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Analysis of Surface Run-Off Potential of Sona River Basin, Jharkhand, India

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Abstract

The present research work was carried out to understand the influence of basin morphometric parameters on runoff potential in a basin using satellite images, topographical maps, and rainfall data combined with geospatial techniques. The Sona River basin is located in the Chaibasa plain of Ranchi, Khunti, Seraikela & East Singhbhum district, of Jharkhand State, Eastern India. The river Sona and its tributaries are draining through the basin area covering about 484.58 km^2. Kulachki River, Parambera River, Suru Nala, Ragra Nala, Kantnta-Juria Nala, Bapra Nala & Kanke Nadi are the six major sub-tributary basins of the river Sona. The quantitative analysis of basin morphometry reveals that the area is influenced by steep ground slopes, with moderate to less permeable rocks, leading to high runoff. The basin is elongated in shape, resulting in a flatter peak of flow for a longer duration. The mean monthly rainfall data from 1991–2020 were used in the estimation of runoff potential. The Surface Run-off Potential was determined by the vegetation cover, integration of land use and land cover, slope characteristics, hydrological soil groups, precipitation characteristics & basin morphometric attributes. It was observed from the analysis that the overall increase in runoff corresponded to the rainfall. The area receives a good amount of rainfall, but most of it is lost as surface runoff (nearly 40% of total rainfall) due to rapid overland flow and impermeable rocks. Analysis of morphometric parameters combined with Surface Run-off Potential approaches can be explored with the help of the *Surface Run-off Potential Index* (SRPI) as an alternative for simulating the hydrological response of the basins. The SRPI value becomes very high (7.95) in the case of Suru Nala (a left bank tributary of Sona) & becomes very low (3.75) in the case of Ragra Nala.

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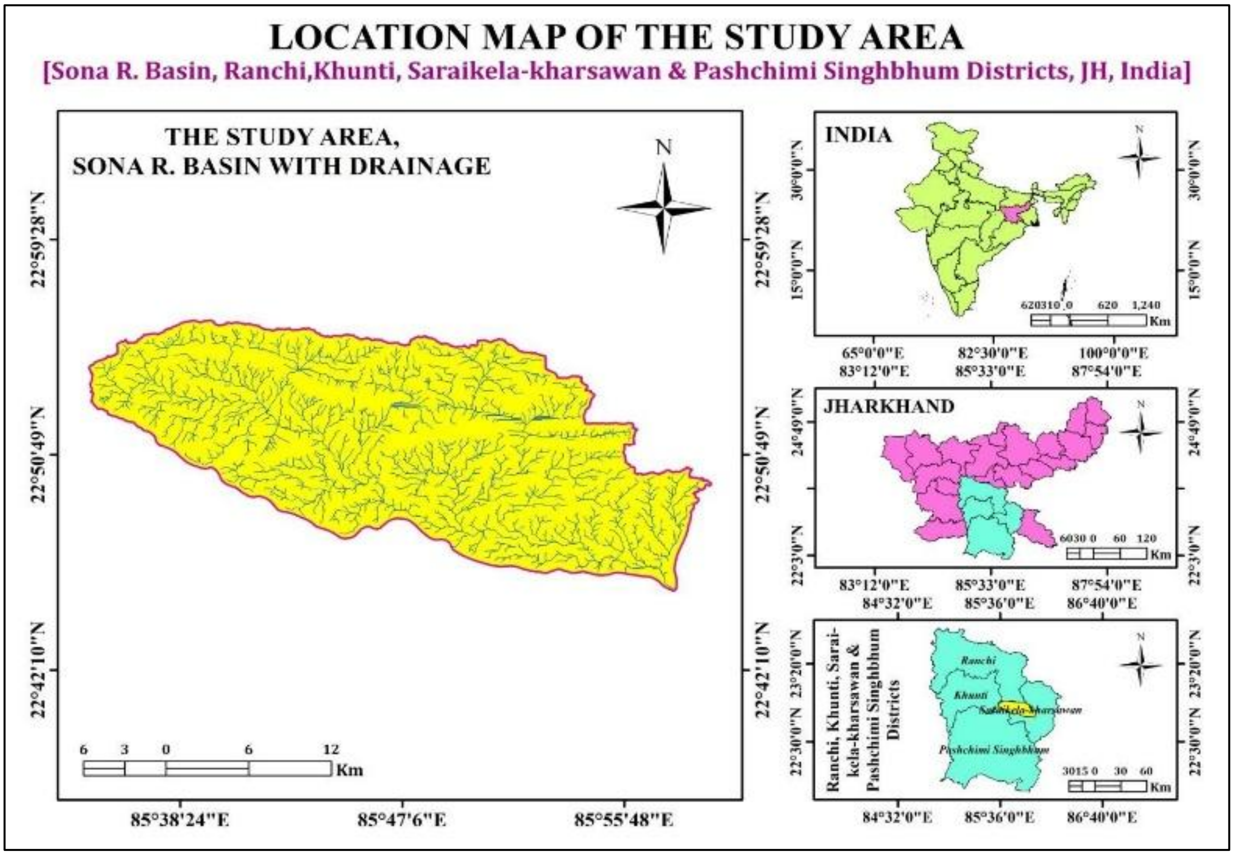
1. INTRODUCTION

