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INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 13, Issue, 12, pp.19811-19816, December, 2021

DOI: https://doi.org/10.24941/ijcr.42668.12.2021

ISSN: 0975-833X

RESEARCH ARTICLE

EVALUATION OF THE FACTORS CONTRIBUTING TO THE FLOODING OF THE CITY OF N'DJAMENA, CASE OF THE 7TH DISTRICT: GIS AND REMOTE SENSING APPROACH

*MAHAMAT NOUR Abdallah, DJONMBE Hounsala, SIDDIG Ahmed Abbas Adam and LOUKMAN Bichara

Université de N'Djamena, Département de Géologie - Laboratoired'Hydro-Géosciences & Réservoirs, N'Djamena, Tchad

ARTICLE INFO

Article History:
Received 05th September, 2021
Received in revised form
19th October, 2021
Accepted 30th November, 2021
Published online 29th December, 2021

Keywords:
N'Djamena,
Flooding,
GIS, Remote Sensing.

**Corresponding author:*
MAHAMAT NOUR Abdallah

ABSTRACT

The management of flooding in the city of N'Djamena in general and that of the 7thdistrict, using GIS software and remote sensing, requires a multi-criteria analysis based on four main factors which are rainfall (rainwater), soil permeability (pedology), relief (topography), slope and land use. The study carried out on these factors shows that flooding in the 7th arrondissement is exclusively of a pluvial nature with an annual rainfall total reaching 200 to 300 mm. The topography factor is unevenly distributed and therefore the altitudes oscillate from 295 to 304 m with an average of 294 m. The slope is weak and is in the order of 0.10 to 2.02% with an average of 1.6% and is oriented towards the north-west instead of the south of the commune to flow into the Chari River. The results observed according to the altitudes of the 7th arrondissement reveal that the bank of the Chari River is higher than the interior of the commune. The other determining factor that causes flooding in the commune is land use with a high level of urbanization that has increased from 13% (926.45 ha) to 77.5% (5471.61) in 2020, i.e., an increase of 64.5%. The exponential growth of the population and the anarchic urbanization leads to the occupation of lowlands and water runoff paths. The pedological factor is to be pointed out because the commune is built on a soil constituted of hydromorphic soils (clay-sandstone and black clay), which have a low permeability that does not favor the infiltration of water towards the water table and generates flooding.

Citation: MAHAMAT NOUR Abdallah, DJONMBE Hounsala, SIDDIG Ahmed Abbas Adam and LOUKMAN Bichara, "Evaluation of the factors contributing to the flooding of the city of N'Djamena, case of the 7th district: GIS and remote sensing approach", *2021. International Journal of Current Research, 13, (12), 19811-19816.*

INTRODUCTION

The world is experiencing the vagaries of climate change in recent decades resulting in natural disasters such as global warming, drought, famine, floods(Brooks & Adger, 2003, McMichael *et al.*, 2006, Banholzer *et al.*, 2014). The UN report from 1995-2005 and 2005-2015 indicates that between 1994 and 2004, natural disasters affected more than 2.5 billion people and caused the death of478,100 people and estimated economic losses of $690 billion. Floods represent the most devastating disaster risk in the world(Pelling *et al.*, 2004). Cities and homes in African countries are the most affected by this phenomenon(Douglas *et al.*, 2008). Located in the Sahelian zone, Chad is one of the countries most confronted with the phenomena of climate disruption that manifest themselves in a catastrophic manner thus constituting a serious threat to humans and their property across several regions of the national territory (Keucheyan, 2017). According to the OCHA report of September 10, 2020, the month of August 2020 caused numerous floods throughout most of the national territory: in the center, south, east, Lake, and the capital N'Djamena. Chadian government statistics indicate that the floods have affected nearly 190,000 people. N'Djamena, the capital of the Republic of Chad, remains the most vulnerable area to flooding. In the space of thirty years, it has experienced several floods (Ramadane, 2015). The most notable are those of 1988, 1998, 2012 and 2020 when more than half of the population was affected. Located to the east of the city of N'Djamena, the 7th arrondissement has been exposed in recent years to the risk of rainwater flooding due to the lack of adequate drainage systems and the high level of uncontrolled urbanization, which obstructs the natural water drainage channels and occupies areas vulnerable to flooding.

