Assessing Water Resource Sustainability in Sarchnar Spring Using (QSWAT+) and Remote Sensing

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ABSTRACT

Safeguarding traditional groundwater systems under mounting environmental and Man-made pressures is a pressing challenge for sustainable water management in semi-arid regions. This study investigates the Sarchnar Spring basin in Sulaymaniyah, Kurdistan Region, a vital karst-fed source supplying approximately 32.5 million cubic meters of potable water annually. An integrated modeling approach, combining the Soil and Water Assessment Tool (QSWAT) with remote sensing, is employed to assess the spring's hydrological dynamics and sustainability. Simulations reveal that recharge is predominantly driven by precipitation and surface runoff, with annual estimates showing 99.17 mm of runoff, 346.60 mm of shallow aquifer recharge, and 18.47 mm replenish deeper aquifers. These results emphasize the critical role of shallow groundwater in sustaining spring flow, which is increasingly threatened by drought, urbanization, and over-abstraction. Field observations confirm declining water levels and reduced recharge capacity. To address these challenges, the study proposes a mitigation framework based on low-impact development (LID), green infrastructure (e.g., bioswales, permeable pavements), aquifer protection zones, and water-efficient technologies. These strategies demonstrate practical potential for enhancing groundwater resilience and aligning with integrated water resources management (IWRM) principles. The findings highlight the effectiveness of combining QSWAT+ modeling and remote sensing for sustainable water assessment in karst environments and offer actionable insights for policy and planning in the Kurdistan Region and similar contexts.

Keywords: Sarchnar Spring, Water Resources Management, Urbanization Impact, QGIS, QSWAT+ Model, QSWAT+ Editor, Groundwater Sustainability.

پوختە

پاراستنی سیستەمی ئاوی ژێر زەوی تەقلیدی لە ژێر فشارە ژینگەییەکان و دروستکراوەکانی مرۆڤدا، تەحەدایەکی زەق و زەقە بۆ بەڕێوەبردنی ئاوی بەردەوام لە ناوچە نیمچە وشـــکەکاندا. ئەم توێژینەوەیە بەدواداچوون بۆ حەوزی کانی سەرچنار دەکات لە شاری سلێمانی لە هەرێمی کوردستان، کە سەرچاوەیەکی گرنگە و ساڵانە نزیکەی ٣٢.٥ ملیۆن

مەتر سێجا ئاوی خواردنەوە دابین دەکات. ڕێبازێکی مۆدێلکردنی یەکگرتوو، کە ئامرازی هەڵسەنگاندنی خاک و ئاو (QSWAT)لەگەڵ هەستکردن لە دوورەوە تێکەڵ دەکات، بەکاردەهێنرێت بۆ هەڵسەنگاندنی داینامیکی هایدرۆلۆجی و بەردەوامیی کانییەکە. هاوشێوەکردنەکان دەریدەخەن کە بارگاویکردنەوە بەزۆری بەهۆی بارانبارین و ڕژانی ڕووکارەوەیە، لەگەڵ خەمڵاندنی ساڵانەدا کە ٩٩,١٧ ملم ئاوی ئاو، ٣٤٦,٦٠ ملم بارگاویکردنەوەی ئاوی قووڵ و ١٨,٤٧ ملم پڕکردنەوەی ئاوی قووڵتر نیشان دەدات. ئەم ئەنجامانە جەخت لەسەر ڕۆڵی گرینگی ئاوی ژێر زەوی قووڵ دەکەنەوە لە بەردەوامبوونی لێشاوی بەهاردا، کە تادێت مەترسی لەسەرە بەهۆی وشکەساڵی، شارنشینی و زیادەڕۆیی لە کۆکردنەوە. چاودێری مەیدانی کەمبوونەوەی ئاستی ئاو و کەمبوونەوەی توانای بارگاویکردنەوە پشتڕاست دەکەنەوە. بۆ چارەسەرکردنی ئەم تەحەددیایانە، توێژینەوەکە چوارچێوەیەکی کەمکردنەوە پێشنیار دەکات کە لەسەر بنەمای گەشەپێدانی کەم کاریگەری(LID) ، ژێرخانی سەوز (بۆ نموونە، بایۆسوال، شەقامە ڕژێنەرەکان)، ناوچەی پاراستنی ئاوی زەوی و تەکنەلۆژیای کارامەی ئاو. ئەم ستراتیژیانە توانای پراکتیکی بۆ بەرزکردنەوەی خۆڕاگری ئاوی ژێر زەوی و هاوتەریبکردن لەگەڵ بنەماکانی بەڕێوەبردنی یەکگرتووی سەرچاوە ئاوییەکان (IWRM) نیشان دەدەن. دۆزینەوەکان تیشک دەخەنە سەر کاریگەری تێکەڵکردنی مۆدێلکردنی QSWAT+ و هەستکردن لە دوورەوە بۆ هەڵسەنگاندنی ئاوی بەردەوام لە ژینگەکانی کارست و تێڕوانینێکی کرداریی بۆ سیاسەت و پلاندانان لە هەرێمی کوردستان و چوارچێوە هاوشێوەکان پێشکەش دەکەن.

