Advanced GIS

http://publish.mersin.edu.tr/index.php/agis/index

e-ISSN:2822-7026

Assessing hydrological modeling approaches: a review of the soil conservation service curve number and the soil and water assessment tool

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Keywords
AHP,
Hydrological Modeling,
Surface Runoff,
Sustainable Land and Water Management,
Water Resource Management

Review Article
Received: 07/04/2023
Revised: 08/07/2023
Accepted: 12/07/2023
Published: 12/09/2023

ABSTRACT

This article reviews two hydrological modeling tools, the Soil Conservation Service Curve Number (SCS-CN) model and the Soil and Water Assessment Tool (SWAT), and the Analytic Hierarchy Process (AHP) method used for estimating surface runoff and evaluating the impacts of land use changes on watershed responses. The SCS-CN model has been widely used for estimating surface runoff from rainfall, and its integration with GIS and remote sensing has improved its accuracy and precision. The SWAT model has also been effective in assessing the impact of land cover and land use changes on hydrologic response. The AHP method has been used to suggest the best locations for rainfall water harvesting in arid regions. However, these models also have limitations that should be considered when applying them to different watersheds. Proper calibration and validation of the models' input parameters are crucial to ensure accurate results, and the models' performance can be affected by uncertainties in the input data and model parameterization. Despite these limitations, these tools remain useful for evaluating surface runoff and its impact on water resource management, flood control, erosion prevention, and sustainable land and water management practices. In conclusion, the SCS-CN model, SWAT model, and AHP method are important approaches to evaluate surface runoff and its impacts, but their limitations and suitability for different watersheds should be carefully considered.

1. Introduction

Hydrological modeling plays a crucial role in understanding the complex relationships between rainfall and runoff processes, enabling accurate assessments of surface runoff. This understanding is vital for effective catchment design, planning, and management. By enabling the estimation of continuous surface runoff and enhancing comprehension of catchment behaviors, hydrological modeling provides valuable insights.

This article reviews three hydrological modeling tools used for estimating surface runoff and evaluating the impacts of land use changes on watershed responses. The first tool reviewed is the Soil Conservation Service Curve Number (SCS-CN) model, which has been widely used for estimating surface runoff from rainfall. The second tool reviewed is the Soil and Water Assessment Tool (SWAT), which is commonly used to simulate hydrological processes and assess the impact of land use changes on hydrologic response. Finally, the third tool reviewed is the Analytic Hierarchy Process (AHP), which has been used to suggest the best locations for rainfall water harvesting in arid regions. While these tools have been found to be effective for hydrological modeling, they also have limitations that should be considered when applying them to different watersheds. Proper calibration and validation of the models' input parameters are crucial to ensure accurate results, and the models' performance can be affected by uncertainties in the input data and model parameterization. Despite these limitations, these tools remain useful for evaluating surface runoff and its impact on water resource management, flood control, erosion prevention, and sustainable land and water management practices. Applying these models in hydrology analysis helps to better comprehend important natural disasters such as floods (Demir & Keskin, 2022).

A comprehensive literature search was conducted using various databases, including Web of Science, Scopus, and Google Scholar. The search was conducted using the following keywords: hydrological modeling, soil conservation service curve number, soil and water analyses tool, and analytic hierarchy process. The search was limited to articles published in peer-reviewed

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Cite this article

Omar, O. O., & Rasul, A. (2023). Assessing hydrological modeling approaches: a review of the soil conservation service curve number and the soil and water assessment tool. *Advanced GIS*, 3(2), 47-52.

journals from 2000 to 2023. The search also included relevant articles identified through the reference lists of the retrieved articles.

2. Methodology

2.1. Criteria selection

The articles were selected based on their relevance to the topic of hydrological modeling and the use of the Soil Conservation Service Curve Number model, the Soil and Water Analyses Tool, and the Analytic Hierarchy Process. The articles were screened by title, abstract, and full text, and only articles that met the inclusion criteria (relevance to the topic, peer-reviewed, and published from 2000 to 2013) were included in the review.

2.2. Data extraction and analysis

The articles were analyzed and summarized based on their research objectives, study area, modeling approach, input data sources, model parameterization, calibration, validation, and model performance evaluation. The strengths and weaknesses of each model were also identified and discussed. The extracted data were synthesized and presented in a narrative format.

