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Determine the Groundwater Recharge Zones in Erbil Basin

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ABSTRACT

The identification and delineation of recharge zones are critical components in sustainable groundwater management. This study focuses on determining the recharge zones within the Erbil Basin, employing a combination of field investigations, hydrogeological assessments, and geospatial analyses using Groundwater Modeling system (GMS) software with the aid of Geographic information System (GIS). The study uses the historical and field observed geological formations data to evaluate the 3D visualization of unconfined, confined and semi-confined aquifer types within Erbil Basin in order to determine the Recharge area. The aim is to provide valuable insights into the spatial distribution and characteristics of areas where groundwater recharge predominantly occurs. The outcomes of this research contribute to a comprehensive understanding of recharge dynamics in the Erbil Basin. The delineation of recharge zones provides essential information for sustainable groundwater management, aiding in the development of effective land use planning and conservation strategies. The results of this study reveal a decline in groundwater levels within the Erbil basin over the period from 2004 to 2023. were 86.2 meters in the Kasnazan well and 125.86 meters in the Mala Omer well, both located within recharge zones of the Erbil groundwater basin. The findings will be valuable for local authorities, policymakers, and water resource managers, offering a basis for informed decision-making to ensure the long-term viability of groundwater resources in the Erbil Basin. The study emphasizes the importance of integrating multidisciplinary approaches to accurately identify and protect the crucial zones responsible for replenishing the groundwater system.

Keywords: Aquifer types, Aquifer system, Erbil basin, groundwater management, Recharge zone.

INTRODUCTION

The Erbil Basin, situated in a region characterized by multiple aquifer types, stands as a critical water resource supporting the diverse needs of its growing population [1]. Efficient management of this vital groundwater system necessitates a thorough understanding of the recharge areas, where aquifers are replenished. This study focuses on determining the recharge

areas within the Erbil Basin, considering the complex hydrogeological nature of the region marked by the presence of multiple aquifer types.

The hydrogeological complexity of the Erbil Basin arises from the coexistence of various aquifer formations, each exhibiting distinct characteristics in terms of recharge mechanisms, hydraulic conductivity, and vulnerability to anthropogenic influences. The presence of these diverse aquifer types underscores the need for a comprehensive assessment to accurately identify and delineate the areas where groundwater replenishment predominantly occurs [2].

Given the dynamic nature of groundwater systems, influenced by geological, hydrological, and anthropogenic factors, a multidisciplinary approach is essential. This study integrates field investigations, hydrogeological assessments, and advanced geospatial analyses to comprehensively determine the recharge areas. Understanding the spatial distribution of these critical zones is paramount for sustainable water resource management, influencing land use planning, and guiding conservation efforts [3]. As population growth and changing climate patterns place increasing pressure on water resources, the identification of recharge areas gains even greater significance [4,5]. This research aims to contribute valuable insights to local authorities, policymakers, and water resource managers, facilitating informed decision-making for the sustainable utilization and protection of groundwater resources in the Erbil Basin. By focusing on the complexities of a multi-aquifer system, this study seeks to enhance our understanding of recharge dynamics in the region, addressing the challenges associated with managing a diverse and interconnected groundwater network.

It is evident from the information provided that the groundwater resources in the Erbil three basins are facing significant challenges, primarily due to overexploitation. The extensive use of both legal and illegal wells for various purposes, including drinking, irrigation, and fire hydrants, has led to a drastic depletion of groundwater levels in the region. The rapid population growth in the selected area has further intensified the demand for water, exacerbating the problems faced by the water resources system [6].

The reliance on groundwater for human activities is common in many regions, and Erbil is no exception. The data from the Directorate of Water and Sewerage of Erbil indicate that groundwater constitutes approximately 45% of the water supply system in Erbil city, with the remaining 55% sourced from surface water. However, the actual percentage of groundwater may be higher than estimated, considering the conditions of the Erbil basins. Monitoring groundwater is crucial for both quantity determination and quality assessment [7]. Groundwater monitoring involves continuous processes, including field observations, satellite observations, data logger observations, and laboratory analysis of physical and chemical variables. The collected data helps in understanding the groundwater levels, recharge rates, and the overall quality of the water. Several studies have been conducted in the Erbil plain to address groundwater-related issues. These studies cover topics such as groundwater potential mapping, water balance, sustainability of groundwater sources, and challenges in managing water resources. Despite these efforts, the existing problems in groundwater management persist, including the lack of determination of aquifer types as a model, the use of different boundaries by researchers, the presence of uncontrolled drilled wells, and sudden depletions

in groundwater levels due to the declining efficiency of wells [8,9]. To address these challenges, there is a need for accurate calculations of groundwater usage, particularly in irrigation and industrial activities. Additionally, efforts should be made to determine aquifer types accurately, establish consistent boundaries, and regulate well drilling to avoid uncontrolled extraction. Sustainable groundwater management practices are essential to ensure the long-term availability of this vital resource in the Erbil three basins [10].