وشەی سەرەکی: کانیاوی سەرچنار، بەڕێوەبردنی سەرچاوەکانی ئاو، کاریگەری شارنشینی، QGIS، مۆدێلی QSWAT+، سەرنوسەری QSWAT+، بەردەوامیی ئاوی ژێر زەوی.

ملخص

يُمثل الحفاظ على أنظمة المياه الجوفية التقليدية في ظل الضغوط البيئية والبشرية المتزايدة تحديًا مُلحًا للإدارة المستدامة للمياه في المناطق شبه القاحلة. تُجري هذه الدراسة دراسةً على حوض نبع سرجنار في السليمانية، إقليم كردستان، وهو مصدر حيوي يتغذى من الكارست، ويُوفر حوالي ٣٢,٥ مليون متر مكعب من مياه الشرب سنويًا. ويُستخدم نهج نمذجة متكامل يجمع بين أداة تقييم التربة والمياه (QSWAT) والاستشعار عن بُعد لتقييم الديناميكيات الهيدرولوجية واستدامته. تُظهر عمليات المحاكاة أن إعادة التغذية تُعزى في الغالب إلى هطول الأمطار والجريان السطحي، حيث تُظهر التقديرات السنوية ٩٩,١٧ ملم من الجريان السطحي، و٣٤٦,٦٠ ملم من إعادة تغذية طبقة المياه الجوفية الضحلة، و١٨,٤٧ ملم من تجديد طبقات المياه الجوفية العميقة. تؤكد هذه النتائج على الدور الحاسم للمياه الجوفية الضحلة في استدامة تدفق الينابيع، الذي يتعرض لتهديد متزايد من الجفاف والتوسع العمراني والاستنزاف المفرط. تؤكد الملاحظات الميدانية انخفاض منسوب المياه وانخفاض قدرة التغذية. ولمواجهة هذه التحديات، تقترح الدراسة إطار عمل للتخفيف من آثارها قائم على التنمية منخفضة التأثير(LID) ، والبنية التحتية الخضراء (مثل: المسالخ الحيوية، والأرصفة النفاذة)، ومناطق حماية طبقات المياه الجوفية، والتقنيات الموفرة للمياه. تُظهر هذه الاستراتيجيات إمكانات عملية لتعزيز مرونة المياه الجوفية ومواءمتها مع مبادئ الإدارة المتكاملة للموارد المائية .(IWRM) تُبرز النتائج فعالية الجمع بين نمذجة QSWAT+ والاستشعار عن بُعد لتقييم مستدام للمياه في البيئات الكارستية، وتقدم رؤى عملية للسياسات والتخطيط في إقليم كردستان والسياقات المماثلة.

الكلمات المفتاحية: نبع سرچنار، إدارة الموارد المائية، تأثير التوسع العمراني، QGIS، نموذج+QSWAT ، محرر QSWAT+، استدامة المياه الجوفية.

1. Introduction:

Assessing water sustainability at Sarchnar Spring with QSWAT+ and remote sensing involves detailed watershed characterization, leveraging local hydrogeological knowledge, advanced remote sensing data integration, and thorough model calibration against observed spring discharge patterns. This enables better water management and planning for the large population dependent on this critical water source.

The Sarchnar Spring is one of the largest and most important springs in northern Iraq, specifically in the Sulaymaniyah region. It supplies municipal water to around 700,000 to 800,000 inhabitants of Sulaymaniyah city. The spring is located in a complex karst hydrogeological setting at the southeastern plunge of Pira Magroon Mountain, where it emerges at the contact between karstified limestone and marly formations. The geological formations primarily include carbonates from the Cretaceous period that influence groundwater flow paths toward the spring [Salahalddin S. Ali, Zoran Stevanovic and Igor Jemcov, 2009, 87]

Throughout the preceding two decades, the Soil and Water Assessment Tool (SWAT) has achieved widespread global adoption in hydrological modeling applications. However, extensive implementation of the model has exposed inherent limitations and highlighted critical areas requiring further development. The accumulation of numerous enhancements and component modifications has progressively complicated code management and maintenance procedures. To address these challenges and accommodate evolving demands in water resources modeling, substantial revisions to the SWAT framework have been undertaken in recent years, culminating in the development of SWAT, A comprehensively restructured iteration of the modeling platform.

Although the core computational algorithms underlying process simulations have been preserved, substantial restructuring has been implemented in both the software architecture through the adoption of object-oriented programming paradigms and the data management system via the integration of relational database methodologies. These architectural refinements are expected to optimize maintenance workflows, expedite future developmental iterations, and foster interdisciplinary collaboration for the integration of emerging scientific methodologies within SWAT+ computational modules. Additionally, SWAT+ incorporates advanced spatial discretization capabilities that enable more sophisticated representation of hydrological interactions and biogeochemical processes across watershed domains, thereby providing enhanced modeling flexibility for complex hydrological analyses [Yihun Dile, R. Srinivasan and Chris George,QGIS Interface for SWAT+: QSWAT+,2024].