Surface run-off is the flow of water that occurs when excess rain water, ice-melted water or other sources cannot be absorbed by the ground and instead flows over the earth's surface. It is a key component of the hydrological cycle and plays a significant role in shaping landforms, replenishing water bodies, and influencing environmental processes. All surface water flow is termed as *"surface run-off"*. It changes the face and out prints of the landscape of the earth by the process of rill, gully and sheet erosion. Strahler (1971: 415) has defined run-off as "all surface water flow both over the land slopes and in streams". Surplus precipitation that escapes evapotranspiration, infiltration becomes surface run-off and directly contributes to the stream flow. Run-off can be defined as the water that reaches streams and leaves the drainage basin as stream flow or stream discharge. The climate, geology, basin morphology, and vegetation cover are some of the important variables that determine the hydrological losses and, in turn, largely control the production of run-off in a drainage basin." Rain water may either take a direct route over land and reach the river or may seep into the soil and eventually reach the river as sub-surface or ground water flow. The relative proportion of water travelling by one of these several paths varies significantly and is governed by a large number of factors such a rainfall intensity, basin slope, soil texture and thickness of the rock permeability, and the vegetation cover. Total run-off from a drainage basin can be split into three main components such as groundwater flow, overland flow, and throughflow. Stream floor is formed by the overland flow, through flow, and groundwater flow. The overland flow is a short-lived, very substantial hydrological event that happens during and for some time after several or persistent rainfall. Stream flow is a more continuous phenomenon because part of the stream flow is also derived from sub-surface contributions of water. Water is unquestionably the fundamental natural resource on which agricultural and industrial development is highly reliant.

The present study attempts to analyse the drainage characteristics related to runoff potential estimation. In the study area, most of the population is dependent on well and spring water for drinking purposes, whereas water supply for agricultural activities is based on streams and springs source. Most of the streams and springs in the mountainous terrain are either dried up or show reduced discharge from mid-January to the onset of monsoon, which leads to water scarcity. However, the area receives noteworthy rainfall, but most of it lost as surface runoff without infiltrating into the surface, due to rapid overland flow on the steep slopes and impermeable rocks. Thus, there is a widespread water shortage in the region. The significant forest alteration is spreading fast in the study area due to various anthropogenic activities, reminding necessity of soil and water conservation to increase the groundwater potential.

Location of Study Area

The Sona River basin of the Indian state of Jharkhand is a very significant geomorphological unit. This basin area deals with a versatile topography, lithology, and rocks. It is also a part of the Chaibasa plain. Sona river basin is situated across some part of Ranchi, Khunti, and Paschimi Sinhbhum districts of Jharkhand. The study basin covers an area of 484.58 square kilometers, which is 0.75% of the Chotanagpur plateau and 21.57% of the Chaibasa plain, respectively.



Sona river basin occupies 93.82% of the total area i.e., 456.68 square kilometers, within Saraikella-Kharswan district and the remaining 28.24 square kilometers area of this basin is in Ranchi district, 0.32% in Khunti district and only 0.15 square kilometers or 0.03% area in Paschim Medinipur district of West Bengal. Maximum altitude of the basin is 918m, and the minimum altitude of the basin is 148m. The Chandil-Gamharia range and the Ranchi plateau are already situated in its northern corner. Paschimi Singbhum and Chsibasa forest range are in its southern side. Dalma Hill and Purba Singbhum took place in its eastern corner, and Khunti is situated in its western side. The Sona River basin has a latitudinal extent of about $22^0$44'39" N to $22^0$57'12" N and a longitudinal extent of $85^0$35'22" E to $85^0$58'52" E.

