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Assessment of Temporal Changes in Depth to Groundwater in Qushtapa and Shamamik Area in Erbil Basin, Kurdistan Region-Iraq

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*Corresponding author
Seber Muhsin M. Ameen
sebarameen@gmail.com

Seber Muhsin Muhamad Ameen [1,2]/ [1]General Directorate of Divan, Ministry of Agriculture and Water Resources, Erbil, Kurdistan Region, Iraq

Rebwar Nasir Dara [2,3]/ [2]Department of Earth Sciences and Petroleum, College of Science, Salahaddin University - Erbil,Kurdistan Region, Iraq

[3]Department of Petroleum Engineering, College of Engineering, Knowledge University, Erbil, Kurdistan Region, Iraq

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Abstract

Uncontrolled groundwater extraction, unregulated activities, and the impacts of global climate change have contributed to the depletion of groundwater resources in the Erbil Basin, Kurdistan Region. This work aims to illustrate the depth to groundwater in Qushtapa and Shamamik areas to highlight the significant disparity in groundwater levels over the past 20 years. The data from 20 monitoring wells were recorded and mapped using GIS, utilizing the IDW spatial interpolation method. The results of this study show the increase in the depth to static groundwater level in the Qushtapa area from 2005-2024 is ranged between about 102.5 m and 30.2 m, measured at the Qushtapa well and Azyana well, respectively. In Shamamik, the increase in the depth to static groundwater level is ranged between 99.6 m and 58.1 m at the Pirdawd well, Tandura well, respectively. A continuous drop in groundwater level, despite increased precipitation, indicate unsustainable groundwater extraction. The interpolated maps show that the intensive decline started in 2015 and became more pronounced by 2024. The most affected area is the center of the Qushtapa, while northwest of Shamamik and northeast of Qushtapa are less affected. These findings offer valuable insights into the need for enhanced water management and enable decision-makers to devise optimal solutions for this resource's sustainability. The Kurdistan Region Government's launch of the strategic Qushtapa Water Project will play a crucial role in protecting the region's water resources from over-exploitation.

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1. Introduction

Globally, Groundwater depletion has emerged as a significant environmental problem, due to both geographic and temporal variability in precipitation, in addition to rapid population growth and enhanced standards of living, the need for water, particularly freshwater, is escalating. Especially in areas where surface water is scarce or inconsistent, such as Qushtapa and Shamamik areas, where groundwater is the principal source for irrigation, industrial, and domestic consumption. The unsustainable extraction of groundwater and climate change can lead to a decline in groundwater levels (Rodell et al., 2018; Scanlon et al., 2023; Richey et al., 2015; Alley and Alley, 2017). Global climate change and population expansion have contributed to water shortages, posing challenges in effectively using and managing water resources (Alley et al., 2002). Water usage has increased by around 1% annually over the last forty years and is expected to persist at this rate until 2050 (UNESCO, 2023).

Water supply continuity is an essential component for both daily life and the maintenance of sustainable communities (Hameed et al., 2025). Iraq currently experiences a deficiency of surface water, but urbanization, population growth, and climate change have resulted in heightened water demand. Consequently, groundwater is considered an alternative resource to satisfy this demand. Particularly, in the Kurdistan Region, there is a strong reliance on precipitation for recharging the aquifers, but the significant drought in the last years has led to the depletion of the water supply in wells, which was unprecedented. In this study, Qushtapa and Shamamik areas south of Erbil City are chosen to show why the depth to static groundwater level has increased continuously. The government drilled new wells to replace the wells that were unable to provide water because of the depletion of groundwater. The depth of the new drilling well, specifically in Qushtapa, reached 700m (Figure 1). The continual extraction of groundwater from aquifers results in the depletion of this resource in several regions globally (Dhungel and Fiedler, 2016). Delineating the groundwater table is a crucial component of groundwater management and planning (Mustafa and Mawlood, 2023b). The precise illustration of the groundwater level and presenting its spatial distribution for the detection of groundwater decline can be essential in evaluating groundwater depletion and offering guidance for the effective management of aquifers.

Mustafa and Mawlood (2023b) mapped the groundwater level for 55 wells distributed on all three sub-basins within the Erbil basin, they found that there are wells with large depletion in the water table, and other wells less declined, most of the wells that in Northern sub-basin that near to the greater Zab river and at the recharge area have less depletion in head of the groundwater, otherwise, the wells at the center of Erbil basin are most declined in the head. Mustafa and Mawlood (2023a) focused on identifying the recharge zones within the Erbil Basin. The results indicate that from 2004 to 2023, the groundwater level in the Erbil Basin decreased by 82.6m in the Kasnazan well and 12.85m in Mala Omer well, both situated in the recharge zone. Mohammed et al. (2024) studied groundwater level fluctuation in Kapran sub-basin. The study shows a substantial decrease in groundwater levels, attributed to reduced precipitation and elevated extraction, with a decline rate between 0.7 and 5.4 m/year. Jasechko et al. (2024) examined the global trend of groundwater level decline, especially in aquifers experiencing stress from excessive extraction, across 170,000 observing wells and 1,693 different groundwater aquifer systems, representing 75% of all worldwide withdrawals, demonstrating substantial drops. They observed that a fast decline in the level of groundwater of more than 0.5m/year has become common in the 21st century, particularly in arid regions with broad agricultural lands.

Previous studies have investigated hydrogeological conditions of the Erbil Basin and even the Kurdistan Region, but there is still limited comprehension of the hydrogeological state of distinct areas, such as the study area, which faces the stress of water shortage as a result of overexploitation of the groundwater resource for agriculture, and industrial activity, besides domestic supply, as well as this research employed a comprehensive hydro-meteorological dataset across an extended duration, which allows a more precise evaluation of the aquifer system and the impact of human activities.