Comprehensive assessment of land cover (LC) change effect on the water balance components using integrated approaches of hydrologic modeling and partial least squares regression (PLSR) provides better understandings of the impact of recent development activities on water resources. The SWAT model was validated at five subbasins and used to simulate the water balance and hydrologic response to LC changes at multiple temporal and spatial scales. PLSR was used to evaluate the significance of the relative influence of LC classes on the hydrologic components [Alemayehu A. Shawul, Sumedha Chakma , Assefa M. Melesse,, 2019,1]

LC changes, like deforestation or agricultural expansion, often increase surface runoff due to reduced infiltration capacity of soils. For example, a study in the Katsina-Ala Basin found that 7.79% increase in surface runoff linked to an 8.19% decrease in forest cover and 11% increase in cultivated land over 20 years, while evapotranspiration and groundwater recharge decreased slightly [Hawa Abdulai1, Helen Oluwakemi Awe-Peter1*, Rakiya Babamaaji1, 2025,1].

SWAT+ hydrological modeling, calibrated through the integration of spatially distributed datasets encompassing topographic elevation, pedological characteristics, land use/land cover classifications, meteorological variables, and discharge measurements, enables the quantification of temporal water balance dynamics. Application within the Diyala River basin in Iraq demonstrated that SWAT+ simulations revealed evapotranspiration comprised approximately 65% of precipitation inputs, while streamflow constituted 37%, with substantial interannual variability in surface runoff generation, thereby illustrating the model's proficiency in capturing spatiotemporal heterogeneity in watershed water balance components [Khudier, Ahmed Sagban and Hamdan, Ahmed Naseh Ahmed,2024,120].

The SWAT+ modeling framework incorporates coupled terrestrial processes (simulating hydrological and nutrient transport mechanisms in response to land management practices) and channel routing algorithms, facilitating comprehensive process representation within watersheds experiencing anthropogenic land use transitions. Sensitivity analyses conducted within these modeling frameworks identify critical parameters governing hydrological response, including the curve number parameter (CNII), surface runoff lag coefficient (SURAG), and soil evaporation compensation factor (ESCO) [Kunle Babaremu, Olalekan Taiwo, Dickson Ajayi,2024]

Land use and land cover transformations exert profound influences on watershed hydrological response patterns, establishing them as fundamental considerations in integrated watershed management and water resources planning strategies. Reforestation scenarios in degraded landscapes demonstrate substantial reductions in surface runoff generation while enhancing groundwater recharge and soil water storage capacity, resulting in increased basin-scale water retention. These findings provide foundational parameters for potential payments for ecosystem services (PES) implementation frameworks [Robertson Fontes Júnior, Abelardo Montenegro, 2019, 110].

Fundamentally, these studies underscore the critical influence of land use patterns in governing catchment water balance dynamics, particularly regarding surface runoff generation, and demonstrate that business-as-usual development scenarios yield elevated water yield and surface runoff compared to afforestation alternatives, though specific quantitative impacts of reforestation require further detailed analysis [Isaac Larbi, Emmanuel Obuobie,2020, 20196]

In this study, an integrated approach will be used to better understand how land use changes and watershed characteristics influence Sarchnar Spring's water balance, supporting effective management for its long-term sustainability.

2. Materials and methods

The impact of change in land cover on water balance components can be effectively studied through hydrological modeling using QSWAT+3.40.8 version. These models simulate hydrological processes such as surface runoff, evapotranspiration, lateral flow, groundwater recharge, and streamflow, allowing examination of how land cover change affects water balance in a watershed.

2.1. Location of the study area

The study area is a sub-basin of the Sharazoor-Piramagroon watershed, located in the northeastern part of Iraq within the Kurdistan Region, specifically to the northwest of the Sulaimani Governorate. Geographically, it lies between latitudes 35°36′00″ and 36°46′00″ N, and longitudes 45°15′00″ and 45°28′00″ E, as illustrated in Figure 1. The total area of the sub-basin is approximately 140 km^2. This basin represents the primary upstream catchment area feeding the Sarchnar Spring—a critical water source for the region—making it central to ongoing concerns about long-term water resource sustainability. The topography of the sub-basin features a gently sloping plain in the western and southern areas adjacent to Sulaimani city, with elevations ranging sharply from 756 to 2088 meters above mean sea level (Figure 2). A significant portion of the land remains untreated or undeveloped. The main river traversing the watershed is ephemeral in nature and extends approximately 23 kilometers in length.

