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Runoff Analysis Using the SCS CN Method: Implications for Hydrological Modeling and Sustainable Development

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Abstract: This study emphasizes the pivotal role of the Soil Conservation Service Curve Number (SCS CN) method in hydrological modeling for runoff analysis. The method, based on land use, soil type, and antecedent moisture conditions, accurately predicts direct runoff, facilitating water resource management and sustainable development. The simplicity and efficiency of the SCS CN method make it invaluable for hydrologists, planners, and policymakers. Through case studies, it demonstrates adaptability and reliability in diverse geographical areas, even with limited data. The research underscores the method's contribution to informed decision-making, effective stormwater management, and risk mitigation. By integrating the SCS CN method, this study promotes sustainable development through improved water resource management, enabling responsible water use in agriculture, urban development, and ecosystem preservation. In conclusion, the SCS CN method significantly enhances hydrological models, fostering better water resource management and contributing to sustainable development goals. The study involved the calculation of the Antecedent Moisture Condition (AMC) using rainfall data and curve numbers of microwatersheds, along with their corresponding hydrological soil groups. These findings underscore the necessity of localized assessments for effective watershed management, emphasizing the importance of tailored strategies to address varying rainfall patterns and enhance sustainable water resource management practices Results revealed significant variations in rainfall distribution across different blocks, with Mandalgarh block recording the highest accumulation at 48,263 TCM (thousand cubic meters), indicative of robust runoff generation and water availability.
Keyword: SCS-CN Method, Runoff, Sustainable Development, Stormwater Management, Hydrological Modeling, Soil Erosion, Infrastructure Development.

I. INTRODUCTION

When water flow through the ground surface outweighs soil infiltration capacity, surface runoff inevitably happens. Planning and management of water resources at the watershed level need a comprehensive evaluation of the hydrologic response of a watershed. Some of its key importance:

a)Water Supply: Runoff water contributes to replenishing water bodies such as rivers, lakes, and reservoirs, which serve as important sources of drinking water, irrigation for agriculture, and industrial use. In areas where groundwater is recharged by runoff, it also sustains wells and aquifers b)Erosion Control: While excessive runoff can lead to erosion, moderate runoff helps to transport sediments, nutrients, and organic matter across landscapes. This natural process contributes to soil formation and fertility, supporting agricultural productivity and ecosystem health. c)Aquatic Ecosystems: Runoff provides essential freshwater input to aquatic ecosystems, maintaining water levels, supporting diverse habitats, and ensuring the survival of aquatic organisms. It also transports nutrients and organic matter that are vital for the health of aquatic plants and animals. d)Flood Regulation: Runoff plays a crucial role in regulating river flow and preventing floods. Vegetation and natural land features can help to slow down runoff, reducing the risk of flash floods and allowing water to infiltrate into the soil, where it can be stored and gradually released. e)Transportation and Navigation: Rivers and streams formed by runoff have historically served as important transportation routes for trade and commerce. Even today, many waterways are used for shipping goods and navigating between different regions. f)Hydropower Generation: Runoff provides the water flow necessary for generating hydropower, a renewable energy source that contributes to electricity production in many parts of the world. Dams and reservoirs built to harness runoff can store water during periods of excess and release it when demand for electricity is high. g)Recreation and Tourism: Lakes, rivers, and coastal areas formed by runoff provide opportunities for recreational activities such as boating, fishing, swimming, and wildlife watching. These natural attractions also support tourism economies in many regions.

Overall, runoff water is a critical component of the Earth's hydrological cycle, sustaining ecosystems, supporting human activities, and shaping landscapes in diverse ways. However, managing runoff effectively is essential to mitigate the negative impacts of erosion, flooding, and pollution while maximizing its benefits for both nature and society.

For ungauged watersheds, it is challenging and time-consuming to get reliable estimates of the amount and rate of runoff from the land surface into streams and rivers. Nonetheless, addressing numerous issues related to watershed development and management requires the use of this knowledge. Significant hydrological and meteorological data are needed for conventional models to predict river discharge. The method of gathering this data is challenging, costly, and time-consuming.

Higher runoff, which refers to an increased volume of water flowing over the land surface, can have significant impacts on both natural ecosystems and human societies. These impacts vary depending on factors such as the magnitude, duration, and frequency of runoff events, as well as the characteristics of the landscape and land use practices. Below are some of the key impacts of higher runoff:a)Increased runoff can lead to accelerated erosion of soil particles and sediment transport ,resulting in the loss of fertile topsoil, degradation of agricultural lands, and sedimentation of rivers, lakes, and reservoirs, impacting water quality, aquatic habitats, and navigation channels.b) Contributes to an elevated risk of flooding, as excessive water accumulates in river channels, floodplains, and urban areas during intense precipitation events or snowmelt periods. Floods pose threats to human lives, property, infrastructure, and livelihoods, causing damage.c)Can lead to water quality degradation as increased runoff can carry pollutants, such as sediment, nutrients, pesticides, heavy metals, and pathogens, from various sources, including urban areas, agricultural fields, industrial sites, and wastewater discharges, into water bodies.d) Higher runoff can modify natural habitats and ecological processes, impacting the distribution, abundance, and diversity of plant and animal species dependent on aquatic and riparian environments.e) Climate change can exacerbate the impacts of higher runoff by altering precipitation patterns, intensifying storms, and increasing the frequency of extreme weather events.

II. ROLE OF REMOTE SENSING & GIS IN RUNOFF ANALYSIS

Gaining knowledge of the hydrological system is the key objective of hydrological modelling in order to produce reliable information for long-term water resource management that will boost environmental protection and human welfare(Vangala Savinai, Dec.2016). In recent decades, the integration of remote sensing technologies and Geographic Information Systems (GIS) has revolutionized the way we analyze and manage water resources, particularly in understanding runoff processes. Hydrological modeling involves the use of mathematical and computational techniques to simulate the movement and distribution of water within the hydrological cycle. At the core of hydrological modeling lies the analysis of runoff. Runoff analysis encompasses the estimation of key hydrological parameters, including runoff volume, peak flow rates, flow duration, and spatial distribution of runoff across watersheds or river basins. These parameters are influenced by various factors such as precipitation patterns, land cover characteristics, soil properties, topography, and human activities. Through runoff analysis, hydrologists seek to understand the processes governing runoff generation, flow pathways, and hydrological responses to different environmental conditions.Remote sensing encompasses a wide array of techniques for acquiring data about Earth's surface and atmosphere using sensors mounted on satellites, aircraft, drones, and ground-based platforms. These sensors capture electromagnetic radiation across different wavelengths, enabling the detection of various land surface characteristics relevant to runoff analysis. Remote sensing data provide essential inputs for understanding factors such as land cover, topography, soil moisture, and vegetation dynamics, which influence runoff processes.