This research aims to show temporally and spatially how the depth to groundwater level increased compared with the last two decades. These maps act as an essential tool to capture the attention of authorities, as they work as universal communication between scientists and non-scientists, carrying considerable visual impact. The findings of this study will provide valuable insights for policymakers, enabling them to make informed decisions to regulate extraction and prevent the overexploitation of groundwater resources. This, in turn, will contribute to better environmental protection and sustainable groundwater management in the region.

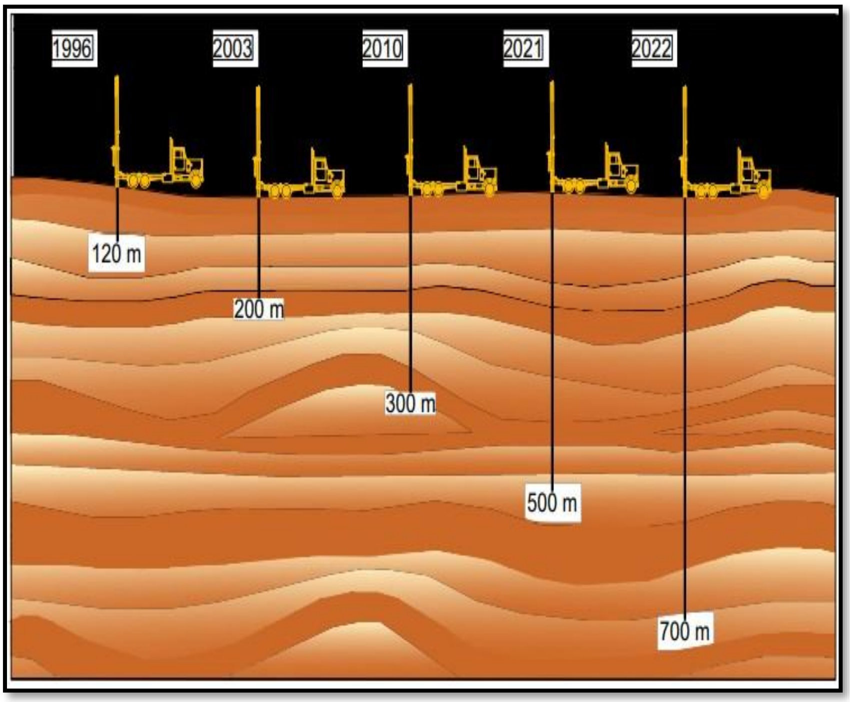

Figure 1. Shows the change in well depth modified from (KRG, 2022)

2. Study Area

The study area is located in the Erbil basin, Iraqi Kurdistan Region, and geographically located between 35° 43' 50'' to 36° 14' 01'' N latitude and 43° 40' 42'' to 44° 17' 55'' E longitude (Figure 2). It encompasses an area of about 1,302 km^2. Its climate is categorized as dry to semi-arid. Tectonically, the Erbil Basin is characterized by many anticlines and synclines. It is situated above a syncline, created by two anticlines, the Permam Dagh anticline to the northeast, and the Kirkuk anticline to the southwest (Buday et al., 1980). The topographical heterogeneity of the Erbil Basin affects the depth of the water table (Gardi, 2017). That’s why it has varying water table levels at minimal distances. The study area from the south is bounded by the Lesser Zab River. Stratigraphically, the major geological formation outcrop units in the study area are recent alluvium, Mukdadiya, and Bai Hassan Formations. According to Mohammed et al. (2013) and Shekhmamundy and Surdashy (2022) the Alluvium and Bai Hassan are composed of conglomerate, gravel, sand, and clay, while the Mukdadiya Formation is composed of thin layers of gravelly sandstone, siltstone, and claystone. Hydrogelogically, the study area is a part of two sub-basins, the Central and Southern sub-basins. Shamamik and a part of Qushtapa are located in the Central sub-basin, and the other part of Qushtapa is regarded as the Southern Sub-basin. According to KRG (2012), most of the agricultural wells are drilled in the Central sub-basin, and most of the illegal wells are drilled in the Southern sub-basin. The main conditions of aquifers in the study area is unconfined aquifers within the intergranular Mukdadiyan and Bai Hassan aquifer system, with recent alluvium aquifers in small areas (Stevanovic and Markovic, 2004).

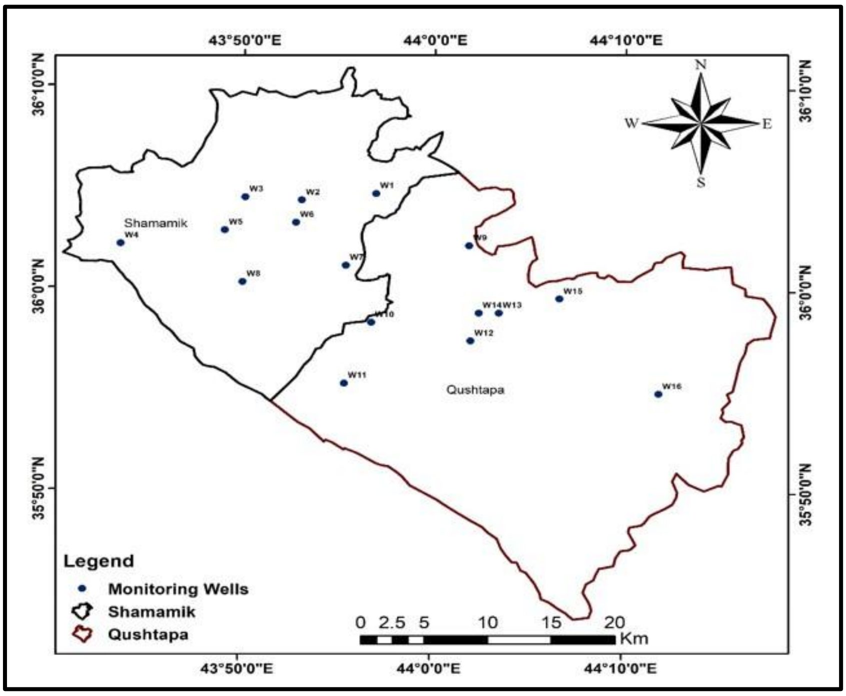

Figure 2. Study area map showing location of monitoring wells in Qushtapa and Shamamik

3. Methodology and Data Collection

The data used in this research is obtained from the Ministry of Agriculture and Water Resources. The static water level is recorded by Directorate of Erbil Groundwater, from years 2005 - 2024. The precipitation data is recorded by Erbil General Directorate of Agriculture from 2008-2024.