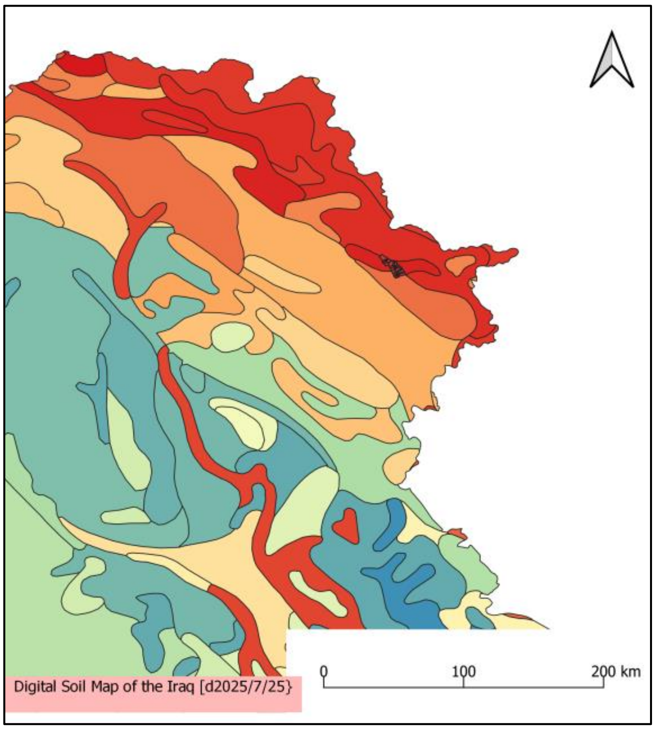


Figure-1: Location of the study area.

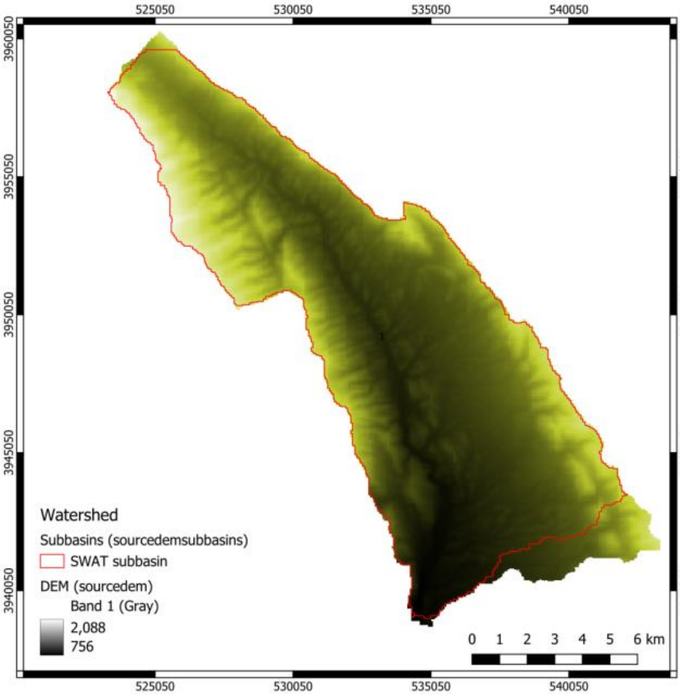


Figure 2: DEM Map of Study Area

2.2. Channel and Stream Network Delineation

The next step involves defining the threshold area for initiating channels and streams within the watershed. This threshold determines where surface flow accumulation is sufficient to form a stream and can be specified in units such as square kilometers. An appropriate threshold value is critical for accurately representing the drainage network (see Figure 3).

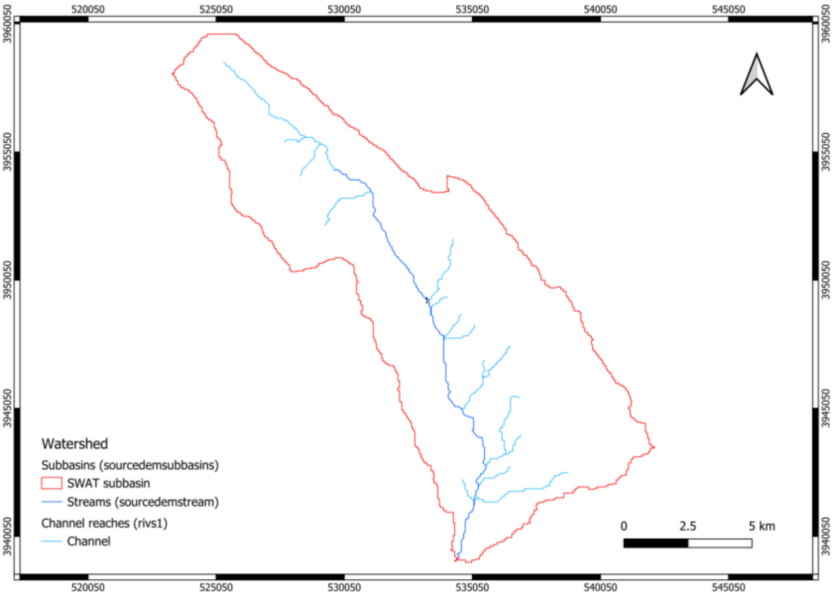


Figure 3: stream and channel of Study Area

2.3. Creating HRUs

2.3.1. Land use

The computational framework requires the determination of Hydrological Response Units (HRUs), which constitute the fundamental spatial discretization employed by SWAT+. These units represent subdivisions of watersheds into homogeneous areas characterized by unique combinations of pedological properties, land use classifications (including crop types), and topographic slope gradients [Salahalddin S. Ali, Zoran Stevanovic and Igor Jemcov, 2009, 89].

