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Research Article

Application of GIS to Flood Risk Understanding: The Case of the Municipality of Sangalkam (Dakar, Senegal)

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Abstract

Flooding is an increasing risk in the peri-urban areas of the Dakar metropolitan region, driven by the combined effects of rapid urbanization, land artificialization, and topographic constraints. This study analyzes the spatial dynamics of flooding in the municipality of Sangalkam using Geographic Information Systems (GIS), by integrating land use, topography, and flow directions to produce geospatial maps. The methodology relies on Sentinel-2 imagery and a 10-m Digital Elevation Model (DEM), processed in ArcGIS Pro using hydrological modeling tools, particularly Fill, Flow Direction, and Flow Accumulation. The results reveal substantial spatial transformation of the territory, characterized by the expansion of built-up areas at the expense of agricultural land and by the concentration of settlements in several sectors, particularly Kounoune, Keur Ndiaye L ô, Keur Daouda Sarr, and Sangalkam. The topographic map shows an elevation gradient ranging from 0 to 136 m, with contour lines reaching approximately 30 m and above in Keur Ndiaye Lo, decreasing to around 20 m near Ndiakhirate and reaching approximately 10 m in Sangalkam village. This topographic configuration controls runoff pathways, with water flowing from the higher areas of Keur Ndiaye L ô and Keur Daouda Sarr toward the lower-lying areas of Ndiakhirate, Noflaye, Kounoune, and particularly Sangalkam. These findings are corroborated by the flow-direction map. Sangalkam therefore emerges as the main spatial hotspot of flooding within the municipality, owing to its low topographic position and its reception of runoff from several directions. Three major drainage pathways converge toward the village, directing runoff toward the Lake Rose watershed. Overall, the findings show that Sangalkam's vulnerability to flooding results from the interaction between topographic configuration, runoff concentration, and rapid urbanization. GIS therefore provides a valuable tool for identifying priority areas and supporting urban planning and flood prevention strategies.

Keywords

Flooding, GIS, Topography, Contour Lines, Runoff, Urbanization

1. Introduction

In African cities, particularly within the Dakar metropolitan area, urban growth, the occupation of low-lying depression zones, soil waterproofing, and inadequate drainage infrastructure modify the hydrological functioning of watersheds and exacerbate flood risks [1-3]. Analyzing this vulnerability requires considering the territorial and environmental factors influencing population exposure and runoff dynamics [4, 5]. Drawing on geomatics and Geographic Information Systems (GIS), this study analyzes the physical, environmental, and territorial factors likely to promote the occurrence and intensification of

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floods in the municipality of Sangalkam. Specifically, it examines the location and spatial configuration of the municipality, the organization of watersheds and runoff, recent precipitation dynamics [6], topographic and hydrogeological characteristics, and land-use changes.

Between 2014 and 2024, the built-up area increased from 7% to over 47%, while agricultural land decreased from 68% to 28% [7]. This land artificialization driven by real estate pressure from the Dakar agglomeration and financial constraints of local governments [8] has reduced natural water expansion spaces. This leads to decreased infiltration and disrupted surface runoff, confirming the Intergovernmental Panel on Climate Change (IPCC) conclusions regarding the combined effect of extreme precipitation and insufficiently planned urbanization in worsening flood risks [2]. In this context, GIS combined with remote sensing provides suitable tools for analyzing the physical and territorial factors of floods and identifying high-risk zones [9-11]. Conducted from this perspective, this study aims to contribute to a better understanding of the spatial dynamics of flooding in the municipality of Sangalkam using geomatics and GIS in particular.

2. Materials and Methods

The article should be written in English. An article should be between 4 and 18 pages, and exceed 2000 words. For original research articles, it should include the headings Introduction, Materials and Methods, Results, Discussion and Conclusions. Other types of articles can be written with a more flexible structure.

2.1. Study Area Description

Located in the department of Rufisque (Dakar region) in the heart of the Niayes zone, the municipality of Sangalkam covers 195 km^2 and encompasses eight traditional villages and their extensions [7]. Bordered by Rufisque, Bargny, Diamniadio, Bambilor, Niaga, and Keur Massar (Figure 1), its territory is characterized by predominantly sandy soils, poor in organic matter and clay (known locally as Dior soils) (60%), alongside hydromorphic and clayey soils (known locally as Deck soils) (12%) [12-14].

