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Research Article

Flood Dynamics in the Outskirts of Greater Lome (Togo)

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Abstract

This study analyzes flood dynamics in the Greater Lome area based on remote sensing and hydrometeorological data analysis. Daily rainfall data from the Lome-Airport synoptic station (2016 and 2020) were collected from the National Meteorological Agency of Togo (ANAMET) during the rainy season (March to October). Daily water levels in the Zio River at Togblekope were collected from the General Directorate of Hydraulics (DGH) during the rainy season (March to October) for the years 2016 and 2020. The time series were subjected to homogeneity tests to identify any artificial breaks in the data collected using RHtests dlyPrcp software. Radar data were processed using SNAP software, while maps were processed in ArcGIS 10.5. During 2016, a peak of 1,608 ha, corresponding to the maximum flooded area, was reached on August 24. At the start of the season, 40.29% of the maximum flooded area was submerged. In 2016, the population was therefore faced with at least thirty consecutive days of rising water levels. Not all districts were affected equally by the floods in 2016. The districts of Abobo, Djagble, and Be-Est were the most severely affected. The intra-annual dynamics of 2020 are similar to those of 2016. During 2020, the peak of 930 ha corresponding to the maximum flooded area was reached on September 2. At the beginning of the season, on June 16, only 11% of the maximum flooded area was submerged. All cantons were unevenly affected by the floods in 2020. The cantons of Abobo, Akepe, Mission Tove, Davie, and Adetikope were the most affected by the phenomenon. The results show a 45% decrease in flooded areas between 2016 and 2020, with a peak of 1,608 hectares reached on August 24, 2016, compared to 930 hectares on September 2, 2020, reflecting earlier and more intense flooding in 2016.

Keywords

Floods, Remote Sensing, Hydrometeorology, Greater Lome

1. Introduction

The capital of Togo, the Autonomous District of Greater Lome (DAGL), geographically spans the prefectures of Golfe and Agoe-Nyive. It is an area that suffers from the adverse effects of flooding. Although rainfall is becoming increasingly heavy and persistent, some authors argue that it cannot be held solely responsible for the chronic nature of flooding [1]. For them, it is rather the urbanization of the city that should legitimately be targeted as the main factor, due to the uncontrolled concentration of spontaneous construction that blocks the passage of runoff water. Other authors take a more nuanced view, recognizing the value of rapid urbanization in terms of development and economic growth [2, 3].

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The Autonomous District of Greater Lome and its surroundings are marked by a significant urban dichotomy. Its urban fabric consists, on the one hand, of urbanized areas and, on the other hand, of areas consisting mainly of spontaneous or informal settlements located in the city's outlying neighborhoods or districts. Generally, cities in developing countries are characterized by urban sprawl that absorbs vast rural areas closer to or further away from old or recent urban centers [4-6]. As a result, the rapidly expanding outskirts of these southern cities are undergoing numerous changes [7]. Several studies have shown that anthropogenic causes are among the main causes of flooding in Lome [8, 9]. The anthropogenic cause is manifested by the failure to respect non aedificandi zones, construction in the major beds of certain watercourses such as the Zio River, the lack of sanitation facilities, and the failure to operationalize the interconnection of stormwater drainage systems [9, 10]. Thus, the need for shelter and failure to comply with the main guidelines of the master plans for development and urban planning (SDAU) have led Greater Lome to a situation of horizontal sprawl [5, 11].

Direct observation in the field has revealed that, generally speaking, the critical peripheral areas that are so often flooded are occupied by disadvantaged groups. These are the lowest points in the city, such as the lower Zio valley, where the topography is dominated by plains with average altitudes of less than 150 m [10]. This low altitude means that the rivers are not enclosed, allowing water to rise to the surface and overflow their banks during periods of high water, thus causing flooding. These high-risk areas are emblematic of the exposure and vulnerability of urban peripheries to flooding.

This situation is so worrying that we must ask ourselves what are the main factors behind the increased frequency of flooding in the Zio Valley today? This concern leads us to analyze the dynamics of flooding in the outskirts of Greater Lome based on remote sensing and the analysis of hydrometeorological data over a given period in order to make a projection of the situation in the face of climate change.

2. Materials and Methods

2.1. Materials

Daily rainfall data from the Lome Airport synoptic station were collected from the National Meteorological Agency of Togo (ANAMET) during the rainy season (March to October) for the years 2016 and 2020. Daily water levels in the Zio River at Togblekope were collected from the General Directorate of Hydraulics (DGH) during the rainy season (March to October) for the years 2016 and 2020. The quality of the daily data collected was checked using Rclimdex 1.0 software [12, 13]. After quality control, the time series were subjected to homogeneity tests to identify any artificial breaks in the data collected using RHtests dlyPrcp software. Since there are no breakpoints in the time series, adjustment is no longer necessary [14].