The LC data for 2014 and 2021 were derived from Landsat 8 OLI images obtained via the USGS Earth Explorer. Image processing and classification were performed using ENVI Classic 5.1 and ERDAS Imagine 2013 to generate accurate LC maps for the study area.

Supervised classification technique has been used to produce digital Land use/Land cover map, The LC classification methods were applied by defining signature files and assigning the number of LC classes. Post-classification analysis was carried out using QGIS 3.40.8. The LC dataset was reclassified into five major LC classes, each assigned a corresponding four-letter SWAT code: cropland (CROP), rangeland/grassland (RNGB), shrubland/mixed forest (FRST), bare land (BARE), and urban/high-density urban (URBN and URHD), as illustrated in Figure 4.

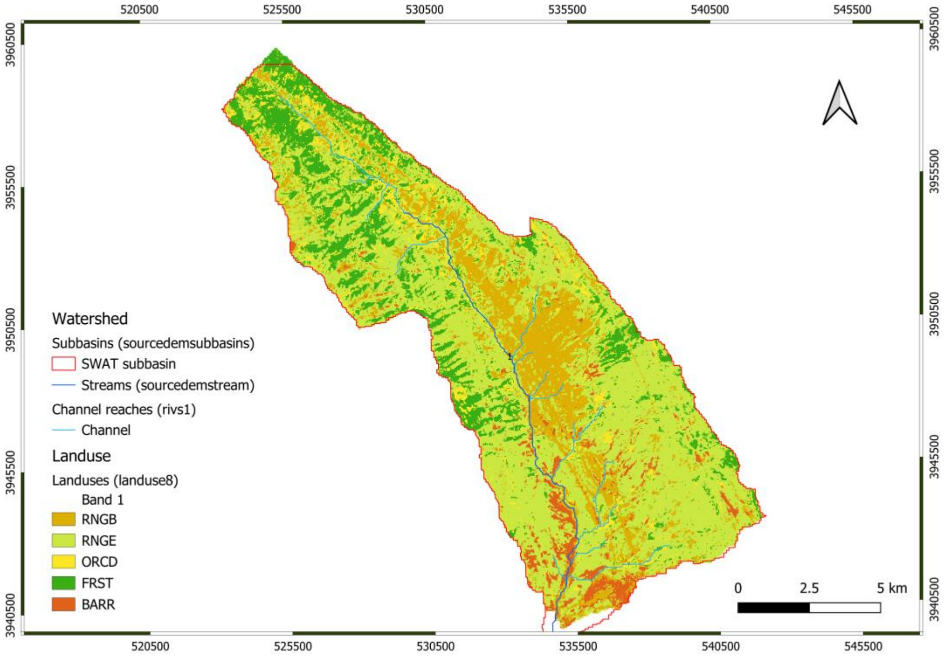


Figure-4: Land Cover Supervised classification.

2.3.2. Soil Map:

Soil physical attributes were initially stored to the SWAT's soil database through an interface, relevant information required for hydrological modeling. The database was linked to soil map through the look up table which was again linked to the soil map. The raster soil map is constructed using five class textures [w. j. Rawls, D. L. Brakensiek and K. E. Saxton ,1982,1318]]as shown inTable:1, and Figure:5.

Table1: Soil database (surface raster layer property) [w. j. Rawls, D. L. Brakensiek and K. E. Saxton ,1982,1318]

CLass texture	%silt	%sand	%clay	%Organic matter	SOLBD	SOLK	SOLAWC	STU	FC	WP
CL	33.01	37.7	29.29	4.65	1.35	0.09	0.14	79.13	33.4	19.23
L	38.48	42.33	19.19	3.64	1.33	0.52	0.14	49.8	28.54	14.04
SaL	24.05	63.15	12.8	2.72	1.4	1.01	0.1	47.36	21.26	10.52
SICL	51.48	14.62	33.9	3.71	1.27	0.06	0.16	52.13	37.6	20.93
SIL	54.29	24.39	21.32	3.54	1.27	0.27	0.18	49.88	32.22	14.5