MATERIALS AND METHODS

Location of Study Site

The Erbil Basin, characterized by its geographical coordinates at approximately 44.00° East longitude and 36.19° North latitude, occupies a significant position within the Erbil Governorate. With an elevation of about 420 meters above sea level (m a.s.l), it stands as one of the largest basins in the region, playing a pivotal role in the hydrological landscape. Bounded by the Greater Zab to the north and the Lesser Zab to the south, the basin is strategically positioned between these prominent rivers, which contribute to its hydrological dynamics. According to [11], the Erbil Basins are further subdivided into three main sub-basins as shown in Figure 1. This division provides a more detailed understanding of the basin's internal structure and helps in managing its water resources effectively [12, 13]. The Greater Zab and Lesser Zab rivers not only define the boundaries but also influence the water flow and distribution within the basin, making it a crucial area for hydrological studies and sustainable water resource management.

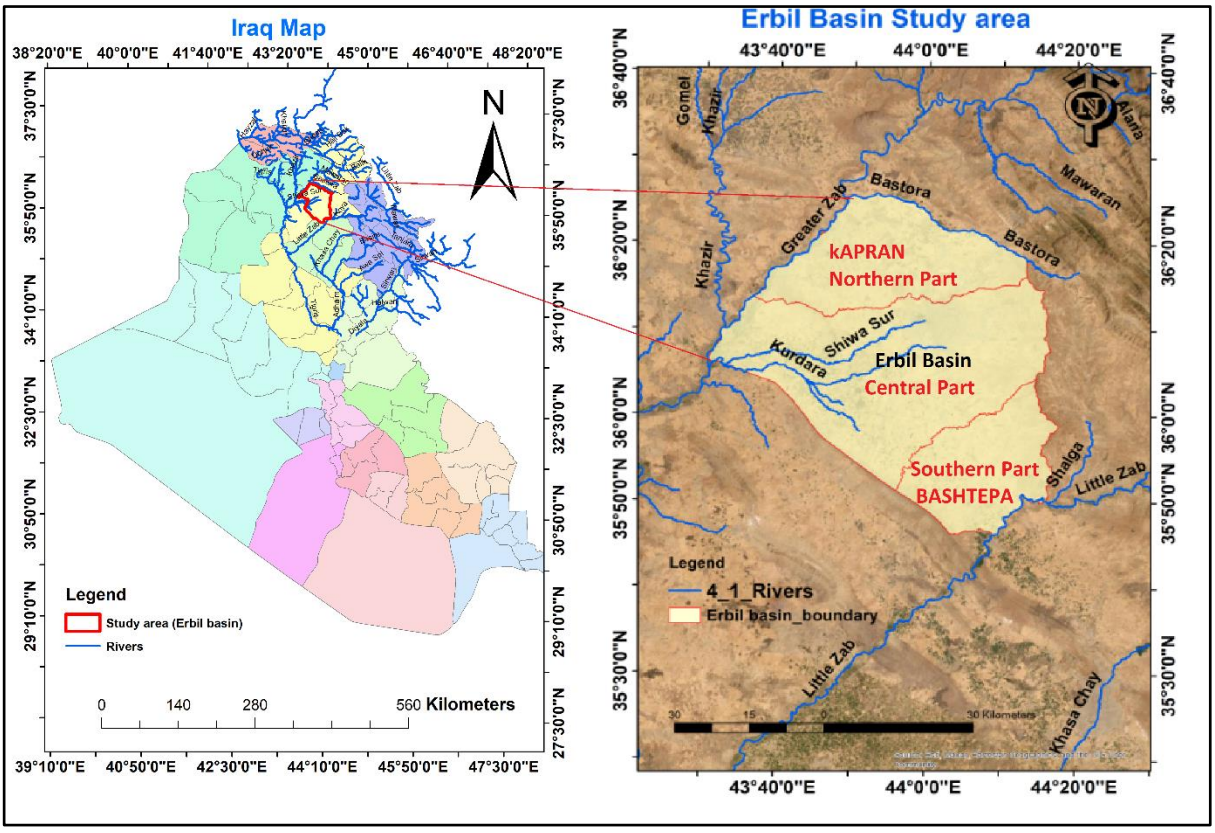


Figure 1: Location of Erbil basin area.

