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Assessment of Spatio-Temporal Variation in Ecological Flow and Anthropogenic Determinants: A Case Study of River Aami

Amar Singh Gautam, Ph.D., **Neha Singh,** Ph.D., Department of ??
H.R.P.G. College, Khalilabad, Sant Kabir Nagar, Uttar Pradesh, INDIA

ORIGINAL ARTICLE


Authors
Amar Singh Gautam, Ph.D.
Neha Singh, Ph.D.
E-mail : dr.amarsinghkld@gmail.com

shodhsamagam1@gmail.com

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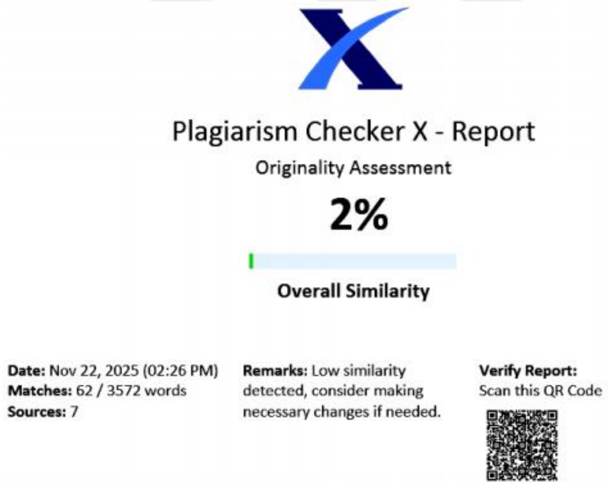


ABSTRACT

Ecological flow (e-flow) is critical for maintaining the ecological integrity and biodiversity of river systems, particularly those subjected to increasing anthropogenic pressure. This study quantifies and assesses the spatio-temporal variation in e-flow requirements and elucidates the primary hydrological and human-driven determinants across the River Aami basin. Utilizing ten years (2011–2020) of measured streamflow data, the study employed a composite hydrological methodology to determine e-flow thresholds. Furthermore, time-series analysis integrated with spatial data on land-use change was used to determine the impact of anthropogenic activities. Results reveal significant inter-annual and intra-annual variability, with the river experiencing critical e-flow deficits, particularly during the post-monsoon and summer periods in the mid and lower reaches. The findings necessitate the adoption of differentiated, reach-specific water management strategies, prioritizing the regulation of non-monsoon abstraction and reservoir releases to ensure the long-term ecological health and sustainable water resource management of the River Aami.

KEY WORDS

Ecological Flow, River Aami, Spatio-Temporal Variation, Anthropogenic Determinants, Water Stress, Sustainable Management.

INTRODUCTION

Rivers are undeniably essential for society to advance. In fact, all of the world's ancient civilizations are found bloomed and perished near river banks, deltas and at their confluences. Previously Rivers, were the primary supply source of freshwater, started to carry effluent as cities grew. Indicators like Pollution and damming indicate how rivers have suffered for fast economic and technical advancement. Nowadays majority of rivers suffer from severe organic, inorganic, and/or pathogenic contamination with the low water flow. Globally, more than 2/3rd rivers are severely affected by human interactions and economic and domestic activities. However, there is a significant increase in the quantity and intensity of anthropogenic stressors endangering these functions. (Giller,2005). The process of urbanisation has impacted every natural resource in its vicinity and its impact upon rivers is identified and defined as "urban stream syndrome" (Walsh et. al. 2005). Human activities which were identified as stressor on aquatic environment are: Industrialisation, Urbanisation, Agricultural and other rural activities and Deforestation.

