Urban expansion-flood damage nexus: Evidence from the Dosso Region, Niger

Land Use Policy 108 (2021) 105547

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Urban expansion-flood damage nexus: Evidence from the Dosso Region, Niger

Maurizio Tiepolo[a,*], Andrea Galligari[b]

[a] DIST-Politecnico and University of Turin, viale Mattioli 39, 10125 Turin, Italy
[b] DIST-Politecnico and University of Turin, Italy

ARTICLE INFO

Keywords:
Disaster risk reduction
Environmental justice
Flood damage
Land cover change
Settlement dynamics

ABSTRACT

The current literature links flood exposure and the consequent damage in the sub-Saharan Africa to urban expansion. The main implication of this pertains to the fact that cities are the target of flood risk reduction. However, our knowledge of the built-up area expansion–flood damage nexus is still too scarce to support any risk reduction policy at the local scale. The objective of this study is to reconsider the link between urban expansion and flood damage widening the observation to rural settlements with open access information alternative to global datasets on flood damages and moderate resolution satellite images. Using very high-resolution satellite images accessible via Google Earth Pro, the expansion of 122 flooded settlements in the Dosso region (Niger) during the past 20 years is evaluated. Spatial dynamics is then compared with the rate of collapsed houses due to flooding. Finally, house collapses and retrofitting are compared. We discovered that cities expand at faster rates and with an opposite trend to that reported by the global datasets. However, hamlets and villages expand even more rapidly and suffer more house collapses than rural towns and cities. House consolidation is quicker than the settlement expansion but this is not sufficient to reduce damage from pluvial flooding. The proportion of the Poor to the total number of inhabitants in rural settlements is three times higher than that in urban settlements. Environmental justice is, therefore, not just an urban issue but a rural urgency.

1. Introduction

Urbanisation of sub-Saharan Africa has had numerous positive effects on development, but it can also have negative implications (Cobbinah et al., 2015). From one viewpoint, urban expansion is largely uncontrolled (Adelekan et al., 2015; Fraser et al., 2017; Amaoko, 2018; Tazen et al., 2018). When it occurs in the form of urban sprawl, it drives inhabitants away from places where there are job opportunities (Nkeki, 2016; Fenta et al., 2017; Abass et al., 2018). Those who cannot afford to pay for transportation tend to stay close to work opportunities and they are burdened with the cost of living associated with hazardous areas. Consequently, constructions encroach onto river banks (Erena and Worku, 2018; Laji et al., 2017; Tiafack and Mbon, 2017). Areas with high slopes and floodplains are developed (Dube et al., 2018; Adelekan, 2010; Amoateng et al., 2018). Building on floodable areas also occur because people cannot afford to buy land in safer areas (Nchito, 2007; Sakijege et al., 2012; Musungu et al., 2016; Kabanda, 2020) or because they do not perceive the hazard (Oruonye, 2013; Nkwunonwo et al., 2016). Rapid spatial expansion accompanied by the destruction of vegetation generates new hazards which include landslides, and along with waste dumping in rainwater drainage channels, increase the occurrence of flash floods (Doodman et al., 2017, p. 8; Douglas, 2017).

Conversely, urbanisation of the sub-Saharan Africa without rural-oriented investments increases social inequality, as rural development is being considered as the best policy to reduce poverty (Diao et al., 2010). In the early 1980s, the delivery of services and facilities in selected rural towns appeared the most appropriate policy to reach rural population (Rondinelli, 1985; Hardoy and Satterthwaite, 1986). Chambers (1995) provided a livelihood perspective instead of debating the choice of the most effective place wherein services and facilities would be delivered to rural populations. The change implied the consideration of the social relation that governed rural development, migration, and remittance flows, which facilitated survival in a rural context (Scoones, 2009). The decentralisation process that occurred in the early 2000s made many rural towns the capitals of the new local governments and assigned them development tasks. However, decentralisation needs participation, freedom from local oligarchies, funding, and infrastructure (Bardhan, 2002). In fact, the decentralisation process

* Corresponding author.
E-mail addresses: maurizio.tiepolo@polito.it (M. Tiepolo), andrea.galligari@polito.it (A. Galligari).

https://doi.org/10.1016/j.landusepol.2021.105547
Received 19 November 2020; Received in revised form 30 April 2021; Accepted 12 May 2021
Available online 24 May 2021
0264-8377/

transferred many competences but few resources (Wisner et al., 2015). Without the latter, development would be difficult to achieve.

Studies have found a link between urban expansion, flood losses and damage. Unplanned urbanisation and the associated increase in population in flood zones has led to increased losses (Di Baldassarre et al., 2010). The results of a study of 55 African countries revealed a correlation between urban expansion, flood disasters, loss and damage (Li et al., 2016). As for future trends, large coastal cities in Africa are expected to expand the share of built-up area in flood-prone zones from 8% to 10% (2000) to 27–28% at the end of the current decade (Güneralp et al., 2015). It is well known that floods in urban areas mainly affect the Poor (Douglas et al., 2006; Hallegatte et al., 2017). However, we do not know if this is also the case in rural areas. Certainly, in Africa, rural poverty is more widespread than urban. According to the latest estimates, it ranges between 82% and 85% compared with 15–18% in urban areas (Castañeda et al., 2018; OPHI, 2018). A survey of 194 rural jurisdictions in 21 countries in tropical Africa revealed that public participation in decision-making on hydro-climatic risk reduction policies is low. Low participation is associated with the spatial dispersion of human settlements that make up a local jurisdiction, followed by gender or social position (Tiepolo and Braccio, 2020, p. 12). Flood impacts that primarily affect the Poor generate questions of environmental justice (Walker and Burningham, 2011).

The problem is to ascertain where the built-up area expansion–flood damage link is the closest. A broader look at both urban and rural contexts is therefore necessary. At the same time, this requires more detailed information sources than those used thus far. The link between urban-expansion and flood damage is usually established using coarse information.

Regarding the flood damages south of the Sahara, the existing literature is based on household surveys (Brida and Owiyo, 2013) or on global datasets, such as the Desinventar offered by the United Nations office for Disaster Risk Reduction (UNDRR), EM-DAT managed by the World Meteorological Organisation (WMO) at the Catholic University of Leuven, and the Dartmouth Flood Observatory (DFO) at Colorado University (Panwar and Sen, 2020). These datasets do not localise the affected communities (Osuteye et al., 2016; Tiepolo et al., 2018) given that local datasets are often lacking (Adelekan, 2019). In some cases, damages are estimated from high-resolution images on demand (Voigt et al., 2016).

Urban expansion is observed using satellite imagery with moderate resolution, such as Landsat and SPOT, or by using already processed information from global datasets, such as the Global Human Settlements (GHS) and the Global Human Built-up and Settlement Extent (HBASE). The spatial expansion is described by observing large- to medium-sized cities, while human settlements in the sub-Saharan Africa are mainly composed of minor settlements as the majority of the population is still rural (Mercandalli and Losch, 2017; UNDESA, 2019). The studies conducted at the regional scale that also considered the spatial dynamics of smaller settlements are limited (Agyemang et al., 2019; Tena et al., 2019; Kogo et al., 2021). These studies have found that the spatial growth of small settlements after 2010 has been very intense and ranged between 6% and 18% per year, depending on the region considered.

Accurate built-up area expansion–flood damage assessment can provide useful information for the development of a public risk reduction policy at the local scale.

Therefore, the objective of this study was to revisit the urban expansion–flood damage nexus widening the observed context to rural settlements and using open-access information, alternative to global datasets on flood damage and moderate resolution satellite images. The objective is pursued by observing the spatial dynamic of flooded human settlements in the Dosso region in Niger (spanning an area of 31,000 km^2 with 2 million inhabitants) (Fig. 1).

This region is known for the flooding of the Niger River, which marks its southwest border. However, Dosso is also one of the most severely pluvial flood-affected regions in West Africa.

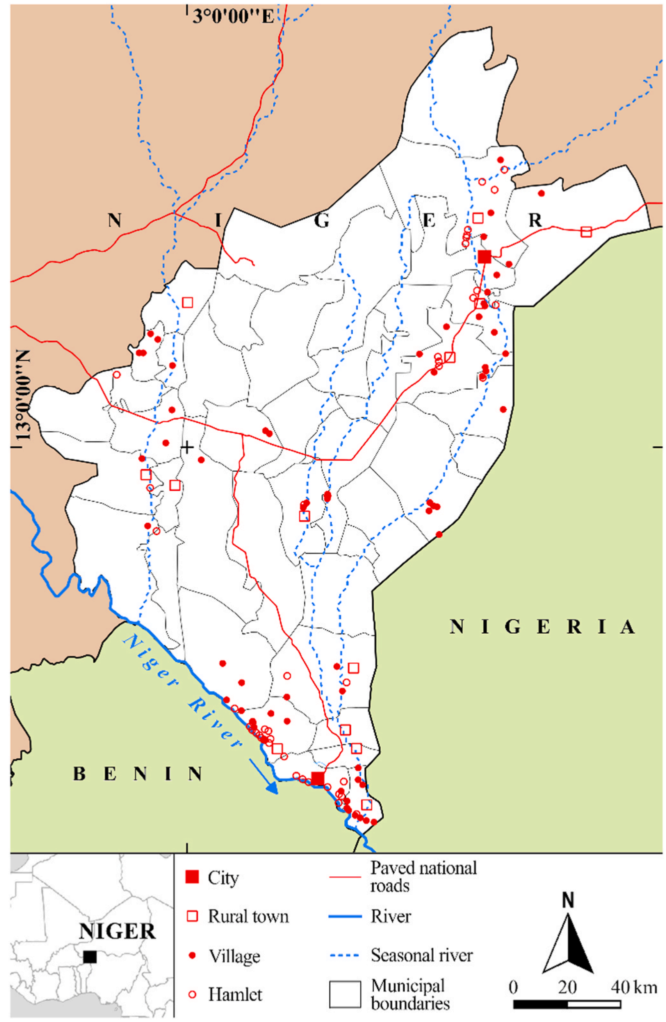

Fig. 1. Flooded settlements (2001–2019) examined in the Dosso region.