2. OBJECTIVES

Keeping this in view, the present study was conducted with the main objective of runoff potentiality estimation and to evaluate drainage characteristics through morphometric analysis in order to understand the hydrological process and predict the hydrological behaviour.

3. METHODOLOGY

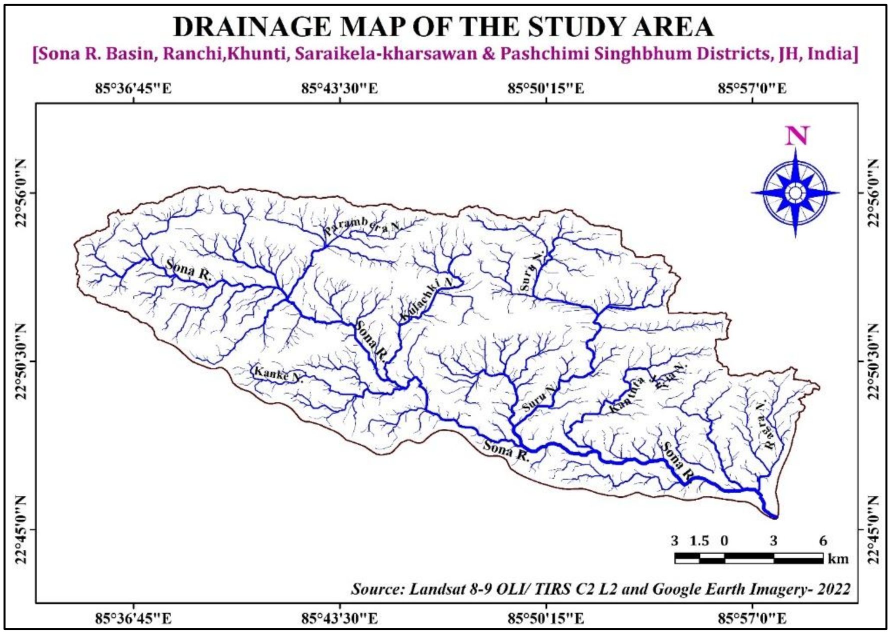
In recent years, the integration of remote sensing and GIS-based methods has revolutionized morphometric studies. Digital Elevation Models (DEMs), such as SRTM and ASTER, enable precise extraction of terrain features including flow direction, flow accumulation, and watershed boundaries. GIS software like ArcGIS, QGIS, ERDAS, TCX Converter, etc. with tools such as ArcHydro and TauDEM, are extensively used to automate stream network generation, order assignment, and spatial analysis of morphometric attributes. Furthermore, geospatial models have allowed for sub-watershed prioritization based on compound morphometric indices, supporting watershed management planning.

Thus, the methodological framework for morphometric analysis of the Sona basin is holistic and data driven, blending conventional techniques with modern geospatial tools to assess the structural and hydrological dynamics of the watershed.