Conceptual Background

A significant portion of the world's rivers suffers from severe contamination, with a 2016 UNEP report finding that one-third of river sections in Latin America, Africa, and Asia are severely contaminated by pathogens, and one-seventh by organic pollutants (UNEP 2016). This pollution is largely driven by untreated wastewater discharge, as approximately 80% of wastewater in poor nations is released untreated (UNESCO n.d.). India exemplifies this crisis, treating only 28% of its urban sewage (CPCB, 2022), resulting in the contamination of over 80% of its freshwater sources, including its sacred rivers like the Ganga and Yamuna (Dey 2015; Haberman 2006, Alley 2002). Traditional and technocratic thought, which viewed water reaching the ocean as waste, led to excessive removal of freshwater, causing the deterioration of major river basins, damaging river ecology, and resulting in issues like oxygen depletion, loss of livelihoods, and seawater intrusion in deltas. Recognizing the critical nature of water flow for ecosystem sustainability, the concept of Environmental Flows (e-flows) emerged, defined by the 2007 Brisbane Declaration as "the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems" (International Water Centre, 2007). In India, the Ministry of Environment, Forest, and Climate Change (MoEFCC) made e-flow maintenance a mandatory condition for environmental approval of river valley projects since 2007-08, with required minimum flows evolving from 10% of minimum flow to 20% of average flow during the lean season, plus larger flows during the monsoon (Thakkar, 2012). Furthermore, a meta-analysis indicates a lack of attention in published research to the basin-scale, social, and policy aspects of e-flows, as well as the roles of groundwater and e-flows in maintaining floodplains and intermittent rivers (Abera, et.al. 2023). This specific study, focusing on the Ami river basin, employs the Smakhtin et al. (2007) methodology, which utilizes "aggregate environmental indicators" to assess how far the river basin has deviated from its natural state, providing a foundational approach for evaluating e-flows in data-scarce regions.

The indicators that are derived are:

A. Percentage of natural vegetation remaining in the basin and in floodplains.
B. Presence of rare and endemic species and species sensitive to flow changes in the basin.
C. Presence of introduced or exotic species.
D. Overall aquatic species richness.
E. Degree of flow regulation.
F. Degree of flow modification.

Objectives

These following objectives are defined to understand the flow regime of river Aami and the influencing factors affecting its course over the ground:

- To define environmental flow (e-flow).
- To detect constraints in the river flow in the context of river Ami.
- To prepare spatial-temporal river regime.
- To study the impacts of stressors on flow.

Data Sources and Methods

A. The study area/ selected river corridor

For the purposes of this analysis, the stretch of river Aami has been divided into five segments, from Rudhauli in Basti to Kauriram in Gorakhpur. These segments are selected on the basis of various geomorphological and land use pattern. These segments of river are:

Sl. No.	Segment/ River Stretch	Purpose
1.	**Segment I** (origin source of river) from Sikhara Taal to diversion of river course from Basti Road	river originate from this Sikhara Taal, which is an oxbow lake formed by river Rapti.
2.	**Segment II** starts near MMIT govt. polytechnic college, Balusasan Sant Kabir Nagar to cremation shed of Balusasan Ghat	Road bridge on NH-328A and construction of new wide bridge, middle stretch after natural GW springs of Belhar kala
3.	**Segment III** from NH-28 Bridge near Kabir Dhuni to *Tedhiya Baba*	Major human settlement, major four lane bridge constructed
4.	**Segment IV** from cremation ghat near Kabir temple to railway bridge	Pavement of right bank, railway bridge, dumping of solid waste
5.	**Segment V** from Bagahaveer baba temple to Ami bridge on NH 24	Road construction is affecting left bank

B. Parameter Selected

The parameters which are selected to analyse the segment flow are vegetation cover, man-made obstructions, land use pattern, obstacles in flow, aquatic life conditions, level of siltation and deposition of solid waste, high bod which responsible for eutrophication, factors affecting river flow in alluvial setting, siltation, dumping of solid waste. These are analysed on spatial and temporal level to understand what are factors, responsible for river flow.

Sample Study on Selected River Corridor and Change of Land use

For the purpose of this analytical study, the Ami river basin has been divided into five segments, from origin at Sikhara Taal to confluence it to river Rapti at Sahgaura, Kauriram. These segments are explained with their flow regime and factors affecting them.