The monthly static water level is recorded from 80 productive wells within the Erbil basin used as monitoring wells; 16 of these wells are located in the study area because they are distributed unevenly entire the study area, and the static water level from an extra 4 wells surrounding the study area was used for forecasting groundwater level in the whole examined region (Table 1). The static water level was measured with a sounder instrument; the collected data were used to illustrate the groundwater level decline during the past twenty years. The period is divided into four five-year intervals. ArcGIS 10.8 Version is used to illustrate the depth to groundwater distribution during the past twenty years. The yearly average static groundwater level in the wells in the study area was used for spatial interpolation, while four more wells were used for spatial extrapolation to show more accurate predictions. The modeling was applied with the Inverse Distance Weighting (IDW) spatial analysis tool.

Table 1. Name and coordinates of the monitoring wells

ID	Monitoring Wells	Latitude (°N)	Longitude (°E)	Elevation (m)
W1	Qoretan Chukl	36.0793	43.9494	355
W2	Daldaghan	36.0734	43.8846	333
W3	Tandura	36.0757	43.8354	311
W4	Shekh Sherwan	36.0365	43.7270	303
W5	Mastawa	36.0482	43.8178	301
W6	Sorbash Hawez	36.0550	43.8799	325
W7	Pirdawd	36.0199	43.9237	341
W8	Grd Azaban	36.0057	43.8339	308
W9	Murtka Shahab	36.0368	44.0311	408
W10	Dugrdkan	35.9730	43.9464	343
W11	Qurshaghlu	35.9225	43.9234	338
W12	Qultapa Yaba	35.9583	44.0331	402
W13	Grd Mala	35.9815	44.0576	423
W14	Qushtapa	35.9813	44.0402	413
W15	Kardiz	35.9935	44.1104	444
W16	Azyana	35.9153	44.1975	440
W17	Bestana	36.0793	43.9494	355
W18	Lajan	36.0554	44.1912	655.5
W19	Daratw	36.0549	43.8799	325
W20	Berabat	35.8238	43.8928	360

4. Results and Discussion

The obtained data illustrated to show how the depth to static groundwater level increased during the last twenty years (Figures 3 and 4). The result may raise concerns about the depletion of this resource, where this resource has dramatically declined compared to the primitive data; in some wells, the static water level dropped by more than 100 m below the ground surface. This number must be taken into consideration. The depletion has mostly appeared in recent Quaternary aquifers. This overexploitation is leading to the extraction from deeper aquifers, indicating a transition in the main source of groundwater abstraction. This continuous over-extraction ultimately causes the depletion zone to extend into deeper aquifers, specifically the Bai Hassan aquifer. This results from over-extraction of the groundwater, which exceeds the precipitation rate, which is the main source of recharge of the aquifers. Rising the groundwater table in the aquifers requires a prolonged duration of decreased extraction and adequate precipitation to enable natural recharge of the aquifers.

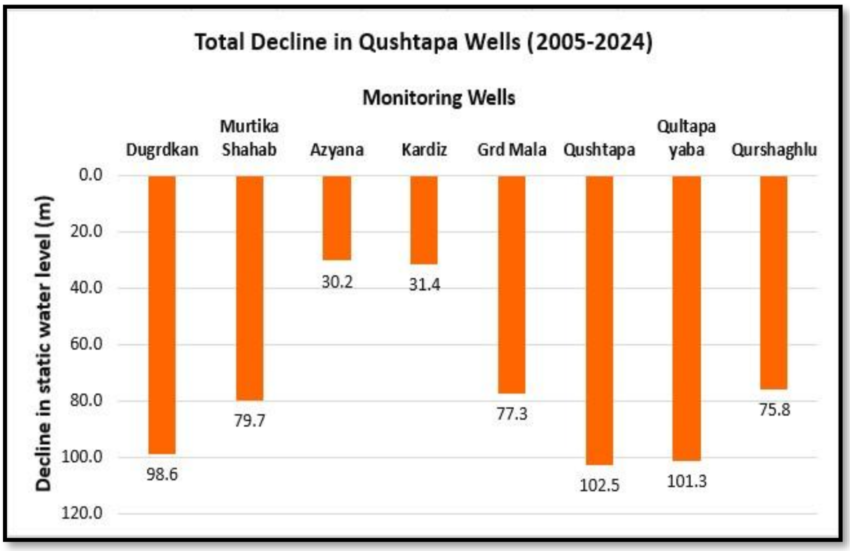

Figure 3. Total drop in static water level between 2005 and 2024 in Qushtapa monitoring wells