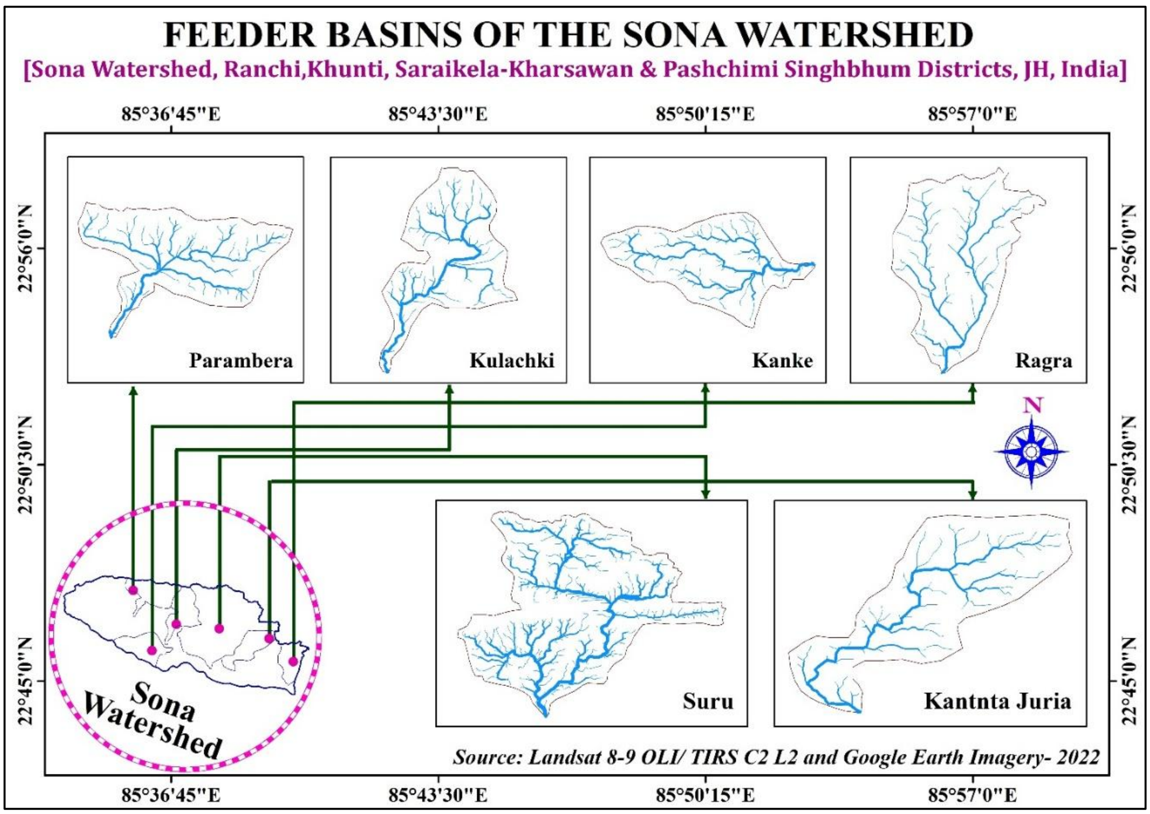
4. RESULTS & DISCUSSION

A. Channel Characteristics: Sona is the main river of this study area or watershed. It is the principal tributary of the river Sanjai. From its origin at 22°55'30" N and 85°36'30" E, this main tributary swings towards southwest and again towards east, guided by the configuration of the land. It originates at an altitude of 660 m above mean sea level near Atra village and finally drops to 150 m at its confluence with the Sanjai near Barudih village. It has a gradient of 1/113.16. Its perennial course, escorted by badlands, starts from Karkota village and terminates at its meeting point with its trunk stream. The Sona negotiates through epidiorite-hornblende-schist, quartzite, phyllite, mica-schist and granite. The west to east course of the Sona receives tributaries mainly from the north an account of higher divides and hilly tracts there. The altitude in the southern counterpart is too low to bring forth large tributaries worth the same. The characteristics of the tributaries of Sona are as follows:

1. **The Kulachki River:** The river Kulachki, a left bank tributary of the Sona, originates at a height of 800 m near Katlauli village situated on the northwestern divide of the Sona basin. Then it cascades towards south and south-west forming narrow gorges between the Kanda Buru and the Raisindri pahar. It again assumes its southerly course and finally merges with the Sona near Karkata village. Its vertical drop from source to mouth is 560 m.
2. **The Parambera River:** The river Parambera, a left bank tributary of the river Sona, takes its birth at a height of 820 m near Burudih village. This river finally merges with the Sona just south of Jojohatu. Its vertical drop from source to mouth is 550 m.