Flood damages are analysed using information stored in the database on floods in Niger, commonly known by its French acronym BDINA (Fiorillo et al., 2018). The database provides the names of 290 flooded settlements, and the type and amount of damage.

The spatial dynamics of flooded settlements is observed with very high-spatial resolution images (size of each cell on the ground less than 1 m) accessible through Google Earth Pro (GE). These images have the original multispectral band data (brightness/reflectance values for each cell) for the optical part only. Nevertheless, they allow us to identify buildings, barns, lot fences, roads, and (in conditions of atmospheric clarity) roof materials. Images cover two decades and facilitate land-cover change detection. These characteristics make very high-resolution images useful for localising and recognising flood prone items. GE is user-friendly. This feature makes it interesting for local officers in the sub-Saharan Africa, where the skills for accessing multi-spectral images are limited. GE applications cover a variety of disciplines (Gorelick et al., 2017) but have rarely been focused on monitoring settlement dynamics in the sub-Saharan Africa (Admasu, 2015; Simwanda and Muryama, 2017; Megersa et al., 2018). GE is more used in other geographical contexts (Malarvizhi et al., 2016; Sam, 2014) to identify minute morphological features of the urban fabric, which escape images with moderate resolution (James and Bound, 2009).

The novelty of this study lies in ascertaining the spatial dynamics not only of urban but also of smaller rural settlements in a regional setting, with open-access information more precise than that currently used in this type of analysis. The results achieved challenge the accuracy of global datasets on flood damages and spatial growth. Current assumptions on settlement expansion in the sub-Saharan Africa, based on which the urban-centric approach to risk reduction is adopted, are discussed.

2. Materials and methods

The analysis identifies flooded settlements with damage, the variation over time of the built-up surface, and the number of buildings with corrugated iron sheet roofing in urban and rural contexts (Fig. 2).

Global datasets, such as Desinventar, EM-DAT, and DFO do not have a very precise coverage of floods. Desinventar is the disaster information system of the UNDRR, which has extended the system created in 1994 by La Red in Latin America to a global scale. The information available by country and region covers flood, drought, forest fires, epidemics, epizootics, accidents, and other disasters. Deaths, injuries, missing persons, damage (housing, educational facilities, health, roads, crops, cattle), number of relocated and evacuated inhabitants and a monetary estimate of damages are recorded. The data are not up to date. The international disaster database EM-DAT is managed by the Centre for Research on the Epidemiology of Disasters established in 1973 at the Catholic University of Louvain, Belgium. Since 1980, the Centre has been part of the World Health Organisation. EM-DAT records natural and technological disasters. The data are freely accessible. The DFO has been set up at the University of Colorado and has been recording floods at a global scale since 1985 and flooded areas by remote sensing.

In the Dosso region, Desinventar, EM-DAT, and DFO respectively recorded 8, 8, and 10 floods, while the national dataset on floods (BDINA) recorded 36 floods between 2011 and 2019. BDINA reports the date of flooding and damage (buildings, infrastructure, crops, livestock) to the individual settlement, as collected by the municipality-wide vulnerability observatories (Tiepolo et al., 2018). With this source, 290 flooded settlements in the region have been identified between 2011 and 2019. These settlements are recognised on satellite images based on the geographical coordinates listed in the Human settlements national directory (ReNaLoc) (RN, 2014).

The spatial dynamic of the flooded settlements was ascertained after consideration of the potential of GHS, HBASE, and GE with respect to the 290 flooded settlements. The Joint Research Centre of the European Commission has created the GHS dataset (Florczyk et al., 2020). Unlike HBASE (Wang et al., 2017) and other global datasets (Potere et al., 2009), GHS reports on the dynamics of 2298 human settlements in the sub-Saharan Africa between 2000 and 2015. Despite appearances, the dataset covers the larger settlements only. The accuracy is variable and depends upon the clarity of the built-up edge. In addition, it does not allow the items exposed to flooding to be quantified. Some studies have relied on the information offered by these datasets (Güneralp et al., 2017; Melchiorri et al., 2018; OECD, 2020). However, the bulk of knowledge on the spatial dynamic of settlements in the sub-Saharan Africa originates from approximately 100 monographic studies that observed urban expansion mostly based on Landsat images (in 97% of

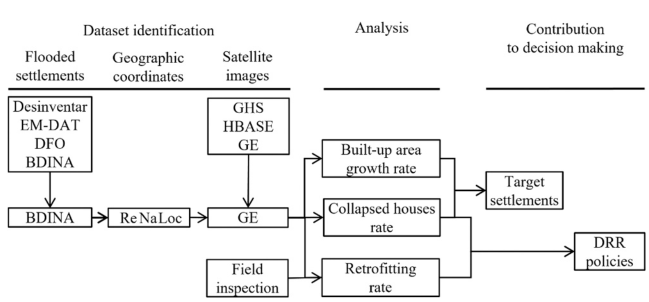

Fig. 2. Analysis flowchart. BDINA- National database on floods, DFO-Dartmouth Flood Observatory, DRR-Disaster risk reduction, GE-Google Earth Pro, GHS-Global Human Settlements dataset, HBASE-Global Human Built-up and Settlement Extent, ReNaLoc-Human settlements national directory.

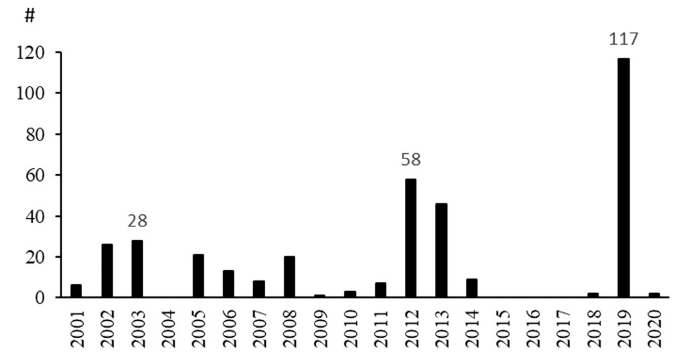

Fig. 3. GE images covering 122 settlements of the Dosso region and respective years.

the cases). These images had an average ground resolution of 30 m and had been freely available for almost every year since 1984. Monographic studies usually considered three dates over an average timeframe of 26 years. Only half of the literature analyses the spatial growth of settlements after 2014.

GHS reports the built-up area for 2000 and 2015 of four cities of the Dosso region: Birni Ngaoure, Dogondoutchi, Dosso, and Gaya. HBASE reports the built-up area for 2010 only. Other cities, larger than Birnin Ngaoure, such as Tanda (126 hectars in 2012), Kiota (154 hectars in 2012), and Karra (184 hectars in 2012) are not considered by GHS or HBASE. GE covers 122 settlements in the Dosso region at three distinct time instances (Fig. 3).

In 2015, the built-up area according to GHS was two to three times less extensive than that determined by GE. Very high-resolution satellite images intercepted the scattered building on the outskirts of Gaya and Dosso after 2010, which comprised 8–12% of the total built area in 2014–16. According to GHS, the built-up area grows more slowly (0.7–1.3%) than the growth rate determined by GE (2.7–6.3%). In addition, the fastest growing cities according to the GHS are those that grow at slower rates, according to the analysis of images accessible from GE, and vice versa (Table 1, Fig. 4).

The choice of the information source to be used to monitor settlement expansion was thus the GE tool.

The 122 settlements considered were cities, capital towns of rural municipalities (henceforth referred to as rural towns), villages, and hamlets. Urban settlements are defined by law as regional and departmental capital cities and urban municipalities (RN, 2014). Rural towns and administrative villages are the other cornerstones of the local

Table 1
Built-up area in four cities of the Dosso region according to the Google Earth Pro (GE), Global Human Settlements (GHS), and the Global Human Built-up and Settlement Extent (HBASE).

Dataset, date	Unit of measurement	Birni Ngaoure	Dogondoutchi	Gaya	Dosso
HBASE 2010	km^2	0.77	2.78	2.34	7.82
GHS 2000	km^2	1.03	3.55	2.20	4.81
GHS 2015	km^2	1.24	3.94	2.46	5.75
GHS $r_{2000–2015}$	%	1.26	0.70	0.75	1.20
GE 2003	km^2	1.34	4.88[a]	3.06	8.08
GE dense 2014	km^2	2.21	6.10[b]	5.54	10.01[c]
GE scattered 2014	km^2	0	0.04	0.47	1.38
GE 2014	km^2	2.21	6.14	6.01	11.39
GE $r_{2003–2014}$	%	4.65	3.79	6.33	2.68

[a] 2007,
[b] 2013,
[c] 2016

administration in Niger and host the minimum level of modern and traditional administration (RN, 2015a,2015b). Common villages (1200 habitants on average on each village) and hamlets (500 habitants on average) are settlements without administrative functions.

GE covers 50% of cities, 62% of rural towns, 57% of villages, and 79% of flooded hamlets (Table 2).

These values allow us to perform statistically significant analyses of the expansion of flooded settlements at the regional scale.

We can therefore analyse the settlement categories over an average period of 15 years split in two sub-periods of 8 and 7 years each, delimited by the average year in which the satellite images were captured. However, the growth rates of the individual settlements are calculated based on the actual dates on which the satellite images were captured.

The built-up area of each settlement was visually identified on three dates using the 'View' and 'Historic imagery' buttons of GE. It was manually measured using the 'Add polygon' GE tool. In many settlements, the built-up area can be divided in two zones. The densely developed zone includes all contiguous built-up lots and the road surface that provides access. Playgrounds, graveyards, communication tower lots are included. Vacant lots or under construction properties and isolated developed lots are excluded (Fig. 5).

