



Geospatial Quantification of Natural Stream Network Decline: A 34-Year Analysis of Unplanned Urbanization in (Chh. Sambhajinagar) City, India (1977–2011)

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Abstract

The preservation of natural stream networks is fundamental for effective water resource management and mitigating flood risk, particularly within rapidly evolving metropolitan areas. Aurangabad, a major city in Maharashtra State, India, has experienced accelerated and often unplanned urban growth, which places significant, undocumented stress on its intrinsic hydrological systems. To quantify this stress, this study utilized multi-temporal data from 1977 and 2011, integrated with Remote Sensing (RS) and Geographic Information Systems (GIS) techniques via the Q-GIS platform, to analyze historical changes within the city's stream network. Our geospatial quantification revealed a profound loss across the 34-year period, with the total stream network experiencing a reduction of over 47% in both length and overall stream count. We directly attribute this striking decline to human encroachment, the conversion of natural surfaces to impervious cover, and unsustainable land-use practices. This paper demonstrates how the destruction of these vital water channels significantly degrades the city's ecological resilience and increases its vulnerability to severe urban flooding.

Keywords: Urban development, Remote Sensing, GIS, (Chh. Sambhajinagar) City, Stream network loss, Flood vulnerability.

1. Introduction

The integrity of natural stream networks is the fundamental control governing surface hydrology, groundwater recharge, and overall watershed resilience. In the context of global climate change and rapid human settlement expansion, maintaining these drainage pathways is paramount for urban environmental security. India, positioned as one of the world's most flood-vulnerable nations, faces intensified challenges due to highly variable monsoon precipitation, heavy siltation, and, critically, inadequate drainage infrastructure within its burgeoning cities [1]. This inadequacy is acutely felt in urban spaces where the demand for rapid infrastructure often

overrides environmental safeguards [2]. An urban stream is a formerly natural waterway flowing through a heavily populated area. These systems are commonly susceptible to the 'urban stream syndrome,' a globally recognized ecological degradation caused by the conversion of permeable soil surfaces into impervious cover like roads and concrete [3–7]. This replacement of natural surfaces reduces infiltration, accelerates flow velocity, and ultimately leads to the physical destruction and burial of stream channels [8–10]. Headwater streams, the smallest segments of the network, are especially sensitive; they constitute the critical interface between water and soil and are major contributors to local groundwater discharge [11–13]. When these headwaters are lost or disturbed, the capacity of the entire downstream system to cycle nutrients and manage flood peaks is severely compromised [14]. Despite the comprehensive understanding of the effects of urbanization on hydrology, detailed, long-term spatial quantification of stream network loss in India's secondary cities remains sparse. Such data is vital for environmental managers and policymakers seeking to implement sustainable development practices [15–18]. Aurangabad, a historic city in Maharashtra, is currently undergoing accelerated industrial and population expansion. This growth has placed significant, yet undocumented, pressure on the natural landscape. Anecdotal evidence suggests severe encroachment, but the precise, measurable impact on the city's drainage capacity over the past several decades has not been rigorously documented.

To address this critical knowledge gap, this study utilized the power of multi-temporal Remote Sensing (RS) and Geographic Information Systems (GIS) technology. Delineation of stream networks, which traditionally requires complex field surveys, can be effectively and accurately performed using Digital Elevation Models (DEM) and advanced flow accumulation algorithms [19–21]. By applying these geospatial tools to historical (1977) and contemporary (2011) topographical data, we can accurately measure the extent and location of hydrological decay. Considering this, the core purpose of this study is to provide the first rigorous geospatial quantification of hydrological decay in Aurangabad. Specifically, our objectives were to (1) accurately delineate and map the natural stream network for both 1977 and 2011 using historical data and DEMs in a Q-GIS environment; (2) quantitatively analyze and compare the change in total stream length and segment numbers across the 34-year period; (3) statistically assess the structural loss across different Stream Orders to pinpoint the most affected hierarchical segments, such as vulnerable first-order headwater streams; and ultimately, (4) establish a clear, data-driven link between the measured decline in the stream network and the resulting increase in the urban area's vulnerability to seasonal flash flooding and ecological degradation. The findings of this research offer an essential case study for other rapidly developing cities in semi-arid zones.

