M., Samani, N. and Barry, D.A., 2007. Effect of wellbore storage and finite thickness skin on flow to a partially penetrating well in a phreatic aquifer. *Journal of Applied Geophysics*, 63(1), 27-38. DOI: 10.1016/j.jappgeo.2007.09.003

27- Quinn, P., Cherry, J.A. and Parker, B.L., 2015. Combined use of straddle packer testing and FLUTe profiling for hydraulic testing in fractured rock boreholes. *Journal of Hydrology, 524, pp. 439-454.* DOI: 10.1016/j.jhydrol.2015.03.008

28- Rackley, S., 2017. 15 - Hydrological and environmental features, events, and processes. *Carbon Capture and Storage (Second Edition).* pp 387-406. DOI:10.1016/B978-0-12-812041-5.00015-5

29- Ramsahoye, L.E. and Lang, S.M., 1961. A Simple Method for Determining Specific Yield from Pumping Tests.

31- Remson, I. and Lang, S.M., 1955. A pumping-test method for the determination of specific yield. *Eos, Transactions American Geophysical Union. 36(2),* pp.321-325.

32- Sahranavard, H., Mohtashami, A., Mohtashami, E. and Akbarpour, A., 2023. Inverse modeling application for aquifer parameters estimation using a precise simulation–optimization model. *Applied Water Science*, pp. 1-12. DOI: 10.1007/s13201-022-01864-4

33- Singh, S. and Tripura, J., 2022. Pumping test analysis for assessment of hydraulic parameters and aquifer system formation in hilly terrain. *Water Practice & Technology, 00 (0),* pp.1-11. DOI: 10.2166/wpt.2022.002

34- Soil Survey Staff., 1993. *Soil Survey Manual. U.S.* Department of Agriculture, Handbook 18.

35- Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *Transactions, American Geophysical Union, 16(2),* pp.519-524.

36- Todd, D.K., 1980. *Groundwater Hydrology (2nd ed.).* John Wiley & Sons. ISBN: 978-0471058574.

37- Williams, J.H., Paillet, F.L. and Kuniansky, E.L., 2002. Use of acoustic televiewer data to characterize fracture networks in boreholes. *Hydrogeology Journal, 10(2),* pp.238–247.

38- Xie, Z., Liu. W., Chen, S., Yao, R., Yang, C., Zhang, X., Li, J., Wang, Y. and Zhang, Y., 2022. Machine learning approaches to reduce interpretation subjectivity in hydrogeological modeling. *Journal of Hydrology: Regional Studies, 58,* pp-102227. DOI: 10.1016/j.ejrh.2025.102227

© 2026 The Author(s). Published by Shahid Chamran University of Ahvaz. This is an open-access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.