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Environmental Factors, Constraints and Risks of Rainwater Runoff in Commune II of Maradi (Republic of Niger)

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Abstract

The Urban Commune of Maradi in Niger experienced increasingly frequent flooding following rainy episodes generating volumes and water flows that are difficult to control in recent years. This study aims to determine the impacts of runoff water in Commune II of Maradi City and to assess the role of urban planning in runoff management, as well as the strengths and weaknesses of urban sanitation in Maradi. The methodological approach used consisted of: 1) an interpretation of documentary data, 2) gathering information on runoff at several sites in the study area, and 3) interviews and questionnaires with local communities. This approach made it possible to understand the degree of vulnerability of the populations to flooding and then to propose sustainable solutions to reduce the vulnerability of the affected populations, through the implementation of effective urban rainwater management practices (USWMP). The results show that the impacts of runoff are mainly related to the lack of adequate storm water drainage networks in the area, but also to the nature of the habitats. Geomorphological factors such as the nature of the soil, the slope of the terrain and the altitude increase the degree of risk. In addition, the inadequacy and dilapidation of the drainage systems of the canals and above all the anarchic occupation of the land linked to accelerated urbanization are the cause of flooding by stagnation of rainwater.

A phenomenon now linked to numerous deteriorations of urban equipment, the runoff of rainwater in the city of Maradi carries so many pollutants that municipalities, businesses and individuals should put in place pollution prevention measures.

Keywords

Niger, Storm Water, Impermeable Spaces, Urban Runoff, Flood, Vulnerability

1. Introduction

The rainy season is a formidable period for the population of Maradi city. Flooding due to rain often sows desolation [1] [2]. At the origin of many devastating effects such as the flooding of ponds, the runoff of the rains affects all the districts and all the social strata of the urban community of Maradi [3]. In fact, after a heavy rain, the streets of the city fill with water for at least one to two days, blocking access to various accommodations and useful services [4] [5] [6]. Thus, the city of Maradi holds the record for disaster victims in Niger, with 2536 houses collapsed (*i.e.* 19,076 people affected) in 2022 [7], to which are added 54,744 victims and 14 deaths in 2021 [8] against 14,481 households (*i.e.* 153,035 people) in 2020 [9]. These rainfall floods, which specialists attribute to changes in hydrological behavior [10] and the siltation of rivers and watersheds [11] [12], are the cause of crop losses each year, but also of many equipment such as drip systems, for many fields and flooded gardens [1]. Among the worrying situations that complicate the management of the risk of flooding in Maradi, let us note that the flooding of the Goulbi, which is a semi-permanent watercourse, originating from Nigeria, invades dwellings [9].

As in several cities in sub-Saharan Africa, the vulnerability of the city of Maradi to flooding stems from natural, socio-economic and political determinants [13] [14] [15] [16] [17]. The effects of the impoverishment of the population, associated to the total absence of rainwater drainage infrastructure, particularly in the outlying districts (Zaria 1, Zaria 2 and North Ali Dan Sofo), contribute to water stagnation [3] [4] [5] [6]. Thus, the accelerated development of the city, which includes empty plots and built habitats often in risky areas such as lowlands, exposes the stormwater drainage network to various processes of degradation of the abiotic and biotic components of the environment [3] [18]. The objective of this work is to highlight the impact of runoff in Commune II of the Maradi city and to determine the role of urban planning in runoff management. More specifically, it involves: 1) providing, through observation and investigation, elements characterizing the factors and constraints acting on rainfall runoff; 2) framing the major impacts of runoff and 3) analyzing the effectiveness of urban development on the flow of rainwater.

2. Materials and Methods

2.1. Location of the Study Area

The Commune II represents the second communal arrondissement of the city of Maradi, which has three (Maradi 1, Maradi 2 and Maradi 3; **Figure 1**). Included between 7.07731˚ and 7.12847˚ East latitudes, Commune II extends from west to east along a median area centered around 13.49997˚ North latitude. It is limited to the north by the Commune of Maradi 1, to the south by the Commune of Maradi 3, to the east by the rural commune of Djirataoua and to the west by the Commune of SarkinYamma [5]. The Commune II comprises three districts, namely: the Zaria 2 district in the east, the Sabon Gari and Makoyo districts in the center and Bagalam in the far west (**Figure 1**).