Hydrogeological and Geological Characteristics of Erbil Basin

Erbil plain, is located in low folded zone. The area bounded by Bastora stream and Pirmam Anticline at Northern part, and at southern part is bounded by Demir Anticline with Shamamk plain. Accordingly, at eastern part the region is bounded by Shalgha Bestana and Lesser Zab river, also at Western part bound by Greater Zab river [1, 12]. The geological formations are composed from:

- Recent deposits: it covers with recent quaternary deposits. These entail alluvial fan deposits, slope deposits, flood plain deposits and river terraces mostly consisting of silty and clayey soil, rock fragments and conglomerates.
- Upper Bakhtiari (Bai Hassan) Formation: it consists of conglomerates, sandstone and claystone.
- Lower Bakhtiari (Mukdadiyah) Formation: it consists of pebbly sandstone, siltstone and claystone
- Upper Fars (Injana) Formation: it consists of sandstone, siltstone and claystone.
- Lower Fars (Fatha) Formation: it consists of gypsum, marl, limestone, red claystone and siltstone
- Pilaspi Formation: it consists mainly of well bedded limestone.
- Gercus Formation: it consists of red sandstone, siltstone and claystone [1,12].

The detail of the geological formation of the study area as described in Figure 2.

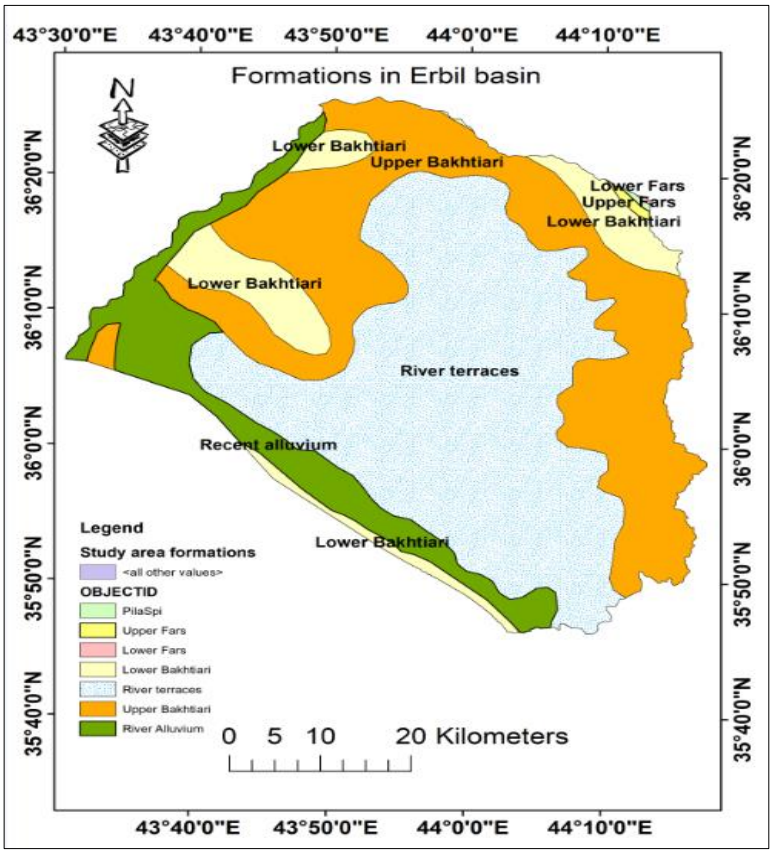


Figure 2: The geological formations of Erbil basin area.

DATA ANALYSIS AND RECHARGE AREA DETERMINATION

Data Collection

The study starts with the acquisition of geological borehole data sourced from the Erbil Groundwater Directorate [14, 15]. This dataset is a foundational element, providing crucial information about the subsurface composition and structure of the Erbil Basin. The collected borehole data is meticulously classified based on the nature of the encountered materials, distinguishing between pervious and impervious layers. The classification encompasses a spectrum of materials such as clay, silt, sand, and gravel. Subsequently, the pervious materials, which include layers with high permeability, are further categorized into aquifers. Aquifers are critical components of the groundwater system as they store and transmit water. These classifications enable a detailed understanding of the distribution and characteristics of the aquifers within the basin. Conversely, the impervious layers, particularly those consisting of clay, are identified and classified as aquitards and aquicludes. Aquitards exhibit lower permeability, slowing down the movement of water, while aquicludes entirely restrict the flow of groundwater. The differentiation between these impervious layers is essential for comprehending the groundwater flow dynamics and the potential barriers to water movement within the basin.

To enhance the visualization and analysis of the geological information, a three-dimensional (3D) model is constructed using GMS (Groundwater Modeling System) software. This modeling tool facilitates the integration of geological data, allowing for the creation of a comprehensive representation of the subsurface environment [16]. The 3D model aids in visualizing the spatial distribution of aquifers, aquitards, and other geological features, providing a valuable resource for further hydrogeological assessments and groundwater management strategies for more detail see Figure 3.