As Ndiaye (2025) [7] emphasizes, the municipality of Sangalkam represents a particularly relevant peri-urban territory. Integrated into the Niayes zone, it is characterized by sub-outcropping hydrogeological resources and a relief marked by depressed sectors. The PROGEP (2023) [15] links the Sangalkam basins to the Kounoune-Sangalkam sub-basin (6,042.13 ha), which is part of the Lake Rose basin. It also notes that the hydrological network of the municipality of Sangalkam primarily falls within the Kounoune and Ndiakhirate watersheds, forming the Kounoune-Sangalkam sub-basin, which accounts for over 34% of the overall Lake Rose watershed [15].

Historically, rainwater was drained toward the Lake Rose depression via a main thalweg of approximately 9 km, characterized by a low overall slope of 0.20% [15, 16], which favors water accumulation and stagnation. This situation is reinforced by recent hydroclimatic evolution, characterized since 2020 by an excess rainfall phase in the Dakar region after a long deficit period [17]. Annual precipitation recorded in 2022 at Dakar-Yoff was around 800.6 mm, compared to an average of 446.8 mm over the 1950–2022 period. Simultaneously, urbanization has extensively transformed the territory.

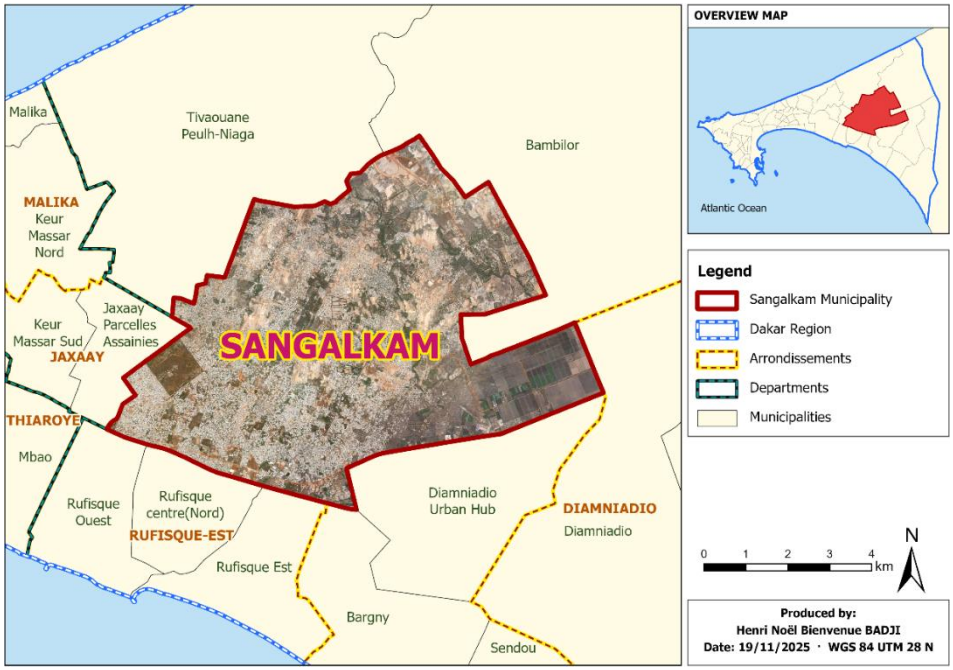


Figure 1. *Delimitation of the municipality of Sangalkam.*

2.2. Study Methodology

The work consisted of assembling, harmonizing, and deriving several baseline data sources to map four themes at the municipal scale: administrative location, land use, relief (elevation), and hydrology (contour lines, drainage network, and flow direction), along with the hierarchical road network. The entire processing chain was conducted in ArcGIS Pro, with data stored in a file geodatabase and referenced in the WGS 1984 / UTM Zone 28N projection system (EPSG: 32628), a metric system suited for the Dakar zone.