2.3. Synthesis of findings

The findings from the selected articles were synthesized to provide an overview of the strengths and weaknesses of the Soil Conservation Service Curve Number model (Equations 1-3), the Soil and Water Assessment Tool, and the Analytic Hierarchy Process (Figure 1). The synthesis also identified the gaps in the current knowledge and the future research directions in hydrological modeling. The limitations of the models were discussed, and recommendations were made for improving their accuracy and applicability.

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \quad (1)$$

where Q = Runoff depth (mm), P = Rainfall (mm), the maximum retention after runoff starts (S), and the initial abstraction (Ia).

$$Ia = 0.2S \quad (2)$$

The proportion of 0.2 is seldom changed.

Equation (3) establishes a connection between the potential maximum retention after runoff starts, represented as S, and the characteristics of the watershed's land use/vegetative cover and soil.

$$S = \frac{25200}{CN} - 25 \quad (3)$$

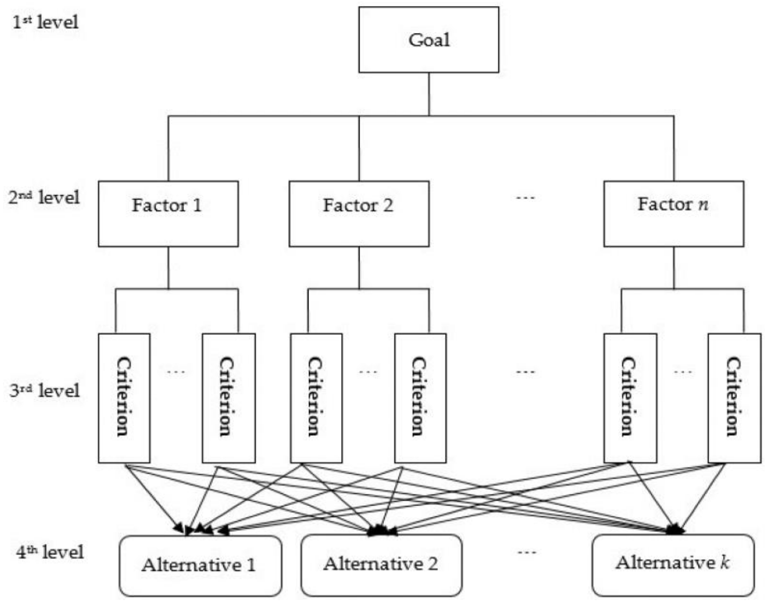

Figure 1. The structure of the analytic hierarchy process (Huang, 2021).

3. Surface water and soil conservation service curve number (SCS-CN)

The Soil Conservation Service Curve Number (SCS-CN) model is a popular and frequently used approach to evaluate surface runoff from rainfall. The model is based on land use and land cover (LULC), soil type, and soil moisture. Geographic Information System (GIS) can be used to merge maps with databases and estimate surface runoff. The integration of GIS and remote sensing can automate the surface runoff estimation depending on the SCS-CN model (Meshram et al., 2017; Weng, 2001). GIS and remote sensing have been successfully utilized to manage non-spatial and spatial databases that illustrate the hydrological properties of watersheds.

Different models have been proposed to investigate the suitability of the SCS-CN model in various types of watersheds. In some watersheds, the response of linear runoff gives better outcomes than the SCS-CN model. The modified version of the SCS-CN model, known as the Mishra and Singh (MS model), integrates previous moisture in direct surface runoff calculations and manages distance better than the existing SCS-CN model (Karn et al., 2016; Suresh Babu & Mishra, 2012). The two-Curve Number approach is able to explain the CN-rainfall variation observed in natural watersheds (Soulis & Valiantzas, 2012).

Remote sensing data with GIS and the SCS-CN method have been utilized to estimate runoff depth, weighted curve number, and volume of runoff in different watersheds. The SCS-CN model has been validated for urban areas, and with the help of RS data with GIS tools, the entire hydrological process can be simulated with higher precision, leading to more accurate results. However, substantial uncertainties exist in using the curve number model for estimating runoff from un-gauged watersheds (Tedela et al., 2012). Curve number selection requires independent calibration to watersheds representative of hydrologic characteristics and the regional landscape.