In addition to meteorological data, radar images with a planimetric resolution of 10 x 10m were acquired at the start of the rainy season over a period of nearly three (3) months, on dates corresponding to flood peaks (Table 1). However, just before the start of the rainy season, a few images were also acquired to serve as reference images. These are Sentinel 1 images downloaded from the Copernicus website (https://dataspace.copernicus.eu/data-collections/sentinel-data/sentinel-1) in order to characterize interannual changes in flooding and those observed during the period from 2016 to 2020. A total of 29 images were acquired between June 1 and September 30 for the selected years (2016 and 2020).

Table 1. Characteristics of downloaded images.

Satellite	Sentinel 1	
Product level	GRD	
Type	Radar C	
Swath width	250 Km	
Spectral band/Polarization	VV	
Spatial resolution	10 m	
Temporal resolution 6 to 12 days	June 2016	06/01/2016
		06/13/2016
		06/28/2016
	July 2016	07/07/2016
		07/19/2016
		07/31/2016
	August 2016	08/12/2016

Satellite	Sentinel 1	
	September 2016	08/24/2016
		09/17/2016
		09/29/2016
	June 2020	06/10/2020
		06/16/2020
		06/22/2020
		06/28/2020
	July 2020	07/04/2020
		07/10/2020
		07/16/2020
	August 2020	08/03/2020
		08/09/2020
		08/15/2020
		08/21/2020
		08/27/2020
	September 2020	09/08/2020
		09/14/2020
		09/20/2020
		09/26/2020

Radar data was processed using SNAP software, while maps were processed in ArcGIS 10.5.

2.2. Methods

After calibrating the processing tools, the images were filtered to remove shimmering using Lee's filter [15]. Geometric errors caused by shadows, an oblique sensor range, and shortening were corrected using an algorithm based on a DEM. The thresholding technique for extracting water [16] was used for classification. The filtered backscatter coefficient histogram shows one or more peaks of different amplitudes depending on the data. Low backscatter values correspond to water, and high values correspond to the non-water class. The threshold value is obtained by analyzing the histogram.

The thresholding technique has been widely used to distinguish flooded areas from non-flooded areas on radar images (Figure 1). This technique is valued for its relative simplicity and short processing times, which are compatible with the tight time constraints associated with crisis management [16]. In general, all pixels in the radar image with an intensity or spectral amplitude less than or equal to a given threshold value (0.045) are considered "non-flooded," while the other pixels in the image are considered "water." To identify a threshold value, the histogram of the filtered backscatter coefficient was analyzed. The histogram shows one or more peaks of different amplitudes depending on the data. Low backscatter values correspond to water, and high values correspond to the non-water class. The choice of a threshold value of 0.045 is based on the clearest distinction observed between the peaks corresponding to water surfaces and non-flooded surfaces in the backscatter coefficient histogram. Values greater than 0.045 are considered to be in one class, and those less than 0.045 are considered to be in another class. Thus, we have two classes: the water class and the non-water class.

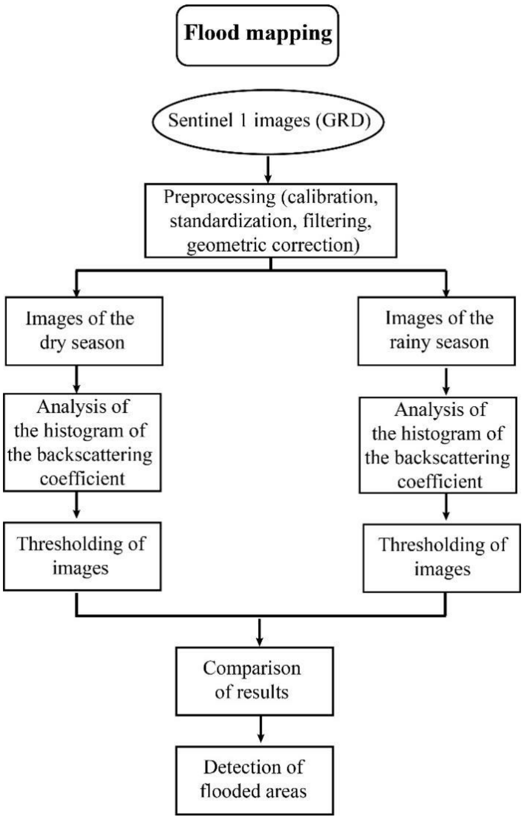

Figure 1. Schematic summary of the methodology.

