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Estimation of Surface Runoff Using SCS-CN Remote Sensing and GIS in Sanjab Watershed

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Abstract

This study estimates surface runoff in the Sanjab watershed, located in Herat, Afghanistan, using remote sensing and GIS. Accurate runoff prediction is vital for hydro-technical project planning and watershed management, and the curve number (SCS-CN) method is a widely used technique based on soil and land use-data. The watershed covers 181 km², and data from 2012 to 2021 were analyzed. Results showed the peak surface runoff in 2019 at approximately 17.3 million cubic meters, while the lowest was in 2014 approximately 9.06 million cubic meters. The average annual runoff was around 12.7 million cubic meters. The area was selected because plans to develop pistachio orchards depended on the available surface water from the Sanjab River, making accurate runoff assessment essential for effective water management and irrigation planning.

Keywords: Remote Sensing, GIS, Watershed, Runoff, and Curve Number

تخمین جریان سطحی حوزه آبریز سنجاب با استفاده از سنجش از دور SCS-CN و GIS

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چکیده

این مطالعه جریان سطحی در حوزه آبخیز سنجاب، واقع در هرات، افغانستان، را با استفاده از سنجش از دور و GIS تخمین . پیش‌بینی دقیق جریان برای برنامه‌ریزی پروژه‌های منابع آب و مدیریت حوزه آبریز حیاتی است، و روش شماره منحنی (SCS-CN) یک روش پرکاربرد بر اساس دیتاهای خاک و استفاده از زمین است. این حوزه آبریز ۱۸۱ کیلومتر مربع مساحت را پوشش می‌دهد و ارقام مربوط به سال‌های ۲۰۱۲ تا ۲۰۲۱ مورد تجزیه و تحلیل قرار گرفتند. نتایج نشان میدهد که اوج جریان سطحی در سال ۲۰۱۹ تقریباً ۱۷،۳ میلیون متر مکعب بوده است، در حالی که کمترین میزان آن در سال ۲۰۱۴ با حدود ۹،۰۶ میلیون متر مکعب بوده است. اوسط جریان سالانه حدود ۱۲،۷ میلیون متر مکعب بوده است. این منطقه انتخاب شد زیرا برنامه‌های توسعه باغ‌های پسته به آب سطحی موجود از حوزه فرعی سنجاب وابسته بود و ارزیابی دقیق جریان را برای مدیریت مؤثر آب و برنامه‌ریزی آبیاری لازم است.

واژه‌های کلیدی: ریموت سنسنگ؛ حوزه آبریز؛ جزیان سطحی و منحنی (SCS-CN)

Introduction

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Afghanistan is a country with a land area of 65 million hectares and a population of 38 million, 71% of whom live in rural areas. A dispersed human population and a rough, hilly terrain distinguish it. Agriculture and cattle are the country's main drivers of economic growth. Tiny-scale subsistence farmers who inhabit small parcels of land make up the majority of the rural population. As a result, effective water resource management is crucial to fostering economic development and alleviating hunger. Accurate surface runoff estimation is key component of effective water management (Sarwar *et al.*, 2002). Afghanistan has abundant water resources, including lakes, springs, glaciers, snow, and rainfall. The Hindu Kush Mountain ranges, at heights over 2,000 meters, are the source of more than 80% of the nation's water resources, which are estimated to be 75 billion cubic meters (BCM), of which 55 BCM are surface water and 20 BCM are groundwater (Sarwar *et al.*, 2002). These resources have historically been used for drinking, housing, agriculture, and business. According to estimates, 80% of the population depends on natural resources for their livelihood, and water reserves are a crucial resource for them. Agriculture is the primary source of income and a significant influence on people's lives (Buraihi & Shariff, 2015). The majority of agriculture in this region is rain-fed, with a small amount irrigated due to a lack of water storage facilities. People still rely on an ancient form of agriculture that diverts water directly from rivers, without accounting for crop demands (Tibebe et al, 2011).