The Soil Conservation Service Curve Number (SCS-CN) model has been widely used for estimating surface runoff from rainfall. It has proven to be an effective method for hydrological modeling, and its integration with GIS and remote sensing has improved its accuracy and precision. The SCS-CN model has been successfully validated for urban areas, and its use has expanded to other types of watersheds. The model is also useful for the evaluation of land use and land cover changes and their impacts on surface runoff. The SCS-CN model's capability to provide precise estimates of surface runoff makes it a valuable tool for water resource management, flood control, and erosion prevention.

One of the limitations of the SCS-CN model is that it requires independent calibration to representative watersheds (Tedela et al., 2012). The SCS-CN model has been criticized for its lack of flexibility and simplicity, which hinders its suitability for various types of watersheds. The model's reliance on empirical relationships between curve numbers, rainfall, and runoff limits its ability to account for other hydrological processes, such as groundwater recharge and interflow. The SCS-CN model does not provide information on the quality of surface runoff, which can affect water supply and ecosystem services. As a result, the SCS-CN model's accuracy can be affected by uncertainties in the input parameters and assumptions.

In conclusion, the SCS-CN model is a useful tool for estimating surface runoff from rainfall, and its integration with GIS and remote sensing has improved its accuracy and precision. However, the model's limitations, such as its lack of flexibility and simplicity, reliance on empirical relationships, and uniform assumptions, should be considered when applying it to different watersheds (Table 1). Careful calibration and validation of the model's input parameters are required to ensure accurate results (Zlatanović & Gavrić, 2013). Despite its limitations, the SCS-CN model remains an important approach to evaluating surface runoff and is widely used in hydrological modeling and water resource management.

Table 1. Characteristics of reviewed Hydrological Models for Surface Runoff Estimation and Watershed Management in the study

Model	Purpose	Advantages	Limitations	Example Researches
Surface water and Soil Conservation Service Curve Number (SCS-CN)	The SCS-CN model is widely used for estimating surface runoff from rainfall. The model is based on land use and land cover (LULC), soil type, and soil moisture.	The SCS-CN model has been successfully validated for urban areas, and its use has expanded to other types of watersheds.	The model has limitations, such as its lack of flexibility and simplicity, reliance on empirical relationships, and uniform assumptions, which affect its accuracy.	"Runoff modeling using SCS-CN and GIS approach in the Tayiba Valley Basin, Abu Zenima area, South-west Sinai, Egypt "(Hagras, 2023); "Suitable site selection for rainwater harvesting and storage case study using Dohuk Governorate (Ibrahim et al., 2019) "
Soil and Water Assessment Tool (SWAT)	The SWAT model is widely utilized to estimate surface runoff and assess the impact of land use change on watershed responses.	The model has been effectively used in various hydrology studies, such as those examining the effects of land use changes on surface runoff.	The model's performance can be affected by uncertainties in the input data and model parameterization.	"Hydrological modeling with respect to impact of land-use and land-cover change on the runoff dynamics in Budhabalanga river basing using ArcGIS and SWAT model " (Bal et al., 2021); "Simulating streamflow in an ungauged catchment of Tonlesap Lake Basin in Cambodia using Soil and Water Assessment Tool (SWAT) model" (Ang & Oeurng, 2018)
Analytic Hierarchy Process (AHP)	The AHP is used to suggest the best locations for rainfall water harvesting in arid regions.	The model considers criteria such as rainfall intensity, soil type, land use, and topography to rank potential locations.	The AHP model has limitations, such as the need for careful calibration and validation, and the assumption of equal importance of criteria.	" The use of AHP within GIS in selecting potential sites for water harvesting sites in the Azraq Basin—Jordan" (Al-shabeeb, 2016); "Development and assessment of rainwater harvesting suitability map using analytical hierarchy process, GIS and RS techniques " (Balkhair & Ur Rahman, 2021)

4. Soil and water assessment tool (SWAT)

The Soil and Water Assessment Tool (SWAT) has been widely utilized in various hydrology studies to estimate surface runoff and the impacts of land use change on watershed responses. One such study by Yusuf et al. (2021) examined the effects of land use changes on surface runoff in the Bekasi River sub-watershed. The study utilized the SWAT model and the SCS Curve Number to analyze surface runoff and land use changes, respectively. Similarly, Baker & Miller (2013) used the SWAT model to assess the impact of land cover and land use changes on the hydrologic response of the river Njoro watershed in Kenya's Rift Valley. In both studies, the SWAT model proved to be an effective tool for assessing the relative impact of land cover change on hydrologic response.