3. **The Suru River:** Locally named 'Suru Nala', another tributary of the river Sona, starts its journey near Matuda at an altitude of 722 meters. From there it runs for 2.5 km towards east and then takes a sharp bend towards south. But after flowing only for two kilometers in that direction it bends westward along the northern fringe of the Raisindri-Sira Buru divide. It receives water of Bapra Nala from the west near Chaitanpur village. The Suru Nala swings towards south beyond its conflux with the Bapra Nala, carve out a deep and narrow gorge in the Raisindri-Sira Buru water parting. Flowing for about 6 km in that direction, it turns towards south-west to join hands with the Sona near Kharswan.
4. **The Ragra Nala:** This stream, a tributary of the river Sona originates at a comparatively low altitude of 380 m on the Sini pahar range. Its south-westerly course continues to Gopalpur from where it runs towards south to meet the Sona near Nayadih village (150 m).
5. **The Kantnta Juria Nala:** This stream originates the top of the Jamda Buru (460 m). Its south-westerly course is almost parallel to the Suru Nala. But in the fag-end of its journey, it moves towards south-east and empties its water into the Sona near Lalbazar (190 m). The altitudinal difference between its source and confluence point is 270 m. The Jamda Buru elongated divide runs parallel to the Raisindri-Sira Buru divide about 1.5 km south of the latter and acts as the eradle of the Kantnta Juria.
6. **Bapra Nala:** This river is also an important tributary of the river Sona. It originates about a distance of one kilometer north-east of Katlandi village at 800 m. Thus, the birth places of the Bapra Nala and the Kulachki Nala are only 1.5 km a part. The initial course of the Bapra Nala flows through a moderately sloping terrain, contributing significantly to the drainage dynamics of the area. As it descends, the nala collects water from minor channels and seasonal streams, enhancing its discharge during the monsoon months. Its catchment area supports scattered settlements and agricultural land, which are dependent on its flow for irrigation. The Nala eventually joins the river Sona near the southern edge of the watershed, adding to the overall sediment and water volume. Its role in soil erosion and silt deposition is also notable, especially in lower reaches.



7. **The Kanke Nadi:** Kanke Nadi, also known as the river Kanke, is a significant water body located in the Ranchi district of Jharkhand, India. It plays a crucial role in the region's water management and serves as a popular recreational spot. The river Kanke is dammed to form the Kanke dam, an artificial reservoir situated in the Kanke area of Ranchi. This dam is a vital source of water for the city, providing both irrigation and drinking water to the surrounding areas. The dam is an earth-filled structure, approximately 50 feet high and 500 feet long, and is surrounded by picturesque hills and forests, making it a serene location for visitors.

Fig A: Lower middle View of the river Kanke, reflecting the mature stage of channel features & lateral erosion
Fig B: A stretch of the river Sona near Aruwan Dam illustrating a graded profile in quasi-equilibrium

B. Surface Run-off Potentiality Estimation:

The stream flow and surface run-off of the different parts of the Sona river basin is engaged in changing in face of the land by the process of fluvial erosion which may be observed during the months of rainy season. The nature and characteristics of rocks, the relief, the slope, and the amount of precipitation control run-off. Here, it is essential to note that the terrain as a whole is *"ungraded, causing rapid drainage, flood, and erosion"* (Ahmad, 1965: 103).

Table 1: Seasonal (Monsoon) Mean Rainfall and Run-off from 1991 to 2020 in the Study Area (Sona Basin), Jharkhand

Sl. No.	Name of Month(s)	Rainfall (mm)	Run-off (cm)
1.	June	948.0	59.84
2.	July	956.3	49.61
3.	August	1388.4	88.13
4.	September	1141.7	72.55