For a good management of flood risks in a context of climate change and galloping urbanization in the commune, a better knowledge of flood risk factors is essential. Remote sensing and GIS are particularly powerful tools for studying the risks of natural disasters at the scale of a large site or a region (Meyer, 2001). For a better management of flood risks in a context of climate change and galloping urbanization in the 7th district, a better knowledge of the factor's causing flooding is essential. It is in this sense that the present study entitled "Contribution of GIS and remote sensing to the study of flooding in the city of N'Djamena: case of the 7th district is being conducted ».

Natural setting of the area

Location of the study area: N'Djamena is in west-central Chad, centered at 12°06'36 north latitude and 15°02'34 east longitude (Figure 1). It is the largest and most important city in Chad with a population of over one million. The study area is restricted to the 7th Arrondissement commune. The 7th Arrondissement commune of the city of N'Djamena is located between 15°04'55.34" and 15°11'4.37" east longitude and 12°01'17.11" and 12°07'56.64" north latitude. The commune of the 7th Arrondissement has 12 districts namely: Dembé, Chagoua, Habbena, Atrone, Amtoukoui, Ambata, Boutalbagara, Gasssi, Mandjafa, Kliwiti, Kourmanadji and Digo. It is one of the largest communes of the city of N'Djaména with an area of 7064 hectares and populated by about 357079 inhabitants according to the projection of INSEED (2009). However, the management of this Commune is made complex by the rapid growth of the population.

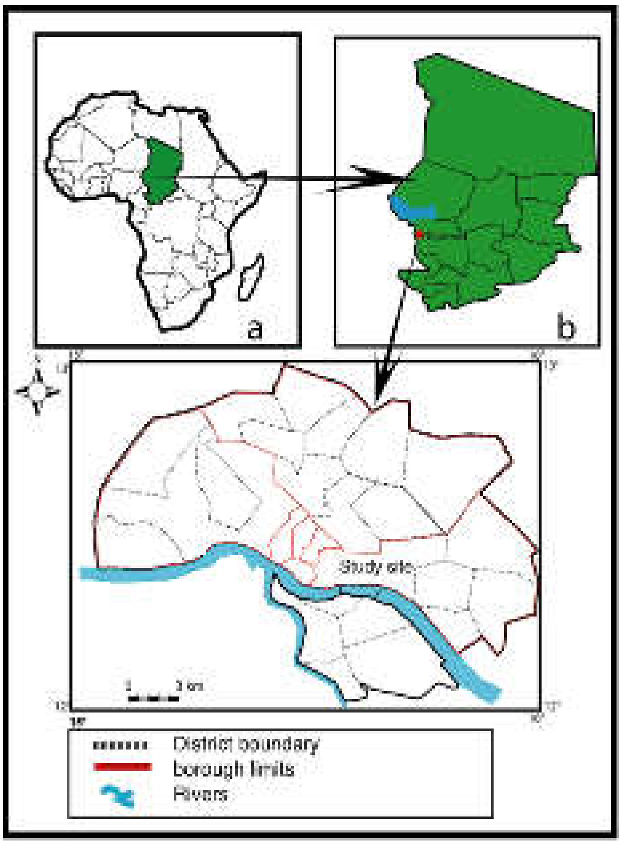

Figure 1. Geographical location of the city of N'D jaména

Geomorphology and geology: The relief of the city of N'Djamena is overall slightly flat. Its highest elevation is 300 m and its lowest is 288 m (Figure 2).