Conventionally, Afghanistan's water resource management relies almost exclusively on natural patterns, and historical data indicate that the country faces the threat of both catastrophic drought and flood events. In the era of water management in this nation, the usage of building infrastructure is infrequent, and some of these infrastructures have been harmed by civil conflict. It is obvious that before making any decisions, water management requires extensive research in hydrology to determine how much water actually exists, especially an accurate estimate of surface runoff in every watershed. Conducting hydrological studies without accounting for potential future scenarios of floods, droughts, or other changes in climatic variables is challenging, given the new climate issues (Zachariah *et al.*, 2012). Hydrological modeling is a prerequisite for this research, and effective modeling requires a more comprehensive survey and investigation. To achieve the highest level of trust and certainty, the hydrological model must also be properly calibrated and tested (Zachariah *et al*., 2012). To estimate runoff, which is necessary for planning, developing, and managing water resources, watershed management involves the proper use of water and other natural resources within a watershed. Runoff results from rainstorms, and the amount and frequency depend on the characteristics of the rainfall event, such as its intensity, duration, and dispersion (Mahmoud et al, 2014). The volume of water that flows through a river cross-section over a given time period, or runoff, cannot be calculated simply from remote sensing data. One of the most frequent issues in applied hydrology the unpredictability of runoff estimates in watersheds. Therefore, straightforward techniques for forecasting runoff in watersheds are crucial for hydrologic applications such as flood design and water balance calculation models (Cook, 1947). One of the most crucial hydrologic variables used in most water resource applications is runoff. For ungagged watersheds, obtaining a trustworthy forecast of the volume and rate of runoff from the land surface into watercourses and rivers is challenging and time-consuming. However, numerous issues with watershed development and management call for this knowledge. Traditional river discharge prediction methods require extensive hydrological and meteorological information. Gathering this data is expensive, time-consuming, and challenging. The requirement to estimate runoff from a watershed for which precipitation records exist but no observed runoff records is the issue that arises most frequently in hydrological investigations (Needelman et al, 2004). One approach to resolving this issue is to compare runoff characteristics to watershed characteristics. Soil type and cover, including land use and land cover, are the watershed variables that can be most easily compared to estimate runoff from a specific rainfall event (Vojtek & Vojteková, 2019). For the cultivation of various crops and fruit trees, this country has a very suitable climate and soil conditions that require adequate water, especially during the summer season. On the other hand, early snowmelt poses a challenge for the agricultural sector, leading to shortages or river drying (Santhoshi, 2021).

Managing water resources in this country is likely to affect the agriculture, mining, and industry sectors. This will pave the way for economic growth and poverty reduction. As a result it will provide sufficient jobs and opportunities that will contribute to peace and stability not only in Afghanistan but across the whole region. Water consumption is essential for a healthy existence and the development of a stable society. Recently, due to the population growth and urbanization across Afghanistan, especially in Kabul, access to drinking water has become a significant problem for its inhabitants. The primary source of drinking water is groundwater which has been rapidly declining in recent years, according to new surveys. Furthermore, the quality of this water is in doubt due wastewater wells that draw from this source without proper treatment, rendering it unsanitary in most parts of the city. People migrate to the major cities due to insecurity and unemployment in most parts of the country, recurring droughts, and climate change. Using surface water resources is a potential alternative that, after treatment, could respond to concerns about drinking water. In the long term, building infrastructure is one of the primary solutions to providing drinking water, electricity, and supporting agriculture and industry.