Segment I

The segment S-1, located between 27°9' 25" N to 27°9'14" N latitude and 82°39'8" E to 82°39'16" E. longitude, is a 445.29 m stretch running from Shikhara Taal of Domariyaganj to the Basti Road cross-section, situated at an average height of 88 m above sea level. Morphologically, this area is part of the flat Rapti-Ghaghra alluvial plain and the Tarai zone of the Ganga plain near the Himalayan foothills, characterized by alluvial deposits of silt, clay, and sand, lacking sand beaches or pebbles. This plain-fed river segment, which is near 8-9 small ponds, draws its water from an ox-bow lake of the Rapti River, small rills, gullies, and crucial underground water springs due to the high water table; the banks are covered with small grasses and scrubs, and the water quality is sufficient to prevent water hyacinth growth. In terms of land use, the catchment area lacks forest cover, which is important for water retention, and is dominated by agricultural fields, fallow land, and human settlements like Jakhali, particularly in the north-eastern part. The river and nearby ponds support local livelihoods, including fisherman communities, and the farmers successfully harvest crops like paddy in both seasons; however, the pond’s expansion is currently constrained by surrounding settlements and roads on three sides, and the area hosts religious gatherings annually for Muharram and Eid, with the western river bank utilized as pastureland.

Figure 1: Satellite images showing LULC Pattern at segment I

*(**Source:** Primary Survey)*

Segment II

The S-2 river corridor, stretching latitudinally between 26°50’53.8"N and 26°50’43.4"N and longitudinally between 83°04’14.6"E and 83°04’30.2"E, is a 524.16 m segment starting near MMIT Govt. Polytechnic college and ending at a cremation shed near Kali Mandir Ghat, with an average elevation of 70 m above sea level. Morphologically, the riverbanks are primarily composed of alluvial deposits (silt, clay, and sand), featuring natural levees, marshy areas due to excess silt, and a slight meander visible from the eastern bridge. The flow is highly impacted by man-made obstructions, notably the recent extension road bridge for NH 328-A widening, which has reduced the river’s width by three-quarters. Land use in this corridor is primarily agricultural, with adjacent rabi crops, and the river supports local fishing, particularly for the village Balushashan. The segment includes religious sites like a Durga Maa temple and faces significant environmental stress: agricultural practices reduce soil water retention and increase sediment runoff, leading to murky water during monsoons, which is further exacerbated by pollution originating from a local industrial complex. Efforts to mitigate pollution include the creation of a new pond, though some residents still utilize the river water.

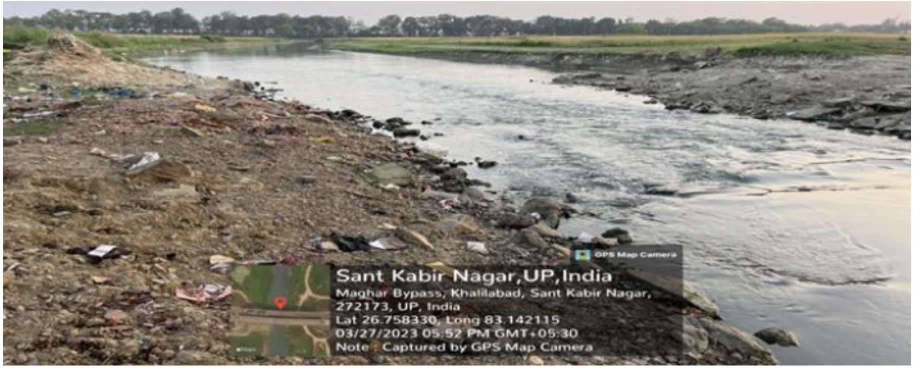
Figure 2: Satellite images showing LULC Pattern at segment II