Another study by Basu et al. (2022) employed the SWAT model to evaluate the impact of landcover changes on runoff in Dublin, Ireland, spanning the period from 1993 to 2019. Their research highlights the importance of incorporating dynamic and time-varying landcover data into hydrological modeling to accurately simulate runoff. Iskender & Sajikumar (2016) compared the performance of the SWAT model and the Geomorphological Instantaneous Unit Hydrograph (GIUH) model in predicting surface runoff from ungagged basins. The study concluded that the GIUH model was marginally better than the SWAT model. Overall, the SWAT model has proven to be a valuable tool for hydrological modeling and can be used to assess the impact of land use changes on hydrological response in various watersheds.

The studies discussed highlight the versatility of the model and its applicability in different geographical regions. The use of the SWAT model in these studies has led to a better understanding of the impacts of land use change on hydrologic response, which is important for sustainable land and water management practices. The ability to assess the impact of land use changes on surface runoff and other hydrological processes using the SWAT model provides valuable information for policymakers, land managers, and water resource professionals.

One of the limitations of the SWAT model is the need for detailed input data, which can be time-consuming and expensive to obtain. This may limit the applicability of the model in regions where data is scarce or not readily available. Additionally, the model's performance can be affected by uncertainties in the input data and model parameterization. Proper calibration and validation of the model are crucial to ensure accurate simulations. Another limitation is that the model may not be able to capture the complex hydrological processes that occur in certain types of watersheds or landscapes, which can lead to inaccuracies in the model output. Despite these limitations, the SWAT model remains a useful tool for hydrological modeling and has the potential to contribute significantly to sustainable land and water management practices.

5. Water harvesting by using analytic hierarchy process (AHP)

Water harvesting is a critical undertaking in arid regions, and Analytic Hierarchy Process (AHP) has been used to suggest the best locations for rainfall water harvesting (RWH). The AHP method integrates researchers' criteria using GIS (Meşin & Demir, 2023), and it has been used to evaluate and optimize the management of gained rainwater collection systems in semi-arid areas. Adham et al. (2016) designed a methodology that can support designers and decision-makers to improve the performance of existing and new rainwater harvesting sites. Al-Abadi et al. (2017) developed a GIS-based model that incorporates AHP and fuzzy logic to identify appropriate sites for water harvesting buildings. The model utilized five influential factors to develop the model, which includes surface runoff depth, distance, slope, hydrological soil group, and land cover to river intermittent. Wu et al. (2018) used the AHP technique to determine suitable locations, incorporating spatial information into six sub-criteria and two major decision criteria: socioeconomic and environmental. Physical features were land use, potential runoff, and distance from roads, soil texture, slope, and distance from agricultural land.

The suitability of the site for harvesting rainwater was also considered in the study by Ibrahim et al. (2019). The model combined several parameters, such as slope, runoff potential, soil quality, land cover/use, stream order, and hydrology, to determine the suitability of the site for harvesting rainwater. In the study by Rajasekhar et al. (2020), AHP was performed to identify the rainwater harvesting places and potential recharge zones using thematic layers such as vadose zone, drainage density, land use/land cover, soil, runoff, geology, and slope. Finally, Sayl et al. (2020) used a GIS-based approach with RS to identify the optimal sites for rainwater harvesting, and the results showed that the rank order method and variance inverse methods affected the ranking priority and considered all of the criteria that were sensitive to impact in the ranking process at the different levels compared to the methods of AHP and fuzzy AHP.