According to the Ministry of Agriculture, Irrigation, and Livestock, the Afghan government plans to build many small and large gardens across the country. One of them is the 14,000-hectare pistachio garden in the Enjeal district of Herat province. The main goal of this garden is to increase pistachio crops in our country. This garden, which will be built in the Enjeal district of Afghanistan's Herat province, will rely solely on the Sanjab River, which flows from the Sanjab watershed. The water in this river is derived from snow accumulation during the winter season and from very little glacier storage. Before reaching the Sanjab Bridge, the water of this river is not utilized for any agricultural purposes. Floods can occur in April and May due to rapid snowmelt and the formation of a prominent runoff peak (Sarwar el al, 2002). Building a reservoir will manage this massive amount of water, slowly releasing it downstream for flood control and environmental management, as well as to irrigate the planned pistachio garden. Climate change is a new phenomenon that has not previously been considered in the water management sector. An increase in GHG (greenhouse gas) levels can lead to greater warming, which, in turn, can influence the world's climate and drive (Li *et al*., 2018). Climate change is defined as long-term changes in climate variables, such as temperature, humidity, wind, and precipitation that may affect water resources. The abundance of evidence across many regions, including the Columbia River basin, indicates that temperatures are rising (Dumedah *et al*., 2021). The water situation in Afghanistan is quite problematic given the apparent effects of climate change. Recent studies in Afghanistan reveal that water availability is decreasing while temperatures and evapotranspiration have increased. The most visible signs of climate change on satellite imagery across the Hindu Kush-Pamir Mountains are decreases in glacier extent and increases in lake numbers. Proper adaptation and water resource management strategies are necessary to combat and mitigate the effects of climate change. This requires conducting field studies on climate change that use hydrological models and that consider possible climate scenarios. This requires conducting field studies on climate change that use hydrological models and possible climate scenarios. This requires conducting field studies on climate change that use hydrological models and possible climate scenarios (Patil et al, 2008).

This requires conducting field studies on climate change that use hydrological models and possible climate scenarios. This requires conducting field studies on climate change that use hydrological models and possible climate scenarios. Very few hydrological models are used in the Afghanistan River basins, and selecting the appropriate model from the available options requires extensive research. There are many reasons, such as limited access to the field and experts, but the most prominent is the lack of sufficient, reliable data, which makes the modeling process very challenging. Studying the future effects of climate change on water resources is only possible through hydrological modeling using climate scenarios (Santhoshi et al, 2021). It has been suggested that comprehensive global climate models are the only tools that account for the complex set of processes that will determine future climate change at both a global and regional level (Mahmoud, 2014). It requires downsizing these scenarios for the study area and applying them to hydrological models for analyzing the future condition of water resources. Remote sensing and GIS are increasingly important in the development of geohydrology and water resources. Remote sensing collects information about the Earth's surface in both the spatial and temporal domains (Shrestha, 2003). One of the most significant advantages of using remote sensing data for hydrological, geological, and geomorphological monitoring and assessment, is its ability to generate multispectral, multi temporal, multi sensor information, which is crucial for successful analysis, prediction, and validation of research. Remote sensing is a better tool by which spatial data in paper maps, charts, high-resolution satellite images, aerial photographs, and cadastral sheets, along with other attributes, can be converted to digital form for data linking, map joining, map overlaying, clipping, preparation of new maps, etc., easily and quickly for analysis and assessment. Further, geo-referencing and geotagging, the two new concepts in geo informatics that enhance plot (cadastral) level feature extraction, feature authentication, and plot-level resource planning, need to be used in watershed action plan generation. GIS technology offers effective alternatives for managing large, complex databases. Satellite information is becoming increasingly important for agricultural research (Tibebe et al, 2011).