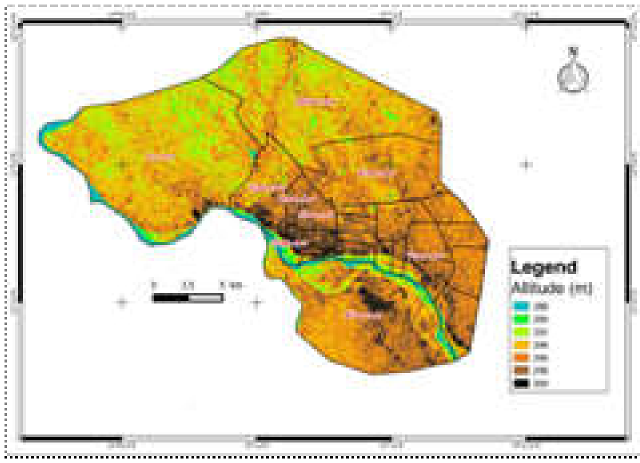

Figure 2. Topographic map of the city of N'Djamena from the DTM (SRTM)

It consists of a series of flood plains and flooded areas from the recent quaternary period, extending on either side of the Chari River. There are low-lying areas or small depressions everywhere that accumulate rainwater during the winter and early dry seasons.

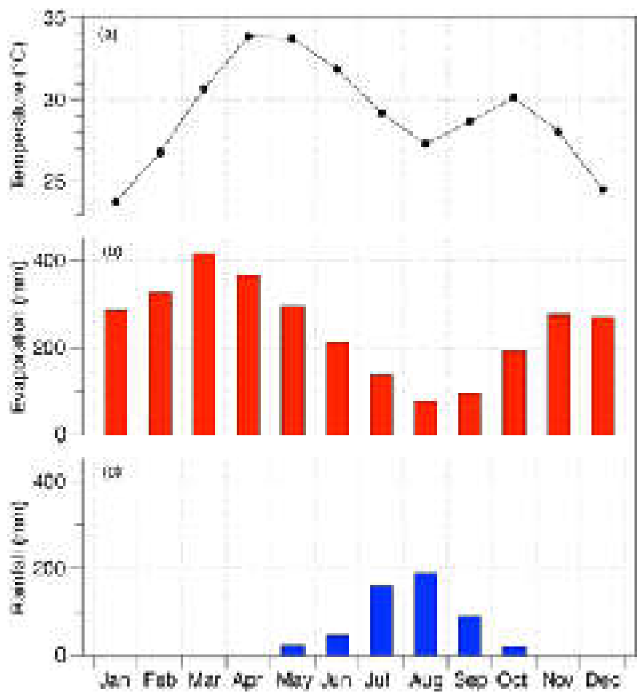

Figure 3. Description of the meteorological parameters (Temperature, evaporation (piche) and precipitation) from 1990-2018 (ANAM)

The geology of the Chari Baguirmi in general and that of the city of N'Djamena is linked to that of the Lake Chad Basin (BRGM, 1988; Kushnir, 1993; Djoret, 2000, Kadjangaba, 2007). The Chari Baguirmi region is underlain by the Quaternary alluvium of the ancient Lake Chad; this alluvium is superimposed on the Precambrian crystalline soil. Its stratigraphy distinguished sedimentary deposits of fluvial, lacustrine or eolian origin during the Quaternary formation (Pias, 1970). Two major categories of soils can be distinguished in the city of N'Djamena, distributed over two major landscape units. They are distinguished by their structure, texture, chemical composition, and relative topographic position (Pias, 1970).