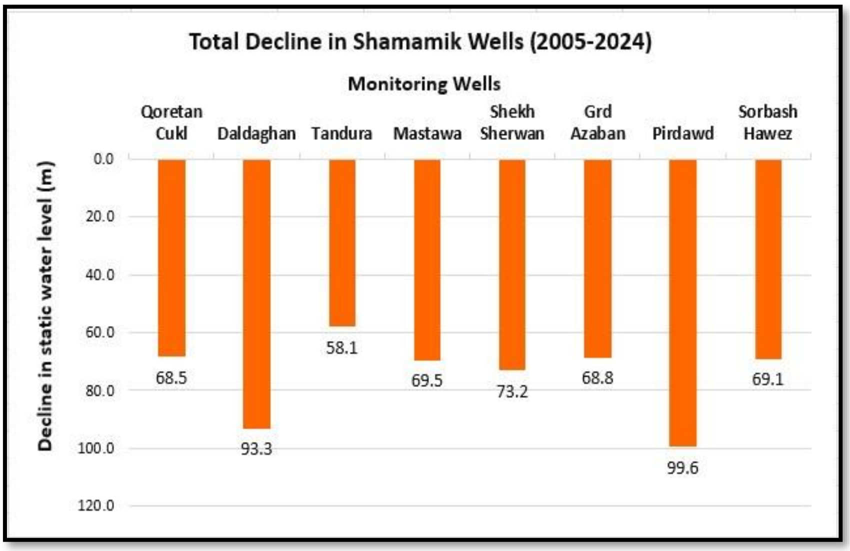

Figure 4. Total drop in static water level between 2005 and 2024 in Shamamik monitoring Wells

It is obvious from the presented bar graph that the total drop in groundwater level in the

Qushtapa area during 2005-2024 ranged between 102.5 m and 30.2 m for the Qushtapa well and Azyana well, respectively, while in Shamamik it ranged between 99.6 m and 58.1 m for the Pirdawd well and Tandura well, respectively. These results are extremely important, indicating that groundwater levels persistently decrease over time, and policymakers must take action to reverse this; otherwise, the aquifers will reach an irreversible state, resulting in a permanent reduction of their storage capacity. In addition to climate change and the reduction of recharge rate, the rapid population growth and the overexploitation of this source for agriculture and industry sectors in the study area result in such a decline in the source. During data analysis, it is noticed that the monthly recorded data of groundwater level shows a temporary cessation in water level during the rainy seasons, which is mostly attributed to limited groundwater extraction rather than direct rainfall, in contrast to the elevated withdrawal rates commonly observed in the hot summer months. The analysis of both precipitation and groundwater level data reveals that the increased precipitation rate did not correlate with a rise in groundwater level (Figures 5 and 6). This decoupling suggests that groundwater extraction rate likely exceeds natural recharge, or that the aquifer has limited infiltration capacity. A continuous drop in groundwater level, despite increased precipitation, may indicate unsustainable groundwater extraction.

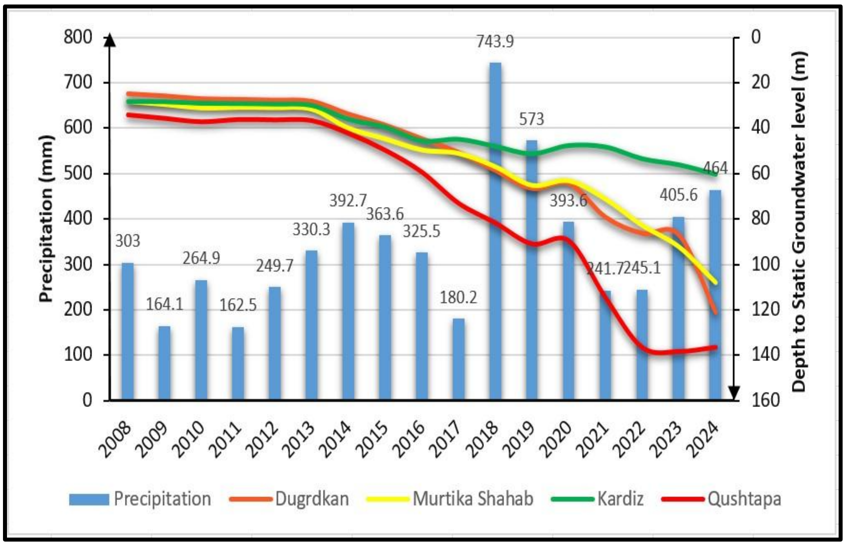

Figure 5. Water level fluctuation with annual precipitation during 2008-2024 in Qushtapa

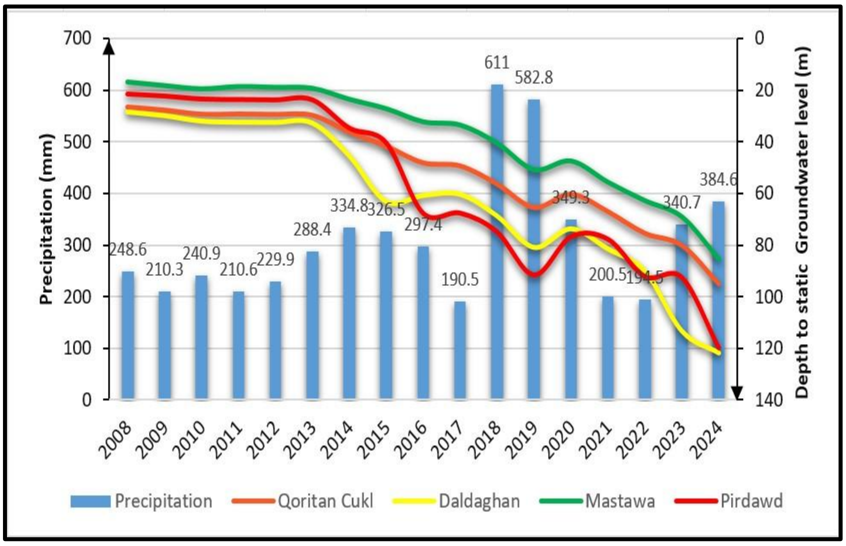

Figure 6. Water level fluctuation with annual precipitation during 2008-2024 in Shamamik

Additionally, dividing the period of monitoring into four five-year intervals and mapping the depth to groundwater (Figures 7-10) shows the intensive increasing in depth to groundwater started from 2015-2019, and in 2020-2024 became more intensive and noted the areas that face the stress especially the center of Qushtapa, this is due to the elevated demand for water in the area, which results from the population stress resulting from shifting populations and the creation of temporary communities in the area, and increasing drilling wells to address the water shortage. In contrast, the eastern part of Qushtapa toward the Lesser Zab River shows less declination (Figure 10). This could be attributed to lower pumping rates and the groundwater is less exploited, or to the presence of a paleochannel in the area with high hydraulic conductivity, allowing more efficient recharge. Additionally, the area is classified as a Moderate to High Groundwater recharge potential zone (Hamad, 2022).