The land-use layer was established from 2020 Sentinel-2 imagery, following the nomenclature of the reference geoportal. It distinguishes residential areas, bare and sandy surfaces, vegetation formations, agricultural spaces, quarries, water bodies, and wetlands. The classification was structured and controlled in accordance with the ANAT's geographic database standards (BDGS), then generalized to the municipal scale and mapped according to the ANAT thematic chart (November 2025). This approach helps characterize the spatial distribution of land use and surfaces likely to influence infiltration and stormwater runoff [18-21].

Topography was analyzed using a Digital Elevation Model (DEM), notably FABDEM (Forest And Buildings removed Digital Elevation Model) and SRTM (Shuttle Radar Topography Mission), whose elevation classes identify low-lying and depressed areas favorable to water stagnation [22-25]. Finally, in ArcGIS Pro, the D8 algorithm was applied to the pit-filled DEM (Fill) to derive flow direction (Flow Direction) and accumulation (Flow Accumulation). These processes characterized preferential drainage axes and runoff convergence zones, helping identify sectors potentially prone to water accumulation and flood exposure [26-29].

3. Results

3.1. Land Use in the Municipality of Sangalkam

The land-use map for the municipality of Sangalkam is presented in Figure 2.

The map shows that within the municipality of Sangalkam, the villages of Kounoune, Keur Ndiaye Lo, and Keur Daouda Sarr exhibit higher agglomeration density compared to villages such as Ndiakhirate, Sangalkam, and Noflaye. Vast surfaces are reserved for rainfed agriculture. Market gardening, irrigated crops, orchards, and plantations are practiced along the bordering areas of the municipality of Sangalkam, such as Bargny and Diamniadio.

It is also observed that areas reserved for rainfed farming feature a significant number of dispersed dwellings between Keur Ndiaye Lo and Ndiakhirate, as well as on the lands of Sangalkam village. Road infrastructure is moderately developed in the municipality. However, access is provided via National Road N08 coming from Rufisque, or Regional Road R010 coming from Keur Massar.