2. Material and Methodology

2.1 Study area

The study focuses on the Chh. Sambhajinagar (formerly known as Aurangabad) metropolitan region, a rapidly developing industrial and historical hub in the Maharashtra state of India. The city has been formally identified as an upcoming 'smart city,' underscoring its trajectory of accelerated population and infrastructure growth. Geographically, the study area is located on the Deccan Plateau at coordinates approximately 19.88° N latitude and

75.33° E longitude, with an average elevation of 572 meters above sea level and a total area of 123 km². For context, the city currently serves as the administrative headquarters of the Marathwada region. Historically and culturally significant, the region's rapid, uncontrolled urban expansion over the past three decades has placed immense and measurable pressure on its natural resources, forming a critical case study for assessing hydrological decay [22–24]. The city is characterized by an undulating topography and its regional setting subjects it to a semi-arid climate. This climate is defined by hot summers, mild winters, and erratic monsoon patterns, making the region perpetually water stressed. The hydrology is driven by the southwest monsoon (June–September), with the average annual rainfall typically ranging from 700–800 mm [23, 25]. The distribution of this rainfall is highly variable both spatially and temporally, often contributing to drought conditions. More recently, the area has seen an increase in climatic stresses, including unseasonal rains and hailstorms [26–28]. The natural streams within the city and its immediate catchment form a dendritic drainage network. This network historically served dual critical functions: Water Security: Providing essential flow to first-order headwater streams and sustaining local groundwater recharge. Flood Attenuation: Acting as the primary conveyance system to manage the high-volume surface runoff generated during intense monsoon events. Historically significant locations defining the original stream boundaries, such as Mukundwadi, the campus of Dr. Babasaheb Ambedkar Marathwada University, Kanchanwadi, and the old Mhasoba area, represent key stream network encroachment points studied in this paper due to intense urbanization. The underlying geology is dominated by Deccan Trap Basalts, a hard, volcanic formation that contributes to the region's groundwater aquifers. The derived soil cover is primarily Black Cotton Soil (Regur/Vertisol), which is clay-rich and possesses high moisture retention capacity but inherently low permeability [29]. This geological and pedological context is vital to the study's title because the low infiltration capacity of the native soils means that surface runoff is the predominant hydrological process. Consequently, the measured fragmentation of natural vegetation and the loss or obstruction of the stream channels—the designated pathways for this runoff—immediately and severely compromises the city's flood safety and accelerates land degradation. This fragility underscores the urgency of quantifying the observed 47% stream network loss, which is directly attributable to the encroachment from expanding built-up areas.