3. Results

3.1. Flood Situation in Greater Lome in 2016

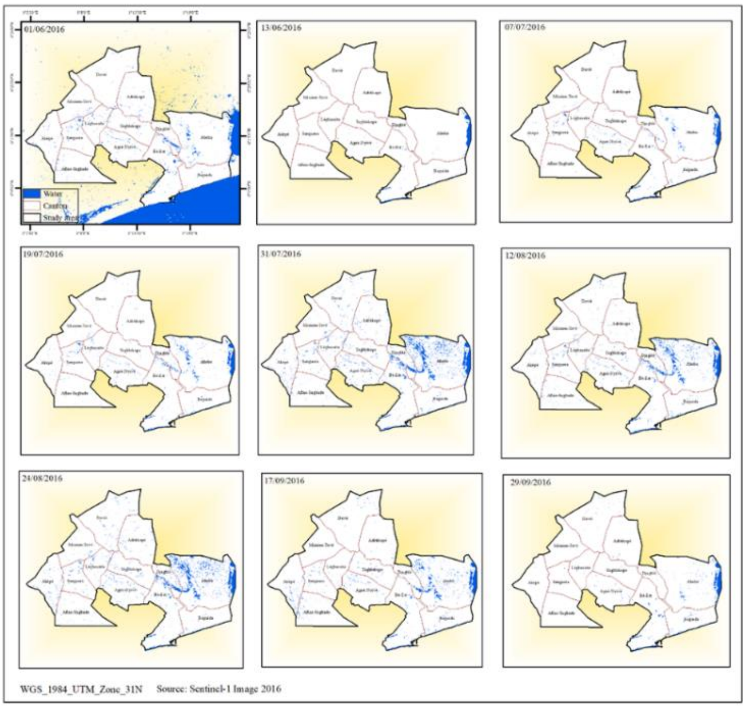

Figure 2. Monthly variation in flooded areas.

Table 2. *Date and flooded areas in 2016.*

Date		**Flooded area (ha)**
Month	**Day**	
June 2016	1er	680
	13	59
July 2016	07	361
	19	576
	31	366
August 2016	12	1127
	24	1608
September 2016	17	930
	29	317

Processing of Sentinel 1 images from 2016 covering the outskirts of Greater Lome reveals that major flooding began in June of that year and ended in late September (Figure 2).

During 2016, a peak of 1,608 ha corresponding to the maximum flooded area was reached on August 24 (Table 2). At the start of the season, 40.29% of the maximum flooded area was submerged. The minimum of 59 ha, or 3.67% of the maximum flooded area, was reached on June 13, 2016. The period from August 12 to September 17 was the high water period. About two weeks before the peak on August 24, 2016, more than 60% of the maximum flooded area was already under water. The same was true after the peak. In 2016, the population was therefore faced with at least thirty consecutive days of rising water levels.

All cantons were affected unevenly by the floods in 2016. The cantons of Abobo, Djagble, and Be-Est were the most severely affected (Figure 3).

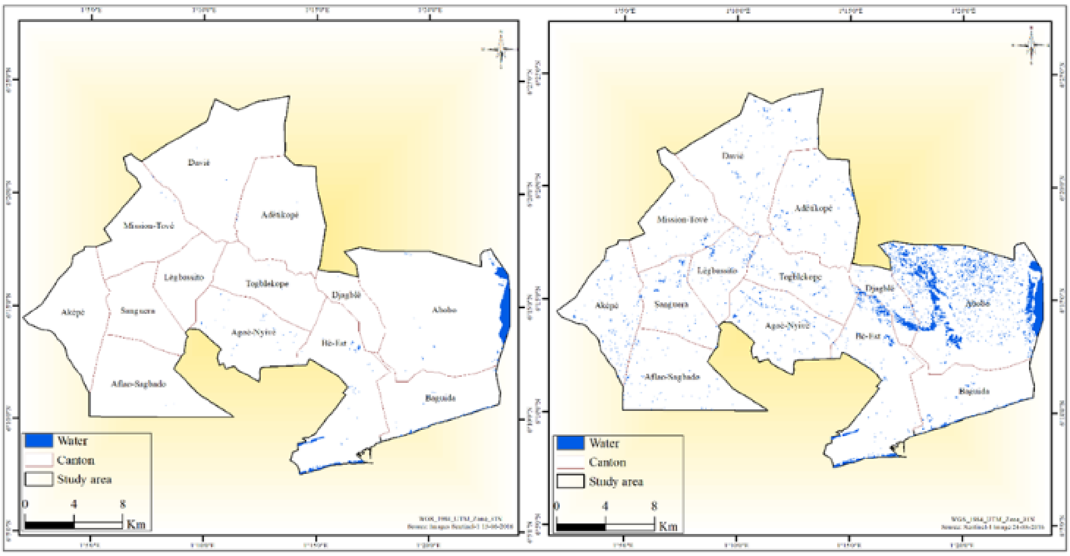

Figure 3. *Peak flooding in 2016.*

In most cases, the discontinuity is caused by roads and developments that have blocked the usual rainwater drainage lines in the city of Lome.

