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Assimilation Model of Erosion and Soil Moisture Based on Remote Sensing for the Hydraulic and Hydrologic Integration of the Taleghan Watershed

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Abstract

This research focuses on investigating the challenges related to watershed management theory and data accessibility in watersheds, specifically concerning the evaluation of hydrological, water, and soil problems. The first part of the research involves the use of the ARC SWAT and Google Earth Engine software to model the Taleghan watershed, analyzing subbasins separately and in communication with each other. Key parameters such as sedimentation, erosion, soil moisture, and hydrological response were investigated after modeling, calibration, validation, and uncertainty analysis and were evaluated on the basis of the region's formation and watershed parameter types. This approach can help identify potential issues and enable more effective management of the watershed.

A comprehensive study was conducted to investigate specific processes of the hydrological cycle in a particular basin, including a detailed assessment of the balance and formations of the basin, as well as an investigation of the influence of soil moisture and curve number and sediment and erosion. The calibration was performed via the SUFI2 algorithm with an objective function, which is commonly used for hydrological modeling. The precise delineation of the basin and subbasin helped to create a high-precision communication model that accurately represents the system being studied. One key area of focus in this research was erosion potential and the hydrological process of soil moisture, which has been extensively investigated and high-resolution spatial and temporal mapped. Potential scenarios have also been proposed for addressing erosion and soil moisture in the area.

Finally, integration was achieved by calibrating sensitive parameters and combining runoff, erosion and sedimentation; soil moisture; the uncertainty parameter range; the optimization scenario; other relevant factors; and swat-cup affected parameters. This integrated model can be used in other areas with similar climatic conditions to predict productivity and integration. Overall, this study provides a practical and valuable model that could be useful for future research and land management efforts.

Keywords: Assimilation model, Soil moisture, Erosion potential, Remote sensing technology, Integration.

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1 Introduction

Resources are considered among the most important assets of the Earth. When considering resources, the usual thought is that of natural resources and the environment. However, resources currently have a broader definition and direction. For example, plans for food, businesses, health, internet and more are examples of resources that depend on each other for survival. Managing resources can greatly help achieve unity and balanced development. For example, when discussing water resources, understanding their role in the growth and production of many other types of resources is crucial. In a plan or idea such as prevention, calming, containment, and creating the resilience of vital natural resources, their impact on future development takes the form of balanced development. Therefore, planning and managing natural resources have become immensely important.

Furthermore, regarding the human impact on resources, it is essential to note that human actions can disrupt and change our environment, affecting the balance of supply and demand. Interventions and changes can play a radical role in disrupting the balance of natural systems. Searching for and employing dynamic equilibriums and new dynamic systems involves changing processes under various conditions. In many cases, these processes inherently demonstrate a positive impact on the value of the natural resources necessary for human survival.

Recent statistics regarding global warming and climate change have highlighted the importance of climate studies. Water stresses, anomalies, and irregular extractions necessitate the examination of future climate scenarios and temporal and spatial uncertainties. The background of climate studies illustrates the importance of watershed agriculture, and components such as the water supply, surface water flow, runoff, evaporation, precipitation, base and peak flows, extreme events, uncertainty, flow rate and potential evaporation and transpiration have been investigated in various studies. (Figure 1)

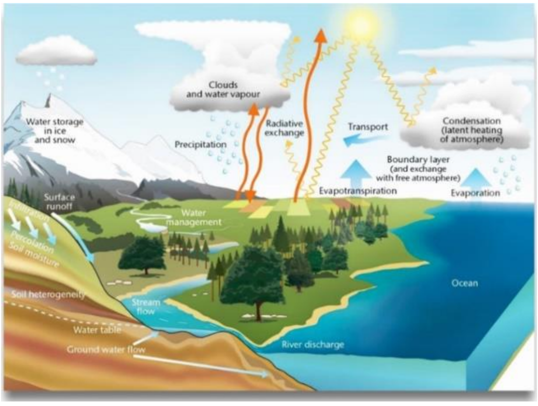


Fig. 1 Diagram of the water cycle M.L. Brusseau, D.B. Walker, K. Fitzsimmons (2019)

Each plays a fundamental role in climate change. In investigations of resources, natural events such as heavy rainfall, floods, soil erosion, and other hardships are among the influential parameters in the watershed.

Owing to their uncertainty, they require assessment, efficiency enhancement, and intelligent management. In investigations of fundamental phenomena, soil erosion is perceived as harmful, and surplus moisture is also considered a major factor in flooding. The phenomena mentioned in the hydrological and hydraulic cycles are influential. This article delves into the precise assessment of these phenomena and hydrological and hydraulic monitoring in the Taleghan water basin, presenting an efficient scenario for increasing efficiency and creating sustainability and coherence. The SWAT hydrological model, which analyzes water balance components and employs all inverse equations and temporal and seasonal variations in the Taleghan Basin, is utilized in this study. The components under investigation include rainfall, climate data, evaporation and transpiration potential, soil type, land cover, slope and elevation, flow direction, water balance, and the hydraulic response of soil inputs to the model. Daily, monthly, seasonal, and annual changes and their combinations are analyzed in advance. These evaluations and ideas pursued in this research are all synchronous with the paradigm of technological advancement combined with state-of-the-art optimization algorithms. One of the main goals and innovations, in addition to determining uncertainty bands and sensitive parameters and defining an applicable hydrological and hydraulic scenario, is to find a close relationship between the model's advanced uncertainty level investigation and the most appropriate time range for changes in basin-level phenomena. Remote sensing, as an executive method and technology-centric method for examining resource-oriented phenomena, monitoring, organizing, and addressing existing gaps from existing conditions as a new cycle, has been proposed. The use of techniques, algorithms, methods for creating time series, appropriate spatial and temporal high-resolution maps and defining a suitable combination of new hybrid models and evolved previous models, along with remote sensing-based satellite image technology, is a new and comprehensive method for innovating in increasing accuracy and harmonizing evaluation and decision-making in the fields of water balance, quantity and quality, practicality, and promotional potential.

The direct impact of changes in erosion and sedimentation processes significantly affects the management and engineering of water and soil projects (Zhou et al.2018). Soil loss due to watershed erosion leads to a reduction in potential and environmental capacity. Downstream of rivers or behind river engineering structures such as dams where the flow rate decreases, a large volume of eroded soil settles, causing reservoir sedimentation or changes in river morphology, which requires substantial costs to address (Li et al., 2020).

Human-induced increases in impermeable surfaces in basins result in reduced water infiltration and a lack of groundwater recharge, which are crucial for preserving groundwater resources, which are essential for environmental protection (Wang et al., 2020). Climate change exacerbates these issues, causing decreased rainfall in arid areas and increased intense rainfall and flash floods, resulting in significant river water loss. The increased occurrence of extreme hydrological phenomena in watersheds, such as droughts, flash floods, local heatwaves, excess moisture, and storms, leads to changes in river hydraulic-hydrological processes and uncertainties (Li et al., 2020). Intense rainfall leads to river flooding, disrupting erosion and sedimentation patterns, altering river morphology, and increasing moisture and flood occurrence. Upstream erosion increases sediment transport rates, whereas downstream sedimentation increases, resulting in environmental consequences, including increased costs for flood control, reservoir siltation, branch channel siltation, and other engineering operations (Kaczan and Orgill-Meyer, 2020). In addition to hydraulic erosion and sedimentation parameters, estimating the effects of climate change and changes in moisture and hydrological cycles is essential for water resource planning. Shaukat et al. (2020) conducted research in the Tarbela watershed in Pakistan and examined the effects of climate change and vegetation cover on hydrological phenomena such as soil moisture and the atmospheric balance. This research also presents an efficient scenario that assumes the significance of surface moisture phenomena in the upper basin.