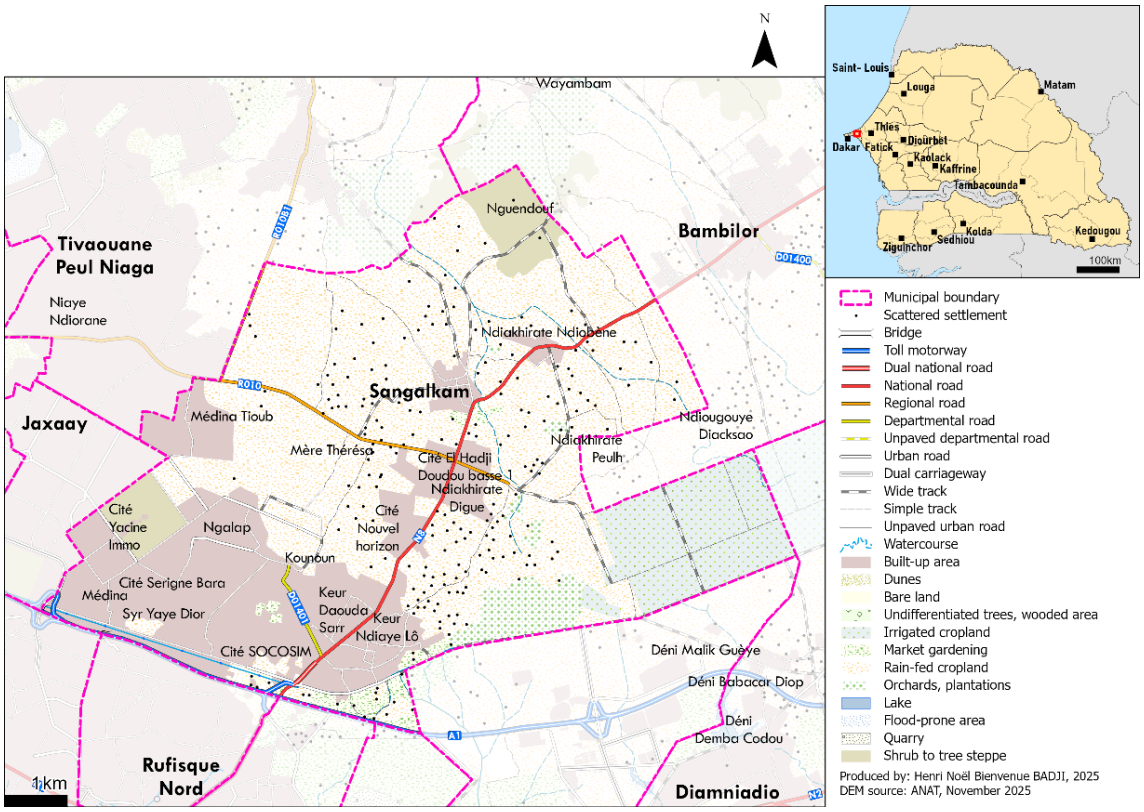


Figure 2. *Land use in the municipality of Sangalkam.*

3.2. Elevations in the Municipality of Sangalkam

The elevation map for the municipality of Sangalkam is presented in Figure 3.

The elevation map indicates that the municipality exhibits an altitudinal gradient of 136 m, directing surface runoff toward lower-lying zones. It shows that the villages of Keur Ndiaye Lo and Daouda Sarr are elevated relative to villages such as Kounoune, Ndiakhirate Digue, and Ndiakhirate Ndiobène. This configuration allows for the understanding of natural stream flow directions and stormwater runoff pathways. Specifically, rainwater naturally flows from Keur Ndiaye Lô (or Keur Daouda Sarr) toward Kounoune—more precisely Ngalap and Médina Tioub—as well as from Keur Ndiaye Lo toward the village of Sangalkam via Ndiakhirate Ndigue.

Certain stormwater flows from Ndiakhirate Digue originating in Keur Ndiaye Lo flow toward Ndiakhirate Ndiobène. Part of the stormwater originating in Kounoune also flows toward Sangalkam village.

The elevation map primarily reveals three watercourses in the municipality of Sangalkam. These watercourses serve as natural collection and drainage pathways for rainwater (Figure 4). The hydrographic network is marked by three main flow axes:

1) *First Axis*: Originating in Ndiakhirate Digue, it crosses Ndiakhirate Ndiobène before joining the second axis.
2) *Second Axis*: Also originating in Ndiakhirate Digue, it passes through Sangalkam. Their confluence forms a single flow axis oriented toward the municipality of Niaga, heading toward Lake Rose.
3) *Third Axis*: Originating in the village of Kounoune, it also crosses Sangalkam before heading toward Niaga and Lake Rose.