The images obtained for 2016 cover four months of observation (June 1 to September 29). Their small quantity (two images per month on average) hides certain information. The satellite observation of June 1, 2016, was preceded by a week of rain on May 23, 24, 29, and 30, with a cumulative rainfall of 40.50 mm, to which 12.2 mm was added on the day of the observation. However, on June 13, 2016, when the images show the second flood peak, no rain was recorded at all. This day was preceded by seven (07) days of rain out of the ten (10) days between it and June 1.

Analysis of daily rainfall, water levels at Togblekope, and flooding events in 2016 (Figure 4) shows that water levels at Togblekope remain very low during much of the main rainy season (March 4 to May 22). No flooding was recorded during this very rainy period. This phenomenon can be explained by the preparation for the arrival of water through the cleaning of drainage structures and, above all, by high infiltration, which allows the groundwater table to be recharged. Flooding is observed after the period of waterlogging and when water levels are very high in Togblekope. However, major flooding was observed after heavy rains when the water level in Togblekope was receding. The peak in flooded areas occurred exactly on the date when the water level in Togblekope was at its lowest.

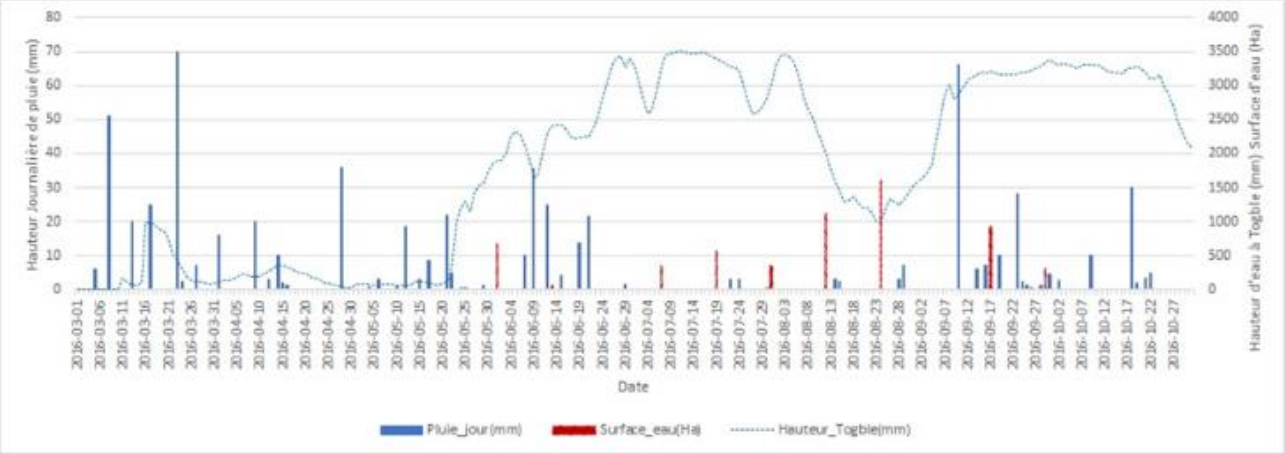

Figure 4. *Daily rainfall curves, water level at Togblekope, and flooded area in 2016.*

3.2. Flood Situation in Greater Lome in 2020

The intra-annual dynamics of 2020 are similar to those of 2016. The flooding period covers July to September (Figure 5). June marked the start of the flooding, with areas flooded from the beginning of the month (Table 3).

However, it should be noted that the flooded areas did not exceed 200 ha throughout June and July. The end of August until mid-September saw more flooding, with an average area of 610 ha flooded.

During 2020, the peak of 930 ha corresponding to the maximum flooded area was reached on September 2 (Table 3). At the beginning of the season, on June 16, only 11% of the maximum flooded area was submerged. The minimum of 14 ha, or 1.53% of the maximum flooded area, was reached near the end of the season on September 26, 2020. One month before the end of the 2020 season, more than 50% of the maximum flooded area was already under water. The peak occurred in the middle of the last month, subjecting the populations of the affected areas to a long period of rising water levels.