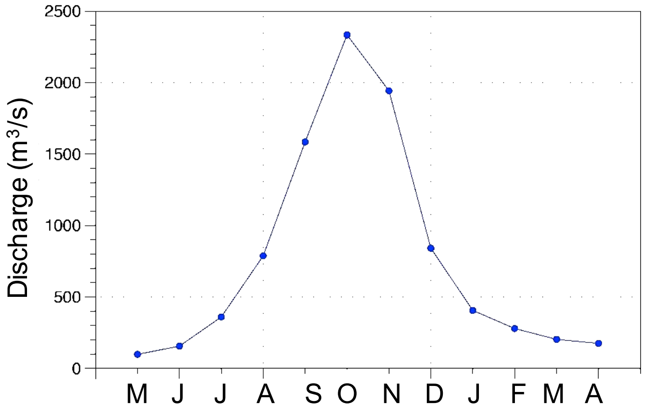

Figure 4. Evolution of the flows of the Chari-Logone over time

Soils in emerged areas: These soils have a good physical structure and are well drained. They are hydromorphic soils-vertisols and hydro morphic-halomorphic soils. Soils in flood zones. These are essentially hydromorphic soils of permanent or temporary very clayey to clayey-sandy.

Climatic framework: The climate in the city of N'Djamena is Sahelian(Mahamat Nour *et al.*, 2019). Average monthly temperatures range from 24°C to 34°C (Figure 3). The variation curve shows two maxima (April and October) and two minima, one in the rainy season during the wettest month (August) and the other in winter (January). The maximum value of evaporation (Piche) is in the dry season, the minimum in the rainy season. The variations of evaporation follow those of the temperature and go in the opposite direction of the rainfall (3). The maximum monthly evaporation is reached in March with 410mm and the minimum value appears in August with 67mm. Analysis of the interannual average monthly rainfall histogram for the city of N'Djamena for the period from 1990 to 2018 shows two seasons, one of which is dry and the other wet. The rainy season begins in May and ends in October (Figure 3). Annual rainfall values show significant irregularities over time with an interannual average of 578mm.

Hydrology: The hydrographic network is dominated primarily by the two rivers: the Chari and Logone. The Chari River flows entirely into the country south of the city of N'Djamena, while the Logone separates it from Cameroon(Mahamat Nour, 2019). The city includes a few temporary streams and flood-prone depressions. Over a period, these streams dry up given the high evaporation and short rainy season. It has been observed that each year the Chari River undergoes a slight rise in water level from September to November (Figure 4). This situation causes flooding and displacement of the population.
Within the first lane of the bypass, all surface water converges towards the Chari River and constitutes an outlet via the drainage networks. During periods of high water, the overflows of the Chari feed the gutters and reservoirs and some depressions via their connections.

Ponds and marigots: They are everywhere in the flood basins of the city of N'Djamena and are either maintained by men or are natural. During the first rains, they collect water from the gullies. At the end of the rainy season, they retain their water for a time before it evaporates. Amongthem, there are mainly (Figure 5):