*(**Source:** Primary Survey)*

Segment III

The S-3 river corridor is a 553.51 m segment of the River Ami, stretching latitudinally between 26°45’30.4"N and 26°45’12.3"N and longitudinally between 83°08’31.6"E and 83°08’28.7"E, starting at the NH-28 road bridge near Kabir Dhuni and ending at the Tedhiya Baba temple in Maghar, with an average elevation of 68 m. Morphologically, this low-lying, middle-basin segment flows straight for about 500 m before meandering and is easily waterlogged, appearing marshy even in late October; its banks are composed of silt, fine clay, and alluvium deposits. Although the deposited khadar plain is mostly flat (with spot height variability of 0.5 to 1.30 m, the river’s natural levees have been occupied by farmers, and construction debris (boulders and cement blocks) is visible near the bridge during the pre-monsoon lean course. The land use is primarily agricultural on the Ami’s low-lying floodplain, where fields remain submerged until late October, forcing farmers to limit cultivation to a single crop season. The Maghar district road, built on a riverbank cliff, acts as a significant artificial obstruction, altering sediment deposition and flow speed, an impact exacerbated by the complete absence of forest cover within a 1 km. radius, which leads to soil erosion and murky water during monsoons, followed by hyacinth growth post-monsoon. Local activities include fishing during wetter periods and the presence of a mango orchard south of the Maghar road.

Figure 3: Satellite images showing LULC Pattern at segment III

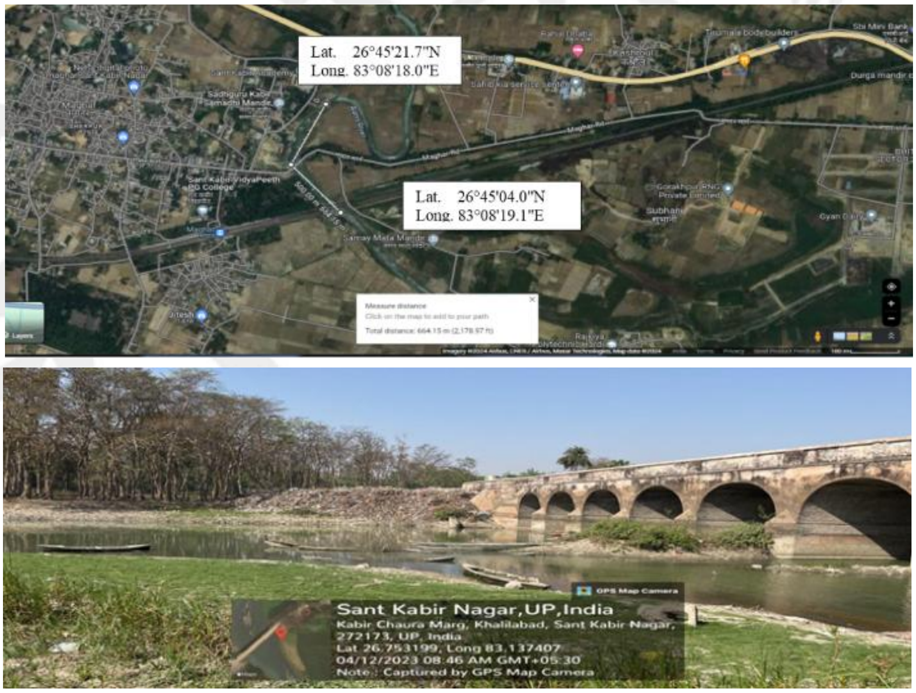


*(**Source:** Primary Survey)*

Segment IV

The S-4 river corridor, spanning 664.15 m between the cremation ghat near Kabir temple and a railway bridge, stretches latitudinally between 26‘“452 21.7”N and 26‘“452 04.0”N and longitudinally between 83‘“082 18.0”E and 83‘“082 19.1”E, with an average elevation of 67 m. Morphologically, this segment lies within a meander loop, featuring a 280.52 m meander neck, a river cliff 0.9 m higher than the slip-off slope, and banks composed of silt, clay, and alluvium deposits. While natural levees are poorly developed in the upper section due to agricultural interference, a 2.1 m high natural levee exists on the lower right bank, and significant silt deposits are visible in the riverbed downstream of the old Maghar road bridge. The adjacent flood plain is generally featureless, with contour variations between 66.5 m and 71.3 m. Land use is mixed, with about one-third dedicated to non-agricultural uses: the right bank features the semi-urban settlement of Maghar nagar panchayat, concrete pavements, and 117.86 m of ghats near Kabir Sthan, which serve as a dhobi ghat and host religious and social events like the Maghar Mahotsav, Kabir Mela, and a cremation ground, while the left bank is primarily agricultural, limited to *rabi* crops due to monsoon flooding. The river suffers from pollution due to waste disposal near the old bridge, causing siltation, and agricultural land on the western side is increasingly threatened by built-up expansion near NH-28.