In a simplified way, three geographical zones are distinguished in Maradi city [5]: 1) a plateau system with an average altitude of 355 m; 2) dune sands strongly subjected to water and wind erosion which are cultivable land in the rainy season and 3) lowlands located along the Goulbi, in the western part of the city (**Figure 2**), with alluvial clay-silty deposits rich in organic matter. With a difference in height varying from 386 m to 343 m from East to West and from 372 m to 343 m from South to North, the core of the city of Maradi is still split in two parts by the line of the belt of ponds (**Figure 2**).

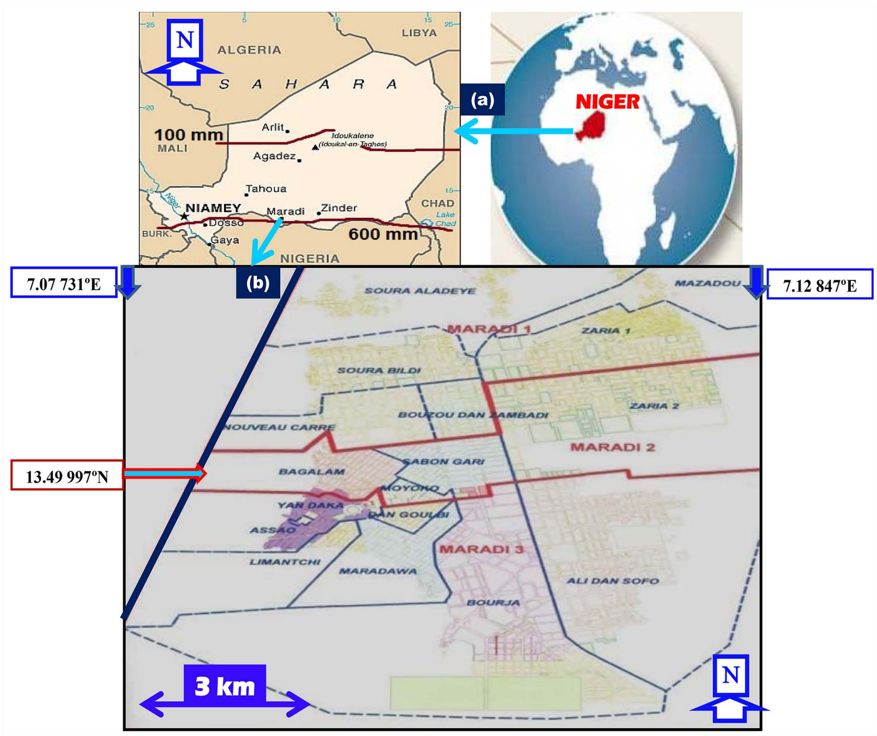

Figure 1. Maps showing (a) the location of Maradi city in Niger and isohyets 600 - 100 mm, and (b) administrative organization of Maradi city (after [3]). The mosaic of red rectangles along latitude 13.49997˚N constitutes the framing of the study area (Maradi 2 namely Commune II with its four districts: Zaria 2, Sabon Gari, Makoyo and Bagalam). Coordinates are in decimal degrees.

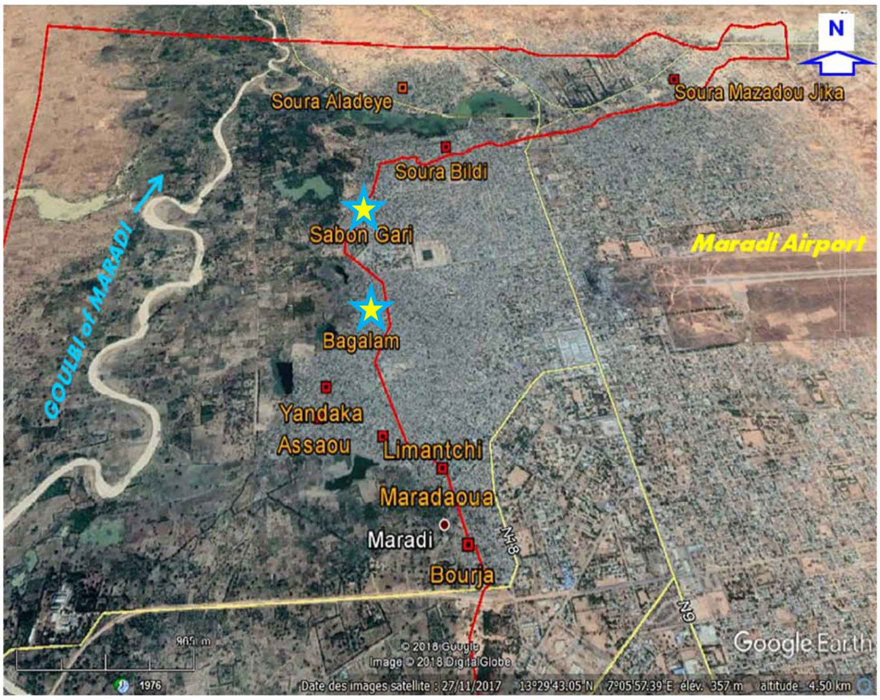

Figure 2. Belt (red frame) of ponds and limit of areas at altitude below 355 m (after [5]). Note that Sabon Gari and Bagalam, to the east of Goulbi and to the west of Maradi airport, are the two districts of Commune II. The yellow lines (N9, N18) represent the main access streets to Maradi city.