Table 3. *Flooded areas in Greater Lome in 2020.*

Date		**Flooded area (ha)**
Month	**Day**	
June 2020	16	101
	22	83
	28	90
July 2020	04	76
	10	166
	31	366
	16	182
	22	157
	28	185
August 2020	03	191
	09	296
	15	232
	21	408
	27	570

Date		Flooded area (ha)
Month	Day	
September 2020	02	930
	08	793
	14	918
	20	358
	26	54

***Figure 5**. Monthly variation in flooded areas in 2020.*

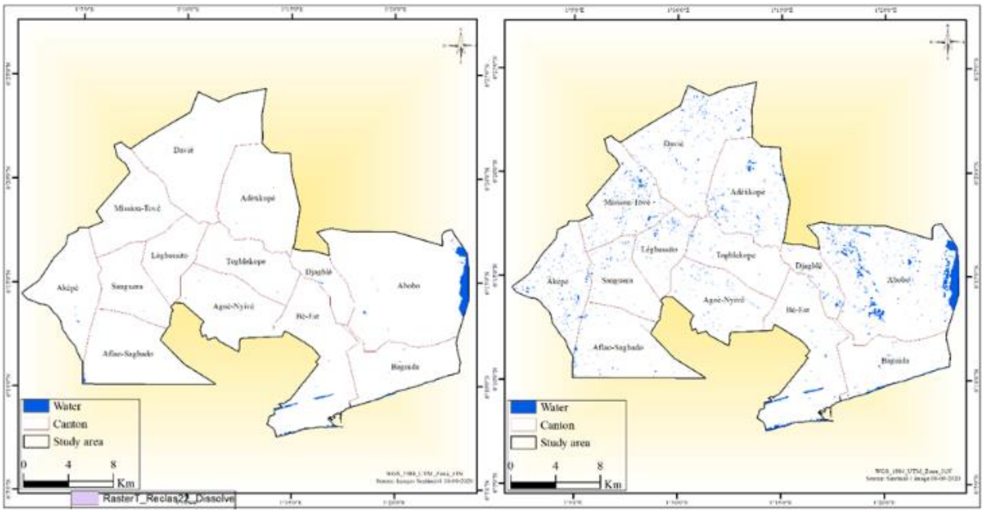

***Figure 6**. Flood peak in Greater Lome in 2020.*

All cantons were affected unevenly by the floods in 2020. The cantons of Abobo, Akepe, Mission Tove, Davie, and Adetikope were the most affected by the phenomenon (Figure 6). The images obtained for 2020 cover just under four observations (June 16 to September 26). Their quantity (four per month on average) shows that the first month of rain (June 16 to July 16) causes water levels to rise over approximately 10% of the maximum flooded area.

The water surface area doubles in the second month and quadruples in the third month, which ends with the peak. The fourth month is devoted to the withdrawal of water. Some populations experience flooding (Figure 7) for four months each year, others for three months, and still others for two months.

Figure 7. *Flooding in Lome (Be neighborhood and Boulevard Notre Dame des Apôtres) in 2020.*

Analysis of daily rainfall, water levels in Togblekope, and flooding events in 2020 (Figure 8) shows that water levels in Togblekope remain very low during much of the main rainy season (March 4 to May 22). No flooding was recorded during this very rainy period. This phenomenon can be explained by the preparation for the arrival of water through the cleaning of drainage structures and, above all, high infiltration, not to mention the recharge of the water table. Major flooding is observed after heavy rains when the water level in Togblekope is receding. The peak of flooded areas occurs exactly on the date when the water level in Togblekope is at its lowest.

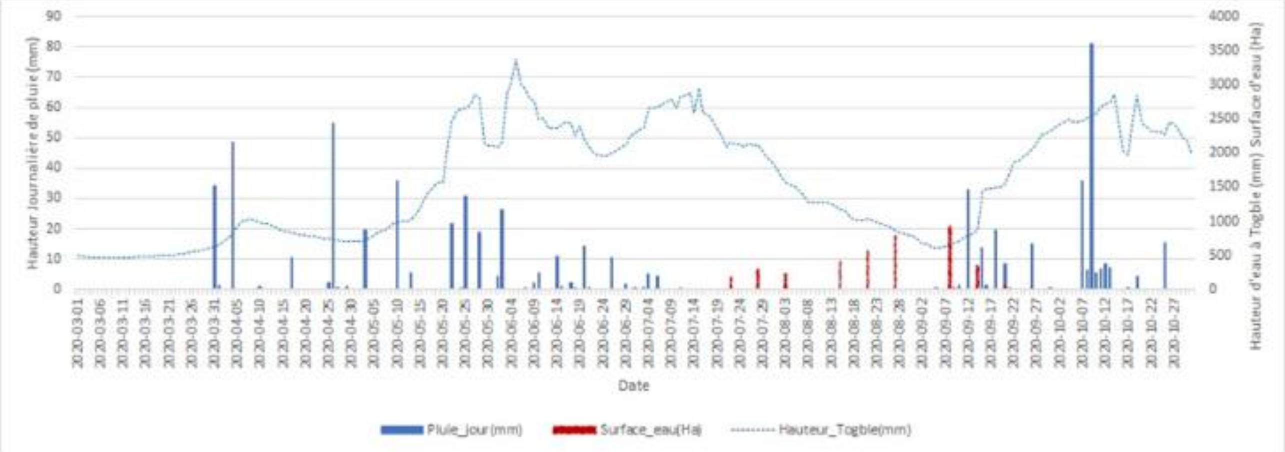

Figure 8. *Daily rainfall curves, water level at Togblekope, and flooded area in 2020.*