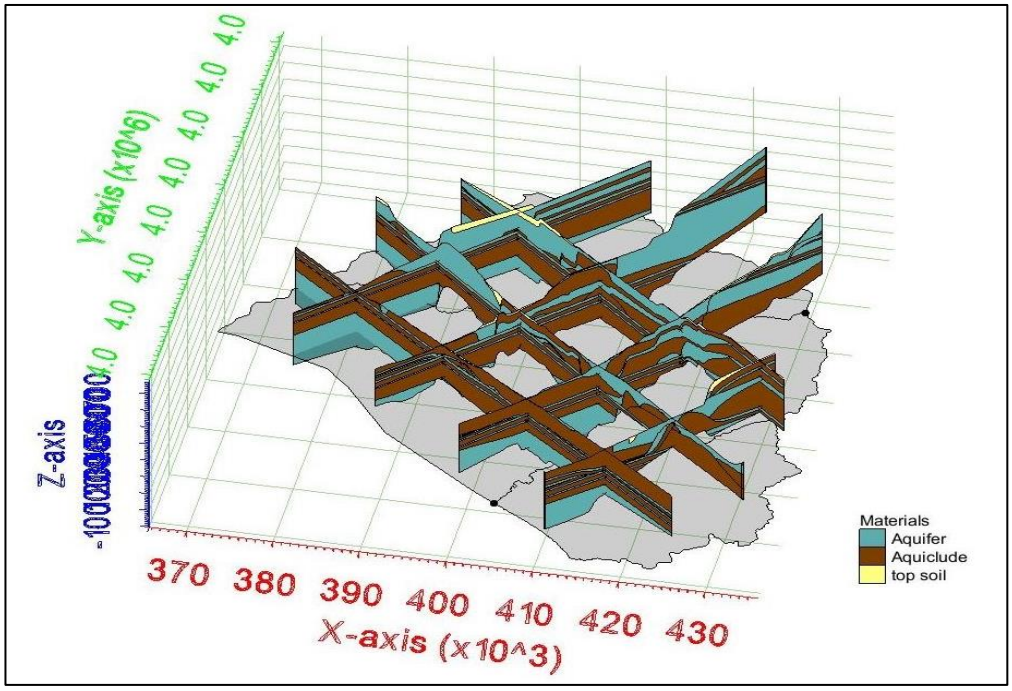


Figure 3: The cross-sectional map of the Erbil basin formations created by GMS v.10.7.

In addition, for unconfined aquifers, where the water table is close to the ground surface and there is no confining layer restricting vertical movement, recharge typically occurs directly from surface water infiltration. Rainfall, rivers, lakes, and other surface water sources contribute to the replenishment of unconfined aquifers as water easily infiltrates the pervious layers [17-19].

However, In the case of confined and semi-confined aquifers, where impermeable layers exist above or below the aquifer, the recharge process is often influenced by specific conditions. Confined aquifers may receive water from distant recharge zones where the pervious layers come into contact with the surface, allowing water to infiltrate and gradually move towards the aquifer [20]. Semi-confined aquifers share similarities with both unconfined and confined aquifers, and the recharge process can be influenced by various factors, including the permeability of the overlying layers are shown in Figure 4.