The climate is of the Sudano-Sahelian type characterized by relatively good rainfall. It is characterized by 1) a rainy season which runs from mid-May to October; 2) a dry and cold season from November to February and 3) a dry and hot season between March and May. Annual rainfall amounts vary between 400 - 600 mm [6]. The Goulbi is the main river of the city (**Figure 2**). The city is also crossed by koris (wadis), particularly at the level of Communes I and II (**Figure 1**). These koris constitute sources of silting up of the Goulbi. The vegetation is largely made up of gardens located mostly around the Goulbi basin and in the various reforestation sites. The Urban Commune of Maradi is experiencing a rapid increase in its population with a growth rate of 4.3%. The population is estimated at 326,804 inhabitants [19]. The city is a cosmopolitan agglomeration where pedestrian automobile traffic is lively, especially on big routes. The vitality of multifaceted exchanges with Nigeria and the existence of major economic operators gives the city the name of the economic capital [3] [6].

2.2. Study Data and Methods

The study uses two types of data [20]. These are primary data from the field survey and secondary data, namely: 1) rainfall data for the city of Maradi, 2) data on the situation of floods caused by runoff in the city of Maradi and 3) data on the situation of the gutters of Commune II, as well as various diachronic referents of the city of Maradi.

2.2.1. Primary Data from the Field Survey

Direct observations in the field were carried out normally at the time of the survey and during rainy periods. The equipment used in this study consists of field equipment (mobile phone to take the photos) and computer tools (USB key used as support and a computer for storage). They make it possible to understand and frame the reactions of populations, in particular their resilient capacity and definitional approach to the correlative link between urban runoff and the vulnerability of structures. After having traveled through the three municipal districts of the city of Maradi, taken illustrative photographs and appreciated the distinctive characteristics of certain districts, we have chosen Municipality II. Also, the field survey has confirmed that a large mass of the population of the city of Maradi is installed in the districts located in the lowlands, in particular the districts which are very close to the belt of the ponds (**Figure 2**). These low points, defined as the places where the altitudes are lower than 355 m [5], constitute the places of convergence of runoff waters, and where the risk of flooding becomes increasingly important. In particular, neighborhoods like Bagalam and Sabon Gari, which are two neighborhoods of Commune II (**Figure 1**), can be considered as the receptacle area and the nadir point of the water surface in the Maradi city (**Figure 2**).

The questionnaire surveys were carried out using a form developed and sent to the population of the commune 2 of Maradi. It should be noted that this form is identical for all the people surveyed, in addition that all these people are surveyed individually. The individual survey sheet contains questions relating to the environmental impacts of runoff water in relation to urban development in the Commune II of Maradi. It also contains questions on stagnation of water, the typology of the soil of the municipality, the advantages and/or disadvantages of stagnation water as well as the damage caused by this water. In order to gather all the necessary and contextual data for the study, fifty-two (52) people were interviewed. The respondents are distributed as follows: 1) 12 people from the Zaria 2 district; 2) seven (7) people from the Sabon Gari district; 3) 13 people from the Mokoyo neighborhood and 4) 20 people from the Bagalam neighborhood.

The interview should make it possible to make a comparison between the results of the survey by questionnaire and those drawn from observation on the one hand and those accompanied by the questionnaire on the other hand, and therefore highlight the concordance or discrepancy between the actual results and theoretical results. Thus, a number of officials from the central town hall, in particular those of the sanitation department and, specifically, the head of the town's hygiene service of the city, had answered the same questions as those administered to the people interviewed in the various districts.

2.2.2. Processing and Analysis of Secondary Data

Rainfall data for the city of Maradi were obtained from the regional meteorological directorate. Data on the situation of floods caused by runoff in the city of Maradi were found at the service of Rural Engineering of Maradi. The data on the situation of the gutters of the commune II of the city were obtained from the central town hall of the city of Maradi. On the other hand, the diachronic referents of the Maradi city were completed by means of a documentary search on the Internet. The secondary data collected were entered, coded, processed and analysed using Excel software.