Source: JSAC & Indian Meteorological Department, Centre: Ranchi

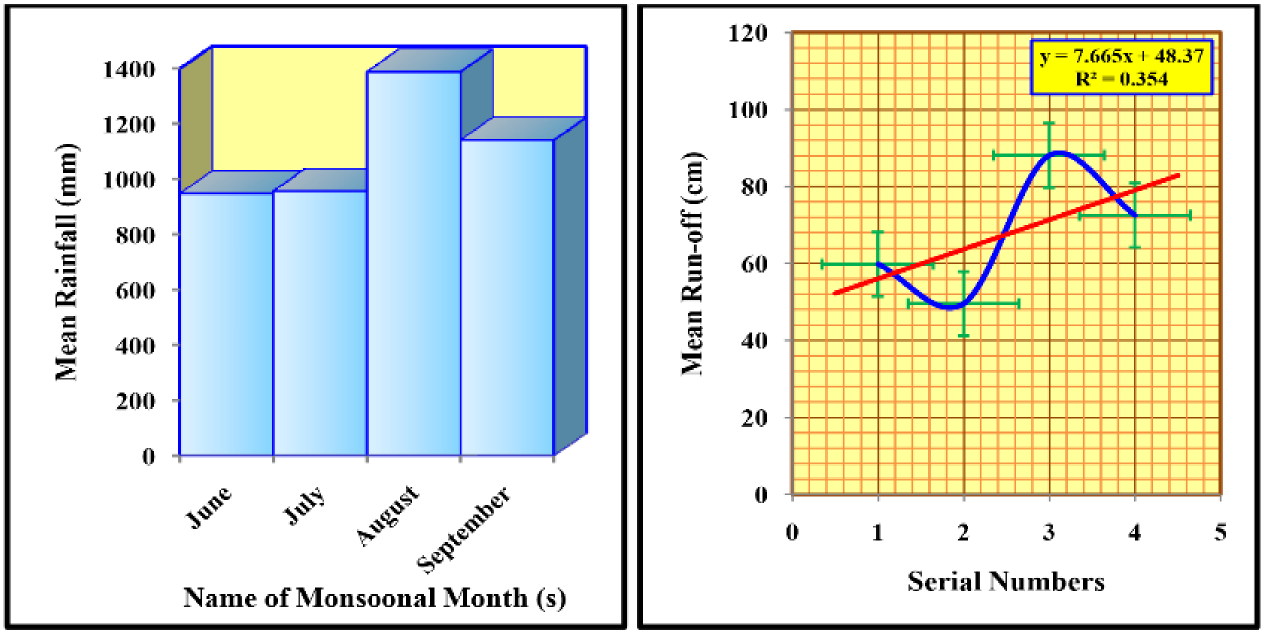


Fig 1: Mean Rainfall & Run-off Characteristics of Sona River basin

1. The data reveals a progressive increase in rainfall from June to August, with a slight decline in September. Peak rainfall in August (1388.4 mm) signifies the climatic climax of the monsoon season. Run-off shows a proportional response, with August recording the maximum run-off (88.13 cm), followed by September (72.55 cm).
2. Although annual averages are used, it's essential to consider inter-annual fluctuations. Years with El Niño or La Niña phenomena may have significantly affected rainfall distribution, causing anomalies.
3. The run-off coefficient (RC) indicates the efficiency of rainfall contributing to surface flow. High RC in August-September implies reduced infiltration due to saturated soils. Lower RC in July (5.19%) despite high rainfall suggests- increased soil permeability and possible water absorption by vegetation during active cropping phase.
4. The soil wetness prior to rainfall events significantly influences run-off. In June, despite moderate rainfall, run-off is relatively high (59.84 cm) due to initial dry compact soil having less infiltration capacity.
5. Surface water availability, the observed values suggest sufficient surface water generation during monsoon months to support irrigation needs, domestic consumption and also aquatic ecosystem sustainability.
6. August and September, with high rainfall-runoff volumes, increase the risk of flash floods, urban flooding (mainly downstream settlements) and soil erosion on exposed terrains.
7. High rainfall during July may lead to maximum groundwater recharge due to lower surface run-off and unsaturated subsurface layers. August shows limited recharge due to already saturated conditions.
8. Run-off in hilly or undulating terrains (like parts of the Sona Basin) will be higher due to steep slopes and less infiltration time. Flat areas may show higher infiltration and delayed run-off, especially in July.
9. The intensity and concentration of rainfall in fewer months is a signal of monsoon shifts, possibly due to climate variability. August's sharp peak could indicate extreme rainfall events, which are increasing under changing climatic regimes.
10. Higher run-off implies a well-drained basin with moderate to high drainage density. It also suggests efficient hydraulic connectivity between rainfall and river channels. Rainfall peaks support kharif crops (paddy, maize, pulses). High run-off in August-September can cause waterlogging in lowland paddy fields and also delayed sowing/harvesting if not managed properly. High run-off can be stored through check dams, ponds, and percolation tanks.