3.3. Comparative Study of Flooded Areas in 2016 and 2020

The cantons were affected to varying degrees by the floods of 2016 and 2020. Some cantons saw an increase in flooding, while the majority saw a decrease. Between 2016 and 2020, the cantons of Abobo, Agoe-Nyive, Baguida, and Be-Est saw a decrease in the initial water surface area before the rains began and in the maximum flooded area. The cantons of Aflao-Sagbado and

Akepe, on the other hand, recorded an increase in the initial water surface area as well as the maximum flooded area. Despite the decrease observed in the cantons of Davie, Adetikope, and Mission Tove in the initial water surface area, the maximum flooded area increased. In contrast, in the cantons of Djagble and Togblekope, the slight increases observed in the initial surface area increased significantly (Table 4).

Table 4. Surface area of initial water body and maximum water body.

Township	Initial water surface area (ha)			Maximum water surface area (ha)		
	2016	2020	Difference	2016	2020	Difference
Abobo	376,0353	361,3628	- 14,6725	1	720,1731	- 619,8861
Adetikope	1,0058	0,5086	- 0,4972	33,0139	86,7774	53,7635
Aflao-Sagbado	0,6847	11,4500	10,7653	19,4692	23,8125	4,3433
Agoe-Nyive	8,2183	1,3623	- 6,8561	49,6225	20,9105	- 28,7119
Akepe	-	2,2012	2,2012	35,8319	69,5352	33,7033
Baguida	33,1110	21,1775	- 11,9335	56,4635	44,6661	- 11,7973
Be-Est	104,7985	70,0637	- 34,7347	234,9472	116,9697	-117,9774
Davie	0,7049	0,5135	- 0,1914	35,9171	70,2483	34,3312
Djagble	0,3423	3,7212	3,3789	116,4755	21,7684	- 94,7071
Legbassito	-	-	-	34,9007	28,7515	- 6,1492
Mission-Tove	1,7839	0,3423	- 1,4415	14,6243	86,8418	72,2175
Togblekope	0,8559	1,0263	0,1704	28,8804	9,1656	-19,7148
Sanguera	-	-	-	39,7714	20,4606	-19,3107

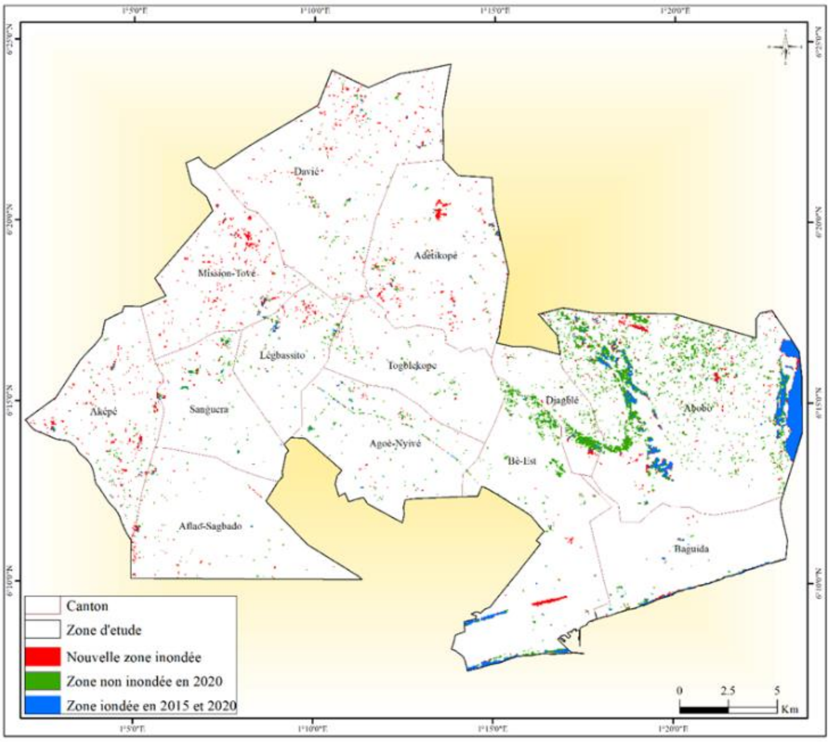

Figure 9. Flood dynamics in Greater Lome between 2016 and 2020.