The scattered development zone includes developed lots separated by each other less than 60 m, or two standard vacant lots. Once the built-up area has been measured, the annual average rate of variation of the cities, rural towns, villages, and hamlets is calculated to ascertain the most rapidly expanding settlement category. The variation rate (r) is

Table 2
Number of settlements flooded in the Dosso region covered by very high-resolution satellite images between 2001 and 2020.

Settlement	Total	Flooded	Flooded and localised	Flooded, localised and covered by GE	
				Built-up	Roofs
City	8	4	4	2	1
Rural town	35	21	21	13	10
Village	1922		117	67	24
Hamlet	3249		53	40	11
Unknown	156		14	–	–
Total	5362	290	198	122	46

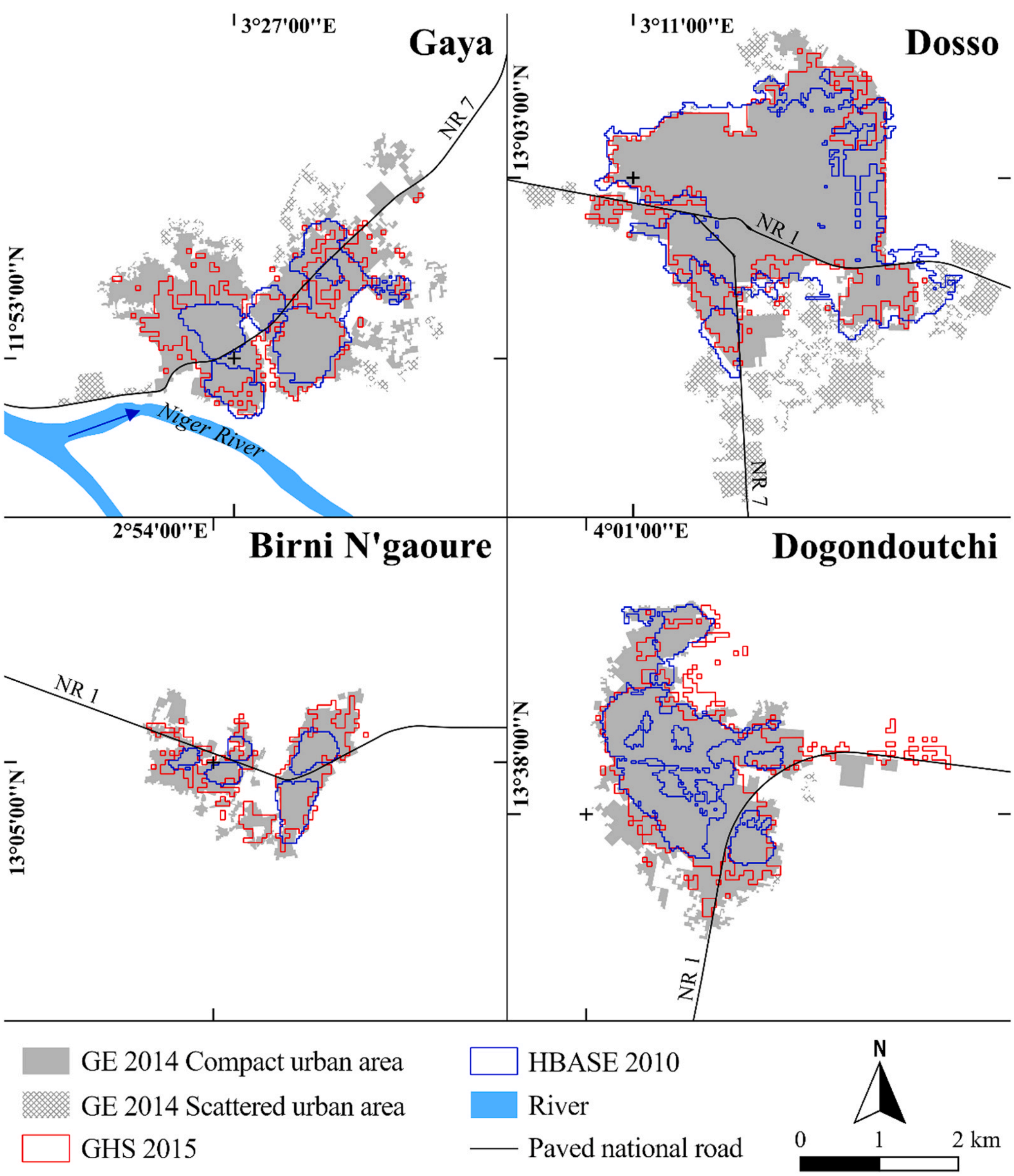

Fig. 4. Built-up area in four cities of the Dosso region according GE 2014, GHS 2015, and HBASE 2010.

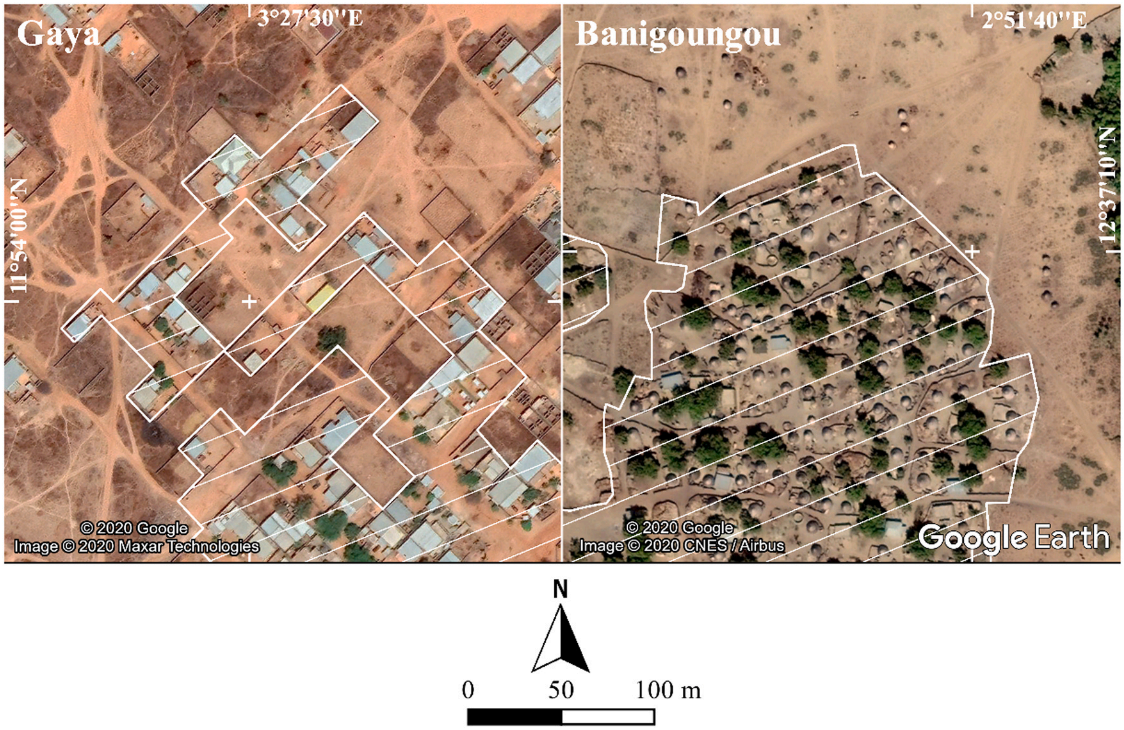

Fig. 5. Built-up area at Gaya and at Banigoungou according to visual photo-interpretation of GE images for 2014 (Image©2020MaxanTechnologies).

calculated accordingly to the following equation,

$$r = ((f/i)1/a-1) \times 100 \quad (1)$$

where f = final value, i = initial value, and a = number of years between f and i.

The share of the built-up area of the cities is compared with the share of collapsed houses. The comparison is repeated for rural towns, villages, and hamlets. This allows the identification of the most affected category of settlements.

The spread of retrofitting is assessed by identifying corrugated iron roofs based on visual photo-interpretation (Fig. 6), validated with field inspections in Gagila, Sabon Birni, and Takoidawa villages, and in the rural towns of Guéchémé and Tessa.

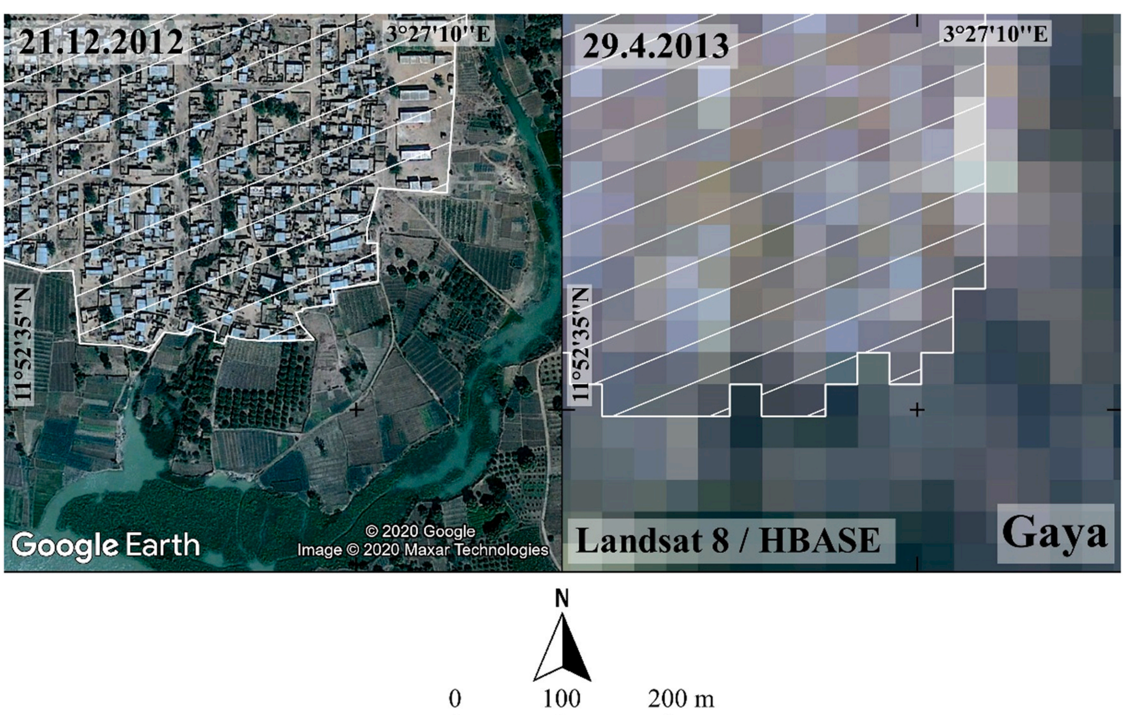

Fig. 6. Gaya built-up edge and corrugated iron roof (bright colours on left) in 2012 according to GE and built-up edge in 2013 according HBASE and Landsat 8 images.