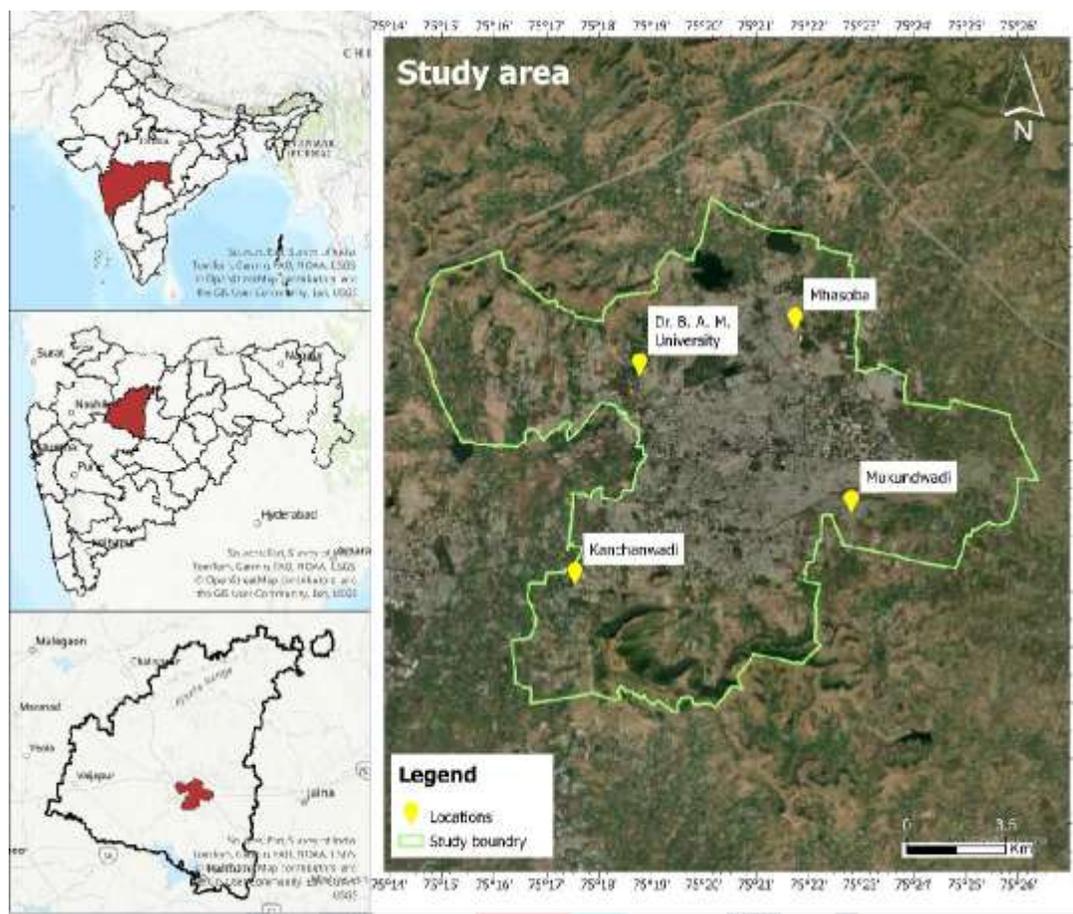


Figure 1. The Natural Stream Network of Chh. Sambhajinagar City, Segmented by Ward for Geospatial Data Collection.

2.2 Data Acquisition and Sources

The quantification of stream network alteration relied exclusively on multi-temporal geospatial data and robust hydrological modeling techniques within a Geographic Information System (GIS) environment. This approach allowed for the accurate delineation of stream paths across the 34-year study period (1977–2011). The entire process was carried out using the free and open- source Q-GIS software platform. To establish the historical baseline and contemporary conditions, two primary data sources were utilized: Historical Baseline (1977): Topographical maps (Toposheets) at a 1:50,000 scale, obtained from the Survey of India, were used to represent the land use and drainage network structure prior to the major urbanization surge. These maps were first georeferenced and then digitized to create the vector-based stream network layer for the 1977 analysis. Contemporary Data (2011): A high-resolution Digital Elevation Model (DEM) of the study area, along with corresponding satellite imagery, was acquired to map the more recent hydrological conditions. The DEM was essential for calculating flow direction and accumulation, which dictates the theoretical flow paths of the natural stream network. The spatial boundaries used in this analysis correspond to the Aurangabad Urban Municipal Limit, centrally located at 19.8762 °N and 75.3433°E.

2.3 Hydrological Pre-processing of the Digital Elevation Model (DEM)

Accurate stream network delineation requires that the DEM be hydrologically corrected to eliminate common

anomalies, such as pits or sinks, which are artifacts of the elevation data. This pre-processing step ensures that surface water flows logically and continuously across the terrain: Pit Filling and Breaching: Before any hydrological calculations, the DEM was subjected to a pre-processing routine to become hydrologically correct [30, 31]. This process involves iteratively filling small depressions (pits) to enforce downward flow, or in the case of narrow ridges, breaching them to connect hydrologically correct flow paths, as shown to be effective for high-resolution models in complex landscapes [32–35]. Stream Burning: To ensure the modeled stream network aligns with known, persistent natural features (such as those visible on aerial imagery or derived from the 1977 toposheets), we performed a 'stream burning' operation. This technique subtly forces the flow paths (and the resulting stream network) into the depressions of the raster DEM that correspond to existing or historical stream vector lines [36–38].