Runoff Modeling

Various parametric models, such as empirical (statistical/metric), Conceptual (semi-empirical) and physical process-based (deterministic) models are available to estimate surface runoff. These models are often grouped the physical processes they simulate, the algorithms that describe those processes, and the models that rely on data. Among all model types, empirical models are typically the simplest. They are statistical in nature, heavily rely on observational analysis, and aim to describe the reaction from these data. Such models typically require less data than conceptual or physics-based models. Conceptual models play a transitional role between empirical and physical process-based models. Physical process-based models account for the combined effects of individual components that affect runoff, including complex interactions among factors and their spatial and temporal variability. Most of these models require information on soil type, land use/land cover, climate, and topography to estimate surface runoff (Kandel, 2004). The Natural Resources Conservation Service (NRCS) Curve Number (SCS-CN) method is widely used to predict direct runoff depth for a given rainfall event. This method was initially developed by the Soil Conservation Service, United States Department of Agriculture (1972). Due to its simplicity, it soon became one of the most popular techniques among engineers and specialists, mainly for small catchment hydrology (Tibebe & Becket, 2011). The SCS-CN model is a simple, empirical model with clearly stated assumptions and few data requirements. As a consequence, it has seen widespread in small agricultural or urban watersheds for runoff prediction from single rainfall events, stormwater modeling, and water resource management. Many hydrological and ecological models have now incorporated the model to calculate runoff. The SCS–CN method was established in 1954 by the USDA SCS and is defined in the Soil Conservation Service (SCS) by the National Engineering Handbook (NEH-4) Section of Hydrology. Two key theories have been put forth, and the Soil Conversations Service-Curve Number technique is based on water-balance calculations. The first idea states that the ratio of actual direct runoff to the maximum runoff equals the ratio of actual infiltration to the prospective maximum retention. According to the second theory, early abstraction accounts for a small portion of the likely maximum retention. To estimate the direct runoff from a watershed in the study region, the Soil Conservation Service Curve Number methodology is typically employed (USDA 1972). Where CN is the curve number, which may be found in Section 4 of the SCS Handbook of Hydrology (NEH-4) (USDA 1972). The SCS curve number is a measure of the ability of soils to allow water infiltration with respect to land use/land cover (LU/LC) and antecedent soil moisture condition (AMC). Based on the predicted runoff rate and ultimate infiltration rate, soils are divided into four hydrologic soil groups, such as groups A, B, C, and D, by the U.S. Soil Conservation Service (SCS). The SCS-CN model has recently been expanded to include sediment yield estimation and soil moisture modeling. The main reason for its success is that it accounts for many factors affecting runoff generation, including soil type, land use, surface condition, and antecedent moisture, by incorporating them into a single CN parameter. Additionally, it is the only methodology that features enthusiastically grasped and reasonably well-documented environmental inputs, and it is well established, widely accepted for use in the United States and other countries (Boughton, 1989).

Research Methodology

Information The accuracy of any prediction tool is heavily reliant on the reliability of the data sets and the methodology adopted. In modeling the hydrologic process like runoff, the causative factors such as rainfall, soil type, and vegetation or ground cover are to be known along with the hydrologic time series data. However, adequate data for a comprehensive analysis are seldom available, leaving no choice but to use only the available information. This research discusses the data collected and the methods used to analyze them for estimating direct runoff depth in the Sanjab watershed, located in the Harrirod River basin in the Enjeal districts of Herat province. The research primarily introduces the study area, the various data sources used, the procedures, and the supplies needed to complete this research.

Study Area and Data Availability

The Sanjab River rises in the Sanjab area, located on the fixed border between the Enjeal and Karokh districts in Afghanistan. This study focuses on surface runoff estimation in the Sanjab Watershed in Enjeal district of Herat province Afghanistan. The Sanjab watershed is shown in (Figure. 1). This watershed is located between 34° 38′ 37″N and 62° 05′ 40″E with an elevation ranging from 1279 to 2557 m above MSL (mean sea level), and covers an area of 181 km2 or 18080 hectares. Over the last ten years (2012–2021), the watershed has received an average annual rainfall of 166.62 mm, with more than 80% of the rainfall falling in January, February, and March. The minimum and maximum temperatures range from 6°C to 39°C. The basin's climate is typically arid. Summer is the driest season of the year. July, August, and September are the driest months of the year. The normal maximum temperature in May is 33.5 °C, and the minimum in February is 6 °C. The soil of the Sanjab watershed and the boundaries of the different soil textures were digitized and created in Arc GIS 10.4. In our study, two types of soil were present (Figure.2) which belong to hydrologic soil groups B and C. The first type is haploalkalides, a soil type that includes carbonates and gypsum (a chemical element with the $CaSO_4 \, 2H_2O$ formula), and the second type is rocky lands. In the rest of the areas, mixed clays, black to brown soil, derived from sandstones and traps, are observed, which are sandy clay in nature.