The visual recognition of corrugated iron roofs requires very high-resolution images with a good radiometry (suitable illumination/atmospheric conditions) (Dietler et al., 2020). Images acquired in the months of February–March (two-thirds) and September (22%) were not usable. Conversely, the images acquired in December–January and June–August have excellent quality and allow coverage of up to 40% of the settlements with three images in the period of interest.

Roof collapse is only one type of damage that a building can suffer because of pluvial flooding. Cracking of walls of an adobe lot fence, flooding of latrines, wells, and the collapse of barns are recurrent damage types. Nevertheless, they are less serious and are usually repaired with mutual community help at no monetary cost. Conversely, roof collapses lead to the loss of homes and force the Poor to rebuild similar or inferior shelters, or allow the conversion of temporary shelters into permanent accommodations (Dube et al., 2018, p. 8). Corrugated iron roofs only protect buildings from the impact of heavy rain on the roof. Runoff can damage adobe houses and cause them to collapse. Rainwater drainage, flood barriers, and raised basement of houses and latrines prevent damages. However, these measures are scarcely used in the Dosso region, especially in the rural settings. Assessing the spread of these measures inside flood-prone zones in the 122 settlements by field inspections encompass the means of this study. For these reasons, we have not considered protection measures other than corrugated iron roofs.

The growth rate of the built-up area is compared with that of the corrugated iron roofs. Finally, the effectiveness of the retrofitting with respect to pluvial flooding is validated by correlating the proportion of corrugated iron roofs with respect to the total number of roofs with the proportion of collapsed houses with respect to the total number of houses.

3. Results

3.1. Pluvial flood damage

Climate change, environmental degradation, settlement expansion in flood zones, and poverty are the drivers of flood damage in the Dosso region. During the past 20 years, extreme rainfall (99th percentile) has increased in intensity in few municipalities only. Conversely, cumulative rainfall in the days prior to a heavy rain increased flood occurrence (Tarhule, 2005). In any case, damages after rainfall increased steadily according to BDINA. Several studies observed an increased runoff due to the degradation of the watersheds owing to overgrazing, rain-fed crops expansion (San Emeterio et al., 2013), fallow duration decrease, and systematic deforestation (Esteves and Lapetite, 2003; Valentin et al., 2004; Brandt et al., 2016). Finally, restless population growth, lack of awareness of flood zones, and widespread poverty led to the expansion of human settlements with adobe constructions in flood-prone zones (Galligari et al., 2020).

From 2011–2019, floods caused the collapse of 6989 houses in the 122 considered settlements according to BDINA. Eighty percent of the 122 settlements have been affected by pluvial flooding and the rest by fluvial flooding. Seventy-two percent of collapses occurred in villages and hamlets, while rural towns and cities respectively suffered 15% and 14% of the collapses (Table 3, Fig. 7).

The damage trend during the period 2011–2019 has a saw tooth profile. It follows the alternation of wet and dry years that characterises the climate in this part of the Sahel. Damages have exhibited very different patterns depending on the category of the settlement. The damages of cities and rural towns do not vary much over time. In contrast, villages and hamlets show tripled damage rates in the observed short time period (Fig. 8).

Table 3
Number of collapsed houses following a flood (2011–19) and number of settlements according to category (2019).

Settlement category	Settlements		Collapsed houses	
	n.	%	n.	%
City[a]	2	2	893	14
Rural town[b]	13	10	1 012	15
Village	67	53	3 141	48
Hamlet	40	35	1 486	23
Total	122	100	6 532	100

[a] Dogondoutchi, Gaya
[b] Bana, Bengou, Dan Kassari, Fabidji, Kankandji, Kiéché, Kore Mairoua, Koygolo, Matankari, Tanda, Tessa, Tounouga, Yelou

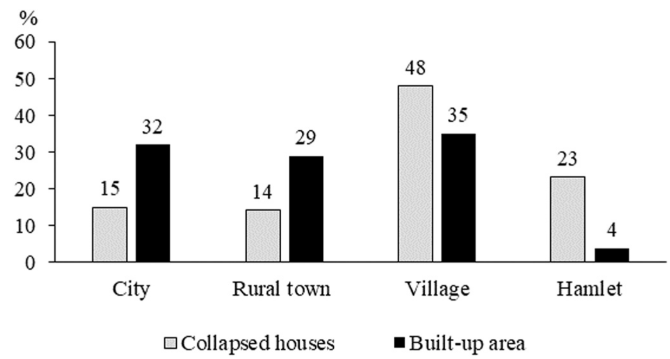

Fig. 7. Houses collapsed in the Dosso region between 2011 and 2019 according to the type of settlement.

3.2. Settlement expansion

Between 2004 and 2019, the 122 settlements expanded at an annual rate of 3.3% on average. Cities expanded faster (3.5%) compared to the average trend for 2000–2015 observed by Melchiorri et al. (2018) in the sub-Saharan Africa (2.5%). Gaya is the fastest growing city (5%). Rural towns expanded at 3.2% with a peak noted in the case of Tanda (5.8%) (Fig. 9).

Villages expanded at 3.2% with a peak noted in the case of Bouma Bamanzo (7.4%), with 464 inhabitants in 2012 in the municipality of Tanda. Hamlets increased at a rate of 3.8% on average per annum with a peak noted in the case of Kofo (9.2%) in the municipality of Gaya, which had 608 inhabitants in 2012 (Fig. 10).

In the two sub-periods, these settlement categories behave very differently. In the period 2004–2012, cities grew at the highest rates, followed by hamlets, rural towns, and villages. After 2012, hamlets were the fastest growing settlements, with a peak noted in Illela Makera in the rural municipality of Yelou (15%). Rural towns followed, with a peak noted in the case of Dan Kassari (7.2%). Villages grew almost at the same rate as towns, with a peak noted in the case of Dey Koukou Ouest Fang in the municipality of Tessa (14%). Cities were ranked last, with a peak noted in the case of Gaya, which is growing at an average annual rate of 5% (Table 4).

The comparison between flood damage and settlement expansion in the 122 settlements shows that cities account for 32% of the built-up area in 2019 but only 14% of the house collapses. Rural towns, with 29% of the built-up area in 2019, account for 15% of the damage.

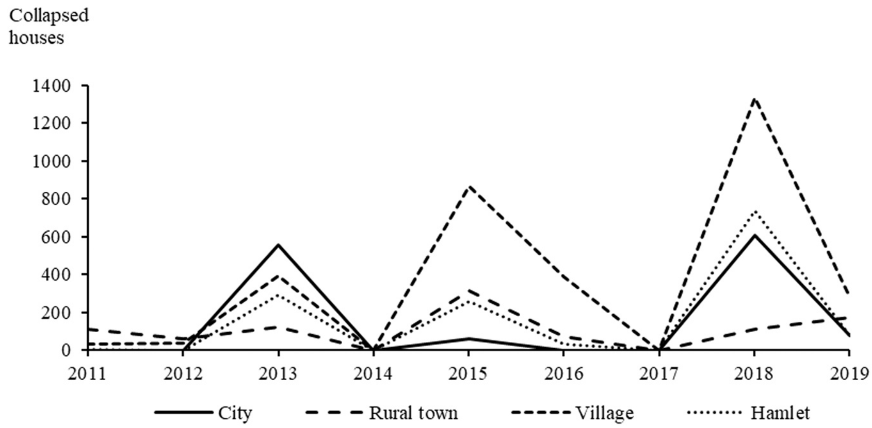

Fig. 8. Percentage of collapsed houses following a flood and built-up area (2019) according to the settlement category.