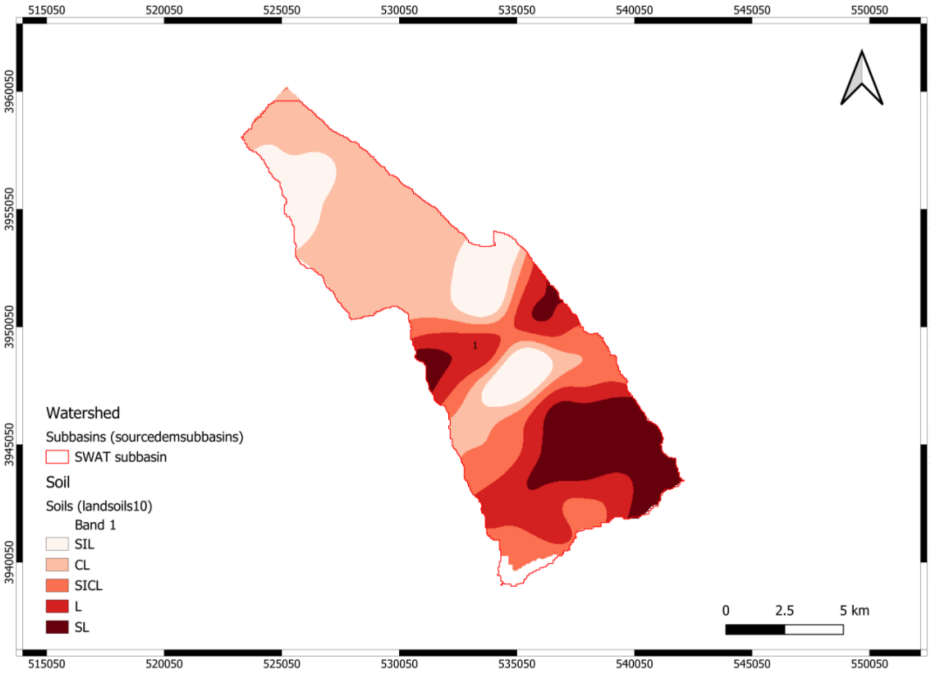


Figure 5: Land Soil Distribution across Study Area.

2.3.3. HRUs Creation

Upon completion of data ingestion and storage procedures, the Single/Multiple HRUs selection becomes available for configuration. The Dominant land use, soil, slope and Dominant HRU methodologies each generate a singular HRU per landscape unit, representing alternative single HRU approaches. The Dominant land use, soil, slope algorithm identifies the land use category with maximum areal coverage within the landscape unit, the pedological class with greatest spatial extent, and the predominant slope classification, subsequently applying these dominant characteristics uniformly across the entire landscape unit. Conversely, the dominant HRU approach evaluates all potential HRU combinations within each landscape unit and selects the configuration with the largest areal representation, designating its associated land use, soil, and slope parameters as representative for the complete landscape unit.

Table 2 presents the land cover disaggregation utilized in the development of Scenario 2, which is subsequently compared with Scenario 1 as illustrated in Figure 6. Following HRU generation, the SWAT+ Editor interface is initiated for model configuration and parameter specification.

3-Results

3.1 Land Cover Change Analysis

The LC change analysis for 2014, 2021, and the projected 2050 scenario—based on the Sulaymaniyah Master Plan—revealed substantial transformations within the Chaqchaq Basin. In 2014, rangeland and grassland (RNGB) dominated the landscape, covering approximately 55.62% of the basin. By 2021, this coverage had declined sharply to 38.50%. In contrast, urban areas (URBN) expanded significantly, increasing from 6.46% in 2014 to 23.81% in 2021. The 2050 expected projection, reflecting planned construction of residential complexes, apartment buildings, commercial facilities, and related infrastructure under the proposed master plan and expanding villages through various detailed plan involving forms to ensure sustainable development and infrastructure, estimates

URBN coverage to reach 57.15% of the Chaqchaq Valley. As shown in Table 2, and illustrated in Figures 9 and 10, the most pronounced urban expansion is concentrated in the mid-southern portion of the basin, particularly in the Sarchnar (Chaqchaq sub-basin) area.

This trend is largely attributed to the region's high population growth and rapid socio-economic development, especially in Sulaymaniyah and its surrounding urban centers. Consequently, natural vegetation and cropland areas have been progressively reduced, with some croplands likely being relocated to adjacent, less developed regions. Additionally, forest and shrubland cover declined throughout the study period, persisting mainly in steeper, upland terrains where land conversion pressures are relatively lower.

Table:2: HRU Report

Area of LC classes

LandCover	RNGB%	Forest%	RNGE%	BARR ,rock%	Urban%	
LC 2014	17.36	15.2	55.62	5.36	6.46	scenario 1
LC 2021	15.23	19.22	38.5	3.24	23.81	scenario 2
LC2050	10.29	15.2	15.00	2.36	57.15	Scenario3 expected Master plan land cover basin 2050