Satellite-based remote sensing platforms, such as Landsat, MODIS (Moderate Resolution Imaging Spectroradiometer), and Sentinel missions, offer multispectral and temporal data for monitoring land surface conditions over large spatial extents and extended time periods. These data are utilized to derive key parameters for runoff analysis, including vegetation indices, land surface temperature, precipitation, and land use/land cover classifications. For example, normalized difference vegetation index (NDVI) derived from satellite imagery serves as a proxy for vegetation density and health, influencing evapotranspiration rates and infiltration capacities, thereby impacting runoff generation.In addition to satellite-based sensors, airborne and drone-based remote sensing technologies provide higher spatial resolution data, enabling detailed mapping of topographic features, land cover types, and hydrological characteristics at local scales. High-resolution imagery obtained from unmanned aerial vehicles (UAVs) facilitates the delineation of drainage networks, identification of impervious surfaces, and estimation of surface roughness parameters critical for runoff modeling.

Geographic Information Systems (GIS) serve as powerful tools for integrating, analyzing, and visualizing spatial data related to runoff processes. GIS enables the creation of digital representations of the Earth's surface, incorporating layers of information such as topography, land cover, soil properties, and hydrological features into a unified geospatial framework.

By overlaying and analyzing these spatial datasets, GIS facilitates the identification of runoff pathways, estimation of flow accumulation, and modeling of hydrological processes.GIS-based hydrological modeling involves the application of mathematical algorithms to simulate the movement of water through the landscape, considering factors such as precipitation, infiltration, evapotranspiration, and surface runoff. Various hydrological models, such as the Soil and Water Assessment Tool (SWAT), Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), and Distributed Hydrology Soil Vegetation Model (DHSVM), are integrated within GIS environments to simulate runoff generation, flow routing, and water balance computations at different spatial and temporal scales. The synergy between remote sensing and GIS enhances the accuracy, efficiency, and scalability of runoff analysis by leveraging the complementary strengths of both technologies. Remote sensing provides spatially explicit data for characterizing land surface properties and monitoring environmental changes, while GIS facilitates the spatial analysis, modeling, and visualization of hydrological processes within a geospatial context.Several studies have demonstrated the utility of integrating remote sensing and GIS in runoff analysis across various geographic regions and hydrological settings. For instance, remote sensing data have been employed to estimate vegetation parameters and soil moisture content, which are subsequently incorporated into GIS-based hydrological models to simulate runoff dynamics and assess water resources availability in watersheds. Furthermore, the availability of open-access satellite imagery and GIS software packages has democratized the application of these technologies, empowering researchers, practitioners, and policymakers to undertake runoff analysis at local, regional, and global scales. They play indispensable roles in runoff analysis by providing spatially explicit data, analytical tools, and modeling frameworks for understanding and managing water resources. The integration of these technologies enables comprehensive assessments of runoff processes, from identifying influencing factors to predicting hydrological responses across diverse landscapes and climatic conditions. As advancements in remote sensing and GIS continue to evolve, their application in runoff analysis holds promise for improving water resource management, mitigating hydrological hazards, and enhancing environmental sustainability in the face of global environmental changes. The integration of runoff analysis into hydrological modeling frameworks involves the utilization of various modeling techniques, data sources, and computational tools to simulate runoff processes and analyze their implications for water resources management. Hydrological models, ranging from simple empirical models to complex distributed models, are used to represent the spatial and temporal dynamics of runoff generation, flow routing, and water balance within hydrological systems.Empirical models, such as the Soil Conservation Service Curve Number (SCS-CN) method and the Rational Method, are widely used for estimating runoff volumes based on simplified relationships between rainfall, soil moisture, land cover, and land use characteristics. These models are suitable for quick assessments of runoff potential and are often employed in engineering applications for stormwater management, urban drainage design, and flood control projects.

III. SOIL CONSERVATION SERVICE CURVE NUMBER (SCS-CN) METHOD.

In hydrology, an empirical parameter known as the runoff curve number (or simply CN) is used to estimate direct runoff or infiltration following surplus rainfall. In the literature, the number is still frequently referred to as a "SCS runoff curve number" and was created by the USDA Natural Resources Conservation Service, formerly known as the Soil Conservation Service, or SCS. The USDA's hillslope plots and small catchment runoff were empirically analysed to determine the runoff curve number. It is a popular and effective technique for estimating the volume of direct runoff from a rainfall event in a specific location.

This method was developed in 1954 and is documented in section 4 of the National Engineering Handbook (NEH-4) published by the Soil Conservation Service of the United States Department of Agriculture (USDA) in 1956. This method is simple, easy to understand and use; stable, and useful for ungauged watersheds. The primary reasons for its wide applicability and acceptability lies in the fact that it accounts for most runoff producing watershed characteristics: soil type, land use/treatment, surface condition and antecedent moisture condition. For drainage basins where no runoff has been measured, the Curve Number Method can be used to estimate the depth of direct runoff from the rainfall depth, given an index describing runoff response characteristics.

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the actual amount of direct surface runoff (Q) to the total rainfall (P) (or maximum potential surface runoff) to the ratio of the amount of actual infiltration (F) to the amount of the potential maximum retention (S). The second hypothesis relates the initial abstraction (Ia) to the potential maximum retention, thus the SCS-CN method consists of:

(a) Water Balance Equation:

$$P = Ia + F + Q \qquad (1.1)$$

(b) Proportional Equality Hypothesis:

$$Q/P\text{-}Ia = F/S \qquad (1.2)$$

(c) Ia -S hypothesis

$$Ia = \lambda S \qquad (1.3)$$

Where P= total rainfall; Ia =initial abstraction; F= cumulative infiltration excluding Ia; Q= direct runoff; and S= potential maximum retention or infiltration.