In summary, AHP method integrated with GIS has proven to be an effective and flexible approach in suggesting the best locations for water harvesting. The studies by Adham et al. (2016), Al-Abadi et al. (2017), Wu et al. (2018), Ibrahim et al. (2019), Rajasekhar et al. (2020), and Sayl et al. (2020) are examples of how AHP can be used to determine suitable locations for water harvesting by considering various factors such as socioeconomic and environmental aspects, surface runoff depth, distance, slope, hydrological soil group, land cover, runoff potential, soil quality, stream order, and hydrology. The utilization of AHP in combination with GIS provides a low-cost, time-saving, and flexible approach for decision-makers and designers to improve the performance of both existing and new water harvesting systems.

The utilization of AHP in water harvesting has demonstrated its usefulness in identifying suitable locations for water harvesting. By incorporating various criteria and factors, such as environmental, socioeconomic, and physical features, AHP provides a comprehensive approach to assess the feasibility and effectiveness of water harvesting systems. It helps decision-makers and designers to make informed decisions and optimize the performance of existing or new systems, leading to more efficient and sustainable water management in arid regions. Furthermore, AHP enables the integration of multiple stakeholder perspectives into the decision-making process, promoting consensus-building and stakeholder participation.

Despite the benefits of AHP, some limitations need to be considered. One limitation is that AHP requires considerable expertise in defining criteria, sub-criteria, and pairwise comparisons, which can be time-consuming and challenging. Moreover, AHP heavily relies on subjective judgments and preferences of decision-makers or stakeholders, which can introduce bias and uncertainty in the decision-making process. The availability and quality of data are also crucial in the AHP method, and inaccurate or incomplete data can lead to inaccurate results. Finally, AHP's complexity and technicality may pose challenges to its adoption by policymakers, practitioners, and stakeholders who lack technical expertise in GIS and AHP methods. Therefore, careful consideration and communication of the results and implications of AHP analyses are necessary to ensure its effectiveness and usability.

6. Future research directions

While the model is widely used in hydrological studies it has some gaps for instance the impact of rain intensities was not taken into consideration (Wang & Bi, 2020). Future research in hydrological modeling should focus on improving the accuracy and reliability of the Curve Number Model. This model has been effective in estimating surface runoff from rainfall, but uncertainties remain. Advancements could include incorporating other hydrological processes such as groundwater recharge and interflow, and improving the model's ability to account for variations in soil properties and land use.

Integrating multiple models could also enhance the accuracy and reliability of hydrological simulations. Future research should explore the potential of combining the SCS-CN model with other models, such as the SWAT model, the Geomorphological Instantaneous Unit Hydrograph (GIUH) model, and other models that can capture different hydrological processes.

Another important area for future research is improving data availability. The availability and quality of data, including meteorological data, soil data, and land use data, are often limited, especially in certain regions. Efforts should focus on improving the availability and quality of data to support more accurate hydrological modeling. Furthermore, incorporating uncertainty analysis in hydrological modeling can help assess the reliability and accuracy of models, accounting for uncertainties in input data, model parameterization, and assumptions. Lastly, the development of decision support systems that incorporate hydrological models could provide valuable information for water resource management and decision-making.

7. Conclusions

In conclusion, the Soil Conservation Service Curve Number (SCS-CN), the Soil and Water Assessment Tool (SWAT), and the Analytical Hierarchy Process (AHP) are three commonly used approaches in hydrological modeling. The SCS-CN model, when integrated with GIS and remote sensing, has proven to be an effective method for estimating surface runoff from rainfall and is widely used in water resource management, flood control, and erosion prevention. However, the model's limitations should be considered when applying it to different types of watersheds. The SWAT model has also been widely used in hydrological studies and has proven to be a valuable tool for assessing the impact of land use changes on hydrological response in various watersheds. Lastly, the AHP approach has been used to prioritize various factors affecting hydrological processes, such as land use and land cover changes, and can assist in decision-making processes related to water resource management. Overall, each approach has its strengths and limitations, and careful calibration and validation of input parameters are necessary for accurate results.

Author Contributions

Farhad Omar: Conceptualization, methodology, writing-reviewing and editing. **Azad Rasul:** Supervision, investigation, writing- original draft preparation.

Statement of Conflicts of Interest

There is no conflict of interest.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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