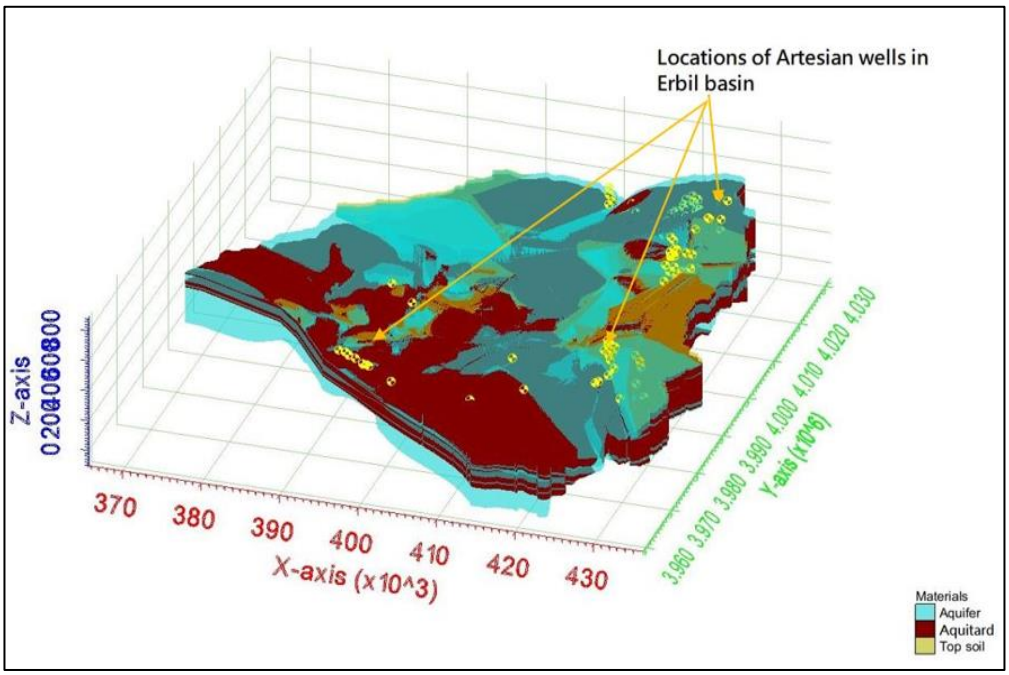


Figure 4: Hydro stratigraphy Modeling of the Erbil Basin using GMS v.10.7

The focus of previous studies on Mala Omer, Kasnazan, and Bastora Valley as recharge areas for the Erbil groundwater basin is in line with recognizing key hydrogeological characteristics in the region. The complex stratigraphy of the area plays a crucial role in influencing the movement and recharge of groundwater. Mala Omer, Kasnazan, and Bastora Valley likely exhibit specific geological features that make them significant contributors to the replenishment of the groundwater basin. The intricate stratigraphy, which refers to the arrangement and composition of different rock and soil layers, influences the permeability and porosity of the subsurface materials. This, in turn, affects the movement and storage of groundwater [20].

Therefore, the study focused on Artesian wells, which are typically characterized by the natural flow of groundwater to the surface due to the pressure within a confined aquifer. The confinement is often provided by impermeable layers both above and below the aquifer. In this case, the confirmation that artesian wells are predominantly located at points where two confining layers intersect indicates that these intersections create conditions conducive to artesian aquifers [20, 21]. Thus, by comparing the observation field data that the locations of about (200) artesian wells coincide with areas where two confining layers intersect in the 3D visualization model suggests a meaningful correlation between the hydrogeological characteristics of the subsurface and the presence of artesian conditions. Thus, the coordinates of the all-artesian wells during (1988 -2023) were mapped using GIS tools as shown in Figure 5.

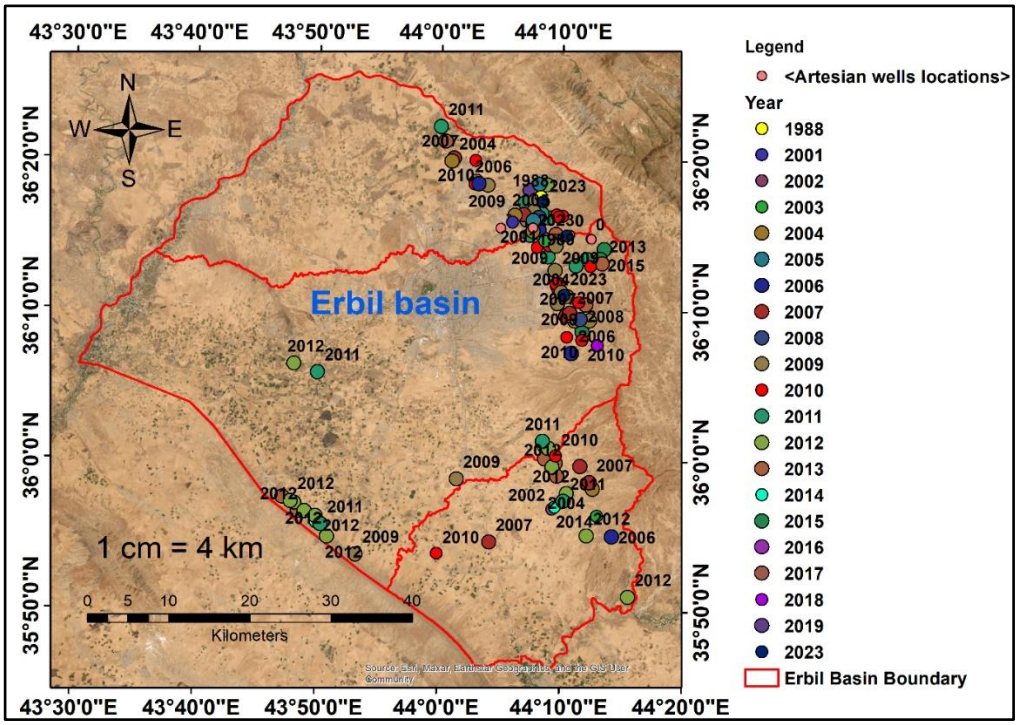


Figure 5: Mapping Artesian wells drilled within Erbil basin during (1988-2023).

As well as, the recharge zones of Erbil basin are created by Arc scene 10.8, and it is shown in Figure 6.