In conclusion, among the specific research goals are as follows:

* Predicting hydrological and hydraulic cycle scenarios by determining uncertainty bands at watershed and subbasin scales.

* Investigating advanced remote sensing-based moisture and erosion potential rate changes and assessment gaps in the basin and subbasins.

* Fully understanding the effectiveness and sensitivity of climatic parameters and hydraulic and hydrological uncertainty parameters in the model.

While many main aspects of research have been discussed, the following section presents a range of relevant topics in the current literature background and some studies in this field. From a climatic perspective and considering the impact of climate change, nearly all ecosystems, particularly water basins worldwide, are affected by climate change, with differences in the intensity and range of influential characteristics in each ecosystem. This phenomenon is currently linked with development and demand. Growth and sustainable development criteria necessitate defining an integrative level to allocate a suitable spatial and temporal portion of phenomena, majorly fluxes and modules with high quality and resolution for better management. A wide range of studies indicate that phenomena such as water balance, peak flow and base flow (Fu et al. 2007); (Caballero et al., 2007); and groundwater recharge

(Scibek and Allen, 2006); Jyrkama and Sykes, 2007), runoff (Nunes et al., 2009), evaporation and transpiration (Calanca et al., 2006), hydro climate phenomena (Xiong et al., 2009), (Cuo et al., 2009), and seasonal changes and anomalies (Thomas et al., 2007) are significant. However, few studies have been conducted on uncertainties and long-term scenarios. In Iran, almost 90% of the water in watersheds is used in agriculture, with most being used for irrigation. Fifty percent of this water comes from surface sources, and the remaining 50% comes from groundwater (Ardakanian, 2005). Traditional methods for irrigation have efficiency rates between 15% and 36%.

Generally, there is a high correlation between management and modeling in research institutions and centers, where allocations, budgets, and attention to current conditions and initial parameters in modeling are highly important. With respect to hydrological modeling and water quality at the watershed level via SWAT software, this method has become more practical in many monitoring institutions and international and regional planning agencies and environmental conservation agencies in recent decades because of the expensive and costly nature of measurement methods (Jakob et al., 2002). Additionally, various watershed studies have led to the creation of short-term and long-term laws and visions. In Switzerland, for example, a 50% target for optimizing the quantity and quality of hydrological and hydraulic parameters at the watershed level has been outlined (Prasuhn and Sieber, 2005). Furthermore, in the same context, an 80--90% reduction in sediment and erosion concentrations was detected in those years. Thus, the previous perspective regarding the quantitative and qualitative behavior of flow, which was mostly agriculture oriented, has changed today owing to various uses and different modules, in line with urban development and sustainable perspectives toward current resources. Modeling and future scenarios have also changed accordingly (Prasuhn and Sieber, 2005).

Inverse modeling for calibration has attracted considerable interest in recent years (e.g., Beven and Binley, 1992); Abbaspour et al., 1997); (Simunek et al., 1999); (Duan et al., 2003); (Gupta et al., 2003); (Wang et al., 2003). This method is useful not only for calibration but also for dealing with uncertainties extracted from the model for the assimilation integration scenario.

Another aspect of the spectrum is the sensitivity analysis and uncertainty of flow and erosion sediment in the model. Generally, quantity and quality are discussed, and calibration and validation are performed in subsequent stages. Suitable measures are taken regarding erosion and sediment, quantity and quality, and multitemporal and uncertainty ranges. Sediment and erosion intensity and frequency depend on soil variables, climate, society, weather conditions, etc. In general, 55% of the world's soils are under erosion, and the maps provided show the erosion potential of the Taleghan Basin. Suitable temporal and spatial quantities for sediment and erosion are determined via remote sensing technology. The combination of physical and statistical models is very practical in this field. Influential factors in the RUSLE model in materials and methods are fully explained, and codes written for remote sensing and practical modules for this basin are also explained. In recent decades, conceptual models have been fundamental and common, and with the integration of statistical models, they have become more prevalent today, providing better insight and more accurate decision-making. The SWAT model includes a wide range of data and processes that are not directly measurable, quantifiable, or analyzable. Therefore, creating integration in modeling and determining sensitive parameters and uncertainties is inevitable. Complexity in modeling, including spatial and temporal changes in meteorological components such as precipitation and temperature, altitude effects, seasonal regimes, and hydraulic and hydrological processes, poses various challenges in creating a comprehensive and practical model (e.g., Kulkarni Kalra et al., 2010; Ahmad and Singh, 2011; Singh and Goyal, 2016). Owing to these issues, numerous recent studies have explicitly addressed conceptual modeling and integration with statistical models in mountainous watershed areas (e.g., Andrianaki et al., 2019; Wang et al., 2018; Jeong et al., 2020; Zhang et al., 2021).

After a wide range of relevant topics related to the subject under study are presented, we can outline the main objective of this research. Since almost all natural resource basins in the world are facing climate change and this phenomenon has exacerbated water availability, water stress, and water supply issues, they require risk management. The focus of this research is on the Taleghan Basin, which plays a crucial role in supplying drinking water to surrounding areas and has a significant dynamic role in environmental sustainability. Therefore, long-term climate planning with the application of spatially and temporally differentiated impact quantification methods is necessary.

However, despite the importance of the Taleghan region in such monitoring and management, a literature review does not reveal a substantial focus on scenarios at the uncertainty level and the integration of physical and advanced science and conceptual watershed management. as well as the impacts of land use changes and various climates. The range of hydrological models often used in assessing this category of impacts, among other models, includes WaterGap3, HBV, MIKE-SHE, and the Soil and Water Assessment Tool (SWAT). Among these, SWAT has been deemed more suitable because it overcomes data accessibility constraints and has the ability to examine various watershed processes.

Finally, modeling, calibrating, and determining sensitive parameters and uncertainty bands in the basin and subbasins after multiple iterations and customizing combinations have resulted in a specific scenario. This scenario generally includes several hydrological and hydraulic terms and encompasses sensitive uncertainty parameters such as curve number, base flow coefficient, watershed and subbasin delay and concentration, snow melt, erosion model influencing factors, hydraulic conductivity coefficients of flow and soil, etc.

2- Descriptive modeling THEORY and research algorithm and chart

The study area acts like a homogeneous space on a large and practical scale. Modeling starts by dividing the watershed into subbasins. Each subbasin is divided into discrete hydrological response units (HRUs), which are combinations of soil land use parameters, soil moisture content, surface runoff, nutrient cycle, sediment yield, crop growth, and simulated management strategies for each HRU. All the data are subsequently weighted and averaged for the subbasins. Physical characteristics such as slope, channel path length, and climate data are determined for each subbasin. The computational flow, sediment yield, and nutrient force, quantity and quality obtained for each subbasin are harmonized dynamically with the specific basin system. Channel path simulation is performed via storage variables or the Muskingum method.

The sediment yield in SWAT is calculated from the MUSLE equation developed by William and Berndt in 1977. The sediment routing model includes the interaction of two components, sediment deposition and sediment transport, which determine sediment movement at various points along a path on the basis of particle velocity. The settling velocity is determined via the law of (Chow et al., 1988) and is defined as a function of the particle diameter. The depth of deposition during movement is a function of the settling velocity.

In SWAT, water is accounted for at four hydrological response unit levels: snow, the soil profile (0–2 m), shallow aquifers (2–20 m), and deep aquifers. Surface runoff from daily precipitation is calculated via the SCS curve number method, which considers the amount of water present in land cover, soil type, and soil moisture conditions. Peak flow runoff prediction can be computed from explicit formulas (Chow et al., 1988). The watershed concentration time is calculated via the Manning formula considering the channel velocity and watershed area.