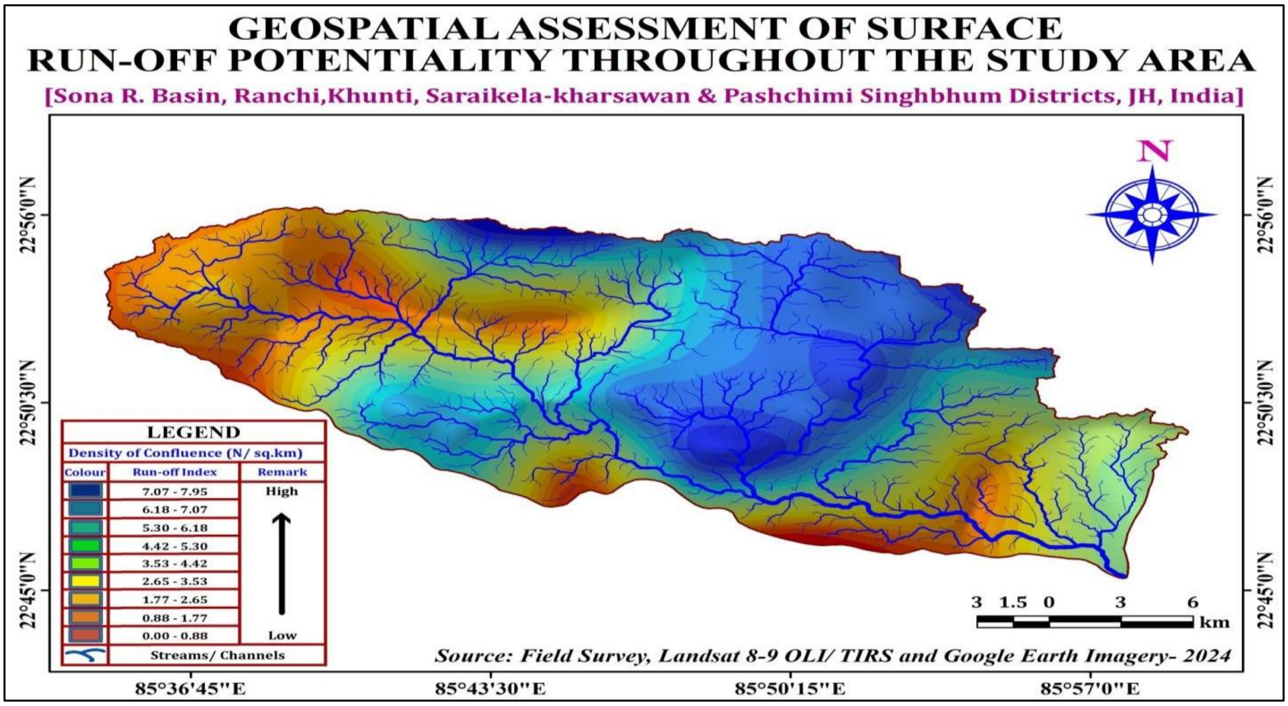
Table 2: Surface Run-off Potentiality of All Sub-Basins in the Study Area

Name of Sub Basin(s)	**Major Dimensions/ Factors related to the Surface Run-off**													**Surface Run-off Potential Index [SRPI = ∑ (W x X)]**	**Remarks on Run-off Potential**
	LULC (W= 0.20)			**Soil (W=0.20)**			**Slope (W= 0.25)**			**Rainfall (W= 0.15)**			**DD (W=0.20)**		
	Total Weight for Integrated Dimensions/Factor = 1.00														
	Factor Specific Scores (X) (N=10)														
	Each Factor (F) is Ranked from 0-10 for Surface Run-off Contribution														
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**F_6**	**F_7**	**F_8**	**F_9**	**F_{10}**	**F_{11}**	**F_{12}**	**F_{13}**		
P	5	6	7	6	7	6	6	6	6	7	6	5	6	**6.35**	**H**
Mean:	**5**			**6**			**7**			**6**			**6**		
K	6	6	7	5	6	6	6	6	7	6	7	8	6	**6.10**	**H**
Mean:	**6**			**7**			**5**			**7**			**6**		
S	7	7	8	9	7	8	8	8	8	9	8	7	9	**7.95**	**H**
Mean:	**7**			**8**			**9**			**8**			**9**		
K*	4	5	4	5	4	4	4	4	5	5	5	5	4	**4.40**	**M**
Mean:	**4**			**5**			**4**			**5**			**4**		
K**	6	6	6	6	6	6	6	6	6	6	6	6	6	**6.00**	**M**
Mean:	**6**			**6**			**6**			**6**			**6**		
R	3	4	4	3	5	3	3	3	4	3	3	6	3	**3.75**	**L**
Mean:	**3**			**4**			**3**			**4**			**3**		