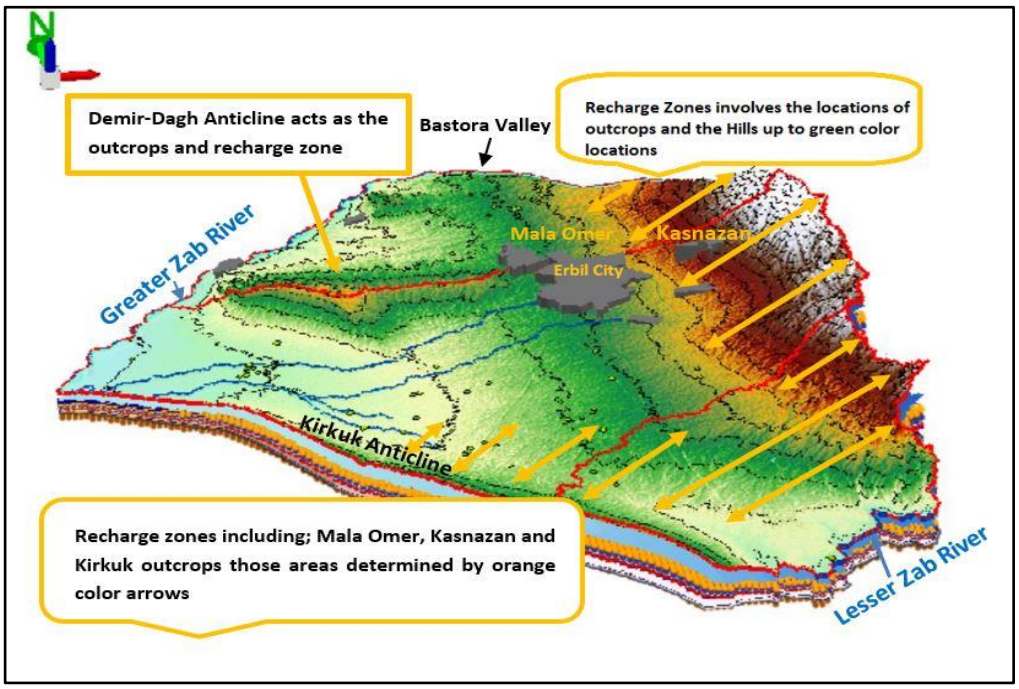


Figure 6: Erbil Basin Recharge zone created by Arc Scene 10.8.

It is considered based on those data that the Recharge zones located in the area of having artesian wells.in order to avoid building the urban area in those locations to keep the water flows into deep aquifers and increase the groundwater levels in the area.

Groundwater Recharge Estimation

Estimating groundwater recharge is a critical aspect of managing water resources, especially in regions like the Erbil Basin where water availability is crucial for various purposes. The groundwater fluctuation method serves as a valuable tool for assessing recharge levels. In the context of the Erbil Basin, this method involves analyzing fluctuations in groundwater levels over time. By closely monitoring changes in water table elevations, hydrologists can gain insights into the dynamic interplay between precipitation, evaporation, and human-induced influences on the groundwater system [20,21]. The estimation of recharge using this method involves accounting for factors such as climatic conditions, land use, and geological characteristics specific to the Erbil Basin.

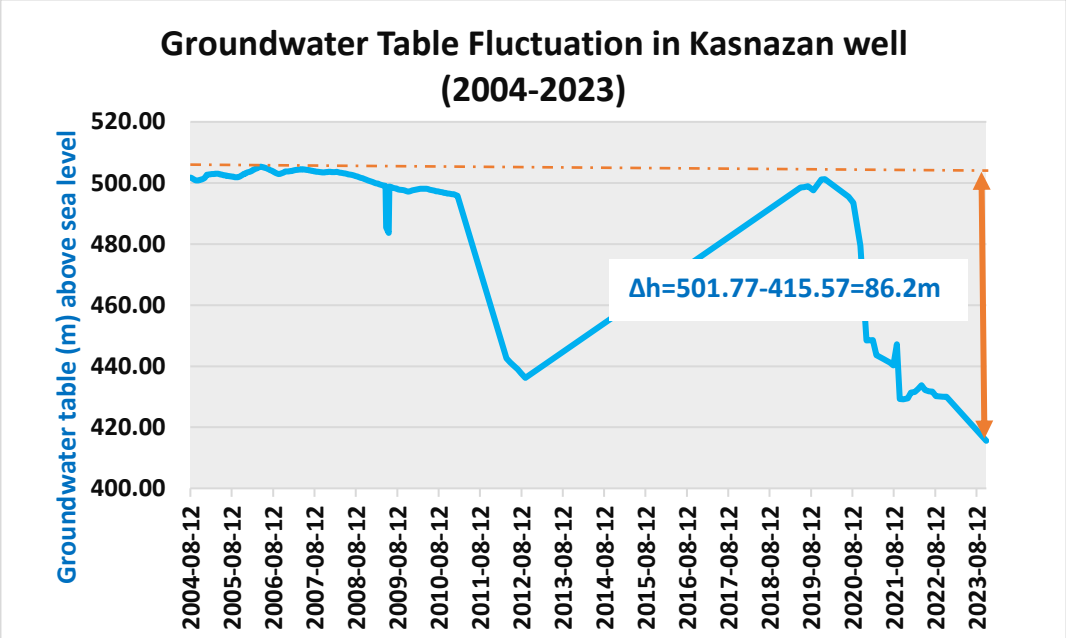


Figure 7: Decline in groundwater table in Kasnazan well during (2004-2023).