Figure 4: Satellite images showing LULC Pattern at segment IV



*(**Source:** Primary Survey)*

Segment V

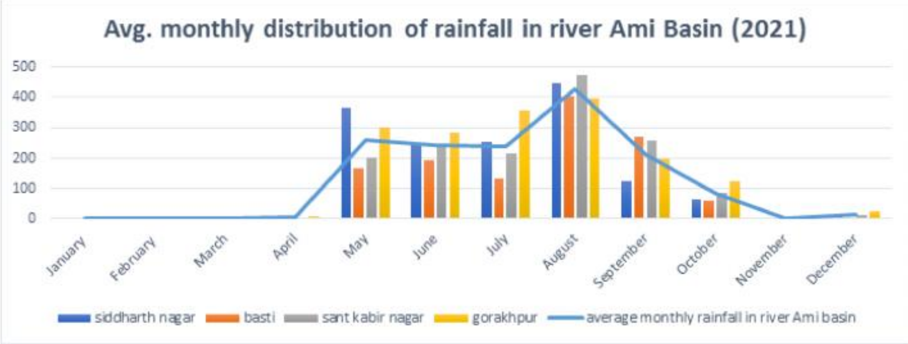
The S-5 river corridor stretches over 1052 m latitudinally between 26°33’22.9"N and 26°32’40.1"N and longitudinally between 83°25’04.8"E and 83°24’44.6"E, starting at the Baghaveer Baba temple in Kauriram and ending at the NH-24 road bridge where the river turns left towards Sohgaura village, maintaining an average elevation of 75 m. Morphologically, this segment features a vast, featureless flood plain, jointly deposited by the River Ami and River Rapti, extending 2 to 3 km from both banks with a low contour gradient and spot heights ranging from 73.7 to 77.9 m. The banks are composed of silt, clay, *reh*, *kallar*, sand, and alluvium, and the river forms two meander loops before the temple, with less prominent natural levees varying in height from 0.9 m to 2 m, and visible patches of shoal and river bars near the eastward turn. The land use is dominated by this flood plain, which is submerged during the monsoon and post-monsoon periods due to its shallow basin and backflow from the River Rapti, limiting farmers to winter crops like wheat and mustard, which yield well after the water recedes. Non-agricultural land, including human settlements like Kauriram, Jagdishpur, and Sonbarsa, is concentrated south of the right bank, while the land near the Baghaveer Baba Shiva temple is used for religious gatherings and *melas*. The construction of NH-24 has artificially restricted the river flow toward its left bank, forcing the Ami to follow a straight path for 1 km, and the prolonged waterlogging prevents forest or orchard growth, with the western temple area instead being utilized for pasture and animal rearing, where grasses like *kermaua* and *barsimh* are harvested as fodder; additionally, fishing communities use this segment to catch fish and prawns for sale along the NH-24 highway.

Figure 5: Satellite images showing LULC Pattern at segment IV

*(**Source:** Primary Survey)*

River ami is a plain-fed river system, which primarily rely on rainfall for its continuous flow. The temporal and spatial distribution of rainfall affects the availability of water in the river basin. Observation and surveys made frequently in sampling segments. River Ami flows its full in the month of September and October. Post monsoon period there is plenty of water available in river basin. So, it flows on full might. During the period of 2013 to 2019 dip in annual rainfall is found. The lean river flow observed in the months of march, April, may and first week of June. This has affected the Availability of water in the river with reference to water available in the basin in the month of august.