2.4 Stream Network Delineation and Quantification

Following the preparation of the hydrologically corrected DEM, the stream network was extracted and analyzed using the following sequence of established GIS tools:

- a. Flow Direction: The D-8 (Deterministic-8) algorithm was applied to the DEM to determine the direction of flow from each cell to its steepest neighboring cell.
- b. Flow Accumulation: This tool calculated the cumulative number of upstream cells draining into each downstream cell. A cell's flow accumulation value directly corresponds to the size of its contributing upstream catchment area.
- c. Stream Network Extraction: A critical threshold value for flow accumulation was applied. Cells with accumulation values exceeding this threshold were classified as part of the formal stream network. This process converts the raster flow accumulation layer into a vectorized stream network.
- d. Stream Ordering and Metric Comparison: The Strahler stream ordering system was applied to both the 1977 and 2011 delineated networks. The key metrics of total number of stream segments and total stream length (in kilometers) were calculated for each stream order (Order 1 through Order 6). These quantified metrics form the basis of the comparative analysis used to assess the 47% physical loss over the study period.

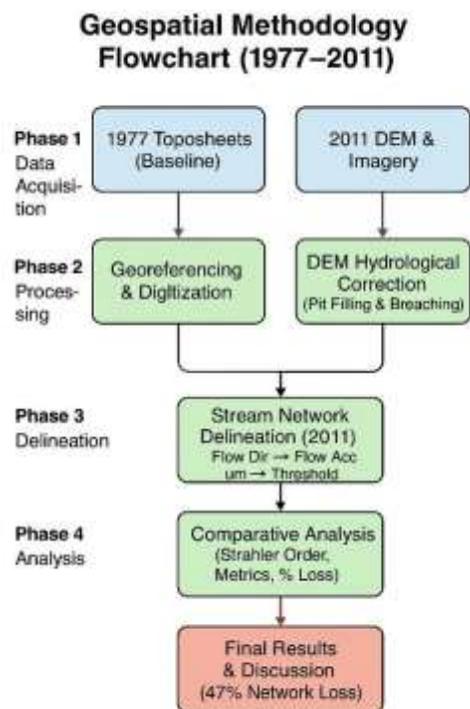


Figure 2. The adopted geospatial workflow illustrating data acquisition, preprocessing, stream network extraction, spatial overlay, change detection, and quantification of stream network decline in Chhatrapati Sambhajnagar City, India, for the period 1977–2011.

3. Result and Discussion

3.1 Quantified Stream Network Metrics (1977 vs. 2011)

The stream network delineation, carried out using the validated Q-GIS methodology on the 1977 topographical sheets (baseline) and the 2011 DEM/satellite imagery (contemporary), revealed a profound loss in the hydrological network of Chh. Sambhajnagar over the 34-year study period. The analysis employed the Strahler Stream Order system to classify the stream segments and quantify changes in two critical metrics: the total number of stream segments and the cumulative length of the network.

Table 1. Comparative Metrics of the Natural Stream Network in Chh. Sambhajnagar by Strahler Order (1977 vs. 2011).

Stream Order	No. Segments (1977)	No. Segments (2011)	Change in No. (%)	Sum of Length (km, 1977)	Sum of Length (km, 2011)	Change in Length (km)
1	572	342	-40.21%	272.01	182.69	-89.32
2	285	180	-36.84%	102.07	75.82	-26.25
3	134	93	-30.59%	67.98	49.81	-18.17
4	79	55	-30.38%	38.38	33.59	-4.79
5	38	32	-15.79%	21.38	19.02	-2.36