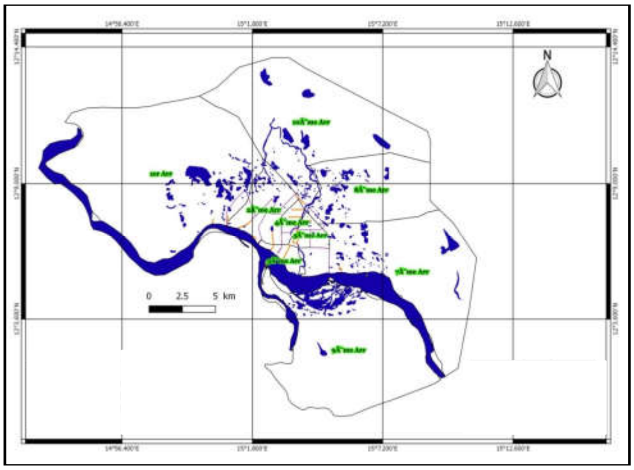

Figure 5. Map showing the Chari-Logone and the ponds of the city of N'Djamena

- **The Jardiniers marigot:** 2.5 km long, it crosses the watershed bearing the same name. A former side arm of the Chari, it is located between the Ardepdjoumal and Paris-Congo neighborhoods. It collects and drains rainwater into the Chari. It was a natural shallow swamp towards which all the water from the outlying districts converged. Its course was recalibrated between 1978 and 1988 as part of the city's rainwater drainage program.
- **The Amriguebé marigot:** this 2 km long marigot has its source in the city center and is the main drain of the watershed bearing the same name. In the 1970s and 1980s, it was a shallow natural swamp towards which all the water from the outlying districts converged. Its course was also recalibrated between 1978 and 1988 to become a large open channel.
- **The Saint Martin basin:** this was an ancient natural watercourse, a tributary of the Chari. It divided the old town (Fort Lamy) into two parts in a north-south direction. A sanitation study was carried out in 1959 to create a basin upstream that would act as a collector of runoff water. The first works took place in 1960, thus giving birth to the Saint Martin canal (MADJ-NDEUDE, 2009).
- The others are small retention basins and small ponds in the different districts of the city.

Data and methodological approach: The approach adopted to achieve the expected results includes several steps including the collection of meteorological, documentary, satellite, and direct field observations. This approach also uses remote sensing and GIS mapping tools.

Hydro-climatic data: The climatic data (temperature, rainfall, and evaporation) used are those of the city of N'Djamena from 1990 and 2018. They were acquired from the Agence National de la Météorologie (ANAM) of Chad. The flow of the Chari River was obtained from the Direction de Ressourceen Eau (DRE). These data cover the period from 1990 to 2016 and come from the Chagoua measuring station.

Satellite data: The availability since 1972 of Landsat data, the oldest Earth observation program, makes it an exceptional documentary source. Indeed, Landsat data provides a global coverage of the Earth since 1972 thanks to the MSS (Multi Spectral Scanner, 1972-1992), TM (Thematic Mapper, since 1982 and still operational in 2006 with Landsat 5), and ETM+

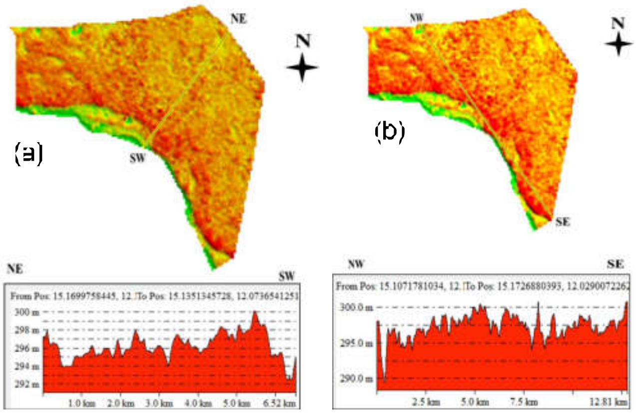

Figure 6. Digital terrain model. (a) topographic profile (NE-SW) and (b) topographic profile (NW-SE)

(Enhanced Thematic Mapper, since 1999 and operational in 2000 thanks to Landsat 7) sensors. The analysis of Landsat archive images allows the extraction of essential information concerning the extension of the study area and the sites affected by flooding in order to establish the thematic maps. Landsat imagery also gives the possibility to track. Finally, the Landsat data allows to follow the global evolution of the land use, especially the state of the natural vegetation and the urban dynamics. The exploited satellite database includes Landsat 7-ETM+ images, acquired on November 17, 1999 and Landsat 8 OLI/TIRS acquired on October 01, 2000. In addition to the landsat data, our research required the acquisition of radar data including an SRTM image from 2009.