Combining equations 1.1 and 1.2, it becomes

$$Q = (P - Ia)2/(P - Ia + S) \qquad (1.4)$$

Equation is valid for P ≥ Ia. For λ = 0.2, the equation can be written as:

$$Q = (P - 0.2\ S)2/(P + 0.8\ S) \qquad (1.5)$$

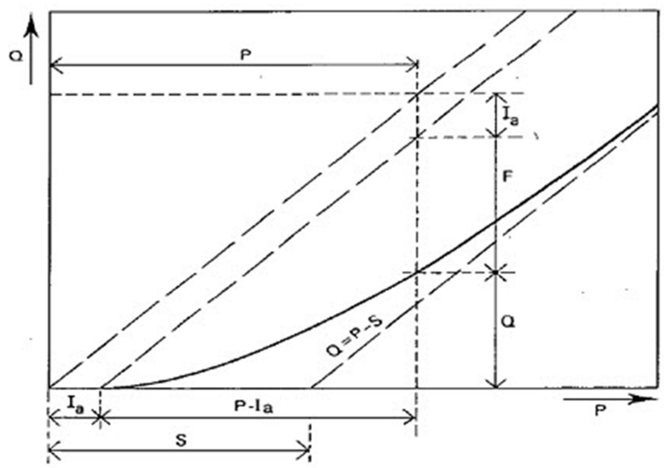

Fig. 1.1: Accumulated runoff Q versus accumulated Rainfall P according to the Curve number Method. (Source: http://ecoursesonline.iasri.res.in/mod/page/view.php?id=1900)

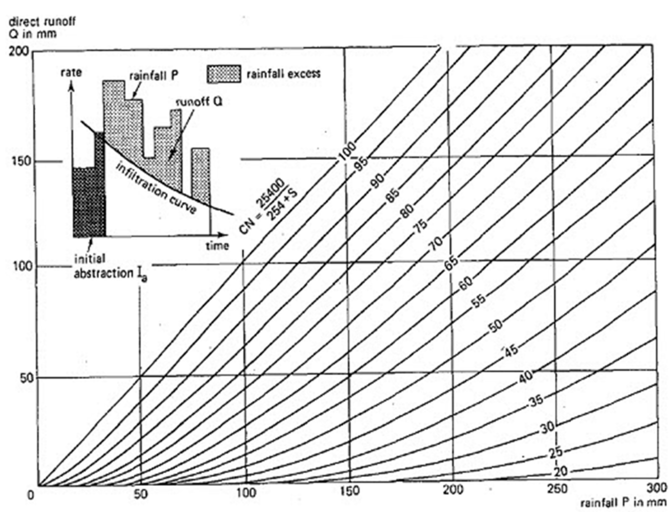

Fig. 1.2: Graphical solution of equation 1.4 showing runoff depth Q as a function of Rainfall depth P and Curve number. (Source:http://ecourseonline.iasri.res.in/mod/page/view.php?id=1900)

Since the SCS-CN approach was first created using daily rainfall-runoff data of annual extreme flows, it is a one parameter model for calculating surface runoff from daily storm rainfall. The maximum (P-Q) difference that can happen under the specific storm and watershed state is represented by the constant S. S is constrained by the quantity of water storage that is available in the soil profile or the rate of infiltration at the soil surface, whichever results in a smaller S value. Parameter S is mapped into a dimensionless curve number (CN), fluctuating in a more manageable range 0 ≤ CN ≤ 100, as follows: This is because parameter S might change in the range of 0 ≤ S ≤ ∞. In exceedingly permeable, level-lying soils, S will reach infinity and CN will equal zero, meaning that all precipitation will seep through and there won't be any runoff. The reality in drainage basins will lie somewhere in the middle.

A. *Curve Values of different Variables.*

The NRCS curve number is related to soil type, soil infiltration capability, land use, and the depth of the seasonal high water table. To account for different soils' ability to infiltrate, NRCS has divided soils into four hydrologic soil groups (HSGs). They are defined as follows.

HSG Group A (low runoff potential): Soils with high infiltration rates even when thoroughly wetted. These consist chiefly of deep, well-drained sands and gravels. These soils have a high rate of water transmission (final infiltration rate greater than 0.30 in (7.6 mm) per hour).

HSG Group B: Soils with moderate infiltration rates when thoroughly wetted. These consist chiefly of soils that are moderately deep to deep, moderately well drained to well drained with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (final infiltration rate of 0.15–0.30 in (3.8–7.6 mm) per hour).

HSG Group C: Soils with slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmission (final infiltration rate 0.05–0.15 in (1.3–3.8 mm) per hour).

HSG Group D (high runoff potential): Soils with very slow infiltration rates when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission (final infiltration rate less than 0.05 in (1.3 mm) per hour).

B. *Antecedent Moisture Condition*

The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in three Antecedent Moisture Condition **(AMC)**
Classes:
AMC I: The soils in the drainage basin are practically dry (i.e. the soil moisture content is at wilting point).
AMC II : Average condition.
AMC III: The soils in the drainage basins are practically saturated from antecedent rainfalls (Le. the soil moisture content is at field capacity).
These classes are based on the 5-day antecedent rainfall (i.e. the accumulated total rainfall preceding the runoff under consideration).

COVER DESCRIPTION		CURVE UMBERS FOR HSG			
		A	B	C	D
Open Space (Lawns , Parks, Cemeteries,etc.)	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good condition (grass cover >75%)	39	61	74	80
Impervious Areas	Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and Roads	Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right of way)	76	85	89	91

	Dirt (including right-of-way)	72	82	87	89
	Natural Desert landscaping (pervious area only)	63	77	85	88
Western Desert Urban Areas	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	96	96	96	96
Urban Districts	Commercial and business (85% imp.)	89	92	94	95
	Industrial (72% imp.)	81	88	91	93
Residential Districts	2 acres (12% imp.)	46	65	77	82
	1 acre (20% imp.)	51	68	79	84
	½ acre (25% imp.)	54	70	80	85
	¼ acre (38% imp.)	61	75	83	87

Table 1.1: Table depicting Curve numbers for different Land Use Land cover types according to Hydrological Soil Group.(Source : https://en.wikipedia.org/wiki/Runoff_curve_number)