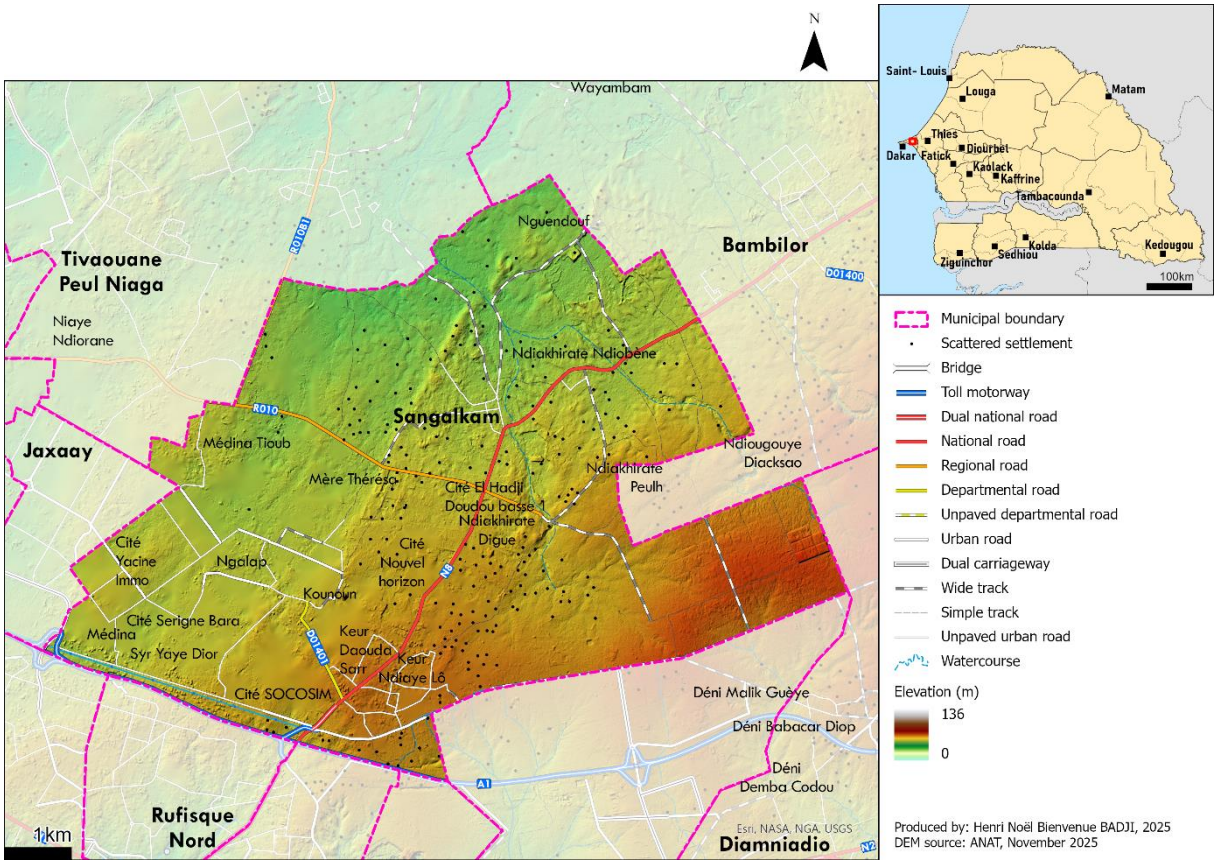


Figure 3. *Elevations of the municipality of Sangalkam.*

These configurations highlight a concentration of flows toward downstream sectors, which can promote water accumulation in topographically depressed zones. Furthermore, elevation analysis highlights a contrasted topographic organization of the municipality. Keur Ndiaye Lo and Keur Daouda Sarr occupy the highest positions, while Kounoune, Ndiakhirate Digue, and Ndiakhirate Ndiobène are located in relatively low sectors. This altitudinal setup is a decisive factor in understanding surface flow dynamics and the spatial distribution of flood risks.

The water flow direction map (Figure 4) confirms the stormwater flow directions deduced from the elevation map

(Figure 3). Natural stormwater and stream flows follow slope gradients—meaning that from Keur Ndiaye Lo, waters run off toward Sangalkam via Ndiakhirate Ndigue. This is attested by contour line differences: 30 m or higher in Keur Ndiaye Lo village; 20 m in Ndiakhirate Ndigue; and dropping down to 10 m in Sangalkam village.

The same applies to waters from Kounoune village, which run off toward new settlements (dispersed habitats) with contour lines dropping from 20 m to 10 m. The watercourse flowing down to Noflaye (with contour lines reaching 20 m) originates west of Ndiakhirate, where contour lines reach 30 m. Part of the rainwater follows this same path.