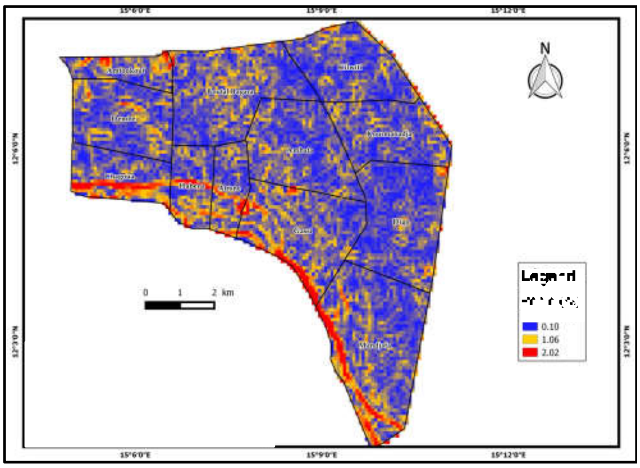

Figure 7. Terrain Slope Map from SRTM

Methodological approach: The goal of our research is to build a GIS on flooding in the 7th arrondissement, with the aim of assisting in early warning and decision making. The GIS should provide information on the extent of flooding, its causes, but also on the urban areas that are vulnerable to flooding. The combination of GIS information layers provides indications of the degree of vulnerability of a given urban area. The GIS layers also include land use maps, slope maps, soil and flood maps, digital terrain models, hydrological and socio-economic data, etc. The different processing applied to satellite data include image georeferencing, spatial enhancement, photointerpretation, principal component analysis and multispectral classification for information extraction. The methodology for processing radar data to produce maps of geomorphology, slope and drainage networks includes four steps: 1) image dezipage; 2) geo-positioning and radar images over the study area; 3) image processing and slicing in QGIS, GrassGIS, Global Mapper and Surfer software and 4) image interpretation and information extraction.

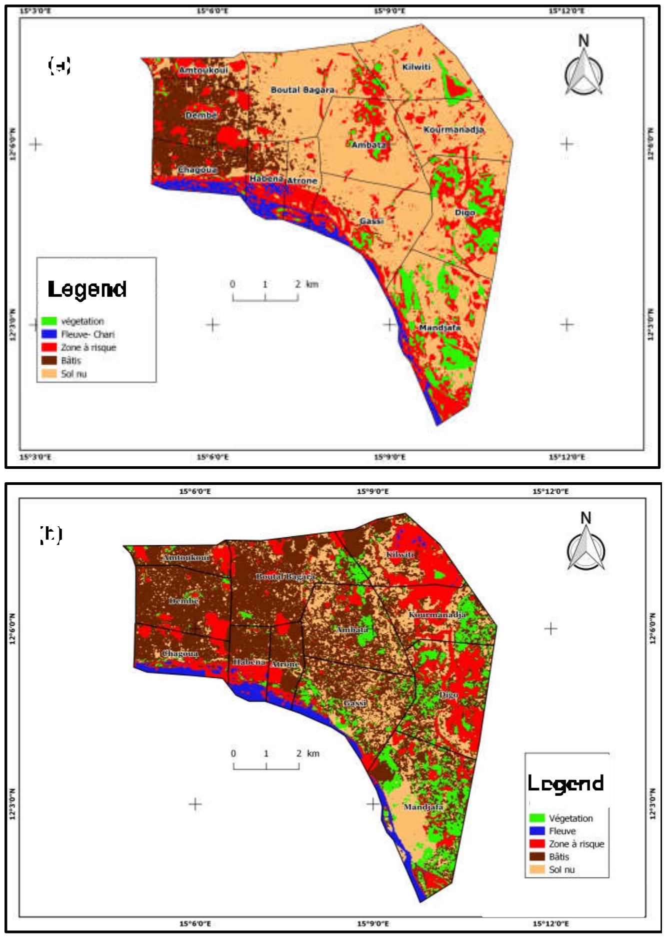

Figure 8. Land use dynamics between 1999 and 2020. (a) 1999 land use map and (b) 2020 land use map

RESULTS

Digital Terrain Model: The analysis and interpretation of the SRTM radar image series allowed the mapping of the digital terrain model (Figure 6), the slope of the area and the water drainage network. These different surfaces can be distinguished on the radar images according to their texture (fine, medium, or coarse), geometry, radiometry and orientation.