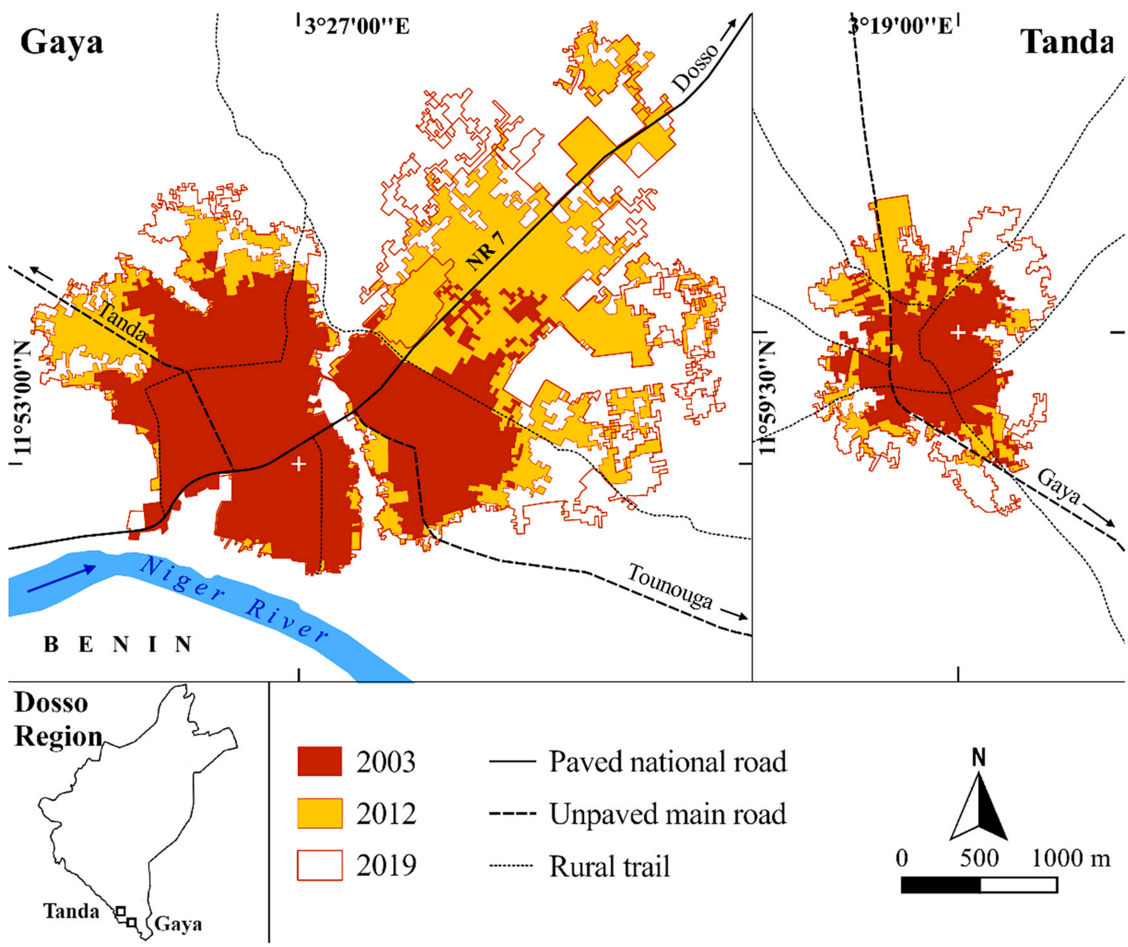

Fig. 9. Dynamics of Gaya city and the rural town of Tanda between 2003 and 2019.

Villages and hamlets, with 39% of built-up area account for 71% of the damage (Table 5).

3.3. Building retrofitting

During the considered period, corrugated iron roofs increased at an average annual rate of 10.6%. The spread of corrugated iron roofs was more rapid in hamlets (15.9% on average annually), followed by cities (12.2%), villages (10.6%) and rural towns (5.8%). Between 2004 and 2012, the consolidation proceeded at the average annual rate of 16.7% and slowed down in the subsequent seven years (4.8%) (Table 6, Fig. 11).

The average annual growth rate of corrugated iron roofs was always higher than the built-up expansion irrespective of the category of settlement (Table 7).

Given the prevalence of pluvial floods compared with the fluvial floods in the considered locations, it remains to be observed if retrofitting of buildings with corrugated iron roofs reduces collapses. The analysis ascertains that there is no correlation between the share of corrugated iron roofs in 2012 and the share of collapsed houses in the

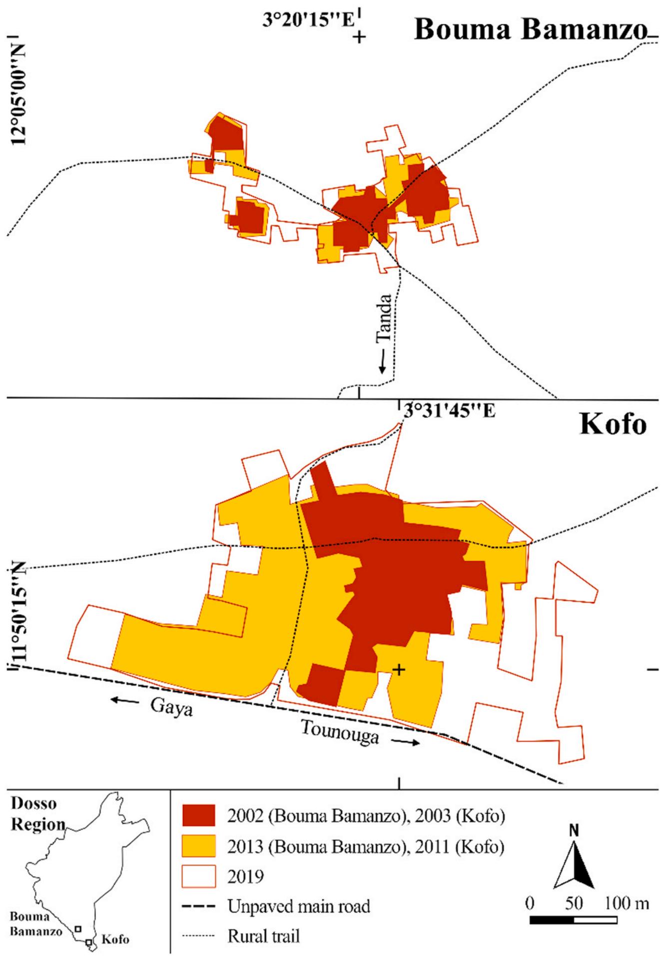

Fig. 10. Built-up areas of the village of Bouma Bamanzo in the municipality of Tanda, and in Kofo in the municipality of Gaya.

Table 4
Growth rate (*r*) of the built-up area by flooded settlement category between 2004 and 2019.

Settlement category	$r_{2004–12}$	$r_{2012–19}$	$r_{2004–2019}$
City	4.97	1.84	3.50
Rural town	3.21	3.13	3.17
Village	3.07	3.09	3.23
Hamlet	4.08	3.54	3.83
All	4.21	2.79	3.26

Table 5
Collapsed houses following a flood (2011–19) and built-up area (2019) of settlements.

Settlement category	Collapsed houses		Built-up area	
	n.	%	ha	%
City[a]	893	14	1 330	32
Rural town[b]	1 012	15	1 210	29
Village	3 141	48	1 429	35
Hamlet	1 486	23	181	4
Total	6 532	100	4 150	100

[a] Dogondoutchi, Gaya
[b] Bana, Bengou, Dan Kassari, Fabidji, Kankandji, Kiéché, Kore Mairoua, Koygolo, Matankari, Tanda, Tessa, Tounouga, Yelou

Table 6
Spread of corrugated iron roofs of 49 flooded settlements in the Dosso region in 2012.

Settlement	Number			Average yearly rate		
	1st date	2nd date	3rd date	$r_{2005–12}$	$r_{2012–19}$	$r_{2005–19}$
City	1640	6897	8216	22.78	2.53	12.20
Capital town	1600	2918	3535	8.96	2.78	5.83
Village	631	1243	2593	10.17	11.08	10.62
Hamlet	38	136	300	19.98	11.97	15.90
Total	3909	3526	14,644	16.73	4.79	10.60

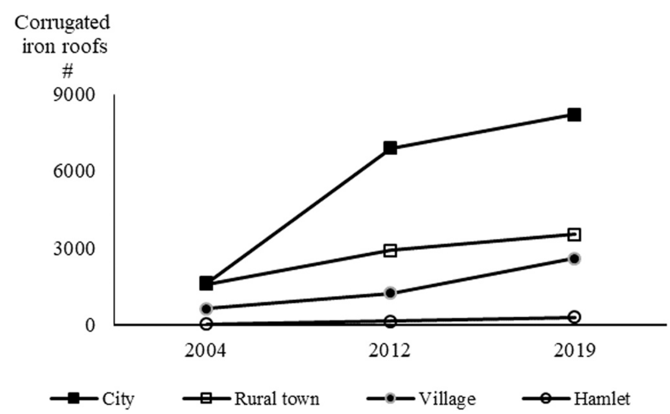

Fig. 11. Number of corrugated iron roofs between 2004 and 2019 by settlement category.

Table 7
Increase of corrugated iron roofs and built-up area in 49 settlements of the Dosso region between 2004 and 2019.

Settlements	Corrugated iron roof $r_{2004–19}$	Built-up area $r_{2004–19}$
City	12.20	3.75
Rural town	5.83	3.04
Village	10.62	4.07
Hamlet	15.90	5.41
Total	10.60	4.16

Table 8
Correlation between share of corrugated iron roofs (2012) and share of collapsed houses (2012–19) in 49 settlements studied herein.

Settlement	Iron roofs - collapsed houses correlation
City	–
Rural town	0.27
Village	0.10
Hamlet	-0.07
Total	0.02

subsequent years (Table 8).

Among the settlements, in which over half of the buildings have corrugated iron roofs in 2012, some report collapses at rates > 40% of properties in subsequent years, including the Wadata/Gaya municipality (53%), Sabana Dey (50%), Belande (47%), and Karra (43%).

4. Discussion

In recent decades, sub-Saharan Africa has been struck by catastrophic floods. The urban expansion–flood damage link has been used to suggest an urban-centric disaster risk reduction approach (Dodman et al., 2017; Satterthwaite, 2017). However, the urban expansion–flood damage link is influenced by the category of the observed settlement. Monographic studies on the spatial dynamics of human settlements in the sub-Saharan Africa cover almost all large to medium-sized cities but less than 2% of minor settlements. Knowledge is extracted from satellite images with moderate resolution, which do not allow the built-up area to be identified with accuracy (Figs. 4 and 6). For these reasons, this study used very high-resolution images accessible through GE to revisit the urban expansion–flood damage nexus with a focus on rural settlements. Reduction of the potential flood damage requires storm-water drainage, flood barriers, building retrofitting proportional to the extension of the built-up area, soil and water conservation works to slowdown runoff proportional to the watershed surfaces that settlements belong to. Gaining knowledge on the settlement's spatial expansion is thus particularly relevant. Demographic growth is less appropriate given that data are sometimes overestimated (Potts, 2012a; 2012b; Garenne, 2016) or do not follow the same dynamic as the built-up area (Sumari et al., 2020).