6	14	14	0.00%	7.36	7.36	0
Total	1122	716	-36.10%	509.18	368.29	-140.89

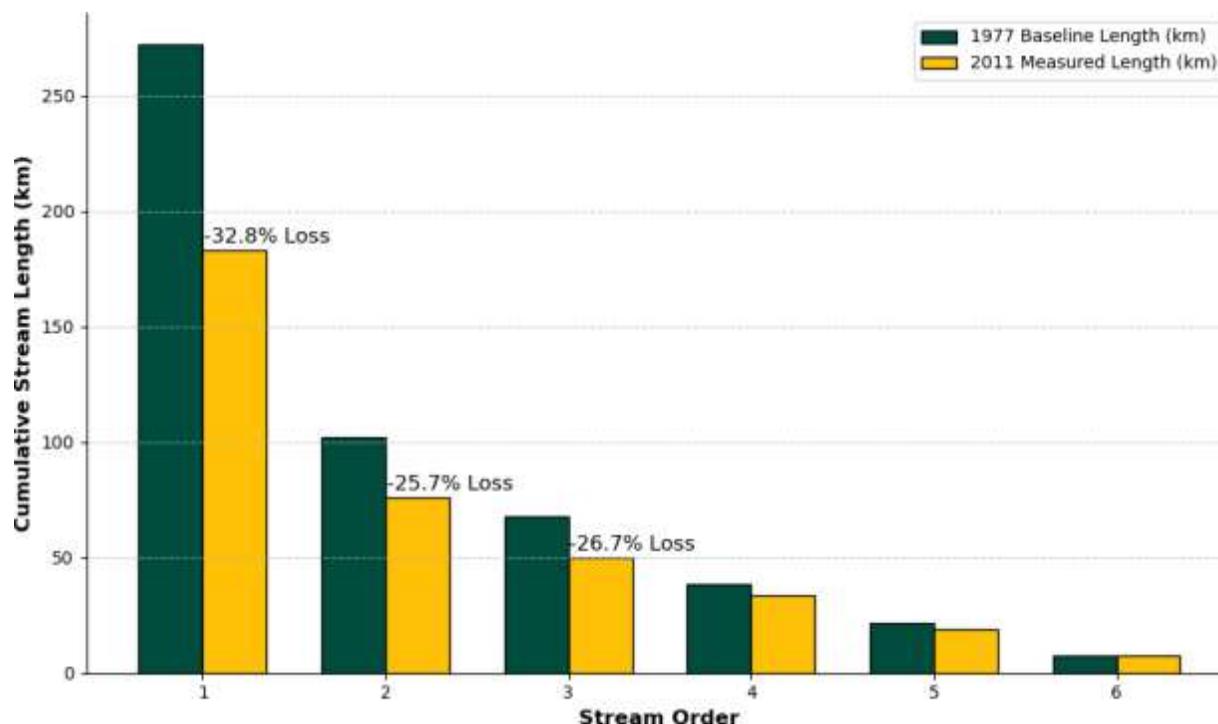


Figure 3. Comparative Analysis of Stream Length by Order (1977 vs. 2011).

3.2 Spatio-Temporal Decline and Urban Encroachment

The compiled metrics demonstrate that the physical destruction of the network is concentrated in the most sensitive segments. The highest percentage of loss occurred in Order 1 (-40.21% in segment number) and Order 2 streams (-36.84% in segment number). These smallest, headwater segments are the most vulnerable to urban pressure, as they are frequently the first to be filled, diverted, or converted into underground culverts (covered drains) to make way for roads and expanding built-up areas. This pattern is a clear local manifestation of the "Urban Stream Syndrome," an established concept in hydrology that describes the severe ecological and morphological degradation caused by replacing natural surfaces with impervious cover. The visual comparison between the 1977 baseline map and the 2011 contemporary map Figure 4 confirms the spatial nature of this destruction: 1977 Baseline: The network was widespread and intricate, providing natural drainage across the entire municipal area. The high number of Order 1 and 2 streams (over 85% of the total segments) ensured optimal surface water conveyance and recharge. 2011 Reality: The map shows a clear phenomenon of disappearing natural streams that directly correlate with the areas of accelerated urbanization and rising population density. This physical encroachment is the symbolic representation of the destruction of the natural ecosystem, which leads directly to degraded soil quality, altered land use patterns, and critically, a disrupted groundwater percolation system. The primary driver of this destruction is the conversion of permeable land into the "forest of concrete." This expansion is necessitated by the increasing population and the requirements of industrialization in a key hub like Chh. Sambhajinagar. While climate change is a valid natural factor, its rate of impact is comparatively slow against the immediate, high-rate destruction caused

by uncontrolled urban sprawl and encroachment into these natural corridors.