Graph



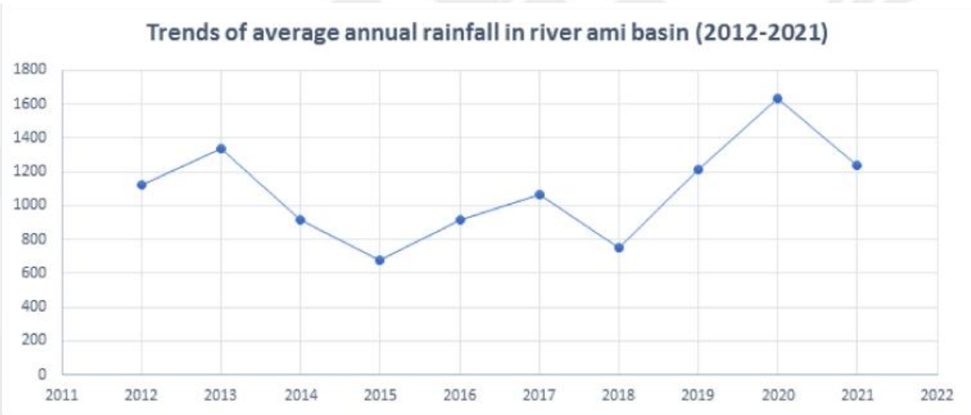
*(**Source:** IMD annual reports)*

Table

Year/District	Siddharth Nagar	Basti	Sant Kabir Nagar	Gorakhpur	Average annual rainfall in river Ami basin
2012	1228.4	1008.5	1141.0	1096.3	1118.550
2013	1402.9	1373.6	1115.0	1471.0	1340.625
2014	961.5	928.5	866.5	898.3	913.700
2015	706.8	685.9	608.8	717.3	679.700
2016	719.5	878.4	1182.7	897.6	919.550
2017	1159	908.6	1156.0	1022.5	1061.525
2018	850.8	701.1	536.5	922.5	752.725
2019	989.1	1384.1	1146.6	1318.3	1209.525
2020	1539.4	1910.4	1433.8	1650.6	1633.550
2021	1261.3	1032.7	1244.0	1414.4	1238.100