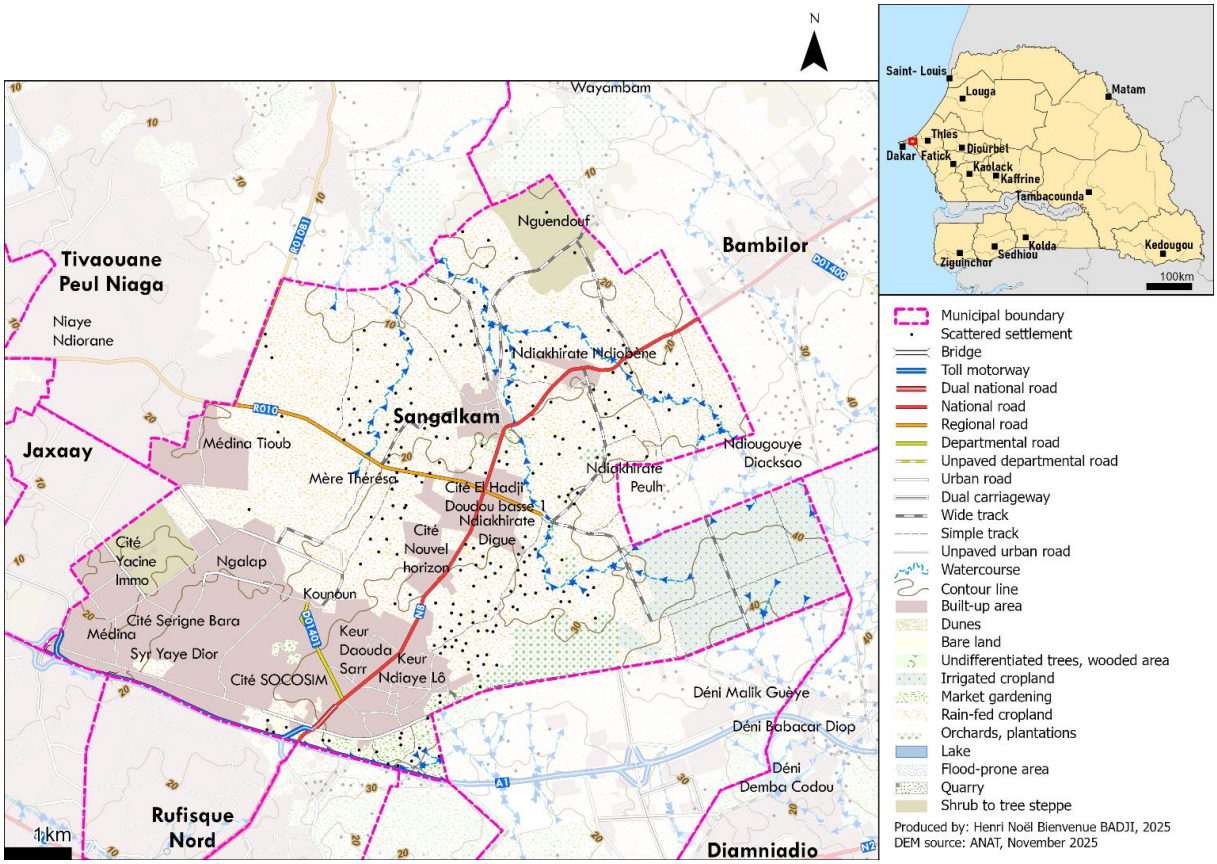


Figure 4. *Water flow direction map (watercourses and stormwater).*

4. Discussion

In the context of urban and peri-urban flooding, the geospatial approach constitutes a structuring analytical tool for grasping the complexity of socio-environmental risks [29, 30]. It simultaneously articulates natural physical factors (topography, soil nature, hydrographic network configuration) and anthropogenic factors (land-use dynamics, urban sprawl, population pressure) [31, 32]. The integration of GIS mapping offers fine-scale modeling of interdependencies among vulnerability components, facilitating the identification and prioritized spatialization of high-exposure zones [33, 34].

The results of this study show that floods in Sangalkam do not stem solely from extreme rainfall events, but result from the systemic interaction between physical environmental constraints and rapid spatio-temporal mutations induced by uncontrolled urbanization [35, 36]. Land-use analysis highlights a strong progression of housing—particularly in Kounoune, Keur Ndiaye Lo, Keur Daouda Sarr, and Sangalkam—as well as a proliferation of constructions between Keur Ndiaye Lo and Ndiakhirate (Figure 2), indicating the conversion of arable land for housing needs.

Aware of this, municipal authorities have developed and launched a Land Use and Allocation Plan (Plan d'Occupation et d'Affectation des Sols - POAS) for the sustainable and consensual management of resources. This land conversion dynamic reflects the influence of Dakar's metropolization, characterized by urban extension toward peripheral communes driven by demographic growth, real estate pressure, and infrastructure development [37]. The progressive conversion of agricultural and natural spaces into built-up areas is part of a peri-urbanization process observed in several African cities [38]. However, increased impervious surfaces reduce stormwater infiltration and increase runoff, thereby aggravating flood risks [39, 40].