Figure9: Satellite Image 2014-09-15, and masterplane Sulaymaniyah

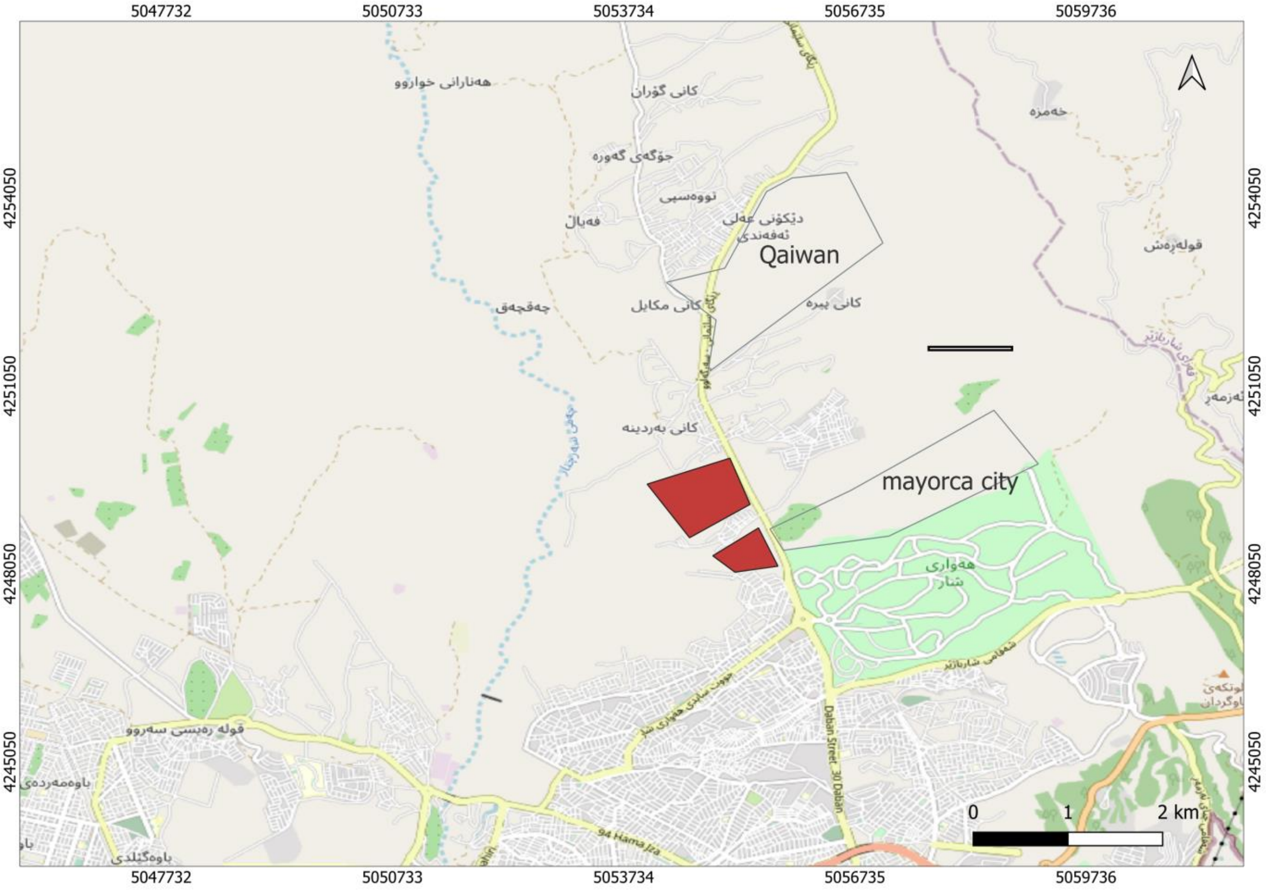
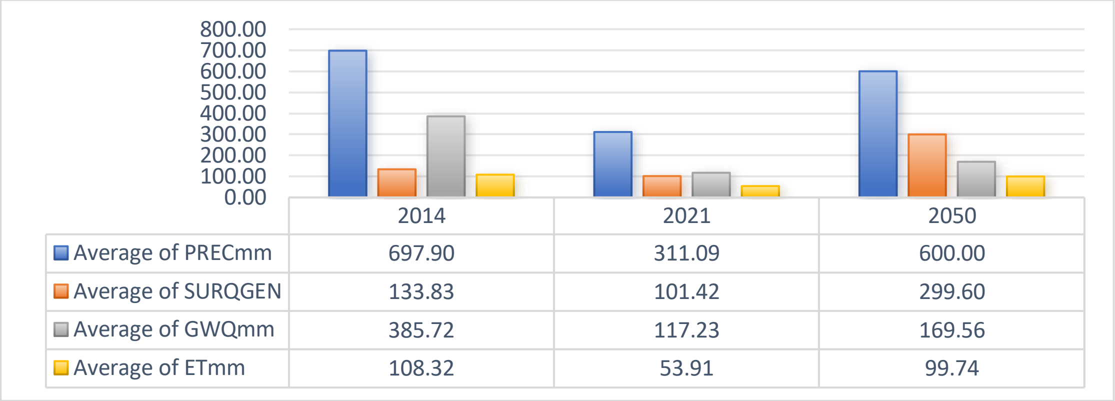


Figure-10 Street Map 2021.

3-2 Impact of Land Cover Changes on Hydrologic Components

The effects of LC changes on key hydrologic components—namely surface runoff (SurfQ), lateral flow (LatQ), groundwater flow (GWQ), and actual evapotranspiration (ET)—were assessed on a mean annual basis for the Chaqchaq basin. The analysis was conducted through three separate QSWAT+ simulations, corresponding to LC scenarios from 2014, 2021, and the proposed master plan for the city of Sulaymaniyah, for 2050. The 2050 scenario was developed by splitting the dominant land cover types to reflect anticipated trends, as summarized in Table 2.

Results indicated that changes in SurfQ and LatQ exhibited greater variability compared to GWQ and ET, as shown in Figure 12. Notably, the 2050 LC scenario yielded higher surface runoff and reduced groundwater and lateral flows relative to earlier periods. This trend can be attributed to increased urban expansion, which reduces infiltration capacity and enhances surface flow. The shift from vegetated to impervious surfaces is a key driver of these hydrologic alterations. Figure 11 shows Annual hydrologic values (mm) for three selected years, further highlighting the hydrological impact of ongoing land use transformation.



	2014	2021	2050
🟦 Average of PRECmm	697.90	311.09	600.00
🟧 Average of SURQGEN	133.83	101.42	299.60
⬜ Average of GWQmm	385.72	117.23	169.56
🟨 Average of ETmm	108.32	53.91	99.74

Figure 11: Annual hydrologic values (mm) three year for basin

4. Discussion

The LC change analysis and SWAT+ simulations for 2014, 2021, and projected 2050 scenarios in the Chaqchaq Basin reveal clear hydrologic impacts driven by urban expansion and vegetation loss. The most notable change is the significant increase in surface runoff (SurfQ) under the 2050 scenario, primarily due to the growth of impervious urban areas, particularly in the Sarchnar subbasin. This urbanization reduces infiltration, thereby increasing runoff and the risk of flash floods, while simultaneously reducing groundwater recharge.

Lateral flow (LatQ) and groundwater flow (GWQ) both showed declining trends over time, indicating diminished subsurface contributions to the water balance. This reduction threatens long-term groundwater sustainability and weakens baseflow during dry periods. Meanwhile, actual evapotranspiration (ET) declined slightly, likely due to the loss of forest and shrubland areas, which were mostly confined to higher elevation zones.

The percentage changes in annual water balance components (Figure 11) further emphasize this shift toward a runoff-dominated system, with reduced hydrologic buffering capacity. This transformation aligns with patterns seen in other rapidly urbanizing basins, where land conversion leads to more variable and intense hydrologic responses.

These findings underscore the importance of sustainable land use planning. Without mitigation—such as reforestation, green infrastructure, and urban zoning controls—continued development will intensify hydrologic stress in the basin. SWAT+ proves to be a valuable tool for forecasting such impacts and guiding integrated watershed management strategies that balance growth with water resource sustainability.

5. Recommendations to Enhance Baseflow

To mitigate the declining trend in groundwater contribution and enhance baseflow in the Chaqchaq Basin, the following measures are recommended:

1. **Reforestation and Vegetative Restoration**

Increasing vegetation cover, particularly in upland and degraded areas, can significantly enhance infiltration and soil moisture retention, promoting groundwater recharge and sustained baseflow.

2. **Implementation of Green Infrastructure**

Urban areas should adopt green infrastructure practices such as permeable pavements, green roofs, rain gardens, and bioswales to reduce surface runoff and enhance local infiltration.

3. **Protection of Recharge Zones**

Identifying and conserving natural recharge areas—especially in karstic and alluvial zones—is essential. Development in these zones should be restricted to maintain their hydrologic function.

4. **Rainwater Harvesting and Managed Aquifer Recharge (MAR)**

Capturing stormwater through surface structures (e.g., check dams, retention ponds) and directing it toward infiltration basins or injection wells can help artificially recharge aquifers and increase baseflow.

5. **Soil Conservation and Land Management Practices**

Encouraging conservation tillage, contour farming, and cover cropping in agricultural areas can improve soil structure and reduce surface runoff, thereby increasing infiltration rates.

6. **Urban Land Use Regulation**

Limiting impervious surface expansion through zoning policies and promoting low-impact development (LID) can minimize the negative effects of urbanization on baseflow.

Public Awareness and Community Involvement

Engaging local communities and stakeholders in watershed stewardship initiatives ensures long-term success and sustainability of baseflow-enhancing practices.

6. Conclusions

This study assessed the impacts of LC changes on key hydrologic components in the Chaqchaq Basin using SWAT+ simulations for the years 2014, 2021, and a projected 2050 scenario. The results revealed a marked increase in surface runoff alongside a decline in groundwater and lateral flows, driven primarily by urban expansion and the reduction of vegetative cover. These shifts indicate diminished infiltration, reduced baseflow, and heightened hydrologic variability, all of which threaten the long-term water sustainability of the region.

To mitigate these risks, an integrated watershed management approach is imperative. Recommended measures include reforestation to restore vegetation cover, adoption of green infrastructure within urban areas, protection of natural recharge zones, and promotion of low-impact development practices. Such interventions can improve infiltration, enhance baseflow, and strengthen water security for Sulaymaniyah and its surrounding communities.

If current patterns of unregulated urban development—such as the construction of residential complexes, high-rise buildings, and other infrastructure—continue unchecked, the Sarchnar Basin is likely to face severe reductions in spring discharge, potentially leading to seasonal or permanent drying of key water sources in the future.

The SWAT+ modeling framework proved to be a reliable and effective tool for quantifying land use impacts on watershed hydrology, offering valuable support for informed, data-driven decision-making in water resource planning and management.

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