3. Results

3.1. Major Factors and Constraints Acting on Runoff

The factors and constraints affecting runoff are numerous and varied. These include: rainfall intensity, soil moisture, rising water tables, clogged gutters and land use.

3.1.1. Annual Variation in Rainfall Intensity

Figure 3 represents the variation in annual rainfall totals observed between 1983 and 2019 at the Maradi airport station (Figure 2). The wettest year in this chronicle is 2018 with 668.4 mm. The year with the most deficit is 1987 with 270 mm. The average over the whole series is estimated at 500.26 mm with a standard deviation of 103.47 mm. The three-year moving average curve (in orange) highlights three major wet periods (1984-1990, 1990-2009 and 2009-2020) of changes in rainfall trends over the 36 years of observation. It can be seen clearly general (see straight line in red) a positive rainfall trend since 1983.

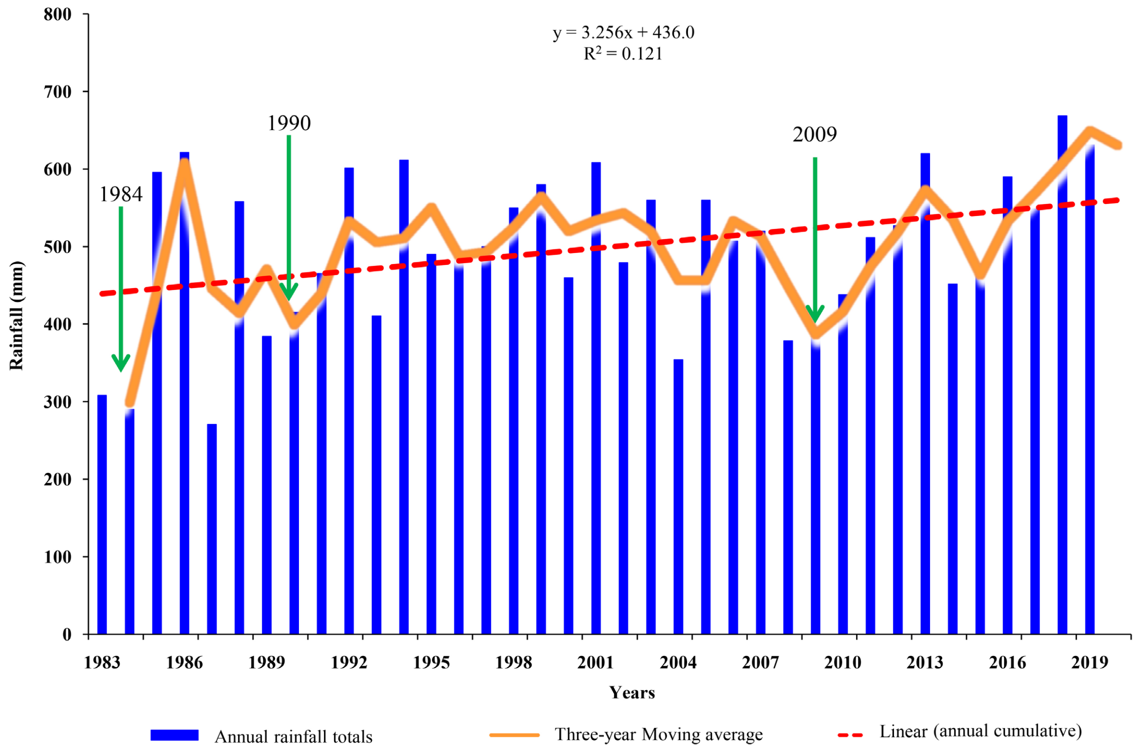

Figure 3. Annual precipitation at Maradi airport station from 1983-2019. The orange polish curve and the linear red line represent the curve of three-year moving averages and the average annual water supply, respectively. The years 1984, 1990 and 2009 represent the beginning and/or the ending of the three major wet periods mentioned above.

Figure 4 illustrates the evolution of the intensity rate of annual rainfall from 2000 to 2020. It appears that some years have low rainfall accumulations with a large number of rainy days, while other years record high annual accumulations with a reduced number of rainy days. However, most years of this rainfall series (dotted red line, Figure 4) show a real positive evolution in the intensity of rainfall in the city of Maradi.