Very high-resolution satellite images accessible through GE are also helpful for the study of the process of building retrofitting with corrugated iron roofs when they have adequate resolution and clarity, and the buildings are clearly separated from each other, as is common in villages and hamlets (Fig. 6).

We have found that cities such as Gaya, Dosso, Birni Ngaoure, and Dogondoutchi, have much larger built-up areas and are expanding much more rapidly than the expansion rate ascertained by global datasets (Fig. 4). A possible explanation of the deviation pertains to the patterns of urban expansion in the last 10 years that changed from compact to scattered, as observed in other cities south of the Sahara (Nkeki, 2016; Fenta et al., 2017; Abass et al., 2018), which cannot be easily identified with coarse images.

However, over the past fifteen years, hamlets grew at faster rates (3.8% per year) compared with cities (3.5%), although at slower rates than those observed in other regions south of the Sahara by Agyemang et al. (2019), Tena et al. (2019), and Kogo et al. (2021). Rural towns (3.2%) grew at lower rates compared with other settlement types. This is the opposite of what could be expected from the creation of central places in rural areas based on the theory proposed by Rondinelli (1985) and implemented in Niger through the creation of new local jurisdictions in 2004. Decentralisation failed in providing rural towns with the essential ingredients recalled by Bardhan (2002): true participation, financial support, and infrastructure. Women and minority participation in rural decision making was low (Tiepolo and Braccio, 2020).

The restless expansion of hamlets and villages challenged the urban-centric approach to risk (Dodman et al., 2017; Fraser et al., 2017). The perspective should be shifted from cities and rural towns to livelihoods (Chambers, 1995; Scoones, 2009).

The truly significant deviation between the rates of expansion of rural towns, such as Tanda, and cities, such as Gaya (Fig. 9), and those of hamlets and villages (Fig. 10) could be explained by the growth of the rural population (Mercandalli and Losch, 2017; UNDESA, 2018) and the demographic pressure on arable lands. Nevertheless, there is still room for rain-fed agricultural expansion that may keep rural people tied to their locations. Additionally, the most intense expansion is that associated with smaller settlements, as those of the villages of Kofo and Bouma Manzo (Fig. 10). Another explanation is attributed to seasonal migratory flows directed abroad, where there are more job opportunities rather than the cities of the region, which expanded by a lesser extent (Afifi, 2011). The role of migration and remittance flows referenced by Scoones (2009) in the understanding of the livelihoods of rural households is arguably essential.

Villages and hamlets accounted for 71% of collapses from flooding in 39% of the built-up area, while rural towns recorded a rate of 15% compared with 29% of built-up area. Additionally, cities recorded 14% of damages compared with 32% of the built-up area. These rates were compounded by a trend, whereby damage in villages and hamlets tripled within a period of six years. By contrast, damages in cities remained stable and decreased in rural towns (Fig. 8).

Once again, attention paid to cities and to small towns is disputed (Hardoy and Satterthwaite, 1986; Sattertwaite, 2017). Environmental justice is not just about the Poor in urban context (Douglas et al., 2006; Hallegatte et al., 2017). In the Dosso region, rural populations are more affected by floods than urban populations. In Niger, rural poverty is three times higher than urban poverty (RN, 2013). The main implications of 'unjust rural waters' concern the following:

(i) Limited resources of rural municipalities to cope with flooding owing to the incomplete fiscal decentralisation (Wisner et al., 2015).
(ii) Minority and gender participation in decision-making related to the measures to be taken to cope with floods (Walker and Burningham, 2011). Awareness and preparedness should be addressed to the flood prone settlements first.
(iii) Scales of operation. Several flooded settlements belong to trans-municipal catchments. For example, in the case of the large village of Sabon Birni (municipality of Tounouga), the upper part of the watershed belongs to the municipality of Gaya. This implies the involvement of different administrative entities for its management.
(iv) Damage compensation.

The vulnerability of the built-up environment of villages and hamlets in the Dosso region lies in the way they expand, without subdivision plans, storm-water drainage, and with adobe constructions. This is the opposite of what occurs in cities and rural towns. Corrugated iron sheets protect the adobe constructions from the impact of intense rainfall on the roof but do not avoid collapses. Runoff should not impact the adobe constructions. It must be slowed down, reduced, and channelled into storm-water drainage. Entrance doors of homes should be protected with flood barriers. Above all, houses must be built with durable materials. These measures can make a lot of difference but are not yet foreseen by municipal development plans.

These analyses led to various unexpected results: (i) a significant deviation between the built-up areas estimated by global datasets and those measured through GE, (ii) the restless spatial expansion of any village and hamlet; (iii) the greater vulnerability of villages and hamlets compared with cities and rural towns, and (iv) the concentration and the growth of damage over time in villages and hamlets.

The results of the study are limited in the following aspects. First, an overestimation of the average annual variation rates of the built-up areas of the four categories of human settlements in the observed period owing to the use of an average date of the initial, intermediate, and final satellite images.

Second, the identification of the corrugated iron roofs limited to 37% of settlements restricted the significance of the results.

Third, the runoff protective measures, such as rainwater drains, flood barriers, raised basements, and house entrances, were not considered. Inundation maps are needed to include them. However, currently, these are only available for few settlements (Katiellou et al., in press).

Finally, a systematic analysis of the reasons behind settlement expansion driven by public and private initiatives, and the injustices in the exposure to flooding, were not developed.

This work concluded with the following recommendations to local and central governments.

Municipalities should inform the inhabitants of the flooded settlements to refrain from building in flood zones and disseminate some low-cost best practices to allow them to protect their homes, such as the application of thresholds and flood barriers to entrance doors, and the raising of the latrine basements. More efforts should be expended to include women, minorities, and representatives from remote flooded settlements in the decision making. Finally, municipalities should add to their development plan a flood-risk reduction section listing the measures that need to be taken on a year-by-year basis. The most important municipalities can prepare their own risk reduction plan.

The Dosso regional council should establish a geodatabase of the flooded settlements. Flood zone maps should be prepared in association with municipalities. This will be useful for local flood-risk management.

The Ministry of Spatial Planning and Community Development should supplement the guidelines for preparing municipal development plans with a request to include at all stages of plan preparation (diagnosis, identification of measures, programming, and budgeting), and implementation (monitoring and evaluation) representatives of the inhabitants of flooded areas.

Suggestions for future research may include (i) the consideration of the use of open access high-resolution images available through new satellite constellations, such as the Sentinel, once the image archive is extended to cover a larger number of years, (ii) the use of images from open repositories captured by unmanned aerial vehicles, such as http://map.opeaerialmap.org for a larger number of settlements compared with the four currently covered in the Niger region.

5. Conclusions

The objective of this study was to revisit the urban expansion–flood damage nexus in the Dosso region widening the observation to rural settlements with open access information on flood damage and spatial dynamics more precise than those currently used.

The analysis was developed from the information provided by BDINA that allowed the identification of 290 flooded settlements. Of these, 122 were covered by images freely accessible from GE. GE is user-friendly and it can be used by unskilled local staff.

The built-up area expansion ascertained through GE highlighted faster and opposite trends to those offered by global datasets that use moderate resolution images. With GE, the expansion of all categories of human settlements (not just cities) was verified for an average time-frame of 15 years. We discovered that, in the past seven years, hamlets and villages have expanded at faster rates compared with cities. However, the analysis also showed that house collapses from flooding were unequally concentrated in hamlets and villages. Collapses in these minor rural settlements tripled in six years, in cities they were stable, while in rural towns they decreased.

Thus, the built-up area expansion–flood damage nexus was confirmed. However, this does not concern the urban sector but the rural. The spatial expansion was accompanied by an accelerated consolidation of houses through the use of corrugated iron roofs. Roof improvements are not sufficient to protect the settlements from flooding. It is necessary to reduce the runoff and to strengthen and protect houses. These policies, contrary to what is recommended by literature, should be implemented in villages and hamlets first because damage and poverty rates are higher in minor rural settlements. In the Dosso region, this means intervening in 109 minor settlements instead of concentrating on two cities and 13 rural towns only.

The geographical information extracted from this research can constitute the major part of a geodatabase for informed decisions on disaster risk reduction at a local scale.

Human settlements can be monitored based on GE even in other regions in the sub-Saharan Africa to identify the most exposed settlements and most suitable measures to benefit the public risk reduction policy at a local scale.

When the expansion of human settlements is extensive, long lasting, and generalised as in the Dosso region, some villages could become the rural towns of tomorrow. In sub-Saharan Africa, an exclusively urban perspective may lead to policies that are ineffective in reducing the risk of flooding and are environmentally unjust.

Funding

This work was supported by the ANADIA 2.0 project, co-funded by the Italian Agency for Development Cooperation, Italy; Bio Economy Institute of the National Research Council, Italy; DIST-Politecnico and University of Turin, Italy; National Directorate for Meteorology, Niger.

CRediT authorship contribution statement

Maurizio Tiepolo: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Writing - original draft, Writing - review & editing; **Andrea Galligari:** Conceptualization, Data curation, Investigation, Visualization, Writing - original draft, Writing - review & editing.

Acknowledgements

The authors would like to thank Professor Fabio Giulio Tonolo for his comments on the first draft of this manuscript, and the three anonymous reviewers for the insights they provided that have substantially improved this article. The authors are grateful for the support provided by the Italian Agency for Development Cooperation, Italy to ANADIA 2.0 project through AID 10848.

Author contributions

Conceptualization (MT, AG), Data curation (MT, AG), Formal analysis (MT, AG), Funding acquisition (MT), Investigation (MT, AG), Methodology (MT), Project administration (MT), Resources (MT), Software (MT, AG), Validation (MT), Visualization (AG), Writing - original draft (MT, AG), Writing - review & editing (MT, AG).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2021.105547.