The soil profile is divided into several layers, and these layers affect the water processes in the soil, including infiltration, evaporation, lateral flow, and percolation to lower layers. The infiltration component of SWAT predicts flow in the root zone via the soil water storage capacity technique, including return flow, infiltration from ghost flows, and higher flows. The model separately calculates soil and plant evaporation. The evapotranspiration potential can be estimated via the Penman–Monteith, Priestley–Taylor, or Hargreaves methods, depending on data availability.

The soil moisture content is calculated via a distribution function of the soil depth and water content. Crop evapotranspiration is considered a linear function of the evapotranspiration potential. The leaf and root zone environmental indices are limited by the soil water content. For more detailed model descriptions, see (Arnold et al., 1998).

Remote Sensing theory

The capability to define any type of module for phenomena in a time series is available. Spatial and temporal quantification and differentiation with high resolution are fundamental and practical in remote sensing. This science enables the collection of information and customization of surface phenomena without physical contact through the registration and measurement of electromagnetic waves on the Earth's surface. Various factors affect electromagnetic waves, such as atmospheric collisions and radio waves. Then, the waves are reflected, and data are collected at ground stations and analyzed to define and solve questions and hypotheses in a specific field and achieve ideal goals, such as stability, monitoring, and integration

(Figure 2). The number of phenomena and the extent of their changes are determined through analysis. The soil daily temperature and maximum and minimum daily air temperatures are obtained via digital and mathematical methods. Remote sensing has seven main elements. The first phenomenon is the energy source (electromagnetic wave reflector or sunlight), which has an electric and magnetic field, each with a wavelength and frequency. The fourth element is the spectrum. The electromagnetic wave spectra used in remote sensing differ and include the following ranges: ultraviolet, reflective and thermal infrared. The fifth element is the wavelength, with each wavelength in a specific range. Electromagnetic wave dispersion occurs in different directions and is a function of various factors. There are three general scattering processes in the atmosphere. In addition, remote sensing is considered the most conventional application of remote sensing in various fields. These methods include forest monitoring, climate change impact assessment, and military surveillance. The use of Landsat 4-5, 7, and 8 satellites to extract satellite images spanning several decades can provide valuable information for long-term studies and trend analysis. Remote sensing technology has been rapidly advancing, with new sensors and platforms being developed to improve the quality and resolution of the data collected. It is exciting to see how this technology will continue to evolve and be applied to new areas of research and development; moreover, many objects and theories, such as the LULC effect, canopy backscatter, CO_2 diffusion, and runoff dynamics, are presented concerning soil moisture and other components of watersheds (Figure 2).

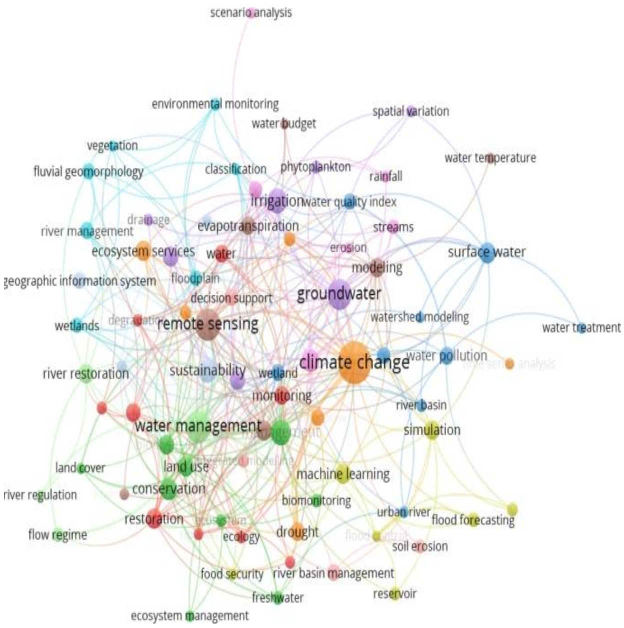


Fig. 2 Homogeneous space of remote sensing data and GIS technologies based on soil and water management systems. Chatrabhuj, Kundan Meshram, , Umank Mishra & , Padam Jee Omar (2024)

The theory of the SWAT and SWAT Cup extensions

The discretization of the basin into HRUs (hydrological response units) results in the creation of multiple files and various output formats in SWAT. Each subbasin requires four files to define it: weather, land use, and water quality parameters, whereas each HRU requires six files, such as chemical data, groundwater, topography, flow management, and soil components. For this study, the discretization of the basin and subbasins resulted in 2046 stored files. Therefore, the calibration method must follow the conceptual framework of SUFI-2 for uncertainty analysis and iterations. In SUFI-2, uniform uncertainty analysis is assumed, while the output uncertainty of the model is quantified such that 95% of the predicted uncertainties fall within the 2.5% and 97.5% cumulative distribution levels of the output variables in Latin hypercube sampling. The main concept of uncertainty in the SUFI-2 algorithm is illustrated in Figure 3. This figure shows that the values of independent parameters, represented by dots, act as mediators of the model's independent response, whereas the uncertainty distributions of several parameters, represented by lines, represent the shaded area and 95% confidence interval.

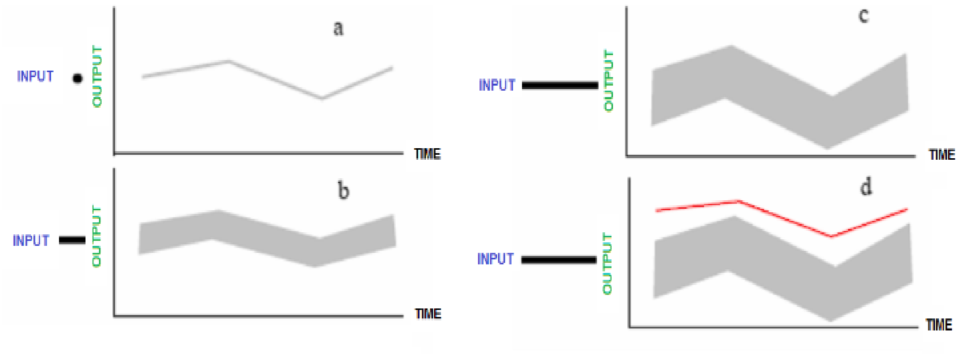


Fig 3 Illustration of the relationship between parameter uncertainty and prediction uncertainty. A single-valued parameter results in a single response (a), whereas an uncertain parameter leads to uncertainty in the prediction depicted by the 95%PPU (b and c). The larger the parameter uncertainty is, the larger the 95PPU (c). If the parameters are at their maximum physical limits and the 95PPU does not bracket the measured response, then the model must be re-evaluated (d). Yang, J., K. C. Abbaspour, P. Reichert, and H. Yang. (2008).