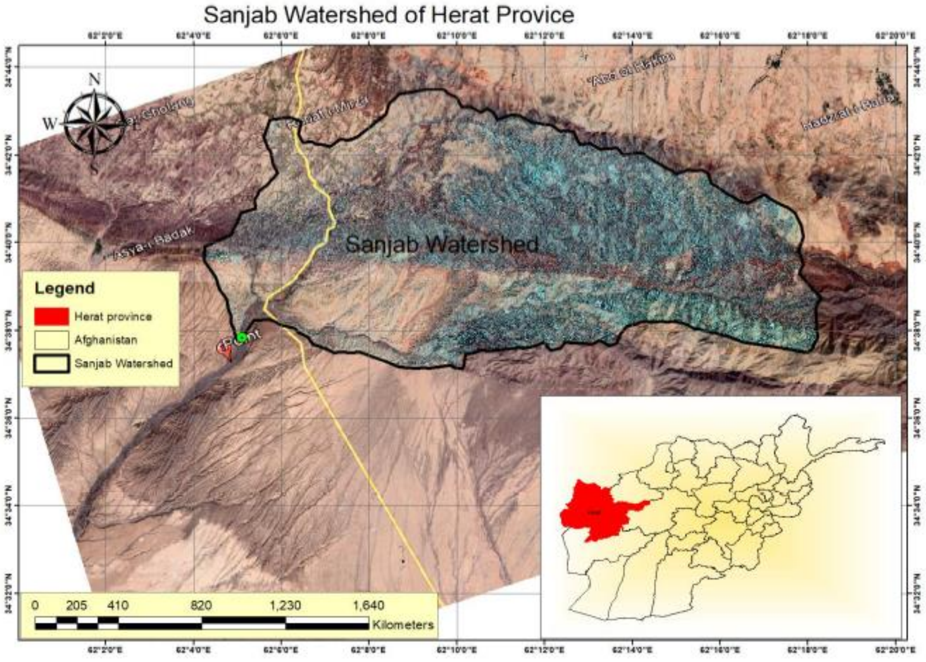

***Figure1**: Location map of study Area*

Data Availability

The area is composed of rising and falling tracts with ridges and valleys. In this watershed, different types of land are found, including hills and hill slopes, summits, uplands, medium lands, and low lands. A part of the micro-watershed is surrounded by a small hill, which contributes to the internal drainage system of the study area. Uplands generally have few stone patches and are undulating and uneven. The agro-climatic zone is located in the lower Sanjab watershed, a suitable area for pistachio gardens. This study requires information regarding rainfall, soil, and vegetation or ground cover in the study area. Data on observed runoff at the watershed outlet are also required for validating estimation model. Topographic maps and other essential maps were extracted from the 25-meter Digital Elevation Model (DEM), land use, and land cover (from FAO 2019), soil cover, and satellite images using the Geographical Information System (GIS 10.4) and remote sensing techniques. 3.1.3 Rainfall data, The rainfall data were used to estimate runoff volume in the

Sanjab watershed study area. The study area has one central rain gauge station, namely Khoshrabad, located at the start point of the Sanjab watershed, near the Sanjab River bridge on the Herat-Torghandi highway. The 10-year (2012–2021) 24-hour rainfall data for the station were collected from the Department of Hydrology of the National Water Authority (NaWARA) or the Ministry of Water and Power.

Soil

In this study, soil data were used to determine the runoff-generating potential of the study area. The soil map of the watershed and the boundaries of the different soil textures were digitized The FAO created this map using geographic information systems (GIS) and remote sensing (RS) techniques. This map is shown below in Figure 2:

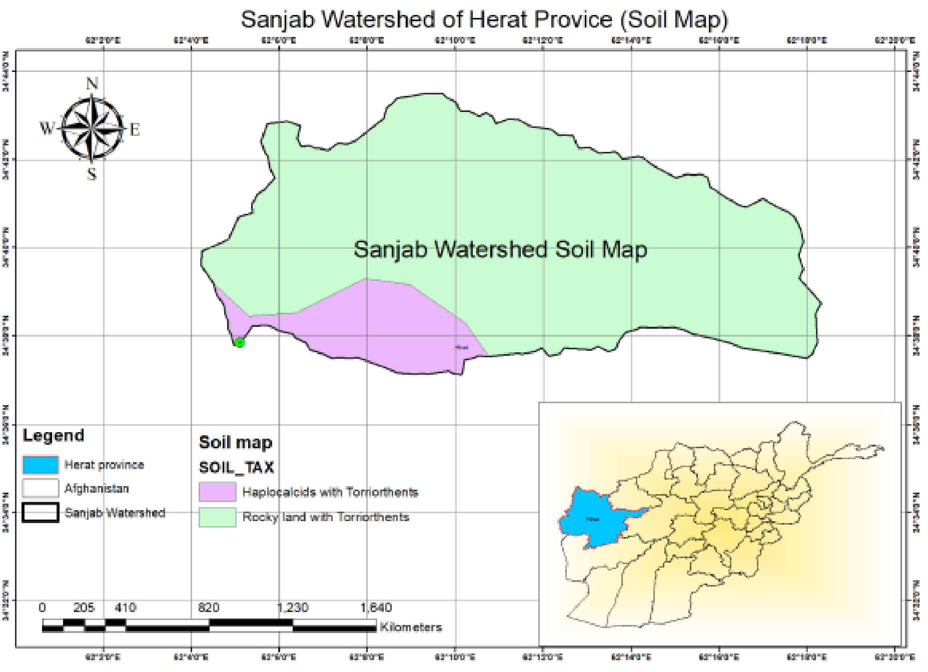

***Figure2**: Soil map of Sanjab Watershed*

Observed Runoff Data

Observed runoff data from the stream and rain gauge station at the outlet point of the Sanjab watershed, near the bridge of the Sanjab River on the Herat-Torghandi highway. The 10-year (2012–2021) 24-hour rainfall data of the station was collected from the Department of Hydrology of the

National Water Affairs Regulation Authority (NaWARA) or the Ministry of Water and Power (MEW). For an accurate estimate of the Sanjab Watershed, fortunately, there is a rain gauge, the Khushrabad Rain Gauge Station.

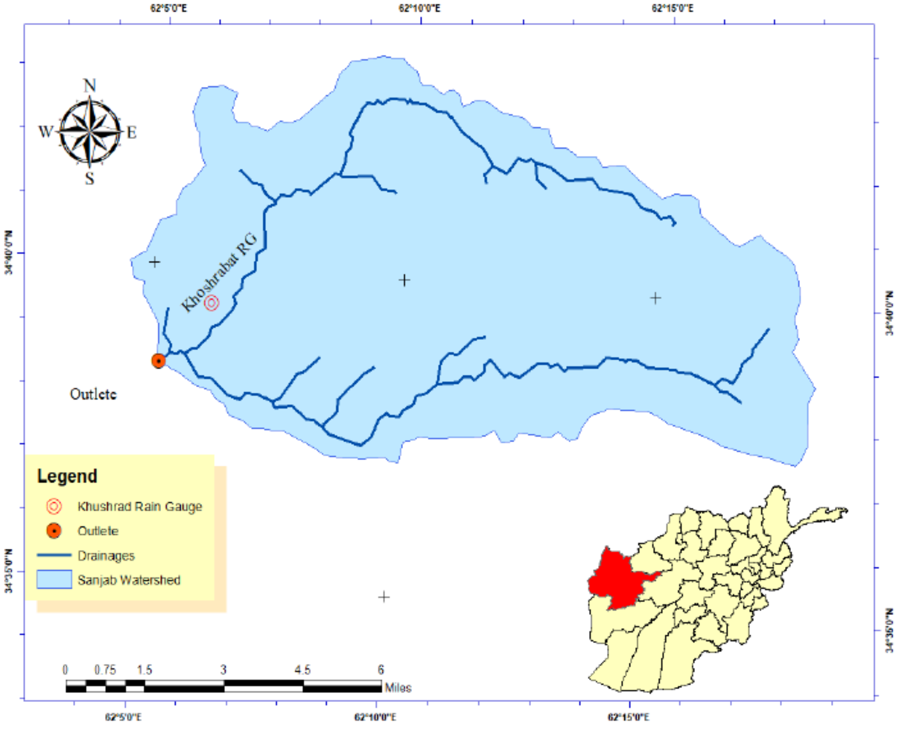

Figure3: *Location of streamflow and precipitation gauging station of Sanjab Watershed*

Results and Discussion

The results obtained by adopting the previously stated methodology are briefly discussed. Using Remote Sensing and GIS techniques, spatial runoff modeling with the Natural Resources Conservation Service Curve Number (SCS-CN) model was performed to estimate direct runoff. The NRCS curve number model requires parameters such as watershed area, soil type, land use/land cover, initial abstraction, and potential maximum retention to estimate the curve number and runoff. Simulated runoff was validated with observed runoff at the watershed outlet.