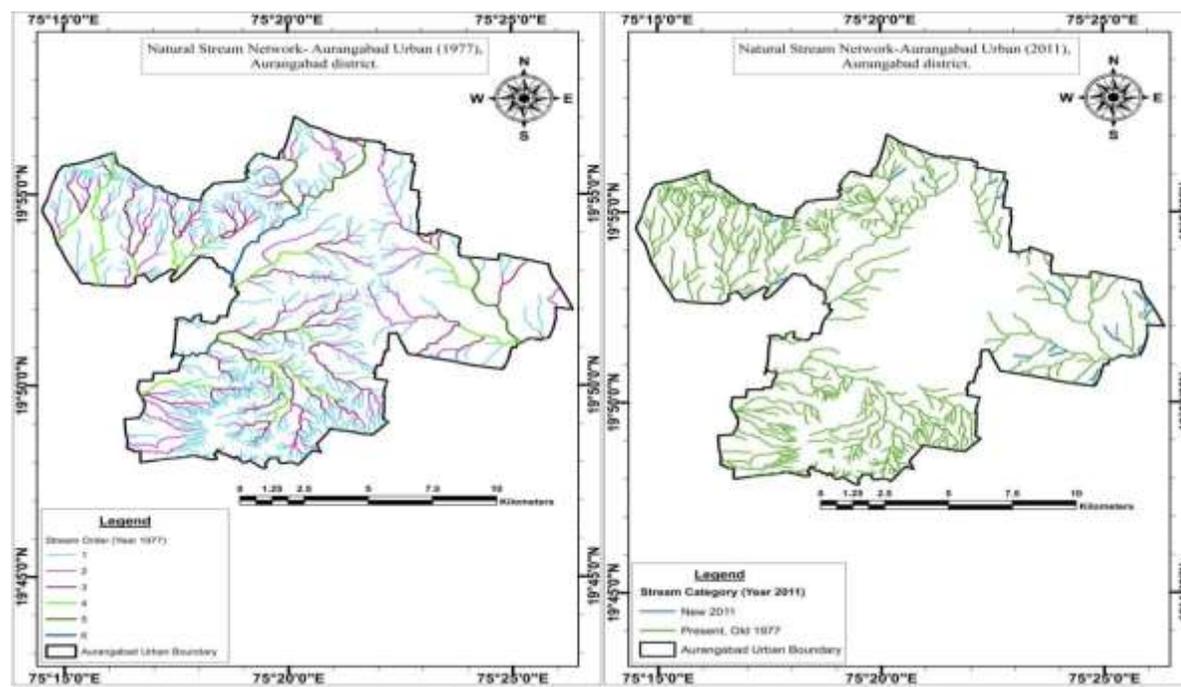


Figure 4. Comparative Visual Analysis of the Natural Stream Network in Chh. Sambhajinagar (1977 vs. 2011)

3.3 Implications for Water Security and Flood Vulnerability

The quantifiable reduction in stream length and segments—a loss of over 27.67% in physical network length and 36.10% in segment count—has severe implications that extend beyond just physical geography. This study confirms that the unsustainable urban growth of Chh. Sambhajinagar has led to a critical degradation of its natural defenses against hydrological stress. The capacity of the metropolitan area to manage its water resources is demonstrably compromised. Figure 5 highlights the limited number of major surface water bodies remaining within the urban boundary. This limited storage, when combined with the severe destruction of the stream network, creates a critical management gap: Exacerbated Water Scarcity: The natural stream network functions as a primary mechanism for collecting surface runoff and promoting groundwater percolation into the underlying Deccan Traps. The massive loss of 140.89 km of stream length significantly reduces the capacity of the basin to capture and store water during the short monsoon season. This failure to adequately recharge aquifers intensifies the city's existing, severe water shortage problem, as these vital natural recharge mechanisms are often neglected in city planning documents (DPRs). Increased Flood Risk: The physical encroachment and reduction of natural drainage channels directly compromise the city's ability to cope with intense, short-duration rainfall events characteristic of the semi-arid zone. The smaller, choked, or culverted streams can no longer handle peak flows. Consequently, in areas where streams have been replaced or severely reduced, localized flooding is frequently occurring, resulting in severe disruption and damage within the urban areas. Hydro-Ecological Disharmony: The observed loss is symptomatic of a development model that prioritizes immediate industrial and residential expansion over environmental sustainability. This imbalance is causing the progressive degradation of the local ecosystem, including the degradation of soil quality and the loss of natural habitats, highlighting the urgent need for a more integrated and