3.1.2. Impermeability of Surfaces and Receiving Environments

Table 1 shows the main areas of impermeability and their proportion (%) within the municipality II. These areas are essentially made up of four (4) types of developed roads, namely: 1) paved (1.92%); 2) tar (25%); 3) pavement and tar (48.08%) and 4) pavement, tar and laterites (25%). Field observations show that this impermeability is associated with other factors, such as soil humidity, the slope of the land and the vegetation cover, which increase the volume of water runoff and land cover change. However, this increase in flow volumes would lead to the overflow and spreading of surface water. The insufficiency and lack of water collection and drainage networks in some places in the municipality could partly explain the floods observed in recent years in the Maradi city.

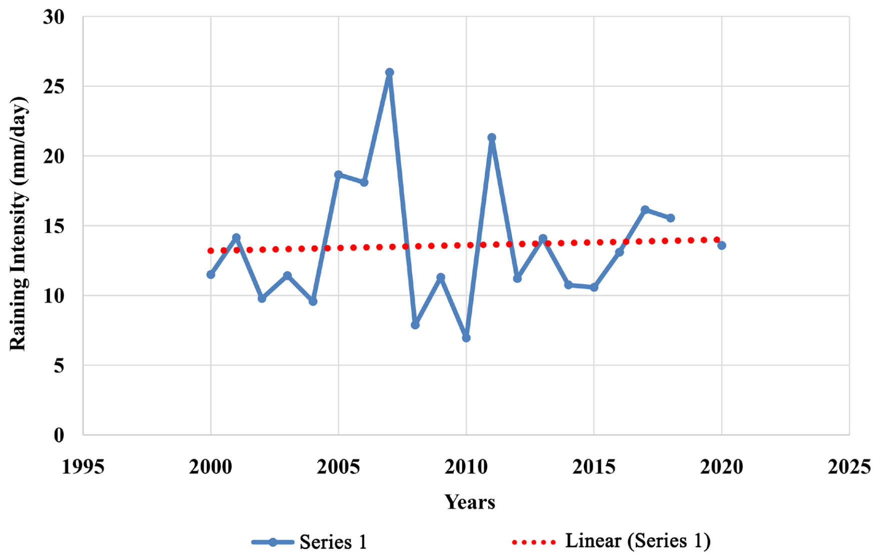

Figure 4. Interannual evolution (series in blue) of rainfall intensity (annual cumulative rainfall/number of rainy days per year) in the city of Maradi (2000-2020). The line in red is the linear regression line of the series in blue.

Table 1. Proportion (%) of the main areas of impermeability within the Commune II.

Types of developed roads	Proportions
Pavement	1.92%
Tar	25%
Pavement & Tar	48.08%
Pavement & Tar & Laterites	25%

3.1.3. Drainage Channels: State of Sewers and Gutters

The results of the survey show that 83% of respondents say that the rainwater drainage channels are cleaned and collected each year, before the rainy season. The reality on the ground shows that rainwater drainage channels in the study area are almost non-existent in some neighborhoods. However, in the neighborhoods where they exist, these channels are either very old or clogged (**Figure 5**). In the first (**Figure 5(a)**), as in the second case (**Figure 5(b)**), the water is no longer evacuated properly. This increases the risk of water spreading and flooding in these areas. Similarly, the lack of cleaning of these sewers and certain usual practices of the local population increase this risk. These practices, which are customary among the local population, include: the disposal of household waste, the evacuation of waste water and the connections with private latrines (**Figure 5(a)**). Despite the increase in gutters in the neighborhoods upstream of the city of Maradi (e.g. Ali Dan Sofo (ADS) district; **Figure 1**), it must be recognized that these gutters also silt up following water runoff during the rainy season (**Figure 6**).

As a result, since the rainwater drainage networks are inadequate and do not meet gutter sizing standards, and moreover, the new gutters to the east of the ADS neighbourhood have given rise to a new risk: gullying (**Figure 6**). Thus, regardless of the cleaning frequency, the runoff carries the solid waste and leads it to the open gutters. However, as the wintering period progresses, the rainwater drainage structures become more saturated with sand and the soils develop to the stage where everything that falls settles and vegetation takes hold (**Figure 7**). The various litter and this floral biodiversity prevent the supply of the various waters collected in the alleys and increase the risks of overflowing of the gutters.

3.2. Diagnostic Elements of the Runoff Impacts

The impacts caused by runoff water are classified into two categories, namely: 1) impacts on the environment and 2) impacts on the population.

Figure 5. Status of rainwater harvesting facilities in the municipality II, according to the reality of the ground. (a) Old gutter connected to private latrines. (b) Old gutter considered as a receptacle for all types of waste.