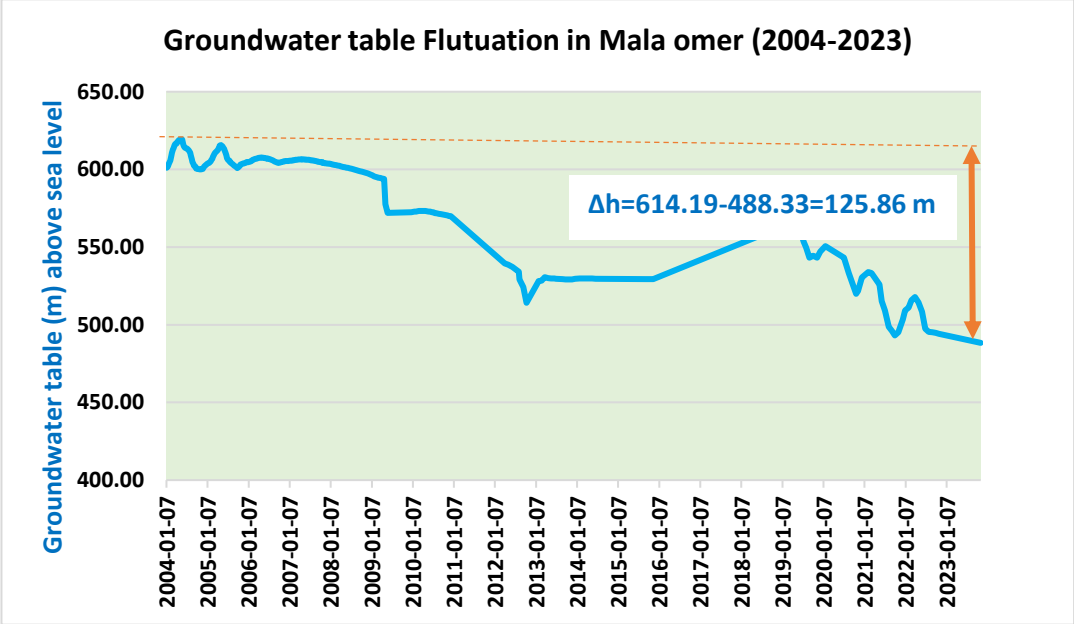


Figure 8: Decline in groundwater table in Mala Omer well during (2004-2023).

Figures 7and 8 illustrates a concerning trend in groundwater levels from 2004 to 2023, revealing a significant decline of 86.2 meters and 125.86m in Kasnazan and mala omer wells respectively. This data underscores a worrisome scenario of groundwater depletion rather than replenishment during the specified period. The substantial decrease in the groundwater table raises alarm bells about the sustainability of water resources in the region [2,4]. Such a decline may have far-reaching consequences, impacting both ecosystems and human activities that rely on this vital water source. Urgent attention and proactive measures are essential to

address the root causes of this depletion and implement sustainable water management practices to safeguard the availability and quality of groundwater for the future [2, 6,13]. To calculate the amount of the groundwater Recharge:

Sample of calculation for Kasnazan well data:

$$\text{Specific yield (Sy)= Recharge (R)/ Change in head (}\Delta h) \quad (1)$$

$$Sy=R/\Delta h \quad (2)$$

$$R =Sy * \Delta h \quad (3)$$

R=0.24 * 86.2 (Δh=-86.2 m, this value obtained from Figure 7).

Thus:

R=-20.70 m (the negative sign means decline in groundwater table).

Sample of calculation for Mala Omer well data:

$$\text{Specific yield (Sy)= Recharge (R)/ Change in head (}\Delta h) \quad (4)$$

$$Sy=R/\Delta h \quad (5)$$

$$R =Sy * \Delta h \quad (6)$$

R=0.24 * 125.86 (Δh=-125.86 m, this value obtained from Figure 8).

Thus:

R=-30.20 m (the negative sign means decline in groundwater table).