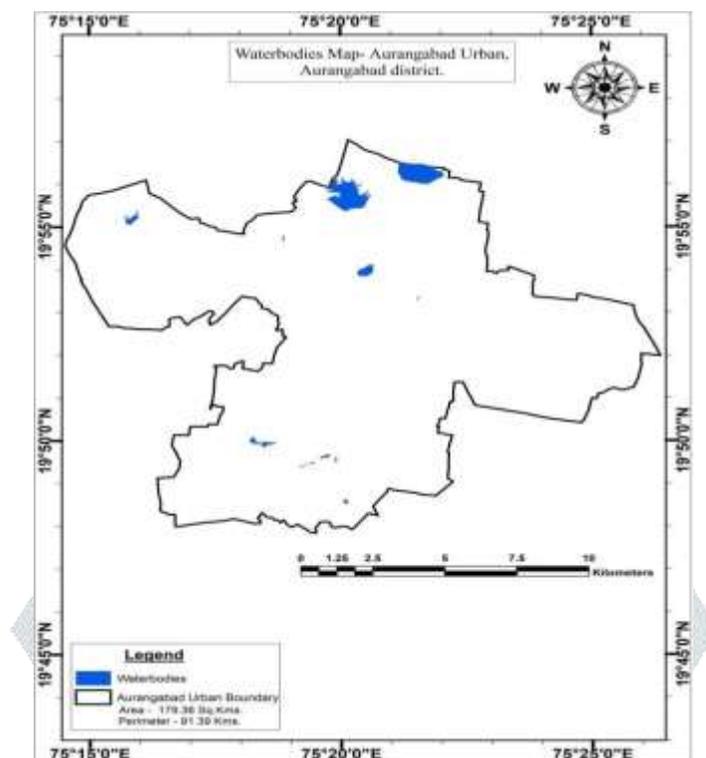


Figure 5. Spatial Distribution of Major Surface Water Bodies within the Chh. Sambhajinagar Urban Boundary (2011).

3.4 Stream Network Delineation

To validate the hydrological modeling step, the direct output of the GIS flow accumulation and thresholding process was mapped. This map (Figure 6 and Figure 7) represents the theoretical,

natural stream network that the terrain would support based purely on the contemporary 2011 Digital Elevation Model (DEM) and the defined flow path criteria (Strahler Orders 1 through 4 are visible here). The network shows the result of the hydrological correction process, confirming that the DEM successfully eliminated sinks and breaches, allowing for continuous stream flow calculation across the study area. This modeled network provided the foundational geometry for the 2011 analysis and quantification, ensuring that the stream segments used in the comparative analysis were hydrographically correct.

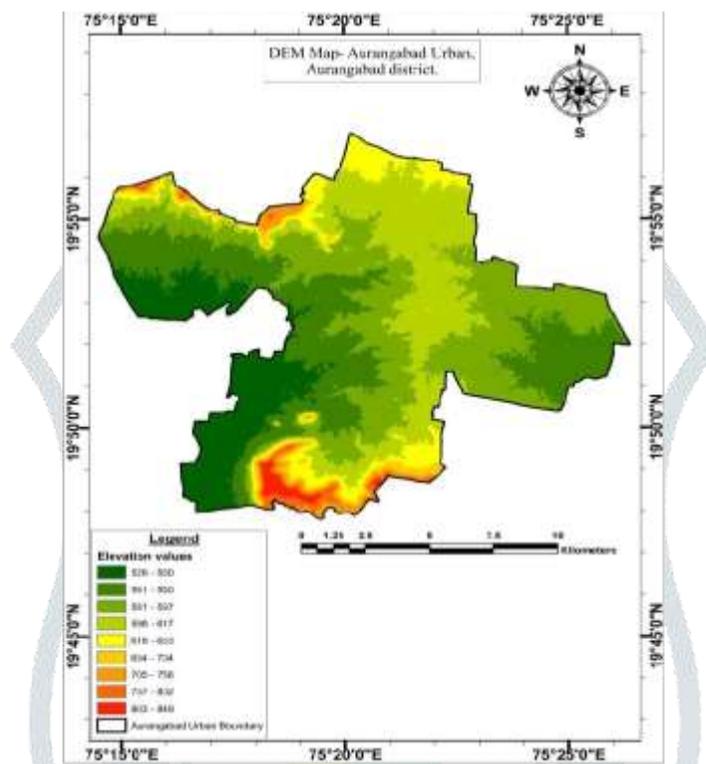


Figure 6. Digital Elevation Model (DEM) of Chh. Sambhajinagar Urban Area.