References

Abass, K., Adanu, S.K., Agyemang, S., 2018. Peri-urbanisation and loss of arable land in Kumasi Metropolis in three decades: evidence from remote sensing images analysis. Land Use Pol. 72, 470–479. https://doi.org/10.1016/j.landusepol.2018.01.013.

Adelekan, I.O., 2019. Urban dynamics, everyday hazards and disaster risk in Ibadan, Nigeria. Environ. Urban. 32 (1), 213–232. https://doi.org/10.1177/0956247819844738.

Adelekan, I., Johnson, C., Manda, M., Matyas, D., Nberu, B.U., Parnell, S., Pelling, M., Satterthwaite, D., Vivkananda, J., 2015. Disaster risk and its reduction: an agenda for urban Africa. Int. Dev. Plan. Rev. 37 (1), 33–43. https://doi.org/10.3828/idpr.2015.4.

Adelekan, I.O., 2010. Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environ. Urban. 22 (2), 433–450. https://doi.org/10.1177/0956247810380141.

Afifi, T., 2011. Economic or environmental migration? The push factors in Niger. Int. Migr. 49 (S1), e95–e124. https://doi.org/10.1111/j.1468-2435.2010.00644.x.

Agyemang, F.S.K., Silva, E., Poku-Boansi, M., 2019. Understanding the urban spatial structure of sub-saharan African cities using the case of urban development pattern of a Ghanaian city-region. Habitat Int. 85, 21–33. https://doi.org/10.1016/j.habitatint.2019.02.001.

Admasu, T.G., 2015. Urban land dynamics, the nexus between land use pattern and its challenges: the case of Hawassa city, southern Ethiopia. Land Use Pol. 45, 159–175. https://doi.org/10.1016/j.landusepol.2015.01.022.

Amaoko, C., 2018. The production of flood vulnerability in Accra, Ghana: re-thinking flooding and informal urbanisation. Urban Stud. 55 (3), 2903–2922. https://doi.org/10.1177/0042098016686526.

Amoateng, P., Finlayson, C.M., Howard, J., Wilson, B., 2018. Dwindling rivers and floodplains in Kumasi, Ghana: a socio-spatial analysis of the extent and trend. Appl. Geogr. 90, 82–95. https://doi.org/10.1016/j.apgeog.2017.11.007.

Bardhan, P., 2002. Decentralization of governance and development. J. Econ. Perspect. 16 (4), 185–205. https://doi.org/10.1257/089533002320951037.

Brandt, M., Hiernaux, P., Rasmussen, K., Mbow, C., Kergoat, L., Tagesson, T., Ibrahim, Y. Z., Wélé, A., Tucker, C.J., Fensholt, R., 2016. Assessing woody vegetation trends in Sahelian drylands using MODIS based seasonal metrics. Remote Sens. Environ. 183, 215–225. https://doi.org/10.1016/j.rse.2016.05.027.
Brida, A.-B., Owiyo, T., 2013. Loss and damage from double blow of flood and drought in Mozambique. Int. J. Glob. Warm. 5 (4), 514–531. https://doi.org/10.1504/IJGW.2013.057291.
Castañeda, A., Doan, D., Newhouse, D., Nguyen, M.O., Uematsu, H., Azevedo, J.P., 2018. A new profile of the global poor. World Dev. 101, 250–267. https://doi.org/10.1016/j.worlddev.2017.08.002.
Chambers, R., 1995. Poverty and livelihoods: whose reality counts? Environ. Urban. 7 (1), 173–204. https://doi.org/10.1177/095624789500700106.
Cobbinah, P.B., Erdiaw-Kwasie, M.O., Amoateng, P., 2015. Africa's urbanisation: implications for sustainable development. Cities 47, 62–72. https://doi.org/10.1016/j.cities.2015.03.013.
Diao, X., Hazell, P., Thurlow, J., 2010. The role of agriculture in African development. World Dev. 38 (10), 1375–1383. https://doi.org/10.1016/j.worlddev.2009.06.011.
Di Baldassarre, G., Montanari, A., Lins, H., Koutsoyannis, D., Brandimarte, L., Bloschl, G., 2010. Flood fatalities in Africa: from diagnosis to mitigation. Geophys. Res. Lett. 37 (22), 1–5. https://doi.org/10.1029/2010GL045467.
Dietler, D., Farnham, A., de Hoogh, K., 2020. Quantification of annual settlement growth in rural mining areas using machine learning. Remote Sens. 12, 235.
Dodman, D., Leck, H., Rusca, M., Colenbrander, S., 2017. African urbanisation and urbanism: implications for risk accumulation and reduction. Int. J. Disaster Risk Reduct. 26, 7–15. https://doi.org/10.1016/j.ijdrr.2017.06.029.
Douglas, I., 2017. Flooding in African cities, scales of causes, teleconnections, risks, vulnerability and impacts. Int. J. Disaster Risk Reduct. 26, 34–42. https://doi.org/10.1016/j.iidrr.2017.09.024.
Douglas, I., Alam, K., Maghenda, M., McDowel, Y., McLean, L., Campbell, J., 2006. Injust waters: climate change, flooding and the urban poor in Africa. Environ. Urban. 20 (1), 187–205. https://doi.org/10.1177/0956247808089156.
Dube, E., Mtapuri, O., Matunhu, J., 2018. Managing flood disasters on the built environment in the rural communities of Zimbabwe: lessons learnt. Jamba Potchefstroom South Afr. 10 (1), 542. https://doi.org/10.4102/jamba.v10i1.542.
Erena, S.H., Worku, H., 2018. Flood risk analysis: causes and landscape based mitigation strategies in Dire Dawa city, Ethiopia. Geoenvironmental Disasters 5 (16), 1–19. https://doi.org/10.1186/s40677-018-0110-8.
Esteves, M., Lapetite, J.M., 2003. A multi-scale approach of runoff generation in a Sahelian gully catchment: a case study in Niger. Catena 50 (2–4), 255–271. https://doi.org/10.1016/S0341-8162(02)00136-4.
Fenta, A.A., Yasuda, H., Haregeweyn, N., Belay, A.S., Hadush, Z., Gebremedhin, M.A., Mekonnen, G., 2017. The dynamics of urban expansion and land use/land cover changes using remote sensing and spatial metrics: the case of Mekelle city of Northern Ethiopia. Int. J. Remote Sens. 38 (14), 4107–4129. https://doi.org/10.1080/01431161.2017.1317936.
Fiorillo, E., Crisci, A., Issa, H., Maracchi, G., Morabito, M., Tarchiani, V., 2018. Recent changes of floods and related impacts in Niger based on the ANADIA Niger flood database. Climate 6 (3), 59. https://doi.org/10.3390/cli6030059.
Florczyk, A.J., Corbane, C., Schiavina, M., Pesaresi, M., Maffenini, L., 2020. Global human settlements database 2015. Joint research center-EU commission. ⟨http://cidportal.jrc.ec.europa.eu/ftp/jrc-opendata/GHSL/GHS_BUILT_S1NODSM_GLOBE_R2018A/GHS_BUILT_S1NODSM_GLOBE_R2018A_3857_20/V1–0/⟩ accessed 2020, 10.26.
Fraser, A., Leck, H., Parnell, S., Pelling, M., 2017. Africa's urban risk and resilience. Int. J. Disaster Risk Reduct. 26, 1–6. https://doi.org/10.1016/j.ijdrr.2017.09.050.
Galligari, A., Giulio Tonolo, F., Massazza, G., 2020. Floodplain settlement dynamics in the Maouri dallol at Guéchémé, Niger: a multidisciplinary approach. Sustainability 12 (14), 5632. https://doi.org/10.3390/su12145632.
Garenne, M., 2016. La pression de la population dans les pays sahéliens francophones: analyse des estimations et projections de population 1950–2100, FERDI working paper 168.
Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: planetry scale geospatial analysis for everyone. Remote Sens. Environ. 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031.
Güneralp, B., Güneralp, I., Liu, Y., 2015. Changing global patterns of urban exposure to flood and drought hazards. Glob. Environ. Chang 31, 217–225. https://doi.org/10.1016/j.gloenvcha.2015.01.002.
Güneralp, B., Lwasa, S., Masundire, H., Parnell, S., Seto, K.C., 2017. Urbanization in Africa: challenges and opportunities for conservation. Environ. Res. Lett. 13, 015002 https://doi.org/10.1088/1748-9326/aa94fe.
Hallegatte, S., Bangalore, M., Bonzaingo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., Vogt-Schilb, A., 2017. Shock Waves: Managing the Impacts of Climate Change on Poverty. The World Bank, Washington. https://doi.org/10.1569/978-1-4648-0673-5.
Hardoy, J.E., Satterthwaite, D. (Eds), 1986. Small and intermediate urban centres. Their role in Regional and national development in the Third World. London, Hodder and Stoughton and IIED.
James, P., Bound, D., 2009. Urban morphology types and open space distribution in urban core areas. Urban Ecosyst. 12, 417–424. https://doi.org/10.1007/s11252-009-0083-1.
Kabanda, T., 2020. GIS modelling of flooding exposure in Dar es Salaam coastal areas. Afr. Geogr. Rev. 39 (2), 134–143. https://doi.org/10.1080/19376812.2019.1650082.
Katiellou, G.L., Tarchiani, V., Tiepolo, M., (Eds.), in press. Risque et adaptation climatique dans la région Dosso, Niger. L'Harmattan, Paris, 320 pp.
Kogo, B.K., Kumar, L., Koech, R., 2021. Analysis of spatio-temporal dynamics of land use and cover changes in Western Kenya. Geocarto Int. 36 (4), 376–391. https://doi.org/10.1080/10106049.2019.1608594.
Laji, A., Ayonga, F.D.J., Mireri, C., 2017. The dual pathways in the process of urban development and their influence on flood damage in Kisumu city, Kenya. Int. J. Sci. Res. Publ. 7 (10). ISSN 2250-3153.
Li, C.-J., Chai, Y.-Q., Yanng, L.-S., Li, H.-R., 2016. Spatio-temporal distribution of flood disasters and analysis of influencing factors in Africa. Nat. Hazards 82, 721–731. https://doi.org/10.1007/s11069-016-2181-8.
Malarvizhi, K., Vasantha Kumar, S., Porchelvan, P., 2016. Use of high resolution Google Earth Satellite imagery in land use map preparation for urban related applications. Procedia Technol. 24, 1835–1842. https://doi.org/10.1016/j.protcy.2016.05.231.
Megersa, T., Tulu, T., Argaw, M., 2018. Effects of urban land use/cover dynamics on peri-urban natural environment in Nekemte city, Oromia, Ethiopia. Int. J. Energy Environ. Sci. 3 (3), 51–60. https://doi.org/10.11648/j.ijees.20180303.11.
Melchiorri, M., Florczyk, A.J., Freire, S., Schiavina, S., Pesaresi, M., Kemper, T., 2018. Unveiling 25 years of planetary urbanization with remote sensing: perspectives from the global human settlement layer. Remote Sens. 10, 768. https://doi.org/10.3390/rs10050768.
Mercandalli, S., Losch, B. (Eds.), 2017. Rural in motion. Dynamics and drivers of migration South of the Sahara. FAO and CIRAD, Rome.
Musungu, K., Drivdal, L., Smit, J., 2016. Collecting flooding and vulnerability information in informal settlements: the governance of knowledge production. South Afr. Geogr. J. 98 (1), 84–105. https://doi.org/10.1080/03736245.2015.1117013.
Nchito, W.S., 2007. Flood risk in unplanned settlements in Lusaka. Environ. Urban. 19 (2), 539–551. https://doi.org/10.1177/0956247807082835.
Nkeki, F.N., 2016. Spatio-temporal analysis of land use transition and urban growth characterization in Benin metropolitan region, Nigera. Remote Sens. Appl. Soc. Environ. 4, 119–137. https://doi.org/10.1016/j.rsase.2016.08.002.
OECD-Organisation for Economic Co-operation and Development/Statistics, 2020. Built-up area and built-up area change in countries and regions, ⟨https://stats.oecd.org/Index.aspx?DataSetCode=BUILT_UP⟩.
OPHI-Oxford Poverty and Human development Initiative, 2018. Global multidimentional Poverty Index 2018: The most detailed picture to date of the World's poorest people. University of Oxford, UK.
Nkwunonwo, U.C., Whitworth, M., Baily, B., et al., 2016. Review article: A review and critical analysis of the efforts towards urban flood risk management in the Lagos region of Nigeria. Nat. Hazards Earth Syst. Sci. 16, 349–369. https://doi.org/10.5194/nhess-16-349-2016.
Oruonye, E.D., 2013. An assessment of flood perception and response in Jalingo metropolis, Taraba State, Nigeria. Int. J. For. Soil Eros. 3 (4), 113–117.
Osuteye, E., Johnson, C., Brown, D., 2016. The data gap: an analysis of data availability on disaster losses in sub-Saharan African cities. Working paper 11 Urban Africa Risk Knowledge.
Panwar, V., Sen, S., 2020. Disaster damage records of EM-DAT and Desinventar: a systematic comparison. Econ. Disasters Clim. Chang. 4, 295–317. https://doi.org/10.1007/s41885-019-00052-0.
Potere, D., Schneider, A., Angel, S., Civco, D.V., 2009. Mapping urban areas on a global scale: which of the eight maps now available is more accurate? Int. J. Remote Sens. 30 (24), 6531–6558. https://doi.org/10.1080/01431160903121134.
Potts, D., 2012. Challenging the myths of urban dynamics in Sub-Saharan Africa: the evidence from Nigeria. World Dev. 40 (7), 1382–1393. https://doi.org/10.1016/j.worlddev.2011.12.004.
Potts, D., 2012. Viewpoint: what do we know about urbanisation in sub-Saharan Africa and does it matter? Int. Dev. Plan. Rev. 34 (1), v–xxii. https://doi.org/10.3828/idpr.201.
RN-Republic of Niger, 2015a. Loi n° 2015–01 du 13 janvier 2015 portant statut de la chefferie traditionnelle en République du Niger.
RN, 2015b. Recensement general de la population et de l'habitat 2012. État et structure de la population du Niger en 2012. Niamey, INS.
RN, 2014. ReNaLoc-Répertoire National des Localités. Institut National de la Statistique du Niger, Niamey.
RN-Institut National de la Statistique, Banque Mondiale, 2013. Profil et determinants de la pauvrété au Niger en 2011. Premièrs résultats de l'enquête nationale sur les conditions de vie de s menages et de l'agriculture au Niger. INS, Niamey.
Rondinelli, D., 1985. Applied Methods of Regional Analysis. The Spatial Dimensions of Development Policy. Westview Press, reprint New York, Routledge, 2018.
Sakijege, T., Lupala, J., Sheuya, S., 2012. Flooding, flood risks and coping strategies in urban informal residential areas: the case of Keko Machungwa, Dar es Salaam, Tanzania. Jàmbá 4 (1), 10. https://doi.org/10.4102/jamba.v4i1.46.
Sam, K., 2014. Changing land use and land cover in fringe area using GIS: a case study of Barddhaman town, West Bengal. Int. J. Geomat. Geosci. 5 (2), 243–252. ISSN: 0976-4380.
San Emeterio, J.L., Alexandre, F., Andrieu, J., Génin, A., Mering, C., 2013. Changements socio-microenvironnamentaux et dynamiques des paysages ruraux le long du gradient bioclimatique nord/sud dans le sud-ouest du Niger (regions de Tillabery et de Dosso). VertigO 13 (3) doi: 10.400/vertigo.14456.
Satterthwaite, D., 2017. The impact of urban development on risk in sub-Saharan Africa's cities with a focus on small and intermediate urban centers. Int. J. Disaster Risk Reduct. 26, 16–23. https://doi.org/10.1016/j.ijdrr.2017.09.025.
Scoones, I., 2009. Livelihoods perspectives and rural development. J. Peasant Stud. 36 (1), 171–196. https://doi.org/10.1080/03066150902820503.
Simwanda, M., Muryama, Y., 2017. Integrating geospatial techniques for urban land use classification in the developing sub-saharan African city of Lusaka, Zambia. Int. J. Geo-Inf. 6 (4), 102. https://doi.org/10.3390/ijgi6040102.