Figure 6. Runoff, erosion and gully (A) around the new gutters of Ali Dan Sofo (Commune III of Maradi). Insert (B) highlights the processes of rainwater gullying along roadways and upstream of structures. Source: fieldwork 2022.

Figure 7. New gutter in the Ali Dan Sofo District subject to silting and the establishment of diverse flora and vegetation during the rainy season. Source: field August 2023.

3.2.1. Environmental Impacts

Urban runoff causes flooding. These floods, which are sometimes significant, are the immediate consequence (**Figure 8**) of roads that are submerged and/or clogged with rainwater (60% of respondents) and the collapse of habitats (73.07% of respondents). **Figure 9** shows that road degradation and soil erosion expose crumbling headlands to land clearing, frequent landslides and settlements, as well as damaged roads and canals.

Figure 8. Views of a flooded road (a) and a collapsing habitat (b).

Figure 9. Views of a damaged canal (a) and a degraded road (b).

Table 2 summarizes the rate of mention of the various reasons and causes of collapses (Figure 8(b)) in Commune II. For 78.83% of respondents, these collapses are due to the intensity of the rain (rainwater runoff) and the lack of adequate planning. Among the other types of causes of collapses, the investigation shows two causal factors, namely: the typology of the soil and the nature of the construction materials (cement or mud). Thus, 69.23% of respondents confirm that the constructions are made of mud or mudbank (Table 2), just as field observations have shown that the collapsed houses are made of mud (Figure 8(b)). Similarly, clay soils are dominant in the study site with 50% as a percentage, then sandy soils with 48.08% and finally sandy-clayey soils with 1.92% (Table 2). Clay is not permeable, it is a type of soil that stores water. This stored water makes the clay sensitive and therefore exposed to the risk of movement. Clay swells on contact with water and disperses easily. And, it is this dispersion that makes the clay fragile.

Table 2. Most sensitive parameters and their quote rate.

Main causes		Quote rate
Rain Intensity		40.38%
Inadequate planning		5.76%
Rainfall intensity and Inadequate planning		32.69%
No Collapses		21.17%
Other factors	**Soil and Habitat Characteristics**	
Type of Soil	Sandy	48.08%
	Clayey	50%
	Sand-Clayey	1.92%
Nature of Construction materials	Cement	28.84%
	Bank	69.23%
	Other	1.93%

3.2.2. Impacts on People and Property

With an exploitable area of 2775.5 ha spread over approximately 12 km, the Goulbi valley has significant potential for irrigable land for the municipalities of Maradi (Figure 2). However, during the second decade of July and the first of August, it is normal that the heavy rainfall recorded in the sub-region caused the overflow of the Goulbi. Rainfed crops, which represent 80% of the total usable area in rainy season, were thus carried over damaged by such an overflow of the Goulbi. In fact, the Goulbi valley is not only used for the practice of rainfed crops, but market gardeners have opted for the intensification of both irrigated crops and arboriculture. According to the Rural Engineering of the city of Maradi, since the repetitive floods of 2018, market gardeners have encountered enormous difficulties, in particular the total loss of agricultural inputs and the lack or defect of irrigation means. Thus, 100 market garden wells, 150 agricultural boreholes and 100 motor pump units were damaged. On the other hand, it is losses of various infrastructures which are observed within the Commune II of Maradi. The Regional Directorate of Rural Engineering (DRGR) recorded the following results: an area of 480 ha flooded in Commune II, while 42 houses in this area collapsed (Figure 8(b)). During these floods, *circa* 1412 people were affected.

3.3. Diagnostic Elements of the Rainwater Development and Management System

According to 81% of those surveyed, works in line with a much more effective strategy for channeling rainwater into groundwater to avoid overflows or stagnations of water points in streets exist. On the other hand, some 19% of respondents declare that they were not aware of the existence of these same works in the Commune II. The interviews, coupled with the reality on the ground, make it possible to affirm that Commune II of the city of Maradi has only two (2) major collectors (collectors no. 5 and no. 6) for the evacuation of rainwater. Collector no. 5 has a total length of 7640 linear meters and collector no. 6 has a length of 1420 linear meters. According to the Hygiene and Sanitation Service of the city of Maradi, collector no. 5 has a capacity of containing 5348 m^3 of sludge, while collector no. 6 can only contain circa 1136 m^3.