Cover Description			Curve Numers for HSG			
Cover Type		Hydrologic Condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[a]		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Brush—brush-weed-grass mixture with brush the major element.[b]		Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
Woods—grass combination (orchard or tree farm).[c]		Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
Woods.[d]		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
Desert shrub—major plants include saltbush, geasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.		Poor	63	77	85	88
		Fair	55	72	81	86
		Good	49	68	79	84
Fallow	Bare Soil	______	77	86	91	94
	Crop Residue Cover [e]	Poor	76	85	90	93
		Good	74	83	88	90
Row Crops	Straight Row	Poor	72	81	88	91
		Good	67	78	85	89
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured & Terraced	Poor	66	74	80	82
		Good	62	71	78	81

Table Table 1.3: depicting Curve numbers for different Vegetation types according to Hydrological Soil Group.(Source: https://en.wikipedia.org/wiki/Runoff_curve_number)

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[a] Poor: <50% ground cover or heavily grazed with no mulch; Fair: 50-75% ground cover and not heavily grazed; Good: >75% ground cover and light or only occasionally grazed.

[b] Poor: <50% ground cover; Fair: 50-75% ground cover; Good: >75% ground cover.

[c] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[d] Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning; Fair: Woods are grazed but not burned, and some forest litter covers the soil; Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

[e] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year

IV. STUDY AREA

The study area for runoff analysis in Bhiwara District is a crucial aspect of watershed management and sustainable development initiatives. While Bhiwara District serves as the broader geographical context, it's important to note that the runoff analysis does not encompass the entire district. Instead, it focuses on specific areas within the district, delineated by the Integrated Watershed Management Program (IWMP) for targeted interventions. The la

The IWMP, implemented in selective blocks and specific areas within Bhiwara District, represents a strategic approach to execute projects aimed at improving water resource management, soil conservation, and overall environmental sustainability. The selection of these areas is guided by various factors, including topography, land use patterns, hydrological characteristics, and socio-economic considerations. By concentrating efforts in these designated areas, the IWMP aims to maximize the impact of interventions and effectively address local challenges related to water scarcity, soil erosion, and agricultural productivity. The project boundary delineated for the 2021-26 period serves as the operational framework within which activities related to runoff analysis and other watershed management initiatives are conducted. This boundary provides a spatial context for data collection, analysis, and implementation of measures aimed at enhancing water retention, minimizing soil loss, and promoting sustainable land use practices. Through a combination of field surveys, remote sensing techniques, and hydrological modeling, researchers and practitioners can assess the runoff dynamics within the designated study area, identifying critical zones prone to erosion and guiding the formulation of targeted interventions. While the runoff analysis may not cover the entirety of Bhiwara District, its focus on the IWMP-selected areas underscores a strategic approach to watershed management, reflecting a broader commitment to environmental stewardship and community resilience. By integrating scientific analysis with local knowledge and community engagement, the runoff analysis contributes to informed decision-making processes, laying the foundation for sustainable development and the conservation of natural resources in Bhiwara District and beyond.

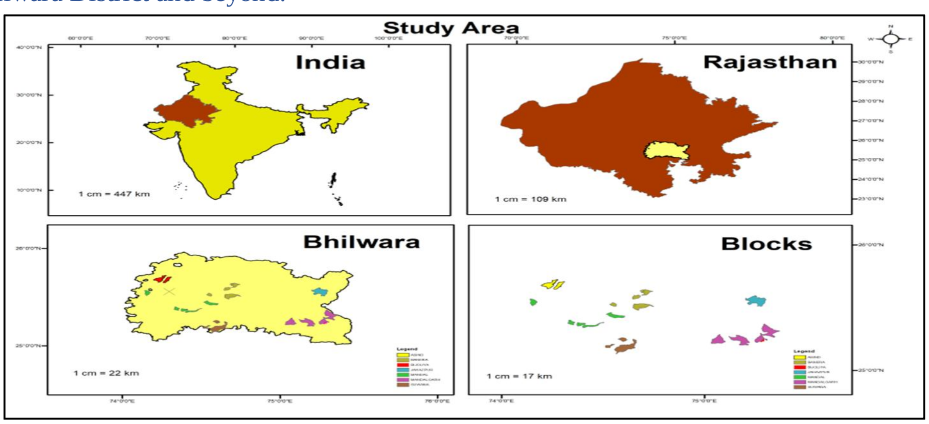

Fig. 1.3: Map of the Study Area – Project Boundary of IWMP Bhilwara 2021-2026.
(Source: Boundaries procured from Watershed Development and Soil Conservation Department , Bhilwara(Raj.))

V. METHODOLOGY

The first step in implementing the SCS CN method for runoff analysis involves comprehensive data collection. This includes gathering various datasets such as digital elevation models (DEMs) for terrain analysis, soil data for hydrological soil group (HSG) classification, land use/land cover (LULC) data, and precipitation records. These datasets provide essential inputs for characterizing the physical properties of the watershed and its response to rainfall events.

Once the required datasets are collected, they are processed and prepared as input layers for the runoff analysis. This involves preprocessing DEM data to derive slope and flow direction layers, which are crucial for determining surface runoff pathways. Soil data are classified into hydrological soil groups (HSGs) according to their infiltration characteristics. LULC data are categorized into different land cover classes, each assigned with corresponding CN values based on their hydrological characteristics.

The next step is to calculate the CN values for each land cover class within the watershed. This involves referencing the SCS CN method tables or equations, which provide CN values based on soil type, land use, and hydrological soil group. CN values represent the runoff potential of different land cover and soil combinations, ranging from highly impervious surfaces to highly permeable soils. These values are assigned to corresponding land cover classes in the LULC layer, forming the basis for runoff estimation. With the CN values assigned to land cover classes, the input layers are integrated using GIS software. Spatial analysis techniques are employed to overlay the LULC, soil, and slope layers, creating a composite representation of runoff potential across the watershed. By considering the spatial distribution of CN values, the analysis identifies areas with varying degrees of runoff potential, facilitating targeted watershed management interventions. Finally, runoff estimation is performed using the integrated input layers and the SCS CN method equations. The results provided valuable insights into watershed behavior, guiding decision-making processes related to flood risk management, water resource planning, and erosion control. Key datasets included Landsat 8 Operational Land Imager (OLI) satellite imagery, acquired at a spatial resolution of 30 meters, for Land Use and Land Cover (LULC) generation. This high-resolution imagery provided detailed information about land cover types within the study area, essential for understanding landscape dynamics and resource allocation.Additionally, soil maps were obtained offering valuable insights into soil types and properties across the watershed. These soil maps provided critical information for assessing soil suitability, erosion risks, and hydrological characteristics, informing land management decisions and conservation strategies.Rainfall data, sourced from the Meteorological Department in Jaipur, served as a fundamental input for hydrological modeling and runoff estimation. This dataset provided long-term precipitation records essential for understanding rainfall patterns, intensity, and variability within the watershed area.The modeling process was executed in GIS software, facilitating data integration, analysis, and computation of hydrological parameters. Furthermore, spatial data layers were also prepared and analyzed using the ArcGIS and QGIS software. These platforms enabled the creation of geospatial datasets, visualization of spatial relationships, and spatial analysis, enhancing the accuracy and efficiency of watershed assessment and management efforts.

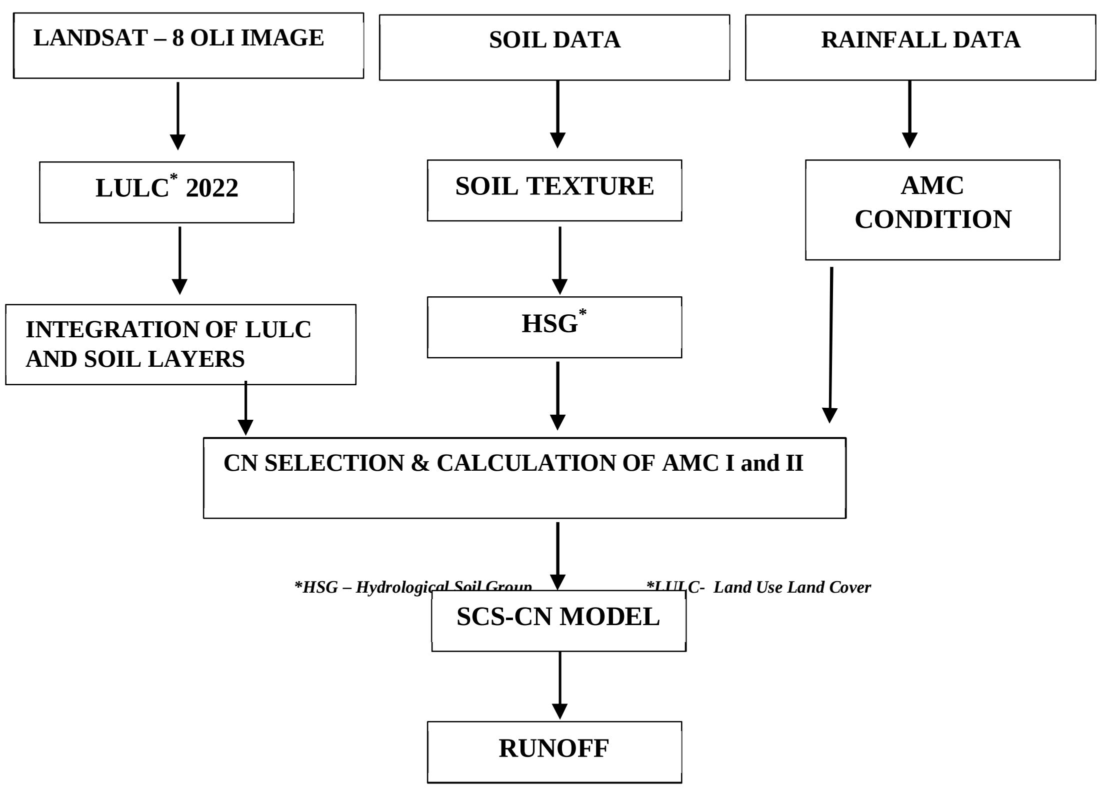

Fig. 1.4: Methodology Chart for Runoff Estimation using SCS- CN Method.

VI. ANALYSIS & CONCLUSION

In the pursuit of comprehensively understanding the landscape characteristics and soil composition within the micro project boundary of the Integrated Watershed Management Program (IWMP), a detailed analysis was conducted using remote sensing data and soil information. This analysis aimed to provide valuable insights into the land use and soil types prevalent in the designated area, which are pivotal for effective watershed management strategies. Utilizing Landsat 8 Operational Land Imager (OLI) data in QGIS, a Land Use and Land Cover (LULC) layered map was generated. This process involved the classification of satellite imagery into distinct categories representing different land cover types. Five primary categories were identified within the micro project boundary:Agriculture,Wasteland,Built-Up, Water-Body and Forest. In conjunction with the LULC analysis, a soil composition analysis was conducted by procuring soil data from the Soil Department. Soil layers were generated for the micro project boundary to characterize soil types prevalent in the area. Upon analysis, it was observed that Fine Loamy soil dominated the landscape, followed by Coarse Loamy and Loamy Skeletal and Fine soil types. Fine Loamy soil is less prone to generating surface runoff compared to sandy soils but more susceptible than clayey soils. It allows some water infiltration before saturation, which can reduce surface runoff and erosion, Coarse Loamy soil is more prone to generating surface runoff compared to Fine Loamy soil. Its higher permeability facilitates rapid infiltration, but it also means that water may quickly reach saturation levels, leading to increased surface runoff during intense rainfall events. However, its coarse texture may reduce the risk of soil erosion compared to finer-textured soils. The hydrological behavior of Loamy Skeletal and Fine soil can vary depending on the ratio of fine particles to gravel. Generally, it exhibits moderate permeability, allowing for both infiltration and some surface runoff. The presence of gravelly material may enhance drainage, reducing the risk of saturation-induced runoff, but it can also increase surface runoff by reducing water retention capacity in finer-textured portions of the soil and therefoe Loamy Skeletal and Coarse Loamy were assigned in HSG A , Fine Loamy assigned HSG C and Fine soil under HSG D. After compiling and assigning Hydrologic Soil Groups (HSG) to the soil types identified—Fine Loamy, Coarse Loamy, and Loamy Skeletal and Fine—the corresponding Curve Numbers (CN) were assigned based on the Land Use and Land Cover (LULC) classification and HSG for each micro-watershed boundary. This process involved integrating the hydrological characteristics of the soil types with the land cover characteristics to estimate the runoff potential within each watershed grid.Following the assignment of Curve Numbers, an ultimate number was inferred for each micro-watershed boundary. The inferred ultimate number represents a composite value derived from the combination of soil type, land cover, and other hydrological parameters within the watershed area. This ultimate number serves as a key input for estimating runoff potential, which is crucial for watershed management and planning efforts.Using the inferred number and average rainfall data spanning a period of ten years, runoff was estimated for each watershed grid. The estimation of runoff takes into account various factors, including precipitation patterns, soil infiltration rates, land cover characteristics, and topographic features within the watershed area.By integrating soil data, land cover information, and rainfall data into runoff estimation models, it becomes possible to assess the hydrological behavior of the watershed and predict the magnitude and timing of runoff events. This information is invaluable for watershed management practitioners, allowing them to develop effective strategies for mitigating flood risks, managing water resources, and protecting the environment.Overall, the process of assigning Curve Numbers, inferring ultimate numbers, and estimating runoff provides valuable insights into the hydrological dynamics of each micro-watershed boundary.

In conclusion, the runoff analysis conducted in the study area revealed significant variations in rainfall distribution across different blocks. Mandalgarh block exhibited the highest rainfall accumulation, recording a substantial volume of 48,263 TCM (thousand cubic meters), indicating a robust potential for runoff generation and water availability. Conversely, Suwana block experienced the lowest rainfall accumulation, with only 3,037.03 TCM, highlighting a comparatively limited contribution to runoff and potential water resources. These findings underscore the importance of localized assessments and watershed management strategies tailored to address the varying rainfall patterns and runoff potential across different geographical regions, thereby enhancing water resource planning and management efforts to ensure sustainable water availability in the study area.

Block	Total Runoff *(Th. Cubic Metre)*
Asind	*130609.79*
Banera	*186481.13*
Bijoliya	*198180.39*
Jahazpur	*220915.23*
Kareda	*141747.37*
Mandal	*44835.93*
Mandalgarh	*204515.6*
Suwana	*105048.63*

Table 1.4: Blockwise Total Runoff in Thousand Cubic Metre.

Sr.No.	Block	Macro/Micro Watershed	Runoff (Th. Cubic Metre)
1	Mandalgarh	08/07	2500
2	Mandalgarh	08/06	5000
3	Mandalgarh	08/08	2933
4	Mandalgarh	08/11	3289
5	Mandalgarh	09/04	5549.27
6	Mandalgarh	09/08	3910
7	Mandalgarh	09/05	8699
8	Mandalgarh	17/03	6244
9	Mandalgarh	16/34	4539
10	Mandalgarh	09/07	9865
11	Mandalgarh	09/03	4599
12	Mandalgarh	17/01	12333
13	Mandalgarh	08/13	6259
14	Mandalgarh	17/02	17895
15	Mandalgarh	16/33	15123
16	Mandalgarh	16/31	11236
17	Mandalgarh	16/30	20656
18	Mandalgarh	16/32	33556
19	Mandalgarh	09/06	30330
20	Mandalgarh	16/35	2500
21	Suwana	17/04	3037.03
22	Suwana	18/01	4450
23	Suwana	17/01	21424.67
24	Suwana	18/02	29759.47
25	Suwana	21/08	46736.6
26	Mandal	20/01	5770
27	Mandal	17/10	8006.85
28	Mandal	20/02	10355.97
29	Mandal	15/16	18600.35
30	Mandal	24/05	20702.45
31	Mandal	11/03	22589.47
32	Mandal	15/17	27828.02
33	Mandal	15/15	35172.29
34	Mandal	15/14	37557.22
35	Jahazpur	23/04	3471.08
36	Jahazpur	23/05	8272.25
37	Jahazpur	23/07	12595.49
38	Jahazpur	23/06	14270.9
39	Jahazpur	23/02	15123.25
40	Jahazpur	24/02	15469.55
41	Jahazpur	23/08	15537.11
42	Bijoliya	08/09	22589.47
43	Banera	09/01	4169.51
44	Banera	08/15	9220.53
45	Banera	08/16	13691.44
46	Banera	07/06	18600.34

47	*Banera*	*08/09*	*22589.47*
48	*Banera*	*08/10*	*35280.22*
49	*Banera*	*07/03*	*40070.62*
50	*Banera*	*07/02*	*42858.95*
51	*Asind*	*16/01*	*5086*
52	*Asind*	*15/01*	*8007*
53	*Asind*	*15/04*	*17769*
54	*Asind*	*15/03*	*18600*
55	*Asind*	*15/02*	*20433*
56	*Asind*	*15/05*	*29492*
57	*Asind*	*16/02*	*31221.81*

Table 1.5: Runoff Quantities within Demarcated Macro Watershed Project Boundaries of IWMP.

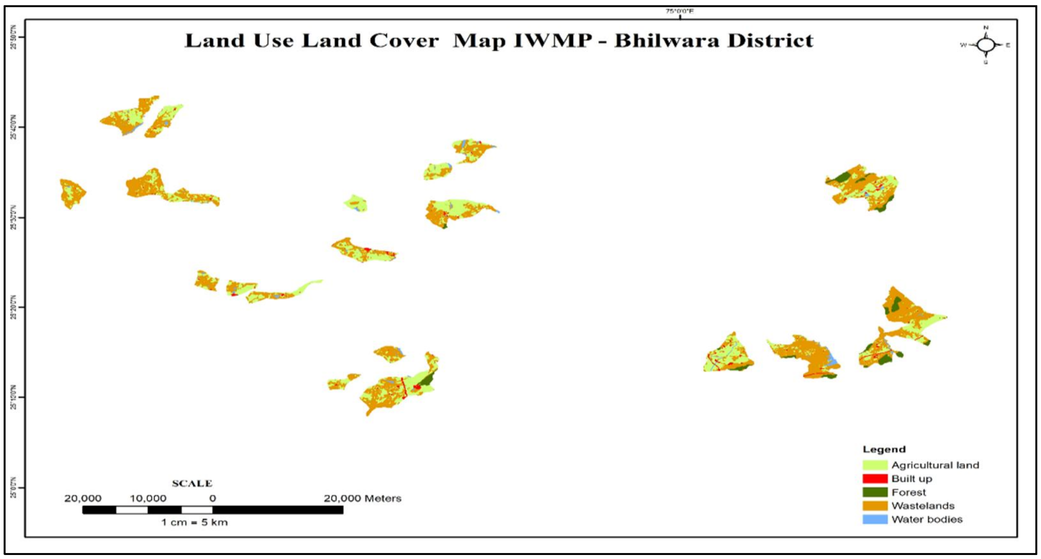

Fig. 1.5: Land Use Land Cover Map of the Study Area.
(Source:Prepaed using Landsat -8 Data of May 2022)

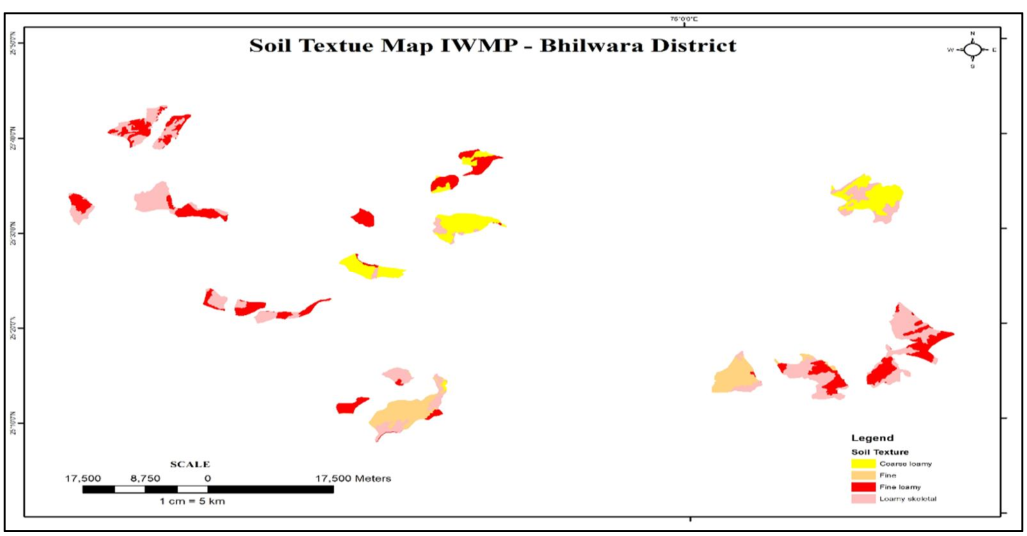

Fig. 1.6: Soil Texture Map of the Study Area.
(Source: Prepared using Scanned copy of Soil Map provided by WDSC Dept. , Bhilwara (Raj.))

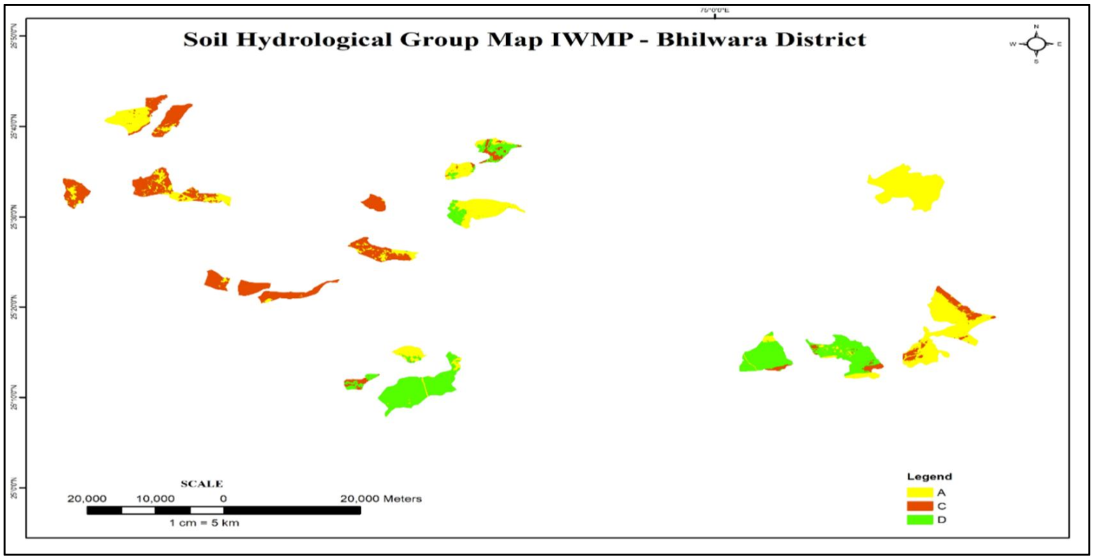

Fig. 1.7: Hydrological Soil Group Map of the Study Area.

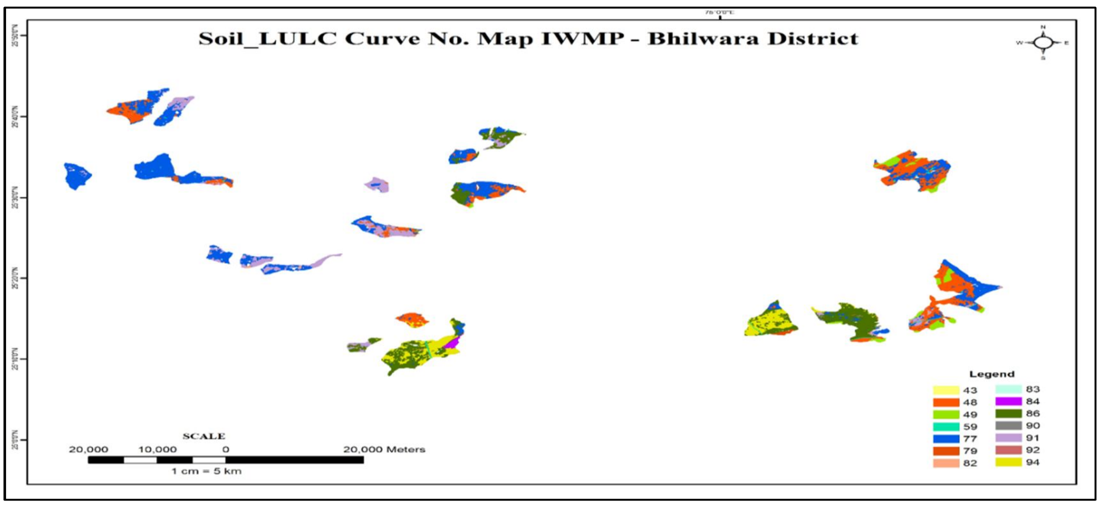

Fig. 1.8: Soil_ LULC Curve Number Map of the Study Area.