The area of flooded land decreased from 1,608 ha in 2016 to 930 ha in 2020, a reduction of 45%. More specifically, during July and August 2020, the areas affected were very small compared to 2016. The peak occurred at the end of August in 2016, while the peak in 2020 occurred in early September. This dynamic can be explained by comparing these data with rainfall data for 2016 and 2020. Rainfall was heavier and earlier in 2016 than in 2020. The difference is remarkable in terms of the spatial distribution of flooded areas. There are new areas that were not affected by flooding in 2016 but were significantly affected in 2020. In particular, new cantons such as Akepe, Mission Tove, Davie, Adetikope, and Legbassito have been severely affected (Figure 9). This trend could be explained by the uncontrolled urbanization of the outskirts of Greater Lome.

The severity of the 2016 floods compared to those of 2020 can be explained, on the one hand, by the fact that the water level at Togblekope in 2016 was significantly higher than in 2020 (June 14 to October 31). It can also be explained by the total rainfall between March 1 and October 31, which was 651.1 mm in 2016 compared to 640.7 mm in 2020 (Figure 10).

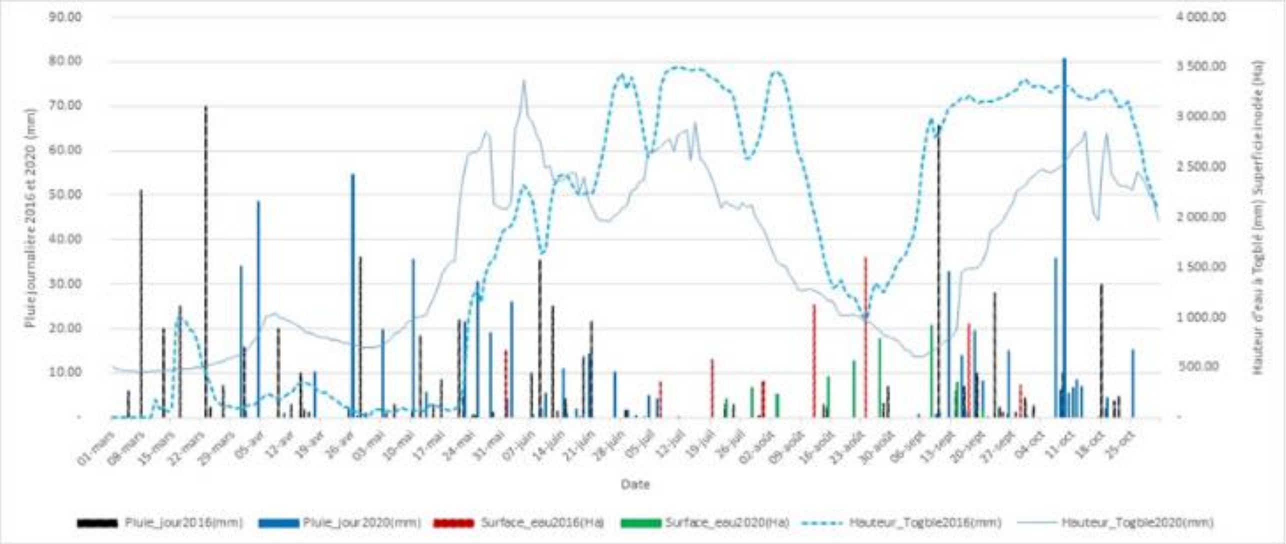

Figure 10. *Rainfall, water depth, and flooded area curves in Togblekope in 2016 and 2020.*

4. Discussion

The increase in the initial water surface area in the cantons of Akepe, Aflao-Sagbado, Djagble, and Togblekope is proof that, regardless of rainfall, flooded areas in Greater Lome are increasing in certain cantons (Table 4). The spread of built-up areas and infrastructure promotes flooding if drainage systems are absent or inadequate. The hydrological process is disrupted in urban contexts: changes in land use alter infiltration factors because permeable surfaces are reduced. Spatial configuration is indeed an important element of a city's identity [17].

Indeed, trees and other plantations, as well as wetlands (normally unoccupied), are considerable assets in reducing the risk of flooding. Vegetation has sometimes been irreparably destroyed, and soils have become very hardened or encrusted. This results in a very significant reduction in the water retention capacity of soils. These soils, which no longer absorb water, having lost their structure and nutrients in the process, may be the reason for the frequently observed failure to perceive improvements in rainfall.

Land use patterns are a key factor in the occurrence of floods [18].