From field work (**Figure 5**), it appears that runoff water carries all kinds of domestic waste and sand that it encounters on its way and brings it into the drainage channels. These domestic wastes and other materials fill the gutters and block the flow of water. Once blocked, all these waters will run down the streets in search of an outlet. Although this issue may seem of little importance to decision-makers, it is nevertheless what ensures the effectiveness of the rainwater drainage system in Commune II of the city of Maradi. Developments in urban areas have effects on stormwater runoff. Tarred roads and cobblestones do not let water infiltrate. This impermeability therefore allows runoff or stagnation in the event of rain. In addition to the fact that the flooding of the roads is linked to the total impermeability of these, the reality on the ground shows that these roads are not connected to a rainwater drainage network. This results in establishing a very difficult traffic system in the city (**Figure 10**).

4. Discussion

Despite the importance of climatic parameters (e.g., height, intensity and duration of rainfall), the results of direct observation and field survey show that physical conditions (e.g., morphology, topography and soil nature) predispose sites to the risk of flooding. The economic situation and a certain current behavior of the people amplify the risks and repercussions of all these parameters, in terms of material, human and environmental damage.

Figure 10. Illustration of a cases of difficult circulation ((a): of people and of cars; (b): heavy vehicle) after water stagnation following a rain event in the Municipality II.

4.1. Threats Linked to the Morpho-Topography and the Nature of the Soil

An East-West section in the topographic profile of the city of Maradi gives an elevation difference of 386 m to 343 m from East to West, while the section towards the North shows an elevation difference of 372 m to 343 m from South to North (**Figure 2**; [5]). With a slope average of 0.9% to −0.7% (East-West section) and 1.1% to −0.9% (South-North section), such a drop favors and increases the intensity of the runoff from conflicting occupation of space between water and other elements of land occupation (human habitat, vegetation, production space, etc.) [21]. As a result, the relief of the city of Maradi increases the vulnerability to the risk of flooding for the citizens of the lower districts of Bagalam and Maradawa. In addition, surface flows generated upstream and morpho-topographic factors, as for the city of Abéché in Chad [22], combine to inflate the many koris crossing the city who thus acquire a strong skill, a source of recurrent erosion of the banks and urban spaces. Thus, the east-west dip of the slope exposes the entire city of Maradi to the dynamics of rainwater which mobilizes and transports particles from the Zaria 1 and ADS districts (located upstream) [23] [24].

In connection with the dynamics of old and recent alluvium resulting from active erosive activities in the peripheral districts [23], the humidity of the soil in the Goulbi valley of Maradi, in terms of sub-outcrop of alluvial aquifers, becomes essential for a mass important part of the population of the city of Maradi who lives in the districts located in the lowlands and the belt of the ponds (**Figure 2**). Even if the Goulbi Maradi floods result from uncontrolled discharges of water from the Jibiya dam in Nigeria [5], this implies that the formation between 1 meter and 20 meters of an aquifer favors the stagnation of water during the rainy season. For Malam Abdou [25], this low water infiltration linked to humidity is also accentuated by the low permeability of the clay layers, the textures of the soils of the valley being sandy-clayey (hydromorphic). Thus, the low depth of the water table and the texture of the soil are also factors of vulnerability of the city flooded by the overflow of the silted Goulbi.

4.2. Effects of Economic Situation of Households and Human Activities on Physical Environment

The significance of economic situation of households must be addressed both in terms of its direct effect on the main cause of the collapse of houses and the resurgence of solid waste in Commune II as well as its effect as a form of vulnerability related to the nature of their housing attributable to the poverty of these households (**Figure 8(b)**). The questionnaire surveys show that 69.23% of constructions in the area are made of mud. The 40.38% of collapses observed are due to the intensity of the rain, and the 32.69% others are due to a combination of inadequate planning and rainfall intensity. These results are consistent with those found by Saadou [5], during an assessment of the impacts of flooding on the socio-economic life of the city of Maradi. This author affirmed that "the precarious dwellings generally built in banco are very vulnerable to heavy rains and runoff". Thus, following the floods of June 2018, civil protection services reported that 48 earthen houses collapsed during that year in the neighborhoods of Bagalam, Maradawa and Bourja [26].

Like Niamey, the capital of Niger [27], the results on the elements of the rainwater development and management system prove that one of the aggravating factors of the recurrence floods in Commune II is undoubtedly the absence of prior protective arrangements (**Figure 5**). Indeed, throughout the urban community of Maradi, the reality on the ground shows that when the rainwater drainage network exists, it only serves the most central or richest districts, such as Ali Dan Sofo [3]. In addition, the new infrastructure and certain rainwater drainage equipment in the Ali Dan Sofo district are characterized by their poor functioning due to non-compliance with basic town planning rules (**Figure 6**). Runoff water, collected upstream in the Zaria I and II districts, reaches under the effect of slope the lowlands with significant aggressiveness and harm not only the only two stormwater drainage channels in Zaria II, but also all the traffic lanes [24]. These results corroborate those of Ndongo *et al.* [13] on the city of Maroua in Cameroon who report that existing networks are generally very old and outdated or simply poorly defined.