The various stages of theoretical and practical implementation of the SUFI-2 algorithm by researchers, such as (McKay et al., 1979), (Press et al., 1992), (Legates and McCabe, 1999), (Gupta et al., 1998), and (Duan et al., 2003), have been examined across a wide spectrum of parameters, including the following:

1. Range of uncertainty variables,

2. Influences of initial dimensionless parameters such as soil type, land cover, moisture, and land use,

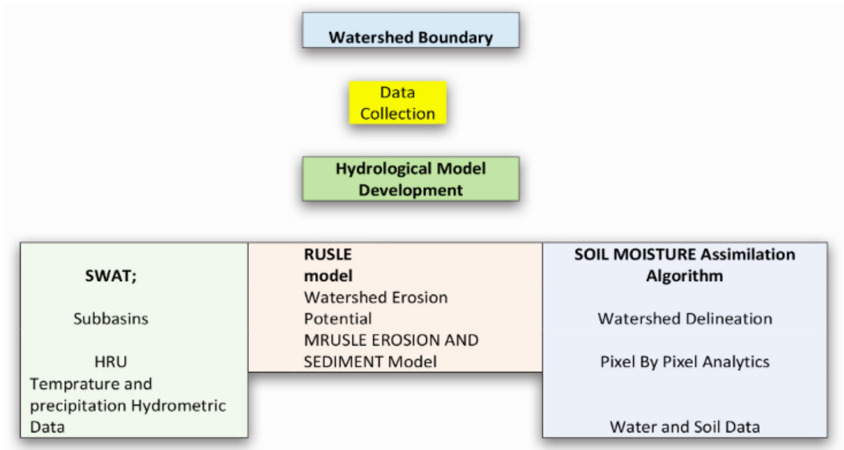
3. The sensitivity matrix is

4. The performance function and other practical indicators,

5. Data standardization in science.

Algorithm and flowchart results for the calibration and validation of the model and the presentation of the hydrological and hydraulic scenarios:

The SWAT hydrological model, in conjunction with hydraulic components, quantifies moisture through algorithms such as the soil moisture routine, soil hydrological response (and the use of extensions such as SWAT in GIS), as well as software such as Google Earth Engine, ENVI, GIS, etc. Some calibration techniques, coupled with the integration of various impact phenomena and risk assessment using different data analysis techniques with remote sensing technology, are considered essential in providing suitable models and scenarios (such as excess moisture, resulting in runoff, and increased water storage and drinking capacity) in conjunction with other concepts previously mentioned. These analyses are calibrated in SWAT-CUP software (Figure 4).



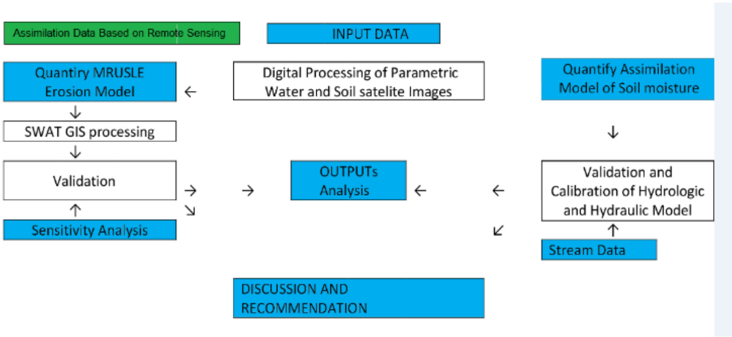


Fig. 4 Modeling, flowchart and scenario outputs and methodology framework

3- Important characteristics of the study area

The study area contains the upstream basin of Taleghan Dam and the stream that flows into the dam. The coordinates of the region range from 40° 05' 36" to 40° 21' 36" north latitude and from 40° 36' 50" to 16° 11' 51" east longitude. (Figure 5). On the basis of the provided information, this study focuses on one of the dynamic forms, the flourishing of various behaviors over different times, which may be influenced by environmental factors. It is intriguing to consider what specific factors are taken into account and how they may impact the biodiversity of this area. Taleghan Dam was built with the aim of supplying drinking water to cities such as Tehran and Karaj and providing water to downstream cities such as Savojbolagh and Qazvin. Additionally, the dam serves as a flood control measure to protect the area from potential floods. Creating a suitable space for tourism was also one of the objectives of this project, as it could contribute to the local economy and foster the development of the tourism ecosystem in the region, and these are current conditions imperative considerations for watershed integration.

3.4. Taleghan Basin climate

In terms of climate, the study area comprises a total of 9 stations, including 6 rainfall stations monitored by the Ministry of Energy and 3 synoptic stations. The rainfall stations recorded the average rainfall over the past 20 years: Shahrak, 471 mm; Jowestan, 549 mm; and Galinak, 446 mm.

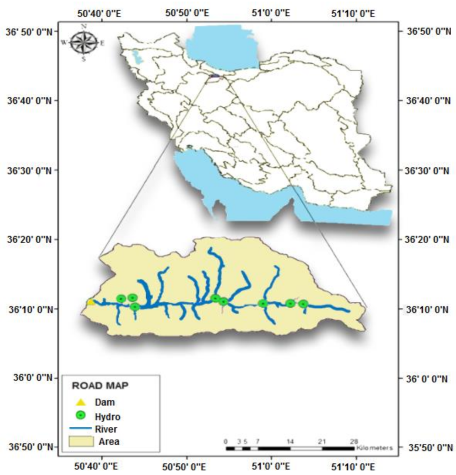


Fig 5. Map of the geographical location of the study area

The upstream Taleghan watershed indicates that land use changes in Taleghan have been negative due to dam construction and growth and demographic changes. This has led to an increase in abandoned lands, emphasizing the importance of land use in the region's economy. The map shows that third-degree rangelands constitute the majority of land use in this area. Villages near rivers have been affected by river sedimentation, highlighting the need for land management activities in rangelands to address this issue. To achieve the research goals, land use maps for different years (2001--2006--2016) were prepared using data from various organizations and satellite images. The impact of land use changes on the intensity of runoff and erosion in the basin is demonstrated via the SWAT model. Addressing negative land use changes in Taleghan and focusing on sustainable land management practices and hydraulic–hydrological calibration and integration based on wet and dry scenarios (soil moisture, erosion, sedimentation, etc.) are crucial for environmental protection and regional economic support. Furthermore, the SWAT model's structure can be highlighted, as it consists of a set of mathematical equations and empirical formulas designed to simulate various parameters on a daily, monthly and yearly basis. Additionally, the hydrological components of the SWAT model based on the water balance equation are presented, providing a tool for assessing water and soil. The hydrological gradient in the SWAT model affects the water balance in different parts of the environment, enabling predictions of how land use changes or management strategies impact water resources.

In addition to its application in the Taleghan watershed, the structure of SWAT can be highlighted. The SWAT model comprises various mathematical equations and empirical formulas designed to simulate different parameters on a daily, monthly and yearly basis (Neitsch et al., 2005). Furthermore, the hydrological components of the SWAT model, which are based on hydrological gradient equation (1), are presented.

Eq. (1) $$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a + W_{seep} - Q_{gw})i$$

Equation (1), the water balance equation, is used for assessing water and soil. This equation calculates the final amount of water in the soil on a daily basis (SWt) on the basis of various factors. These factors include:

*Initial amount of water in the soil (SWo)

* Precipitation on a given day (Rday)

* Surface runoff (Qsurf)

* Evaporation and transpiration (Ea)

* Water in the plant roots (Wseep) and baseflow (Qgw)

The hydrological gradient in the SWAT model depends on the variables of this component at the watershed and environmental levels, which can influence the water balance in different parts of the environment. By modeling hydrological gradients and using the water balance equation, the SWAT model can predict how changes in land use or management strategies affect water resources.

4- Research Findings

4-1-Implementation Results of the SWAT Model

There are two main steps in simulating the hydrological model: the dry phase and the water phase. Advanced modeling In the dry phase, different inputs, such as water, sediment and nutrients, enter the main river network. This is an important stage in simulation because it sets the initial conditions for the movement of water and other components in the next water phase. In the water phase or flow phase, the movement of water, sediment and other nutrients is simulated to understand how they move through the river network. This stage helps modelers understand how various factors, such as land use changes, precipitation patterns, and climate changes, may affect water accessibility and quality. Generally, hydrological modeling is a vital tool for understanding and managing water resources. By simulating real-world scenarios, hydrological models can help decision-makers predict and mitigate potential impacts on water resources and ensure sustainable use for future generations. In this study, a hydrological model using 47 subbasins and 257-hour hydrological response units was developed, and with climate data (precipitation and temperature), this model was implemented for the period from 1992--2018. You have also mentioned selecting a 3-year warm-up period for model preparation before analyzing the results. The warm-up period is necessary to ensure that the model reaches a stable state. Furthermore, the initial results were examined in the SWAT assessment section. However, these results were obtained before the calibration process, meaning that they may not accurately reflect the model's performance. validation (Table 1) is an important step in the model development process, as it allows the model to adjust parameters and improve the accuracy of model outputs. Good progress has been made in the development of hydrological models. Additionally, in this study, the SUFI2 program was used for model validation. For calibration, it is necessary to use 32 parameters affecting the flow in the SWAT-CUP software according to Table 2. In this research, as an innovation in calibrating simulations and observation flows at all the seismic stations and introducing hydraulic and hydrological scenarios and perspectives, the effects of different soil moisture calibration methods, as well as the range of changes in several influential parameters, are presented. The analysis of the uncertainty band (Figure 7) in the Taleghan subbasins also revealed a narrow band width with appropriate uniformity.

Table 1 Evaluation efficiency of the model in the calibration and validation stages

Validation				Calibration				Station	No.
R-FACTOR	P-FACTOR	R^2	NSE	R-FACTOR	P-FACTOR	R^2	NSE		
0	0.03	0.68	0.58	0.03	0.07	0.73	0.64	GoteDeh	1
0	0.2	0.71	0.67	0.42	0.26	0.77	0.72	DAhdar	2
0	0.1	0.7	0.66	0.26	0.29	0.77	0.73	Joestan	3
0	0.3	0.81	0.75	0.4	0.44	0.81	0.8	Alizan	4
0	0.2	0.65	0.56	0.3	0.4	0.72	0.65	Glinc	5
0	0.1	0.56	0.45	0.32	0.56	0.65	0.56	Mehran	6
0	0.3	0.58	0.48	0.71	0.37	0.67	0.53	Narin	7
0	0.09	0.61	0.61	0.14	0.35	0.88	0.76	Taleghan	8

4-2- Determination of Optimal Parameter Values after Validation

A key finding is that the identification of sensitive parameters and uncertainty analysis, following calibration and validation, are deeply advanced and linked with multiple methods, including initial and advanced modeling, as well as remote and combined sensing. The most influential parameter and its optimal value for the studied watershed were extracted after evaluation on the basis of the Nash–Sutcliffe efficiency (NSE) and correlation (R2) indices from among the parameters presented in Table (1) and stabilized for the target model range. After thousands of iterations and combinations, the uncertainty parameters were presented at the entire basin scale, whereas the primary research was conducted at the subbasin scale both temporally and spatially. (Table 2)

TABLE 2 Parameters affecting the amount of upstream runoff in the SWAT-CUP model

Optimum amount	Change range		Parameter	No
0.64	0	1	Alpha_Bf	1
0.69	0	1	Alpha_Bnk	2
20	0	100	Canmx	3
0.09	0	1	SURLAG	4
0.2	0	1	Ch_N2	5
-0.1	-0.06	0.6	Cn2	6
0.26	0	1	Esco	7
0.32	0	1	Epco	8
459	0	500	Gw_Delay	9
0.15	0	50	Gw_REVAP	10
1.3	0	500	Gwqmn	11
454	0	500	Ch_L2	12
10	0	10	Ch_S2	13
0.82	0	1	Rchrg_Dp	14
0.2	0	1	TIMP	15
-1.84	-20	20	Sftmp	16
0.92	0	10	Shallst	17
50	0	50	GWHT	18
9	-10	10	TLAPS	19
7.62	0	20	Smfmn	20
3.25	0	20	Smfmx	21
6.54	0	20	CH_S1	22
6.73	0	20	Ch_L1	23
5.5	0	152	SLSOIL	24
0.9	0	30	OV_N	25
168	0	180	LAT_TTIME	26
-0.05	-0.8	0.8	Sol_k	27
0.7	-0.8	0.8	Sol_bd	28
0.32	0	1	USLE_P	29
0.32	0	1	USLE_C	30
0.26	0	1	USLE_K	31
0.2	0	1	USLE_Landscape	32

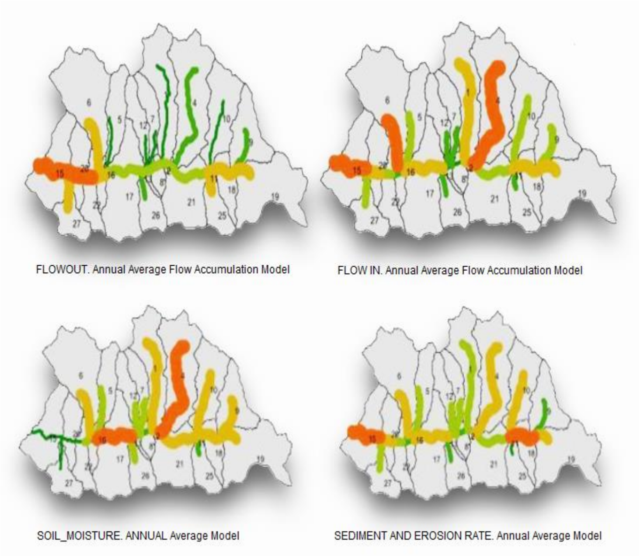


Fig. 6 Integrated assimilation map of the optimized scenario of soil moisture and soil loss potential and flow in the Taleghan Basin

A study was conducted to assess the amount of sediment caused by erosion and the ability of SWAT to estimate sediment levels in the area. The aim was to identify erosion-prone and sediment-prone areas by combining different models and calibrating and validating sediment data extracted from hydrological stations in the region. Additionally, sensitive subbasins and waterways were identified via the SWAT OUTPUT VIEWER software Above (Figure 6). The results of sediment calibration and validation at the respective stations were performed with the SWAT-cup model. Furthermore, erosion-prone subbasins and waterways are displayed in Figure (6). The soil moisture levels from the SWAT algorithm and model calibration were compared via various methods in SWAT CUP software to increase accuracy. A comparison of soil moisture measurement methods was also performed for model calibration to foster innovation. Additionally, the development of the soil moisture model involved the integration of remote sensing techniques. (Figure 9, Figure 10 and Figure 11).

Its simplicity and feasibility, compatibility with GIS and remote sensing techniques, and data availability make the RUSLE (Figure 7) the most widely used empirical model for estimating soil erosion. (Tian et al., 2021); (Kebede et al., 2020); (Maqsoom et al., 2020); (Xiong et al., 2019). The RUSLE model Eq. (2) (A = R*K*C*LS*P) estimates the long-term soil loss rate (A) in t ha−1 year-1 as the product of five RUSLE factors, such as precipitation erosivity (R) in MJ mm ha -1 h-1yr-1 soil edibility (K) in t ha h ha−1MJ−1 mm−1, topographic effect (LS) (dimensionless), cover and management (C) dimensionless and erosion control practice (P) (dimensionless) (Thakuriah, 2023); (Usman et al., 2023); (Luvai et al., 2022); (Teshome et al., 2022); (López-Vicente and Guzmán, 2021); (Biddoccu et al., 2020); (Maqsoom et al., (2020); (Nehaï and Guettouche, 2020); (Renard et al., 1997). The R, K, LS, C and P factors represent measures of the erosive power of rainfall to detach and transport soils (Asmamaw and Mohammed, 2019), the inherent susceptibility of the soil to erosion by water (Gurtekin and Gökçe, 2021); (Panditharathne et al., 2019), how the land slope length and slope steepness influence soil erosion (Panditharathne et al., 2019), how land cover and other management practices prevent the rate of soil erosion (Sinshaw et al., 2021); (Tanyaş et al., 2015) and the effectiveness of erosion control measures to prevent soil loss and runoff (Kebede et al., 2020); (Xiong et al., 2019).

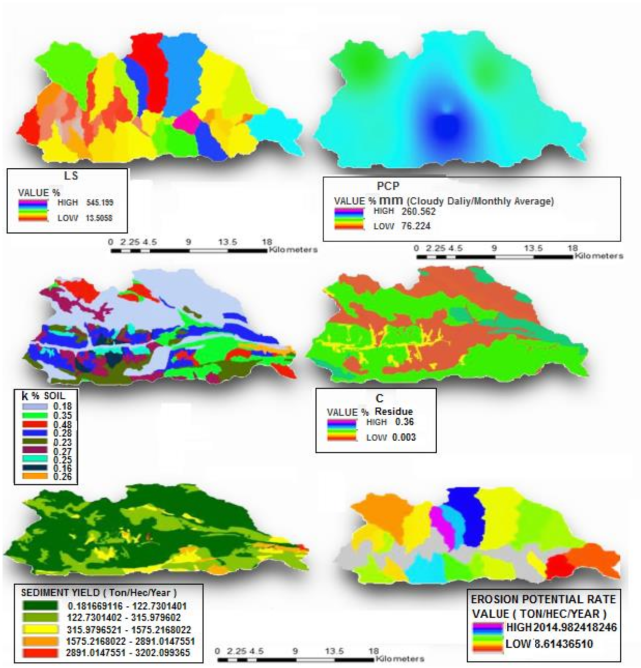


Fig. 7 RUSLE model factor maps and annual soil erosion map in tons per hectare per year and erosion potential assimilation model map of the Taleghan watershed

Some important parameters and finding uncertainty bands (Figure 8) have been studied in this research. For example, uncertainty bands appeared after calibrations and multiple iterations. Before that, modeling was performed via the reverse equation in SWAT software, and model calibration was performed, followed by the output and validation (Table 1) of sensitive parameters (Table 2) being extracted.

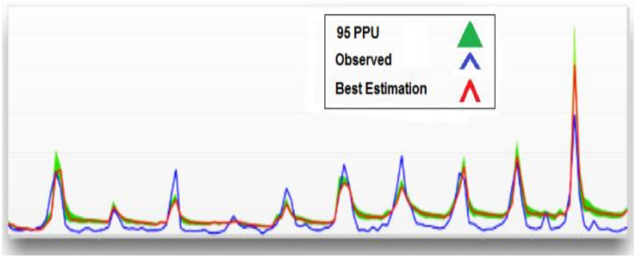


Fig. 8 Uncertainty bond formation after calibration and validation for the watershed

A unified hydraulic and hydrological scenario was presented on the basis of sensitive parameters and other influential parameters to create harmony between hydrology and hydraulics in the watershed (Figure 12). In this scenario, overall, influential parameters such as a 30% range of future CNs for improving climate conditions and preventing floods by reaching the upstream drainage threshold in sensitive subbasins with high altitude impacts were mentioned. Additionally, actions such as groundwater recharge by 25% and 20% sustainable management structural and nonstructural measures, such as reservoirs and ponds, point sources, septic tanks and pollution control systems, land use/land cover management, and vegetation index ranges and filter strips (Table 1), as well as csc practices in specific upstream subbasins for rainy or perennial months or changes in land use and the impact of canopy coverage and its height up to 10%, were considered. The scenario outlined in Table 3 fully identifies the influential parameters on upstream runoff in the basin, and several quantitative and qualitative parameters affecting the mentioned scenario were analyzed. Furthermore, upgrading channel grading and time delay management up to 20% upstream, as well as increasing vegetation cover and upgrading topsoil based on the RUSLE model (Figure 8) parameters mentioned in the runoff and sediment yield scenario and subbasins by 25%, are among the foundations discussed in this research scenario. All changes in this scenario adapt to uncertainty bands and comply with the range of watershed and subbasin parameters and the effects of parameters on each other (Table 3).

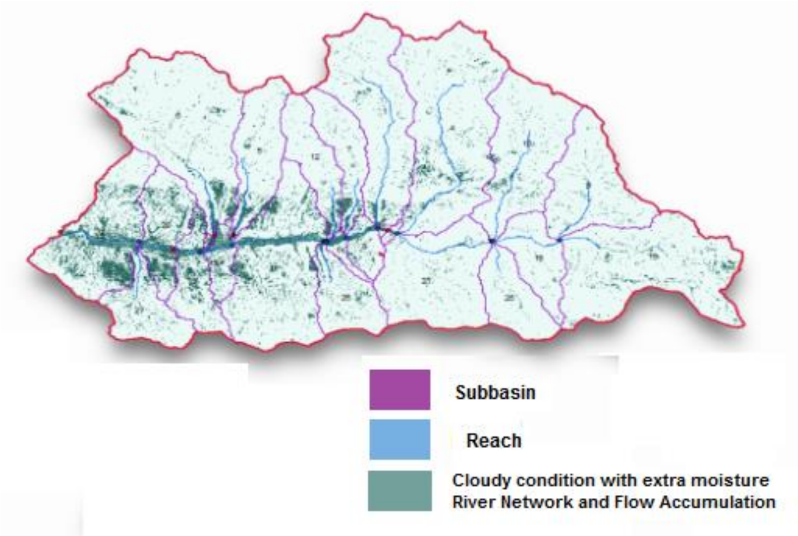


Fig. 9 Rainfall network under cloudy and high humidity conditions

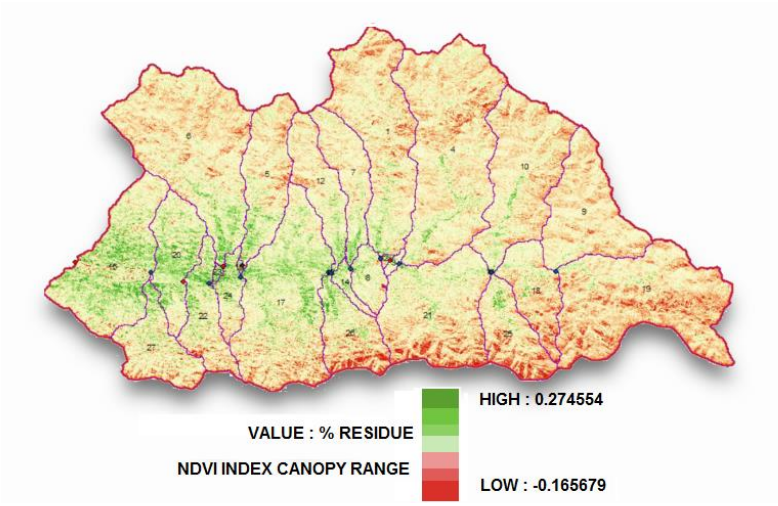


Fig. 10 Canopy distribution index of the taleghan watershed

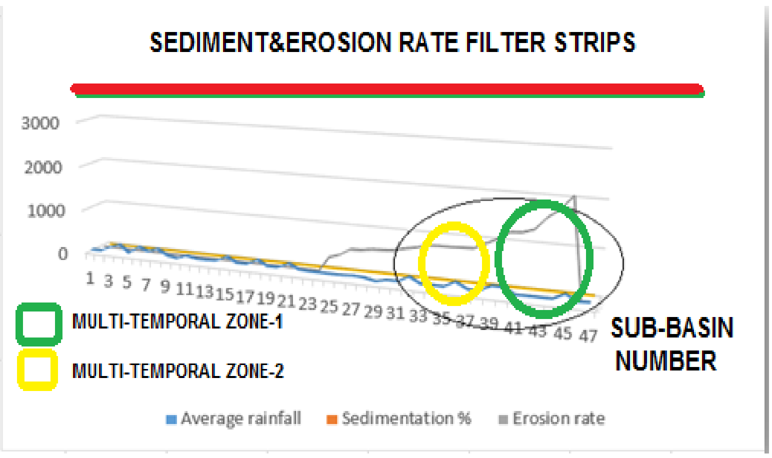


Chart 1 Soil loss threshold strip filter for the Taleghan subbasins

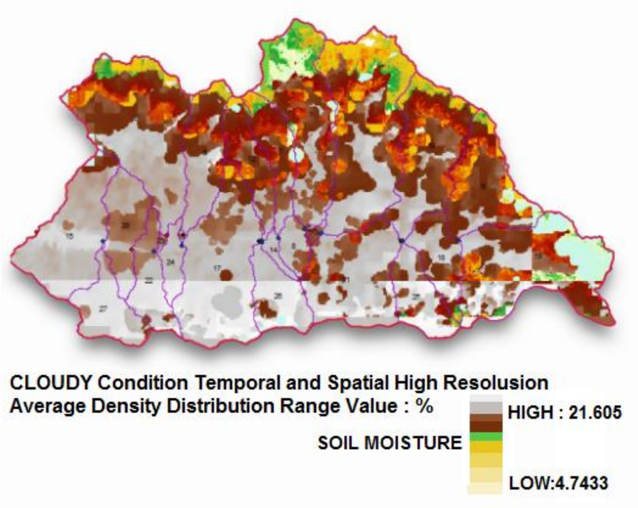


Fig. 11 Assimilation map of the soil moisture of the taleghan watershed

Another range of research is related to the assimilation (Figure 11) of the model with remote sensing technology. In this context, in the Google Earth Engine platform, in addition to investigating the time series of parameters and different modules and majors of the basin and subbins, the Sentinel-1 satellite images were coded and applied for moisture with a spatial and temporal resolution (Figure 11) of 100 m and a cloud time, as were the Landsat-7 satellite data with a spatial and temporal resolution of 10 m and a cloudy time for the developed RUSLE model of erosion, the definitions of the applied cloud filters, the impacts of vegetation, waterway networks, land use and other parameters affecting the soil moisture (Figure 9, Figure 10 and Figure 11) and erosion of the watershed were investigated in advance. Creating a better view for decision-making and the ability to link with SWAT model source codes for the development of SWAT source codes and the spatial and temporal separation of the reality of phenomena with appropriate quality at the basin scale are among the capabilities of model integration.

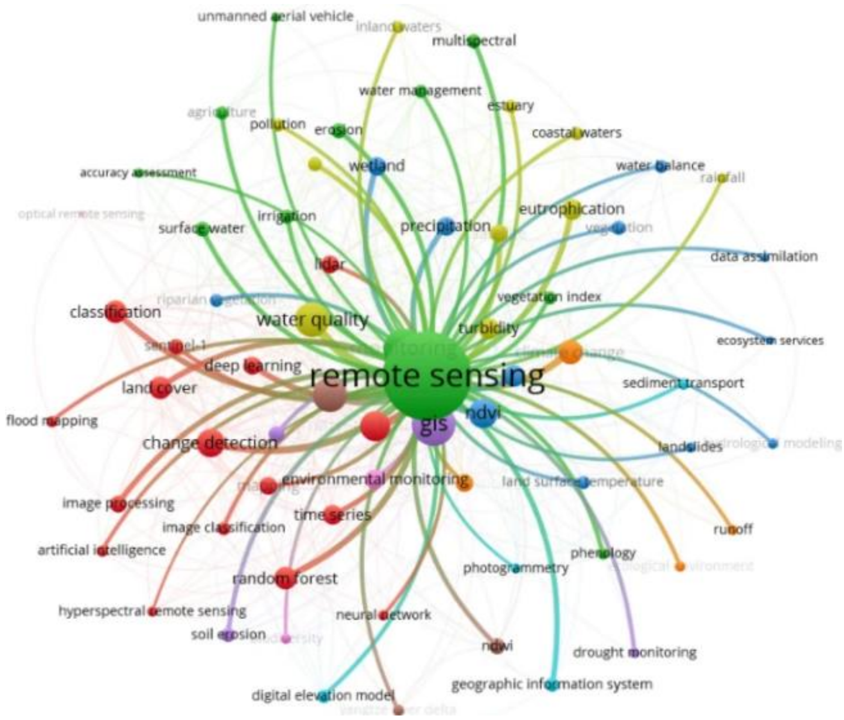


Fig. 12 Integration of space of remote sensing data and GIS technologies in river management systems. Chatrabhuj, Kundan Meshram, , Umank Mishra & , Padam Jee Omar (2024)

Table 3 TALEGHAN watershed integration scenarios

No	PARAMETERS	CHANGE RANGE		OPTIMUM AMOUNT	CLASSIFICATION SCENARIO SENSITIVE PARAMETERS	% INTEGRATION RATE CHANGE CONSIDERATION	THE MOST IMPORTANT INTEGRATION MEASURES
1	Alpha_Bf	0	1	0.64	SURFACE RUNOFF& FLOW	30%	UPSTREAM DYNAMIC DRAINAGE FOR CONTROL EXCESSIVE SOIL MOISTURE AND REDUCE FLOODING POTENTIAL
2	Alpha_Bnk	0	1	0.69			
3	Canmx	0	100	20			
4	SURLAG	0	1	0.09			
5	Ch_N2	0	1	0.2			
6	Cn2	-0.6	0.6	0.1-			
7	Esco	0	1	0.26			
8	Epco	0	1	0.32			
9	Gw_Delay	0	500	459	BASEFLOW	5%	SURFACE LAND USE/LAND COVER CHANGE FOR SHALLOW AQUIFIER
10	Gw_REVAP	0	50	0.15			
11	Gwqmn	0	500	1.3			
12	Ch_L2	0	500	454	HYDRAULIC ENHANCEMENT	20%	RESERVIOR-POINT SOURCES-SEPTIC TANK FOR SUBBASIN
13	Ch_S2	0	10	10			
14	Rchrg_Dp	0	1	0.82	BASEFLOW	5%	DOMINANT LU/LC SOIL CONSERVATION AND WATER MANAGEMENT
15	TIMP	0	1	0.2	SNOW	25%	SUBBASIN SEASONAL MANAGEMENET RESERVIOR &POND AND WATER YIELD
16	Sftmp	-20	20	-1.82			
17	Shallst	0	10	0.92	HYDRAULIC ENHANCEMENT	20%	HYDRAULIC CONDUCTIVITY AND STREAM PLAPS AND TLAPS
18	GWHT	0	50	50			
19	TLAPS	-10	10	9			
20	Smfmn	0	20	7.62	SNOW	25%	FILTER STRIPS
21	Smfmx	0	20	3.25			
22	CH_S1	0	20	6.54	HYDRAULIC ENHANCEMENT	20%	CHANNEL DEGREE
23	Ch_L1	0	20	6.73			
24	SLSOIL	0	152	5.5	SOIL AND POLLUTION	7%	NUTRINET
25	OV_N	0	30	0.9	SURFACE RUNOFF& FLOW	30%	EXCESSIVE SOIL MOISTURE
26	LAT_TTIME	0	180	168	HYDRAULIC ENHANCEMENT	20%	GRADIENT
27	Sol_k	0.8–	0.8	0.05-	SOIL AND POLLUTION	7%	NITRATE AND NITRITES
28	Sol_bd	0.8-	0.8	0.7			
29	USLE_K	0	1	0.24	SEDIMENT FROM CHANNEL & LANDSCAPE	25%	CSC MEARURES FILTER STRIPT LANDUSE/LAND COVER MANAGEMENT GROUNDWATER DISCHARGE MULTI-TEMPORAL DRAINAGE SYSTEM VEGETATION INDEX AND ANOTHER MEASURES FOR REDUCING EROSION POTENTIAL
30	USLE_P	0	1	0.25			
31	USLE_R	0	1	0.27			
32	USLE LANDSCAPE	0	1	0.4			

5. Discussion, Conclusion, and Recommendations

5-1- In this paper, in addition to the presented results, the process of calibration and optimization of model parameters for better fitting of observed and simulated data has been examined. The approach involves not only calibration on the basis of influential parameters such as soil moisture but also the use of a multiobjective function. This objective function can utilize a multiobjective optimization function for calibration by applying up-to-date indices.

Various aspects of integrated water resource management include the impacts of land use changes, urbanization, deforestation, agriculture, industry, hydrological processes, water quality, erosion, water resources, human health, resilience-building methods, identifying appropriate protective measures with significant negative environmental impacts, nutrient pollution, pesticide pollution, sedimentation, and other aspects, such as irrigation effects, livestock waste, greenhouse gases, protective soil cultivation, and the costs and risks of reduction, all of which could be considered updated amendments for the comprehensive management strategy of basins.

5-2- A strip filter has been constructed as an indicator of sustainable losses absorbed by sediment transfer efficiency, erosion rate, and runoff volume as a measure of watershed hydraulic integrity for the Taleghan watershed. The average, maximum, and minimum values in the subwatersheds are measured, and an appropriate strip filter is defined on the basis of a multitemporal approach. (chart 1)

5-3- Generally, when discussing the impacts of climate change, another process to consider is managing watershed and subwatershed structures, both structural and nonstructural. Elements such as water resources (green water flow, green water storage, blue water) and soil moisture, among others, are important factors. Additionally, water quality, sedimentation, evaporation, green water flow, the root zone, the unsaturated zone, the moisture zone, shallow aquifers (unlimited), barrier layers, lateral flow, return flow, food security, deep aquifers (limited), water security (population), green water storage, and other climate change effects of reducing and protecting forests and forest restoration for sustainable agriculture (livestock, etc.), CO2 production, adaptation, adaptive planning—identifying risk areas, surface runoff, groundwater recharge, and management—strategies to address changing precipitation patterns, water scarcity, etc., ecosystem protection, and restoration—preserving forests, wetlands, and coastal areas that provide ecosystem agriculture and food security, health and disaster preparedness, community participation and education, extreme events, compound extreme events, water availability, water flow, water quality, drought, flood, integrated water resource management, integrated water planning, supply and demand for quality water—providing drinking water, irrigation, and ecosystem health, infrastructure, environmental considerations for current and future needs, and stakeholder participation (optimization), governmental organizations, water facilities, farmers, industries, and nongovernmental organizations. Integrated water resource management for climate change adaptation: (updating infrastructure) strategies to adapt to changing weather patterns and extreme events such as floods and droughts, drainage channels, and maximum peackflow and proceeding from bonds, such as total project cost, planned start operations, applicant, who receives water, claimed benefits, ecosystem improvement, water quality control benefits, emergency response, and a new large reservoir for structural integration management subwatershed design, are important factors in climate change that can be individually and separately investigated.

Generally, studies related to soil erosion models in the region have shown that soil erosion has detrimental effects in various directions, as described before. In the present research, in the first step, the accurate calculation of the RUSLE model factors at the remote sensing scale is considered a combination with the physical model, which is a factor that increases accuracy. In the next step, a quantitative and qualitative conceptual remote sensing-based analysis of the factors was carried out with an uncertainty approach, and important phenomena, such as kinetic energy (USLE R, K and P factors), erosivity factors, resistance factors against erosion, accumulated flow, slope, flow length, vegetation cover, dimensionless parameters, land use and vegetation cover, water bodies, and soil diagrams, were investigated in an advanced and accurate manner. In the final step, the uncertainty-influencing parameters, including RUSLE-R, RUSLE-P, and RUSLE-K, are considered as outputs in the uncertainty scenario, and quantitative and qualitative optimization are considered. Some of these measures, such as the results of this research, can be referred to as prediction risk management.

From the perspective of integration as well, owing to the high accuracy of inputs and outputs, remote sensing processing, and the scientific basis of the method, as well as the necessity of using practical satellite imagery as a statistical model in combination with the conceptual and physical SWAT model, it is considered a suitable and scientific innovation."

5-4- Other integrated water resources management

Protection, reducing water losses, promoting water conservation, technology, increasing awareness of responsible water use by officials, protection and restoration of ecosystems, protection and restoration of aquatic ecosystems, wetlands, rivers, and lakes

Some of the important parameters mentioned above and their uncertainties have been specifically investigated in this study. When uncertainty was examined after multiple calibrations and iterations, an uncertainty band appeared. Using the balance equation in SWAT software, modeling was performed, and after the model was calibrated and then the outputs and validation were obtained, sensitive parameters were extracted. A unified hydraulic and hydrological scenario based on sensitive parameters and other influential parameters to create coherence between watershed hydrology and hydraulics was proposed. In this scenario, influential parameters such as a 30% range of future CNs for improving climatic conditions and preventing floods in the form of upstream drainage improvement and other parameters such as 25% groundwater recharge, 30% groundwater discharge, and watershed management actions such as reservoir and pond construction were considered for rainy or perennial months or for changing land use by up to 10%. Additionally, upgrading the canal grading and time delay management and concentration up to 15% upstream, as well as increasing the vegetation cover and soil improvement based on the RUSLE model parameters mentioned in the runoff and sediment yield scenario and subbasins by 25%, are among the foundations presented in the scenario of this study presented in Table 3. All the changes in this scenario are important because they adapt to the uncertainty band and match the ranges of the watershed and subbasin parameters and the effects of the parameters on coherence. Base codes can be improved by combining existing modules and models, updating them, and by combining new algorithms, research with innovations and up-to-date methods can be conducted. As mentioned earlier, reservoir management and outputs and reservoir storage can be proposed as efficient management scenarios, and addressing these scenarios at the watershed level is suggested. Practical scenarios in the form of structural and nonstructural measures should be proposed to improve groundwater and improve snowmelt representation. Modifying the nutrient cycle and water quality modules and adding more options for estimating evaporation and transpiration are suggested, as soil moisture has been used for flow calibration in the model. Additionally, more options for sediment transport can be added. The amount of power that can be generated at a point in the river can be calculated as follows: power = flow velocity * dam height * turbine efficiency. Other important influential factors, such as social and economic factors, watershed management, and the examination of social and economic factors affecting watershed management and the assessment of the role of governance structures, policy frameworks, stakeholder participation, and economic motivations in achieving the goals of sustainable watershed management, are also important issues.

Author Declarations

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Conflicts of Interest

Ethics Approval: This study was approved by the Islamic azad University Scince and research branch . Approval Number : +98 44845205

Consent to Participate: Informed consent was obtained from all individual participants included in the study.

Consent for Publication: All authors have read and approved the final manuscript. Also, The programming codes, remote sensing codes, raw data, and analysis results from this study are accessible.

Note:This research paper is an extract from a doctoral dissertation, and its proposal, after undergoing several rounds of review by both domestic and international professors, has obtained the necessary approvals and has been finally approved

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