Topographic analysis derived from the DEM (Figure 3) reveals an elevation organization that directly influences flows. Keur Ndiaye Lo and Keur Daouda Sarr occupy relatively high positions, whereas Kounoune, Ndiakhirate, Noflaye, and especially Sangalkam are located in lower sectors. These results confirm the major role of topography in determining water concentration zones and flood susceptibility [41-43]. In the Dakar region, several studies have similarly shown that the combination of low elevations, rapid urbanization, and insufficient drainage infrastructure acts as an aggravating factor for floods [3, 44, 45].

Furthermore, the flow direction map (Figure 4) confirms trends observed from the altitudinal analysis (Figure 3). The identified flow directions correspond to the altitudinal gradient, demonstrating the decisive role of relief in organizing hydrological flows. This concordance between topography and flow constitutes a fundamental principle of surface hydrology, whereby water naturally circulates from higher elevations to lower zones under the influence of gravity [46, 47]. Topographic analysis, particularly through slope and drainage network studies, thus accurately models these gravitational trajectories and runoff concentrations [48, 49].

The combination of elevation maps (Figure 3) and flow direction maps (Figure 4) clarifies the hydrological aspects of the municipality. It highlights preferential water transfer axes linking several villages and confirms that Sangalkam acts as a flow convergence zone. Located in a low topographic position (approx. 10 m) (Figure 4), this village receives water from multiple directions, favoring accumulation during heavy precipitation. According to Huang et al. (2019) [50], zones with high hydrological flux accumulation generally correspond to sectors with the highest flood probability. The works of Aristizabal et al. (2024) [42], Al-Kindi and Alabri (2024), and Diémé et al. (2025) [43] further confirm that topographic depressions and runoff concentration zones are particularly vulnerable spaces.

Thus, cartographic results demonstrate that GIS tools are essential decision-support instruments for flood risk analysis. They identify hydrological continuities, water accumulation zones, and priority intervention sectors. As Sagna et al. (2015) [51] emphasize, understanding interactions among relief, drainage, and land use is a prerequisite for sustainable urban planning. The maps produced in this study can contribute to drafting the Land Use and Allocation Plan (POAS) for the municipality of Sangalkam.

Finally, utilizing GIS and remote sensing offers a prospective approach to risk management by anticipating urban expansion effects and directing investments toward priority sectors. Across Africa, Adelekan (2016) [52] and Douglas et al. (2008) [53] note that these tools strengthen urban resilience by facilitating the preventive identification of vulnerable zones. In Senegal, the work of ANAT (2022) [54], CSE (2020) [45], and Ndiaye et al. (2016) [44] confirms the importance of GIS and remote sensing in supporting planning policies and flood risk reduction.

5. Conclusions

Analyses of land use, topography, and flow directions highlighted the organization of natural watersheds in the municipality of Sangalkam and their influence on hydrological dynamics. The territory is structured by drainage guided by topographic gradients, where high zones feed flows toward lower-altitude sectors and runoff convergence spaces. Rapid urbanization at the expense of agricultural land reduces infiltration, increases runoff, and reinforces flood risks in vulnerable zones, emphasizing the role of anthropogenic factors. GIS analysis shows that floods result from the interaction between natural constraints and land-use transformations, highlighting the need for integrated management combining spatial planning, urban growth control, and the preservation of natural hydrological functions.

Abbreviations

PROGEP	Stormwater Management and Climate Change Adaptation Project
ANAT	National Agency for Spatial Planning
DEM	Digital Elevation Model
FABDEM	Forest and Buildings Removed Digital Elevation Model
SRTM	Shuttle Radar Topography Mission

Author Contributions

Henri Noel Bienvenue Badji: Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing

El Hadji Mamadou Sonko: Conceptualization, Methodology, Software, Supervision, Writing – review & editing

Moctar Badji: Conceptualization, Methodology, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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