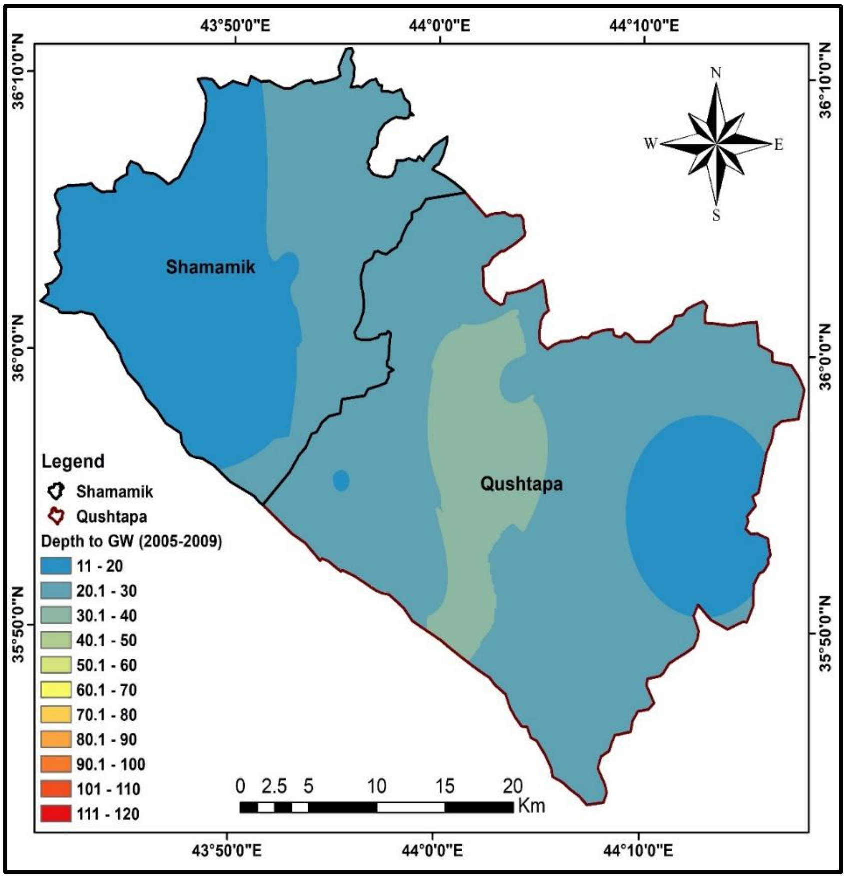

Figure 7. Depth to static groundwater level map from 2005 to 2009

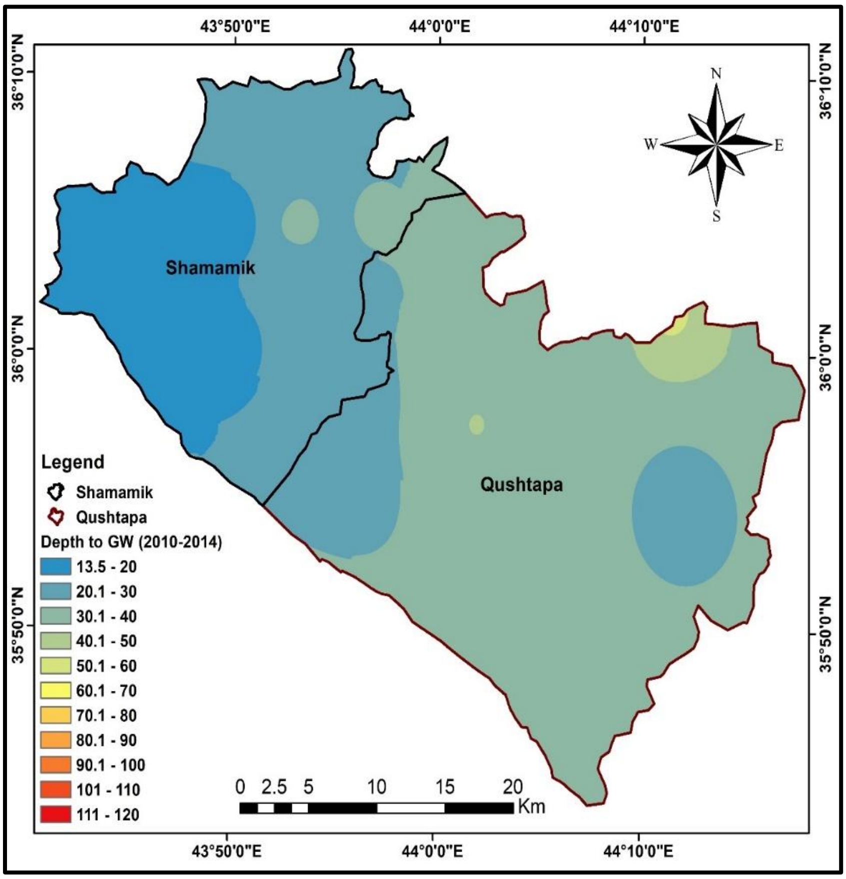

Figure 8. Depth to static groundwater level map from 2010 to 2014

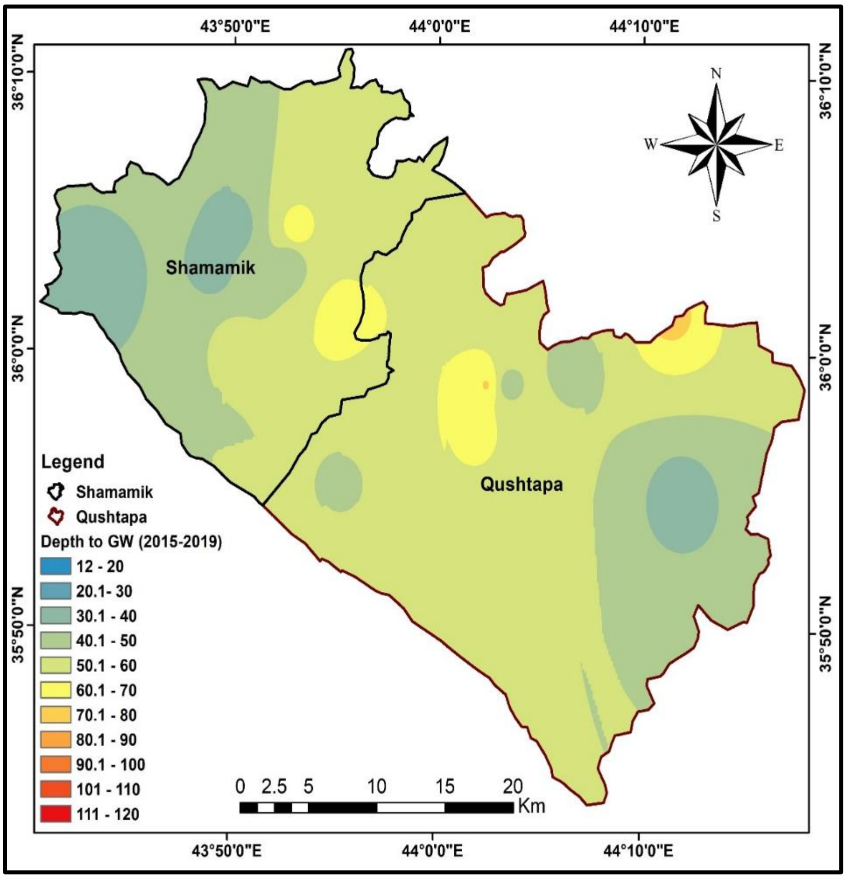

Figure 9. Depth to static groundwater level map from 2015 to 2019

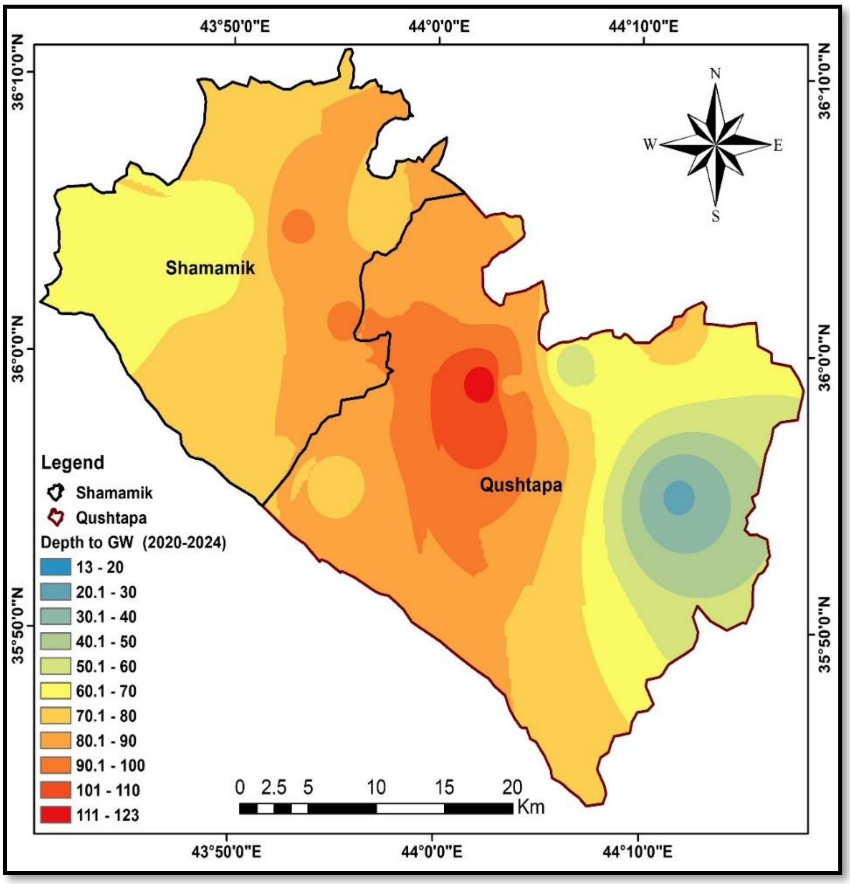

Figure 10. Depth to static groundwater level map from 2020 to 2024

A simple comparison between the number of wells in 2005 in the study area and the wells existing in 2024, shows a large disparity, however, the plotted wells are formally recorded wells, while the illegal wells are not documented and don't have distinct coordination additionally some wells due to their incorrect coordination couldn't be plotted, (Figures 11 and 12).

However, there are some guidelines and regulations for groundwater well drilling that enforce the presence of a suitable distance between the wells, but there is still a lack of commitment to this legal distance. The regulated distance between the wells in the Central sub-basin and Southern sub-basin is 600m and 550m, respectively (KRG, 2015). Dizayee (2014) shows that 25.2% of the wells in the central sub-basin and 20% of the wells in the Southern sub-basin don't meet regulations. Such encroachment hastens the depletion of the groundwater resource, resulting in a continuous decline of the water level, which impedes the aquifer recharge and deteriorates water quality. That's why immediate actions are required to sustainably manage groundwater through collaborative efforts. It is worth emphasizing that the strategic Qushtapa water project effectively contributes to the restoration of the groundwater source in the region. Currently, 20% of the project has been implemented. Upon its completion, water will be supplied to 72 villages, and over 110 wells will be decommissioned (KRG, 2025). These results serve as a valuable resource for formulating groundwater policy and enabling decision-makers to devise optimal solutions for groundwater management.

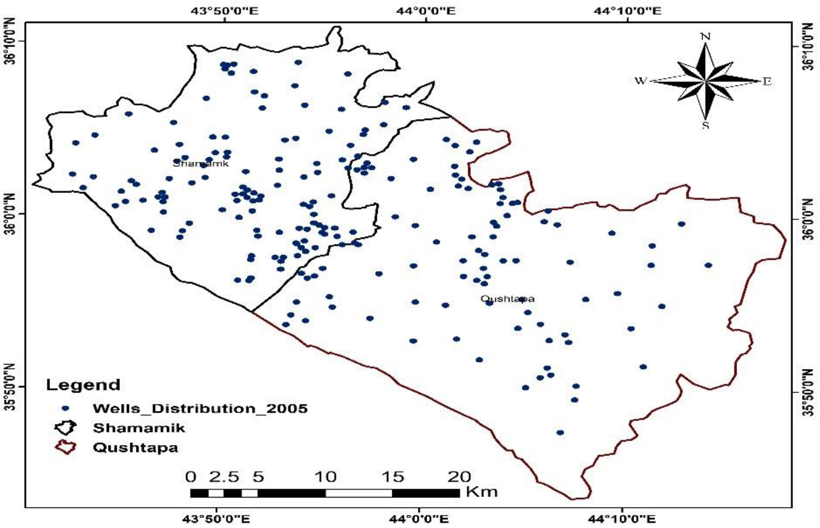

Figure 11. Groundwater Well Distribution in 2005

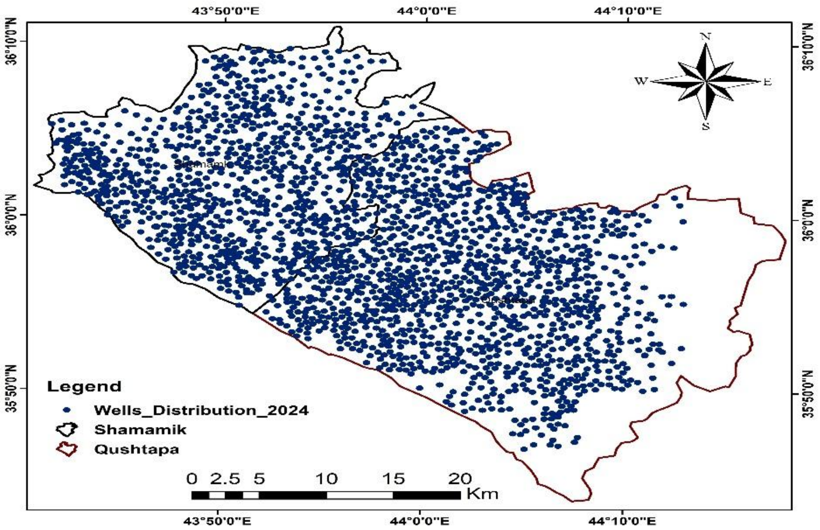

Figure 12 Groundwater Well Distribution in 2024

5. Conclusion

The groundwater level data is used to show the dramatic change in the depth to groundwater during the last two decades. The research concluded that the population growth and the primary reliance on groundwater for agriculture and industrial purposes in the study area, due to the impact of climate change and limited recharge, have led to the depletion of groundwater resources. The overexploitation of the resource is the main factor in increasing the depth to groundwater. The depth to groundwater increased over the monitoring period, signifying a decline in the groundwater level. The study reveals that the areas near the Lesser Zab River and the western part of Shamamik toward the Greater Zab River are less declined compared to the center of Qushtapa and Shamamik.

The initiation of the critical Qushtapa Water Project will help in avoiding the improper use of the resource in the region.

6. Recommendations

Precise monitoring is essential for obtaining and understanding the groundwater condition. In case of the absence of an effective and dependable monitoring system, it's hard to establish strategic water management in the Kurdistan region. That's why it's strongly recommended to establish groundwater level monitoring stations in the study area and even the whole Erbil Basin, equipped with sensors and data recorders to automatically record fluctuations in groundwater levels, rather than relying on a manual monitoring method.

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هەڵسەنگاندنی گۆڕانکارییە کاتییەکان لە قووڵایی ئاوی ژێر زەوی لە ناوچەکانی قوشتەپە و شەمامک لە حەوزی هەولێر، هەرێمی کوردستان- عێراق

سێبەر محسن محمد أمین
بەڕێوبەرایەتی گشتی دیوان، وەزارەتی کشتوکاڵ و سەرچاوەکانی ئاو، هەولێر، هەرێمی کوردستان، عیراق
بەشی زانستەکانی زەوی و نەوت کولێژی زانست، زانکۆی سەلاحەدین – هەولێر، هەولێر، هەرێمی کوردستان، عیراق
sebarameen@gmail.com

ڕێبوار ناصر دارا
بەشی زانستەکانی زەوی و نەوت کولێژی زانست، زانکۆی سەلاحەدین – هەولێر، هەولێر، هەرێمی کوردستان، عیراق
بەشی ئەندازیاری نەوت، کۆلێژی ئەندازیاری، زانکۆی نۆلج، هەولێر، هەرێمی کوردستان، عیراق
rebwar.dara@su.edu.krd