The cantons of Abobo, Baguida, and Be-Est have seen a reduction in their initial water surface area, probably due to the construction of infrastructure for the 4th Lake Lome [19]. The case of the canton of Agoe-Nyive can be explained, on the one hand, by the infrastructure of the Lome bypass and, on the other hand, by the development of urban roads in this canton.

Cantons experiencing rapid population growth that have not benefited from the construction of sanitation infrastructure, such as Aflao-Sagbado and Akepe, are more exposed to flooding [19]. However, it is possible to improve the living environment of the population by implementing appropriate development projects [20]. The goal of a sustainable city is still possible in the long term for the Autonomous District of Greater Lome.

The findings of investigations into the functioning of certain water and sanitation infrastructure within the scope of the study show that rainwater overflow floods and partially cuts off traffic routes, causing certain localities such as Devego, Adamavo, and Kegue Zogbedji to become isolated during periods of heavy rain. The construction of the major bypass road has visibly divided the locality of Kegue Zogbedji into two areas, with the northern side permanently flooded compared to the southern area linked to the Attiegou district, where part of the area remains in the flood zone, as evidenced by the vegetation growing in the floodplains. The difficulty of draining runoff water is a major cause of flooding and its impacts in urban areas. For the Greater Lome urban community, some of these drainage structures do not drain water sufficiently, mainly because silting limits flow in the networks and outlets to the sea are blocked.

The occupation of non-buildable areas in the cantons of Akepe, Mission Tove, Davie, Adetikope, and Legbassito has placed them on the list of new areas at high risk of flooding. This trend, which led the canton of Akepe from being completely dry at the start of the 2015 rainy season to having more than 2 hectares of flooded land at the start of the 2020 season, has made it possible to predict that the cantons of Sanguera and Legbassito, which were dry until 2020, will see hectares of their land under water by 2025 [21].

Despite existing sanitation infrastructure (canals, gutters, retention basins, the Lome lagoon, pumping stations, etc.), flooding has been recurrent in recent years in certain areas of Greater Lome. The increase in flooding is largely linked to the poor functioning of gutters in areas with high building density [22]. It should also be noted that the settlement of populations in flood-prone areas contributes to the increase in flooding in certain areas of Greater Lome that have been declared unbuildable.

The causes of flooding highlighted in this article coincide with those identified by several authors. They are both natural and human in origin [23]. The natural causes are related to the topography of the sites and rainfall. According to [24], flooding is the result of sudden or successive rainfall in low-lying areas, on hydromorphic soils, and in areas with little elevation. This observation is consistent with the causes of excessive rainfall and geographical location cited by the populations to explain the occurrence of flooding in this study. As in [10, 25], excessive rainfall reflects climate change. Human causes are related, on the one hand, to ever-increasing population growth and massive urbanization, which amplify the vulnerability of several African cities to flooding [26]. On the other hand, they highlight the inadequacy of rainwater drainage infrastructure and the behavior of the population. In Lome, [10, 27] identify the following anthropogenic causes of flooding: failure to respect no-build zones, occupation by populations of the floodplains of certain rivers such as the Zio River, and a lack of sanitation and rainwater drainage facilities. [25] reaches similar conclusions when discussing causes such as unregulated land use, uncontrolled urbanization, and the construction of homes in flood zones. In addition to these anthropogenic causes, the practice of dumping waste into waterways during the rainy season [28-30] as well as in the streets and gutters contributes to increasing the phenomenon of flooding [31, 32].

5. Conclusion

The study, combined with satellite images and meteorological data from 2016 and 2020, shows that the city of Lome was affected by several periods of high relative humidity between 2007 and 2020. Satellite images from 2016 and 2020 also showed the appearance of flooded areas during these months, mainly in the eastern part of Greater Lome, which is located in the lower Zio valley. The consequences are enormous. It appears that the populations living in the lower valley seem to be more exposed to the risk of flooding, as do the northern and western parts of the city.

Abbreviations

ANAMET	National Meteorological Agency of Togo
DAGL	Autonomous District of Greater Lome
DEM	Digital Elevation Model
DGH	General Directorate of Hydraulics
GRD	Ground Range Detected
MERF	Ministry of Environment and Forest Resources
SDAU	Main Guidelines of the Master Plans for Development and Urban Planning
VV	Vertical Transmit / Vertical Receive

Author Contributions

Têtou-Houyo Blakime: Conceptualization, Data curation, Methodology, Writing – original draft

Ouro-Djobo Essoavana Samah: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft

Sarakawa Abalo Malibida Kpanzou: Conceptualization, Data curation, Methodology, Writing – original draft

Yaovi Edem Baite: Conceptualization, Data curation, Methodology, Writing – original draft

Botolisam Polorigni: Conceptualization, Data curation, Methodology, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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