Slope: The slope determines the speed at which the runoff water reaches the outlet of the basin. This variable influences the maximum flow rate. A steep slope favors and accelerates surface runoff, while a gentle (low) or no slope could favor water infiltration (Cerdà & García-Fayos, 1997).

Most of the area of the commune has a very low slope of 0.1% (in blue); the average slope in yellow with a value of 1% is found mainly in the Boutal-Bagara, Amtoukoui and eastern edge of the district, specifically in the Chagoua, Habena, Atrone, Gassi and Mandjafa districts (Figure 7). The only areas with slopes greater than 1% (colored in red) are on the banks of the Chari River and in some neighborhoods of the commune, namely the Amtoukoui, Gassi, Chagoua, Habena, and Atrone neighborhoods.

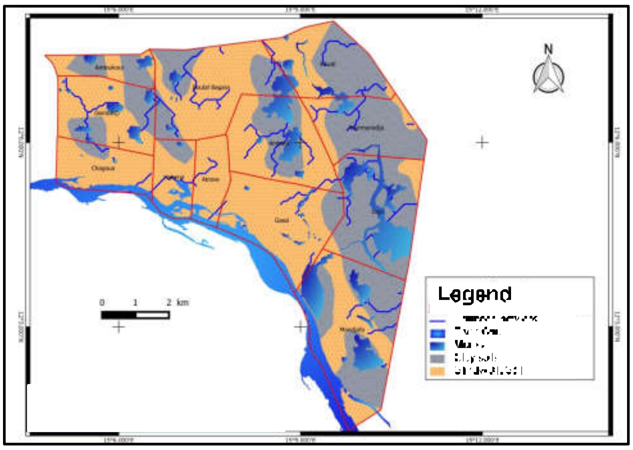

Figure 9. Map of areas at risk of flooding in the 7th district of the city of N'Djamena

Land use and dynamics: The processing and analysis of the landsat imagery allowed the most relevant landscape features to be identified and land use maps to be drawn up. Among the water surfaces, some are not related to flooding (river overflow water due to high flooding and stagnant rainwater). The cross-referencing of the two land use maps from the October 1999 image and the October 2020 image allowed us to carry out an analysis of the land use dynamics and to restore the surfaces flooded in 1999 and 2020 through the extraction of the different land use classes (Figure 8). The map obtained reveals, among other things, that the extent of the flood disaster was much greater in 2020 than in 1999. Furthermore, it shows the areas that are affected during each crisis, and consequently those that are most vulnerable.

Photo 1. Rain flood of September 03, 2020 in the commune of the 7th district (some pictures) Credits photos djonmbé

DISCUSSION

Impact of land use on flooding: The land use maps produced in this study were derived from Landsat imagery. These maps showed the urban growth in the study area during the period from 1999 to 2020. The dynamics of land use showed a very significant urbanization in the space of 21 years. From 1999 to 2020, the urbanized area increased from 926 ha to 5472 ha, i.e. a multiplication by more than 5 in 21 years. This high urbanization would be responsible for the high runoff in the commune, urbanization makes soils impervious and reduces water infiltration(Taylor *et al.*, 2004, Ertan & Çelik, 2021).

The population of the 7th arrondissement commune is 222574 out of 944059 inhabitants in the cities of N'Djamena, a rate of 23% (INSEED, 2009). According to the report of the Agency for Technical Cooperation and Development (ACTED, 2020), the commune is home to more than 500,000 inhabitants, an increase of 27746 inhabitants in 11 years. The galloping urbanization and the development of socio-economic activities have led the municipality to expand in flood-prone areas. The studies of Ramadan (2015) and Mbayam(2012) carried out on the city of N'Djamena confirm that the risk of flooding in the city of N'Djamena is aggravated by the expansion of poorly planned urbanized areas. Poverty and the housing policy which also attracts more and more people to the swampy lowlands