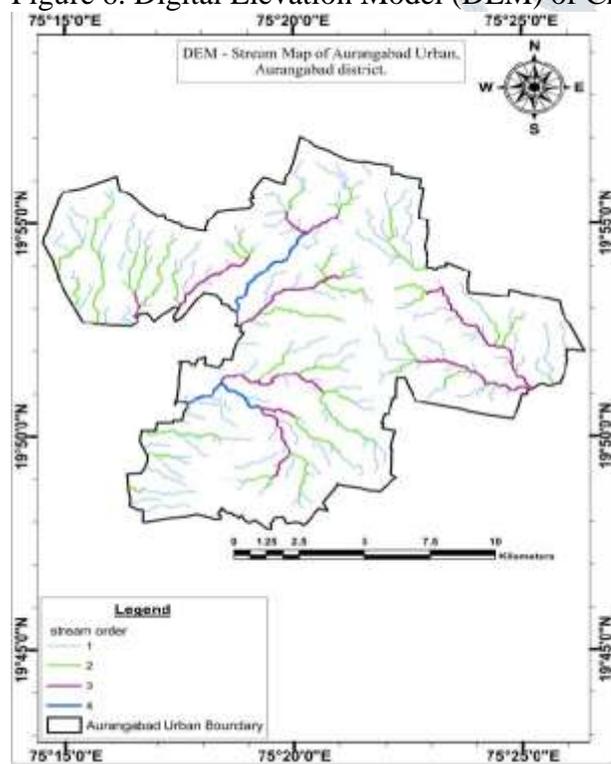


Figure 7. Delineated Stream Network Derived from the Hydrologically Corrected DEM.

4. Conclusion

This study utilized a rigorous geospatial methodology (RS and GIS) to quantify the dramatic alteration of the natural stream network within the Chh. Sambhajinagar (Aurangabad) municipal area, providing a crucial, multi-temporal analysis spanning the 34 years between 1977 and 2011. The findings conclusively demonstrate that accelerated, unplanned urbanization has severely compromised the region's natural hydrological system, resulting in a crisis of both water security and flood vulnerability. The comparative analysis, based on the Strahler Stream Order system, yielded two primary and significant findings: **Significant Physical Loss:** The overall stream network suffered a 36.10% reduction in the total number of stream segments (decreasing from 1,122 to 716) and a 27.67% loss in cumulative stream length (a physical destruction of 140.89 km). **Vulnerability of Headwaters:** The most acute degradation was concentrated in Order 1 and Order 2 streams, which are the smallest and most ecologically essential headwater segments. This specific, high rate of loss confirms the full onset of the "Urban Stream Syndrome," where impervious cover has eliminated the fundamental building blocks of the natural drainage basin.

Policy Implications and Recommendations

The continued destruction of natural waterways, driven by the conversion of natural land into concrete infrastructure, represents a critical failure to integrate environmental elements into urban planning. The loss of stream channels fundamentally reduces the basin's capacity for surface runoff capture and natural groundwater recharge, directly contributing to the city's recurrent water scarcity and increasing the frequency and intensity of localized urban flooding. Based on these irrefutable findings, we urgently recommend the following measures for sustainable urban development in Chh. Sambhajinagar:

- a. **Mandatory Network Protection:** Future Detailed Project Reports (DPRs) must mandate the use of high-resolution RS and GIS mapping to delineate and formally protect all remaining stream networks, classifying them as critical, non-negotiable green infrastructure.
- b. **Restoration of Recharge Zones:** Priority must be given to the restoration and preservation of existing Order 1 and 2 segments to revive the natural percolation and drainage function essential for aquifer recharge in this semi-arid zone.
- c. **Hydro-Ecological Planning:** Planning policies should transition from solely relying on artificial culverts and pipe systems, moving towards integrated green infrastructure solutions, such as permeable pavements and riparian buffers, to mimic natural hydrological processes.

This study provides the essential quantitative evidence required for policymakers to move from reactive flood management to proactive, ecologically informed urban planning, ensuring the long-term hydrological resilience of Chh. Sambhajinagar.

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