پوختە

دەرهێنانی ئاوی ژێر زەوی بێ کۆنترول و چالاکییە ڕێکنەخراوەکان و کاریگەرییەکانی گۆڕانی کەشوهەوای جیهانی بەشداربوون لە کەمبوونەوەی سەرچاوەکانی ئاوی ژێر زەوی لە حەوزی هەولێر لە هەرێمی کوردستان. ئەم توێژینەوەیە ئامانجی ڕوناکردنی قووڵایی ئاوی ژێر زەوییە لە ناوچەکانی قوشتەپە و شەمامک بۆ تیشک خستنە سەر گۆڕانکارییە بەرچاوەکانی ئاستی ئاوی ژێر زەوی لە ماوەی ٢٠ ساڵی ڕابردوودا. داتاکانی ٢٠ بیری چاودێریکردن تۆمارکران و نەخشەیان بو کێشراوە بە بەکارهێنانی سیستەمی زانیاری جوگرافی GIS بە بەکارهێنانی شێوازی ئینتەرپۆلاسیۆنی فەزایی IDW. ئەنجامی ئەم توێژینەوەیە ئاماژە بەوە دەکات کە زیاد بوونی قووڵایی بۆ بۆ ئاستی جێگیری ئاوی ژێر زەوی لە ناوچەی قوشتەپە لە ساڵی ٢٠٠٥-٢٠٢٤ لە نێوان ١٠٢.٥ م و ٣٠.٢ م ە، کە لە بیرەکانی قوشتەپە و ئازیانەدا بە دوای یە ک پێوانە کراوە. لە شەمامک زیاد بوونی قووڵایی بۆ بۆ ئاستی جێگیری ئاوی ژێر زەوی لە لە نێوان ٩٩.٦ م و ٥٨.١ م ە ، لە بیری پیرداود و تەندورە. دابەزینی بەردەوامی ئاستی ئاوی ژێر زەوی، سەرەڕای زیادبوونی بارانبارین، ئاماژەیە بۆ دەرهێنانی ئاوی ژێرزەوی ناپایەدار. نەخشەکان دەریدەخەن کە دابەزینی بەرچاو لە ساڵی ٢٠١٥ دەستیپێکردووە و تا ساڵی ٢٠٢٤ توندتر بووە، زۆرترین ناوچە زیانلێکەوتووەکان سەنتەری قوشتەپە، لە کاتێکدا باکووری ڕۆژئاوای شەمامک و باکوری ڕۆژهەڵاتی قوشتەپە کەمتر زیانیان بەرکەوتووە. . ئەم دۆزینەوانە تێڕوانینێکی بەنرخ دەدەن سەبارەت بە پێویستی باشترکردنی بەڕێوەبردنی ئاو و بڕیاردەران دەتوان چارەسەری گونجاو بۆ بەردەوامیی ئەم سەرچاوەیە پەرەپێبدەن. ئەنجامدانی پرۆژەی ستراتیژی ئاوی قوشتەپە لەلایەن حکومەتی هەرێمی کوردستانەوە ڕۆڵێکی چارەنووسسازی دەبێت لە پاراستنی سەرچاوە ئاوییەکانی هەرێم لە زیادەڕۆیی لە ئیستغلالکردن.

وشە سەرەکیەکان : بیری چاودێری، دەنگدەر، ئاوی ژێر زەوی، قوشتەپە، شەمامک

تقييم التغيرات الزمنية في عمق المياه الجوفية في منطقة قوشتبة وشمامك في حوض أربيل، إقليم كوردستان العراق

سيبر محسن محمد أمين
المديرية العامة للديوان، وزارة الزراعة و الموارد المائية، اربيل، اقليم كوردستان، العراق
قسم علوم الارض و النفط، كلية العلوم ، جامعة صلاح الدين-اربيل، اربيل، اقليم كوردستان، العراق
sebarameen@gmail.com

ريبوار ناصر دارا
قسم علوم الارض و النفط، كلية العلوم ، جامعة صلاح الدين-اربيل، اربيل، اقليم كوردستان، العراق
قسم هندسة النفط، كلية الهندسة، جامعة نولج، اربيل، اقليم كوردستان، العراق
rebwar.dara@su.edu.krd

ملخص

ساهم استخراج المياه الجوفية غير المنضبط والأنشطة غير المنظمة وتأثيرات تغير المناخ العالمي في استنزاف موارد المياه الجوفية في حوض أربيل بإقليم كوردستان. يهدف هذا البحث إلى توضيح مستويات المياه الجوفية في منطقتي قوشتبة وشمامك لتسليط الضوء على التفاوت الكبير في مستويات المياه الجوفية على مدى السنوات العشرين الماضية. تم تسجيل البيانات من ٢٠ بئر مراقبة ورسم خرائط لها باستخدام نظام المعلومات الجغرافية، باستخدام طريقة الاستيفاء المكاني IDW. تظهر نتائج هذه الدراسة أن الزيادة في عمق منسوب المياه الجوفية الساكنة في منطقة قوشتبة، خلال الفترة ٢٠٠٥-٢٠٢٤، تتراوح بين حوالي ١٠٢.٥ مترا و٣٠.٢ مترا، مقاسةً في بئري قوشتبة وأزيانا على التوالي. وفي شامامك، تتراوح الزيادة في عمق منسوب المياه الجوفية الساكنة بين ٩٩.٦ مترا و٥٨.١ مترا في بئري بيرداود وتندورا على التوالي. يشير الانخفاض المستمر في منسوب المياه الجوفية، على الرغم من زيادة هطول الأمطار، إلى استخراج غير مستدام للمياه الجوفية. تظهر الخرائط الموضحة أن الانحدار الشديد بدأ عام ٢٠١٥ وأصبح أكثر شدة بحلول عام ٢٠٢٤ . أكثر المناطق تضررا هي مركز قوشتبة، في حين أن شمال غرب شمامك وشمال شرق قوشتبة هي الأقل تأثرا. تقدم هذه النتائج رؤى قيمة حول الحاجة إلى تحسين إدارة المياه، وتمكن صانعي القرار من وضع حلول مثالية لاستدامة هذا المورد. سيلعب إطلاق حكومة إقليم كردستان لمشروع مياه قوشتبة الاستراتيجي دورا حاسما في حماية موارد المياه في المنطقة من الاستغلال المفرط.

الكلمات المفتاحية: ابار المراقبة ، مرجاس، المياه الجوفية، قوشتبة، شمام