Therefore, the indicated value of recharge presents a compelling indicator of inadequate groundwater management practices in the studied area. The decline in recharge is primarily attributed to the adverse effects of urbanization and the construction of impervious structures. The burgeoning development, characterized by impervious buildings and urban infrastructure, has substantially hindered the natural process of groundwater recharge. The Kasnazan and mala omer region, selected as a representative sample of the recharge area in the Erbil basin, exemplifies the repercussions of unchecked urban expansion. The extensive impervious surfaces in this area obstruct the infiltration of rainfall, contributing to the elimination of vital groundwater recharge resources. This emphasizes the urgent need for strategic planning and sustainable development practices that prioritize the preservation of groundwater resources, particularly in vulnerable recharge zones, to ensure the long-term availability of this essential water source.

RESULTS AND DISCUSSION

The results of this study reveal a substantial and concerning decline in groundwater levels within the Erbil basin over the period from 2004 to 2023. The calculated decline of 86.2 meters in the Kasnazan well and 125.86 meters in the Mala Omer well, both situated within recharge zones of the Erbil groundwater basin, underscores the magnitude of the challenge facing this vital water resource. The observed decline in groundwater levels can be attributed to several interrelated factors. Rapid urbanization and population growth in the basin have led to an increase in impervious surfaces, such as roads and buildings, disrupting the natural process of groundwater recharge. These impervious surfaces limit the infiltration of rainfall into the ground, reducing the amount of water reaching the aquifers. The significant decrease in groundwater levels has immediate and far-reaching consequences for the sustainability of water resources in the region. Depleted aquifers not only impact the availability of water for domestic, agricultural, and industrial use but also pose a threat to ecosystems that depend on groundwater for their survival. The decline in groundwater recharge and levels underscores the urgent need for strategic interventions to ensure the sustainable management of water resources in the Erbil basin. Implementing effective land-use planning measures that balance urban development with environmental conservation is critical. Furthermore, the integration of water conservation practices and the promotion of sustainable groundwater use are essential components of any comprehensive strategy. The findings of this study serve as a valuable resource for policymakers, water resource managers, and stakeholders involved in the sustainable development of the Erbil basin. Addressing the identified challenges will require coordinated efforts, informed decision-making, and the adoption of proactive measures to safeguard and replenish the groundwater resources upon which the region heavily relies [22-25].

The comprehensive analysis conducted in this study reveals a significant decline in the groundwater table within the Erbil groundwater basin, with a specific focus on the Kasnazan and Mala Omer wells as a representative sample. The observed decline is primarily attributed to the combined effects of rapid urbanization, population growth, and increased construction in recharge zones. The study employed rigorous calculations to assess the impact on the recharge rate, which demonstrated a notable decrease due to these contributing factors. Rapid urbanization has led to the expansion of built-up areas, resulting in an increase in impervious surfaces such as roads and structures. This urban development has, in turn, hindered the natural process of rainfall infiltration into the ground, diminishing the recharge capacity of the groundwater basin. The population surge further intensifies the demand for water resources, exacerbating the strain on the already declining groundwater levels.

The choice of the Kasnazan and Mala Omer wells as a focal point for the study allows for a localized assessment of the challenges faced by this specific recharge area within the broader Erbil groundwater basin. The findings underscore the need for region-specific strategies and policies to address the implications of urbanization on groundwater resources. Sustainable land use planning, stormwater management, and conservation initiatives are crucial to mitigating the adverse effects of urban development on groundwater levels [6,13]. This study serves as a valuable contribution to understanding the complex interplay between urbanization, population growth, and groundwater sustainability, providing insights that can

inform informed decision-making for resource management in the Erbil groundwater basin and similar regions facing similar challenges.

CONCLUSION

In conclusion, this research has shed light on crucial aspects of groundwater dynamics within the Erbil basin, emphasizing the identification of recharge zones and the consequential decline in water levels. The study, with a focus on the Kasnazan and Mala Omer wells as a representative sample, have revealed a noteworthy decrease in groundwater recharge, primarily attributed to the rapid growth and urbanization observed in the Erbil basin. The expansion of urban areas and the associated increase in impervious surfaces have hindered the natural infiltration of rainfall into the ground, leading to a decline in groundwater levels. The findings underscore the urgency of implementing effective measures for better managing groundwater resources in the Erbil basin. To address the challenges posed by rapid urbanization and population growth, it is essential to adopt sustainable land-use planning strategies. Incorporating green spaces, implementing stormwater management practices, and promoting water conservation initiatives can help mitigate the adverse impacts on recharge zones and groundwater levels. Furthermore, community awareness and engagement are crucial components of successful groundwater management. Public education campaigns can inform residents and businesses about the importance of responsible water use and the consequences of unchecked urban development on groundwater resources.

Finally, this research not only contributes to the understanding of groundwater dynamics in the Erbil basin but also provides actionable insights for policymakers and stakeholders. A holistic approach that integrates sustainable urban planning, community engagement, and conservation efforts is essential for ensuring the long-term viability and resilience of groundwater resources in the Erbil basin. Implementing these recommendations will contribute to the sustainable management of water resources and foster environmental and economic sustainability in the region.

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