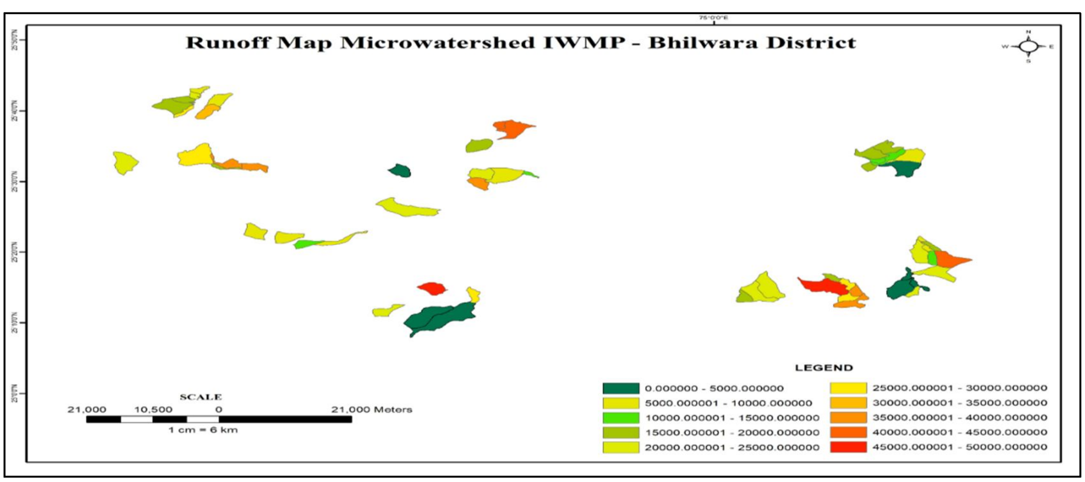

Fig. 1.9: Runoff Map (Thousand Cubic Metre) of the Study Area.

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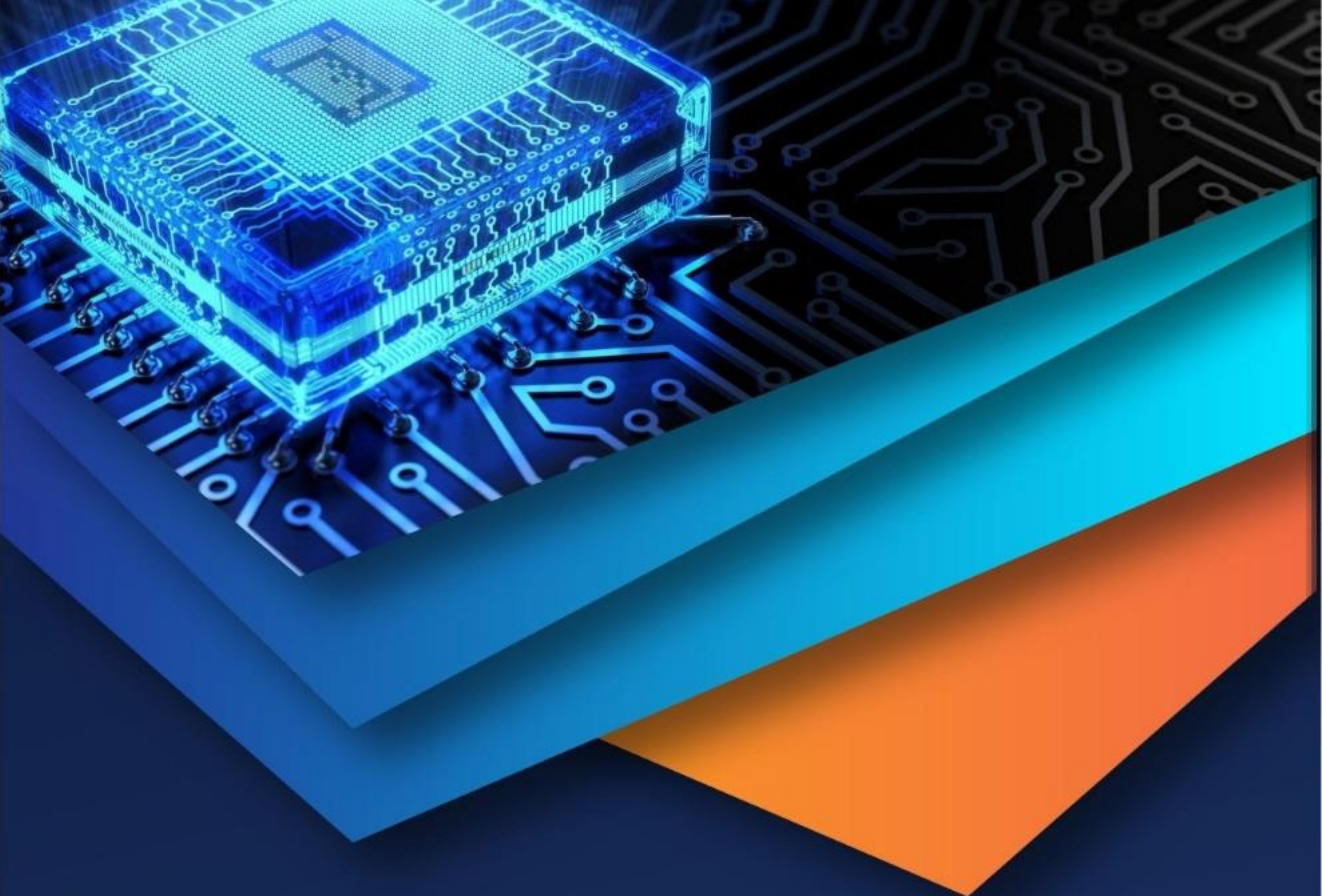

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