Impact of geomorphology: According to the results of the physical characteristics, the commune of the 7th arrondissement has a rugged topographic surface distributed with altitudes varying between 285 and 304 m and a slope that oscillates between 0.1 and 2%. This topographic inequality of the commune does not allow for natural runoff of the Chari River, which has a bank located at high altitudes. Mbayam (2012), states that the city of N'Djamena is not at a high elevation in relation to the level of the Chari, which is what makes the flow of water very difficult. The results of many authors and researchers who have worked on the city of N'Djamena and who assert that the flooding of the city is caused by the flatness of the terrain. Beller (1990), in his results, shows that the city of N'Djamena is located on a very flat alluvial plain, and that the city's watershed has a regular slope towards the north and not towards the Chari River in the south. The work of Dobingar (2001) confirms Beller's result that the low altitude and the absence of a significant slope towards the natural outlets justify this catastrophe. Unlike the results of the works of Mbayam (2012), Dobingar(2001) and Beller(1990), our result shows that the geomorphology of the commune of the 7th arrondissement is hilly and not flat. However, the parts of low altitudes are ponds. The vulnerability of the population to flooding is linked to the very close location of the dwellings to the pools and to the quality of the buildings.

Impact of soil type: The soil of the city of N'Djamena is generally composed of halomorphic soils with a clay-loam dominance. These soils differ from one another by a slightly dissimilar water regime and are all of the sandy-clay type. In contact with water, the clay swells, becomes immediately impermeable and weakens the foundations of the buildings by making them vulnerable to flooding and collapse. Soil science plays an active role in increasing stormwater runoff through some of its characteristics such as permeability. Pias (1968) defined the permeability of the soils by specifying that the clayey soils of lowlands with semi-permanent flooding have a low permeability in wet soil (1,5 to 4 cm/h) to very low (lower than 1,5 cm/h). We can conclude from our interpretation that the black clay soil areas are very vulnerable to flooding because of their very low permeability. Impermeable soils or soils with very low permeability play a very important role in urban hydrology. They increase surface runoff, reduce infiltration and groundwater recharge, and decrease the time of concentration and thus cause flooding.

Risk of flooding from rivers: The Chari River constitutes the main hydrographic network in the district. It is the only permanent watercourse. In addition, there are ponds that reinforce the hydrography of the commune (Figure 9).

Water runoff poses a threat to the residents of the ponds during the rainy season, especially those who have built in the *non-aedificandi zones* (lowlands). They are indeed the most exposed to the risk of flooding. The map in Figure 9 shows that rainwater flows from south to north according to the slope of the land. The Chari River, located to the south of the commune, does not constitute a natural outlet for its runoff. There is also a discontinuity in the outlets of the watercourses. These outlets are mostly located in ponds. The runoff paths of these waters and the outlets are increasingly occupied by buildings, and this is what obstructs the passage of rainwater to flow properly. Rainwater drainage channels are almost non-existent or if they exist, they are undersized and do not promote a good drainage system of runoff water and this is what also causes street flooding (Photo 1).

CONCLUSION

The commune of the 7th district covers an area of approximately 7064 ha. Its altitude varies from 284 to 304 m with an average of 294 m and its average slope is 1.6%. The analysis of land use shows a strong increase in urbanized area compared to other classes of land use, its area has increased from 13% in 1999 to 77% in 2020, a difference of 64%. This change is due to the demographic growth caused by the increasing rate of rural exodus, which has led the population to satisfy its housing needs by occupying even the areas at risk. The waterproofing of the soils of the hydromorphic type in our study area causes urban runoff and this is what increases the risk of flooding. It should be noted that the areas at risk are those located in the depressions. In particular, the districts of Amtoukoui, Boutalbagara, part of Ngassi, Habena, Digo and Ambatta. Most of these neighborhoods do not have rainwater drainage networks. The 7th district is not exposed to river flooding because it is protected by the bank of the Chari River which is at a high altitude.

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