Development of a Model Data Base for SCS-CN

Rainfall (P)

A rainfall map shows the total amount of rainfall received in a given area within a given period of time. The Thiessen polygon for the study area was not created in the GIS environment because we need more than one rain gauge to generate it in this case. I created a rainfall intensity map from elevation data for the Sanjab watershed because, in hydrology, we know precipitation is higher in higher areas than in lower areas. It is depicted in Figure 4 below. Then, specific rainfall values were assigned to specific areas of the rain gauge station to produce a rainfall map. The raster rainfall maps were prepared for individual events. The rainfall map of 14 Feb 2021 is shown for representation purposes.

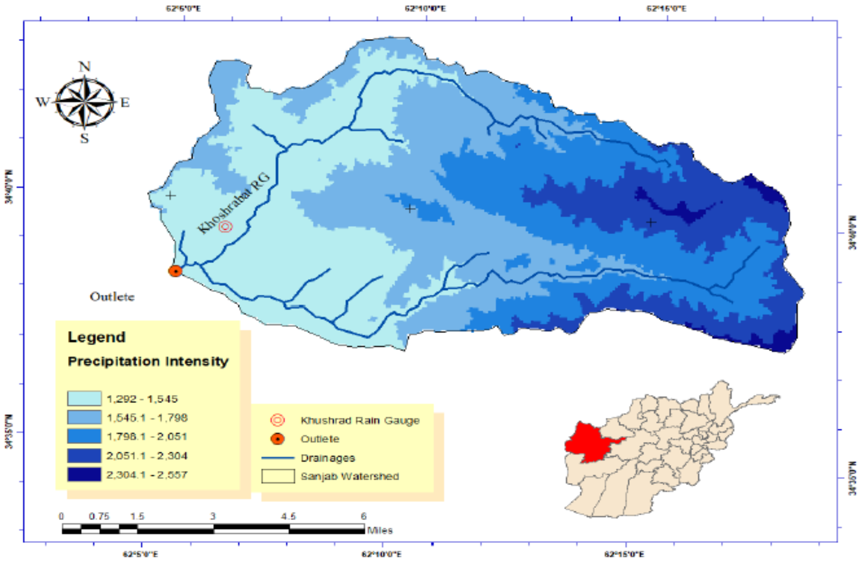

***Figure 4**: Precipitation intensity map of Sanjab Watershed*

Land use/Land Cover Change in the Sanjab Watershed

Land use/land cover LU/LC changes are significant issues of global environmental change. To obtain information on vegetation or ground cover, the land-use and land-cover maps of the study area were prepared in 2019 using ERDAS IMAGINE 2010. The study area has been classified into 7 major land use/land-cover classes: forest, agriculture, wasteland, habitation, water bodies, open land, and river. The land use/land-cover maps for the study area for respective years are shown in Figure5;