And, due to a chronic lack of upkeep and maintenance, these drainage works are and remain in very poor condition. Consequently, this insufficient network is filled by various solid and liquid wastes of anthropogenic origin (**Figure 5**), and by the natural development of flora and plant species (**Figure 7**). A cleaning takes place every year before and after the rainy season, but the combined effect of the wind and the runoff ends up bringing back this waste. This health problem, due to political laxity and various anthropogenic actions, is related by the research results of Laminou Manzo *et al.* [4] and Saadou [5] like those of Saidou and Aminou [28], who pointed out that these networks are the preferred places for the discharge of domestic and industrial wastewater, garbage dumps and faecal sludge, and sometimes even defecation [6]. The same observation was made by Amadou Malam *et al.* [29] who point out that the inhabitants of the city of Zinder transform the gutters and the lowlands into false septic tanks, wild dumps and sewage outfalls. Floods are therefore linked to natural causes (flow of the river which can come out of its bed) and to direct anthropogenic causes. These anthropogenic causes correspond in particular to the impermeability of urban development (tar, cobblestones, laterites), and to the compaction of soils which accentuates runoff. This increase in runoff is the direct consequence of the degradation not only of urban infrastructure and soil, but of the resurgence of waste and the clogging of sandy deposits [3] [14] [30].

In Africa, a considerable number of cities are victims of floods [15] [16] [17] [31] [32] [33] [34]. For Ndongo *et al.* [13], in cities in the South, human activity (in general) and the choices favored by decision-makers (in particular) profoundly modify natural runoff. It is recognized that the problem of sanitation such as the insufficiency of rainwater drainage networks and the construction of habitats in floodplains increase the vulnerability of urban centers [5] [27]. This is why, in the poorer regions of the southern hemisphere, people's attitudes and behaviour are still largely responsible for amplifying flooding phenomena [35]. In an even poorer context like that of Niger, it would therefore be advisable to check and adapt the construction of more suitable sanitation structures. Thus, given the topography of the city of Maradi, closed gutters connected to mesh catch basins could ensure faster runoff of rainwater [36]. As part of an integrated urban approach to stormwater, locally adaptable and even more effective practical methods for better regulation of its runoff at the starting points (soil, koris, traffic lanes) must take precedence over improved sizing and maintenance of the few existing networks [37]. To this end, the use of solutions based on awareness-raising and training of the populations, as well as unblocking closed gutters, will contribute to ensuring compliance with the basic standards which consist of: avoiding construction in exposed areas to the passage of water and ensuring the cleanliness of urban facilities. Hantchi *et al.* [3] show that an extension program in participatory of urban sanitation management is the key to setting up the framework for a fairly effective stormwater drainage plan.

5. Conclusion

This work is motivated by the observation of the extent of the consequences generated by the runoff of rainwater in the city of Maradi, in particular in Commune II. The impacts of runoff are observed over the entire extent of Commune II. Society and the environment are affected with enormous material losses and a high number of disaster victims, in addition to environmental degradation. The agricultural lands of the Goulbi plateau, the roads and the houses are thus devastated by the runoff. Moreover, the results of the present study showed that the severity of the effects is linked to several factors. These are: the galloping and anarchic urbanization, the nature of the habitat, the intensity of rain and the lack of an adequate drainage system for runoff water. It also appears that even in new urban pipeline projects, the authorities responsible for risk prevention and urban actions take very little account of the natural east-west gradient of surface water flow in Maradi City. The determining factors that can be taken into account to better attenuate the aggressiveness of urban runoff and therefore the preservation of sites from flooding include: 1) the construction of a network of deeper, wider and unopened gutters for the evacuation of runoff water in the urban municipalities of the city, 2) the cleaning and collection of gutters each season, and 3) taking runoff water into account during urban developments such as the road connecting certain impermeable soils to a rainwater drainage network, and monitoring the ban on the settlement of the population in flood-prone areas, particularly during the rainy season. It is appropriate that the most effective vulnerability reduction measures should take into account the strengthening of the adaptive capacity of the Urban Municipality of Maradi in the face of floods and the participation of vulnerable populations in the decision-making of programs that fall within the flood management.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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