*(**Source:** IMD annual reports)*

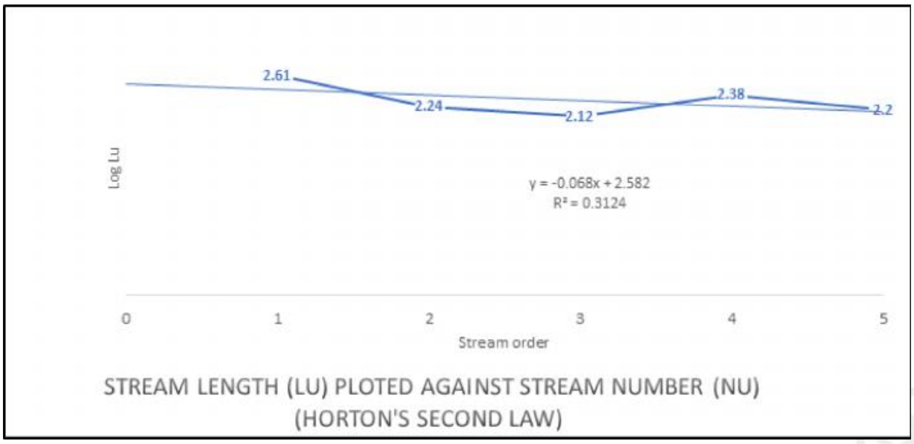
Graph



*(**Source:** IMD annual reports)*

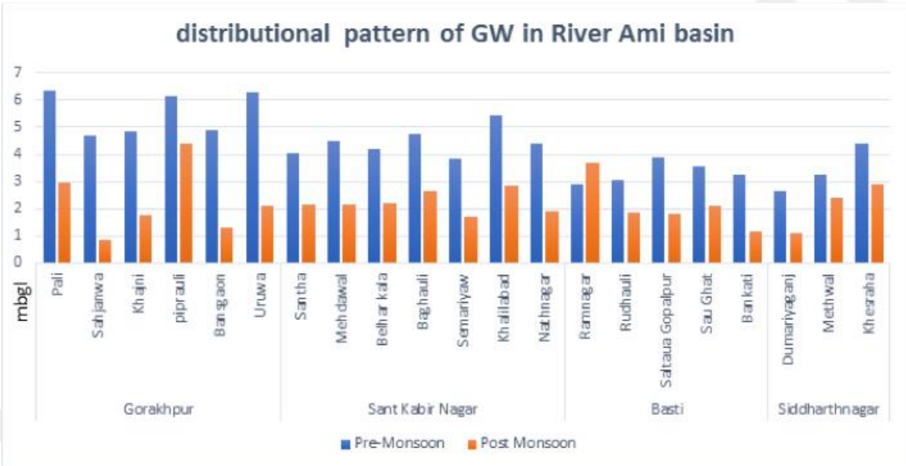
After volume and distribution of rainfall, the second most prominent factor affecting the flow of river is morphology. Relief-ratio *(Rr)* is used to measure surface run-off and intensity of erosion and it is the ratio between basin relief *(R)* and basin length *(L)* (Schumm, 1963). For river Ami basin it is found 0.23 and it indicates low to medium surface run-off, and low stream power for erosion. The value of basin relief is found 24m, which indicates low run-off, low sediment transport capacity and spreading of river water in neighbouring villages. The low difference between highest and lowest point in basin is shown in the following graph

Graph



*(**Source:** Primary Survey)*

Ground water level in this basin is very high. It decreases from north- west to south- east directions. The shallow aquifers of Doomariyanganj, Mithwal ranges from 1.8 to 3.05 mbgl in pre-monsoon period to 1.05 to 2.35 mbgl in post monsoon period. The ground water level in Kauriram ranges 6 to 7.08 mbgl during pre and post monsoon period respectively. This condition leads to water logging problem during post monsoon months and helps in water availability in river Ami. This condition of waterlogging help in aquifer recharge. But gradual expansion of non-agricultural land use activities is reducing groundwater recharge surface.



*(**Source:** GIWP report)*

Forest land use in this basin is only 1.5% to total area of river basin. Santha, Belhar kala and Baghauli blocks collectively represent 38% of total forest land use in basin. the bare land is responsible for next factor to affect river flow. The factor is siltation, bare land is causing soil erosion and increasing silt load in river water. Many river bars are visible in river flow and decreasing the basin depth. Interruptions are reducing the river velocity.

*(**Source:** Primary Survey)*

Man-made obstructions like bridge and roads are posing obstruction in river flow. One railway and 12 road bridges are built on this small tributary of River Rapti. Construction pavement at the banks of river are changing meandering nature of river. The boulders and construction materials are left disregard fully on the site. These are anchoring silt to build river bars in the middle of the river flow. Roads are built on raised platforms are blocking the drainage system to flow naturally. These obstructions are creating stagnation in river water, then high level of nutrient laden run off are producing aquatic plant growth. The eutrophication is again degrading the water quality of river. These factors are forming a vicious cycle of cause and effect factors, which are ultimately affecting the free flow of river Ami. Solid waste disposal near river banks are further poses greater impact quality of river water and its flow.

CONCLUSION

The River Ami is a plain-fed river system that depends on precipitation to run consistently. Numerous elements, including as rainfall amount, topography, ground water level, and non-agricultural land use activities, influence the basin's water availability. The post-monsoon months have a plenty of water, and the river reaches its maximum flow between September and October. Low to medium surface runoff and low stream power for erosion are indicated by the relief-ratio (Rr). Because of the basin's high groundwater levels, post-monsoon waterlogging issues arise. Roads and bridges built by humans have an impact on river flow as well, causing stagnation and runoff that is high in nutrients. This causes eutrophication and the proliferation of aquatic plants, which further deteriorate the river's water quality.

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