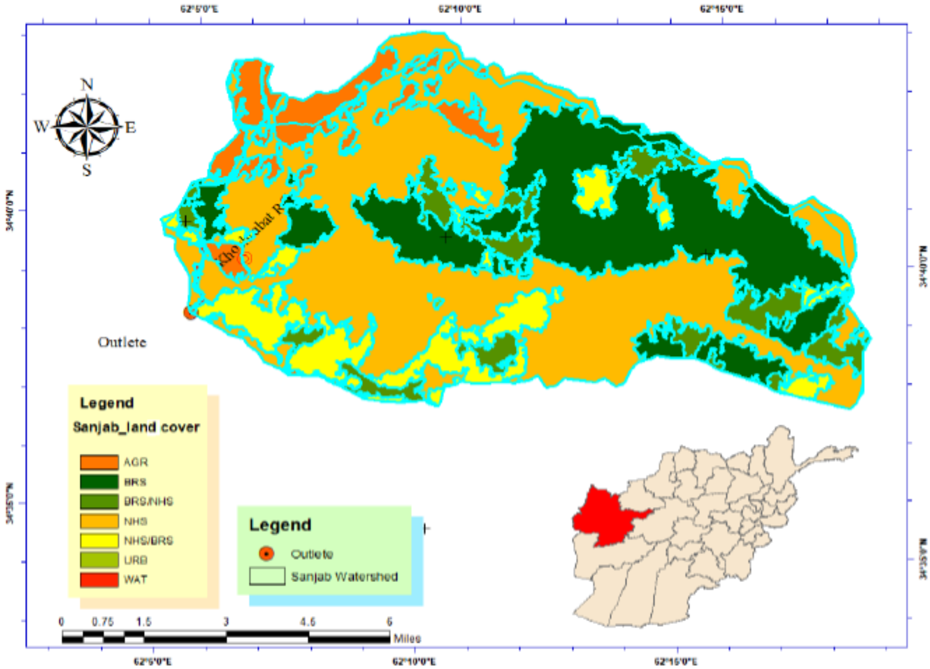

Figure 5*: Land use/land cover (LULC) map of Sanjab watershed of year 2019*

Calculation of Simulated and Observed Runoff Data

The direct surface runoff from observed data has also been calculated from existing data for 10 years. In general, a good association has been found between observed and computed runoff. The calculated runoff is presented in the Table 1.

Table1*. Runoff estimation of Sanjab Watershed*

Years	Total Volume (m^3)
2012	9952171
2013	10805870
2014	9061754
2015	15857686
2016	12225641
2017	10056206
2018	14084502
2019	17298885
2020	14620741
2021	13057921

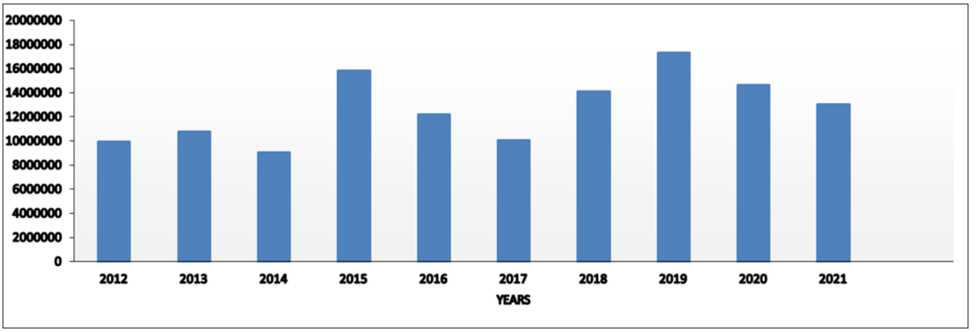

***Figure 6**: Comparison of 10 years runoff volume*

As mentioned above, the precipitation data for 10 years (2012–2021) for the Sanjab watershed was calculated according to the Soil Conservation Service Curve Number (SCS-CN) method and through techniques of the Global Information System (GIS) and Remote Sensing (RS).

Conclusion

The runoff estimated using the SCS-CN method is comparable to that measured by the conventional method. The results show that the simulated runoff processes are in good agreement with the measured runoff processes, with simulation accuracy exceeding 85%, demonstrating that the incorporation of remote sensing, GIS, and the SCS model provides a powerful tool for runoff simulation of the Sanjab river watershed. The Sanjab watershed shows violent in response to against rainfall runoff. It indicates at this particular water needs to apply more pressure to its attributes to produce runoff in response to rainfall storms. This phenomenon might accelerate further erosion processes in the study area. This research is also to those who work in watershed management and in the design of bridges, culverts, roads, and water-absorption wells. Because the central problem the designer of the above structures faces in the design process is determining the accurate amount of surface runoff, this research presents a simple, straightforward way to do so.

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Author Contributions

The first author led the analysis and interpretation of results. The collaborating author managed data collection and numerical data compilation. Both authors contributed to ensuring the quality and accuracy of the final manuscript.

Competing Interests

The author declares that they have no conflicts of interest to disclose .

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