P: Parambera, **K:** Kulachki, **S:** Suru Nala, **K*:** Kantnta Juria, **K**:** Kanke, **R:** Ragra,
F_1: Vegetation Cover, **F_2:** Agricultural Land, **F_3:** Built-up Area, **F_4:** Sandy Soil, **F_5:** Loamy Soil, **F_6:** Clayey Soil, **F_7:** Gentle Slope **(0-5%)**, **F_8:** Moderate Slope **(5-15%)**, **F_9:** Steep Slope **(>15%)**, **F_{10}:** Rainfall in Summer, **F_{11}:** Rainfall in Monsoon, **F_{12}:** Rainfall in Winter, **F_{13}:** Drainage Density. **(DD)**
H: High Run-off Potentiality, **M:** Moderate Run-off Potentiality, **L:** Low Run-off Potentiality

Source: Field Survey cum Author's Critical Thinking and Calculation, 2024

11. Most of the streams of this basin area are seasonal and ephemeral in nature. Immediately after monsoonal showers river regime is marked by sudden ephemeral freshets. But the roaring cascade of water lasts only for few hours, subsiding again to fordability (Ahmad, 1965: 40).
12. The construction of dam and reservoir at Adityapur (Saraikella-Kharswan district) named Sitarampur dam supplies drinking water to Adityapur town. Similarly, Bandi dam has been constructed at the transition of Lakhar and Bandi village. Arwan dam also seen Arwan village. There are Kuchai and Palua reservoirs also found. More dams and reservoirs may be constructed in the middle and lower reaches of Sona and its main tributaries of this study area, to preserve water for irrigation and other purposes even during dry periods.
13. During the months of the rainy season, the landscape development in the region is observed, caused by fluvial action. The expansion of gullies of the Parambera, Kanke, and Suru Nala subbasins are remarkable example. It develops its forms only during rainy months.



"Surface Run-off Potentiality refers to the capacity of a landscape to generate overland flow following rainfall events." It is influenced by factors such as rainfall intensity, soil permeability, land slope, vegetation cover, and land use practices. Areas with high rainfall, steep slopes, and impervious surfaces exhibit greater surface run-off potential, increasing the risk of erosion and flooding. The above table and map present a comparative analysis of Surface Run-off Potentiality Index (SRPI) across six sub-basins in the study area using a weighted index derived from key environmental factors. The Suru Nala (S) sub-basin ranks the highest with a surface run-off index (SRPI) of 7.95, reflecting *high run-off potential* due to consistently elevated scores across slope, rainfall, and drainage density. Both Parambera (P) and Kulachki (K) also exhibit *high run-off potentiality*, with SRPIs of 6.35 and 6.10 respectively, indicating a significant contribution from built-up areas, monsoon rainfall, and moderate slopes. The tremendous Kanke (K**) sub-basin shows *moderate run-off potential* (SRPI= 6.00), as all its factor scores are evenly balanced, reflecting uniform surface characteristics. Kantnta Juria (K*), with an SRPI of 4.40, also falls under the *moderate run-off category*, though its scores are relatively lower across vegetation, soil, and slope parameters. Ragra (R) exhibits the lowest (SRPI of 3.75), classifying it under *low run-off potential*, likely due to sparse vegetation, poor slope condition, and weak soil structure. The variation in SRIs highlights how local land uses (agricultural practices, building like settlements construction, gardening, road construction, rural-urban beautification service-oriented planning, etc.), soil type, rainfall distribution, and slope gradients directly impact surface run-off dynamics.

CONCLUSION

In the present study, a combined approach of morphometric parameters and Run-off potential approach was used to estimate surface runoff potential in the Sona River basin. The results revealed that the understanding of basin geometry is much essential in runoff potentiality estimation. *High run-off zones* are potentially more prone to erosion and require soil conservation strategies, while low run-off areas may benefit more from groundwater recharge interventions. The uniformity in factor scoring for some sub-basins like Kanke

(K**) suggests consistent environmental conditions, making hydrological predictions more reliable in those areas. Overall, the analysis supports integrated watershed planning, enabling targeted soil-water conservation and land management strategies based on sub-basin-specific run-off potential.

The water resource management could make scientific plans for water utilization according to runoff formation and change characteristics in the study area. The suitable groundwater structures, namely check dams, percolation tanks, bench terrace, and contour bunds, may be constructed after detailed studies of groundwater prospective zones. The morphometric parameters and runoff evaluated using geospatial techniques will help to understand various terrain parameters such as the nature of the bedrock, infiltration capacity, and surface condition and also watershed prioritization for soil and water conservation at a microlevel. In conclusion, the methodology used in this study may be limited to measuring the quantity of runoff potential, but it would be helpful where the runoff records were not available.

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