Sumari, N.S., Cobbinah, P.B., Ujoh, F., Xu, G., 2020. On the absurdity of rapid urbanization: spatio-temporal analysis of land-use changes in Morogoro, Tanzania. Cities 107, 102876. https://doi.org/10.1016/j.cities.2020.102876.
Tazen, F., Diarra, A., Kabore, R.F.W., Ibrahim, B., Traoré, M.B., Traoré, K., Karambiri, H., 2018. Trends in flood events and their relationship to extreme rainfall in an urban area of Sahelian West Africa: the case study of Ouagadougou, Burkina Faso. J. Flood Risk Manag. 12, e12507 https://doi.org/10.1111/jfr3.12507.
Tena, T.M., Mwaanga, P., Nguvulu, A., 2019. Impact of land use/land cover change on hydrological components in Chongwe river catchment. Sustainability 11, 6415 doi: 103390/su11226415.
Tarhule, A., 2005. Damaging rainfall and flooding: the other Sahel hazards. Clim. Chang. 72, 355–377. https://doi.org/10.1007/s10584-005-6792-4.
Tiafack, O., Mbon, A.M., 2017. Urban growth and front development development on risk zones: GIS application for mapping of impacts on Yaoundé North western highlands, Cameroun. Curr. Urban Stud. 5, 217–235. https://doi.org/10.4236/cus.2017.52013.
Tiepolo, M., Bacci, M., Braccio, S., 2018. Multihazard risk assessment for planning with climate in the Dosso region, Niger. Climate 6, 67. https://doi.org/10.3390/cli6030067.
Tiepolo, M., Braccio, S., 2020. Mainstreaming disaster risk reduction into local development plans for rural tropical Africa: a systematic assessment. Sustainability 12, 2196. https://doi.org/10.3390/su12062196.
UNDESA-United Nations Department of Economic and Social Affairs, 2019. 2018 Demographic Yearbook. United Nations, New York.
UNDESA-United Nations Department of Economic and Social Population Division, 2018. World urbanization prospects: The 2018 revision, United Nations, New York.
Valentin, C., Rajot, J.-L., Mitja, D., 2004. Responses of soil crusting, runoff and erosion to fallowing in the sub-humid and semi-arid regions of West Africa. Agric. Ecosyst. Environ. 104, 287–302. https://doi.org/10.1016/j.agee.2004.01.035.
Walker, G., Burningham, K., 2011. Flood risk, vulnerability and environmental justice: Evidence and evaluation of inequality in a UK context. Crit. Soc. Pol. 31 (2), 216–240. https://doi.org/10.1177/0261018310396149.
Wisner, B., Pelling, M., Mascarenhas, A., Holloway, A., Ndong, B., Faye, P., Ribot, J., Simon, D., 2015. Small cities and towns in Africa: insights into adaptation challenges and potentials. Vulnerability and Climate Change in Africa. Springer, pp. 153–194. https://doi.org/10.1007/978-3-319-03982-4_5.
Voigt, S., Giulio Tonolo, F., Lyons, J., Kucera, J., Jones, B., Schneiderhan, T., Platzeck, G., Kaku, K., Hazarika, K.M., Czaran, L., Li, S., Pedersen, W., James, G.K., Peoy, C., Muthike, D.M., Bequignon, J., Guha-Sapir, D., 2016. Global trends in satellite-based emergency planning. Science 353 (6296), 247–252. https://doi.org/10.1126/science.aad8728.
Wang, P., Huang, C., Brown de Colstoun, E.C., Tilton, J.C., Tan, B., 2017. Global Human Built-up And Settlement Extent (HBASE) Dataset from Landsat. NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY.