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Individual perceptions on rainfall variations versus precipitation trends from satellite data: An interdisciplinary approach in two socio-economically and topographically contrasted districts in Abidjan, Côte d'Ivoire

Artadji Attoumane [a], Stéphanie Dos Santos [a, b, *], Modeste Kacou [c], Alla Della André [c], Abdul Wahab Karamoko [a, b], Luc Seguis [d], Eric-Pascal Zahiri [b]

[a] *Laboratoire Population Environnement Développement (LPED), IRD, AMU, Marseille, France*
[b] *Institut de Géographie Tropicale (IGT), Université Félix Houphouët-Boigny, Abidjan, Cote d'Ivoire*
[c] *Laboratoire des Sciences de la Matières, de l'Environnement et de l'Energie Solaire (LASMES), Université Félix Houphouët-Boigny, Abidjan, Cote d'Ivoire*
[d] *HydroSciences Montpellier (HSM), Université de Montpellier, CNRS, IRD, Montpellier, France*

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ABSTRACT

Global climate projections show that rising trends in precipitation very probably contribute to the resurgence of the risk of flooding in African cities. There remain however uncertainties regarding the patterns of change in past and future precipitation in the countries of West Africa. There are still too few studies focus on the individual perceptions of populations in Africa on these climate changes, although this is an essential lever for the implementation of warning systems. The aim of present study is to consider in parallel the perceptions of the residents of the city of Abidjan regarding the variability of precipitation and the meteorological data. A survey among 503 individuals was carried out at Abidjan in two districts with contrasted topographical profiles, socio-economic conditions and exposure to flooding, in order to record their perceptions regarding the variations in precipitation between 2009 and 2018. The CHIRPS precipitation data was used to calculate the trends in the climate indicators with the Mann-Kendall method. The results show that there is a similarity between the perception of individuals surveyed and an increasing trend in days of rainfall of more than 50 mm and intensity of precipitation.

1. Introduction

Global climate projections show that the increasing trends in extreme precipitation will very probably contribute to the resurgence of the risk of flooding in the cities in the course of the coming century [1,2]. Worldwide, an overall increase in very wet days has been observed in countries situated in intermediate latitudes of the northern hemisphere and in Australia [3]. In Europe, the generally rising trend in precipitation and in its intensity has been demonstrated on the basis of daily rainfall data [4,5]. In a review of the literature focused on Latin America and the Caribbean and analysing the impact of climate change on various sectors, Reyer et al. [6] concluded in an increase in the intensity of cyclones and the frequency of storms by the end of the century. In Asia, Su et al. [7] and Saddique et al. [8] evidenced an increase in extreme precipitation.

* Corresponding author. Laboratoire Population Environnement Développement (LPED), IRD, Aix-Marseille Université, Centre St Charles, case 10, 3 place Victor Hugo, Marseille, cedex 03, 13331, France.
E-mail address: Stephanie.DosSantos@ird.fr (S. Dos Santos).

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Nevertheless, if the simulated precipitation models of the last century show a greater intensity of precipitation compared to the mean annual precipitation in several regions of the world [9], these simulations remain very uncertain in the tropical and subtropical regions [10].

In particular, in the tropical and subtropical regions of Africa, there remains considerable uncertainty regarding the patterns of change in past and future precipitation. Several studies have confirmed a decline in the quantity of precipitation over the last century, in particular in sub-Saharan Africa [10–12]. In parallel, an increase in precipitation in the coming decades is forecast in certain studies [13,14] whereas others consider the uncertainties too great [15]. In Côte d'Ivoire, it would appear difficult to detect a change in precipitation in the country as a whole and at daily scale [16,17]. However, in a recent study, Yapo et al. [18] have shown, on the basis of CORDEX-Africa simulations models, that the coastal zone of Côte d'Ivoire will see an increase in extreme precipitation of 50–60% between the present and the end of the century compared to the period 1976—2005, their period of reference.

In parallel with this uncertainty regarding knowledge of the physical reality of the climate in sub-Saharan Africa, the populations may have their own perception of the variability of precipitation. In this respect, perceptions on climate change in general, and pluviometric patterns of change in rainfall in particular, are increasingly the focus of research in Africa, in particular because a good understanding of these phenomena is essential for the planning, the deployment and the acceptance of strategies for adaptation in the face of climate change [19]. The populations are increasingly concerned by climate change trends [20]. An analysis of precipitation in terms of the levels and trends in the pluviometry would in addition offer a basis for assessing the perception of risks related to possible extreme rainfall episodes. The analysis of perceptions regarding an extreme event is relevant because it is from these perceptions that actions may then follow, according to the sociologist Erwing Goffman [21] and his frame of analysis. This gives rise to a perception of the risk related to this event. These reference frameworks are multidimensional, differ from one individual to another and even more so from one social group to another, and are replenished at once by knowledge, by objective and subjective interpretation (itself produced by life experiences) and by social conventions regarding the issues (social norms in particular). But knowledge of the risks encourages more efficient preparation and better adaptation to natural risks [21] and thus mitigates vulnerability in the face of climatic hazards.

In a second stage, it was shown that the divergence between these two phenomena contributes to greater vulnerability in the face of extreme events [22,23]. Thus, the comparison of perceptions and quantitative pluviometric measurements is a source of knowledge that may reduce vulnerability.

Furthermore, in order to better tailor the message regarding prevention to the population, it is necessary and moral responsibilities of policy makers and planners to know the convergences and divergences between the perceptions and these quantitative measurements.

Finally, it should be noted that this perception provides a more localised observation of climatic variability that cannot necessarily be characterised by the meteorological data [3].

The literature thus reveals that a decline in precipitation over the past 30 years would appear to be the most widely documented opinion for West Africa [24], in particular on the basis of surveys carried out in Burkina Faso [24,25], Benin [26,27] and Ghana [19,28]. In parallel with this perception of a decline in precipitation, the populations surveyed perceive an intensification of precipitation [29,30], in addition to the idea that the rainy season is different today compared to the last decades, with the rainy season starting later, ending sooner and of shorter duration [24,28]. This perception of increased rainfall could be shaped, on the one hand, by the observation of climate trends which show a strong probability of increased intensity of extreme rainfall since the 2000s in Sahelian West Africa [31,32], and, on the other hand, by the observation of the occurrence of flooding events which are becoming more and more frequent [33].

In a recent review of the literature, De Longueville et al. [24] found that the studies carried out on the perception of climate change in Africa, in particular in West Africa, do not systematically include a comparison with the meteorological data. Those that have done so show either a convergence or a divergence between the perception and the measured data. With regard to the question of the variability of precipitation, several studies have proved the existence of a divergence between the perception and the measured data [24,26,34,35] while certain have established a convergence [36,37].

In recent years, the capitals of the sub-Saharan intertropical zone have undergone major flooding: Niamey (Niger) in 1998 [38–40], Addis Ababa (Ethiopia) in 2006 [41], Abeokuta (Nigeria) in 2007 [42], Ouagadougou (Burkina Faso) in 2009 [43]. Abidjan, the economic capital of Côte d'Ivoire, has not been spared and has also been subjected to frequent flooding over the past ten years [44–46]. The present study therefore seeks to determine the similarities and the divergences between the perceptions of individuals surveyed regarding the variability of precipitation and the trends observed in the meteorological data at Agbekoi and Palmeraie, two contrasted districts (disadvantaged and residential). To this end, we have analysed the results of a survey based on a questionnaire which we have considered in parallel with analyses on the trends observed in the metric indices of precipitation. The perception of individuals has been spatialised to show its intra- and inter-district heterogeneity.

2. Methodology

2.1. Description of the two contrasted study sites

In the framework of the Evidence[1] project, this research has been carried out at two districts of the conurbation of Abidjan, the economic capital city of Côte d'Ivoire: Agbekoi, in the municipality of Abobo, and Palmeraie in the municipality of Cocody (see Fig. 1 in annex). The Abidjan district is under the influence of an equatorial climate with four seasons: the long rainy season (March — July), the short dry season (August — September), the short rainy season (October — November) and the long dry season (December — March). The long rainy season begins on average on 23rd March and ends on 31st July [47]. According to Kouassi et al. [48], two thirds of the annual rainfall is recorded during the long rainy season.

Agbekoi (Fig. 1a) has an area of 1.35 km^2, and is located in the north of the city of Abidjan. The north and the west of the neighbourhood are areas where the altitude is over 35 m while the eastern zone is on the edge of a ravine where the slope may reach 22° maximum. This ravine virtually subdivides the neighbourhood into two sides: the 'south-west side' and the 'north-east side' (Fig. 1a). Palmeraie (Fig. 1b) has an area of 2.40 km^2, and is situated in a low-lying area where the altitude does not exceed 65 m over more than 55% of the total area of the neighbourhood. The 'east side' of the neighbourhood is a relatively high area where the altitude may be as much as 85 m. The two canals subdivide the neighbourhood of Palmeraie into three zones: the 'centre', the 'east side' and the 'west side' (Fig. 1b). The choice of these sites is based first of all on the fact that these two districts are in two municipalities, respectively Abobo and Cocody, where the risk of flooding is very high [46,49].

Furthermore, these two districts exhibit very contrasted habitats. Agbekoi is characteristic of a precarious disadvantage habitat [50], densely populated and longstanding [51], the configurations of which have changed little over the past ten years, like the surrounding districts. In contrast, Palmeraie is a residential neighbourhood recently urbanised over the past fifteen years and located at the time on the outskirts of the urbanised area of the municipality of Cocody.

Finally, at this stage of our knowledge of the site, we might formulate the hypothesis that the two districts differ in the type of flooding phenomena that impact them. Both districts are mainly exposed to pluvial floods caused by heavy rainfall that is not absorbed by the land and then runs over land and urban surfaces before reaching the drainage system and natural watercourses [52]. Pluvial floods are one type of urban floods that cause more damage to buildings, housing and household property [52,53]. The impermeability of the land resulting from urbanisation above the neighbourhood of Palmeraie may contribute to brief, intensive and frequent floods through the overflowing of drainage channels that are today under-dimensioned. In contrast, the combination of the steep slope at Agbekoi with a densely populated habitat may be seen as a factor favouring phenomena of more or less widespread runoff in the streets resulting in particular from the absence of a network of drains for sewage and in particular rainwater.

2.2. Collection of data for the survey

We carried out an initial survey by interview with the local authorities in the field to determine the level of risk of flooding or runoff at the scale of the enumeration areas (EAs). The EAs with a high risk of flooding or runoff cover 58% of the total area at Agbekoi and 54% at Palmeraie. These proportions were applied for the distribution of 250 individuals to survey in each district in order to attempt to achieve a certain spatial representativeness of the sample relative to the flooding phenomenon studied.

On a background of satellite images, we randomly generated 250 points over the area of each of the two districts. By means of a map and a GPS, we detected the households that are positioned at each randomly chosen point. We interviewed the head or an adult of the families of the households situated solely on the ground floor.

The survey was carried out from 7th to December 30, 2018. 503 persons were finally[2] surveyed (Fig. 1a and 1 b). They responded to a questionnaire related to various themes linked to flooding, and recording the socio-demographic and economic characteristics of the households. The questions (closed-ended and open-ended questions) concerning the perception of the characteristics of the rain over the past ten years reflect the individual perception of the person responding to the questionnaire regarding the beginning, the end and the duration of the rains, the rainiest year, the quantity of rain, the intensity of the precipitation and extreme rainfall episodes (see questionnaire in annex, Table 1). Free and informed consent of the participants or their legal representatives was obtained before starting the questionnaire.

2.3. Meteorological data

In the absence of meteorological data from ground observation in the two districts, we used CHIRPS (Climate Hazards Group Infrared Precipitation) satellite data. This product developed by experts from the Climate Hazards Group provides estimations of precipitation at a spatial resolution of 0.05°*0.05° (or ≈ 25 km^2) based on records from synoptic meteorological stations and measurements from infrared observations of clouds [54]. These data are available for the whole of the African continent from 1981 to the present by downloading free of charge online.[3] The quality of the CHIRPS data was assessed on the basis of synoptic station data from five countries in West Africa, including Côte d'Ivoire, and shows a significant correlation coefficient of above 80%, which indicates an acceptable agreement between the two sets of data [55].

[1] EVIdENCE "*Évènements pluvieux extrêmes, vulnérabilité aux inondations et à la contamination des eaux*" (Extreme rainy events, vulnerability to flooding and to the contamination of water) is a project based at Abidjan of which the main aim is to contribute to the mitigation of risks associated with extreme rainfall impacting the living conditions of urban populations (http://www.evidence-ci.org/).

[2] In the field, it turns out that 3 households randomly selected were not available at the time the interviewer was in that zone. The interviewer then interviewed the nearest household with the same selection characteristics. After a few days, these households expressed their desire to participate in the survey and the interviewer collected their questionnaire. We considered these 3 additional households to be more positive than statistically biased. We therefore kept them in the database.

[3] https://www.chc.ucsb.edu/data/chirps.

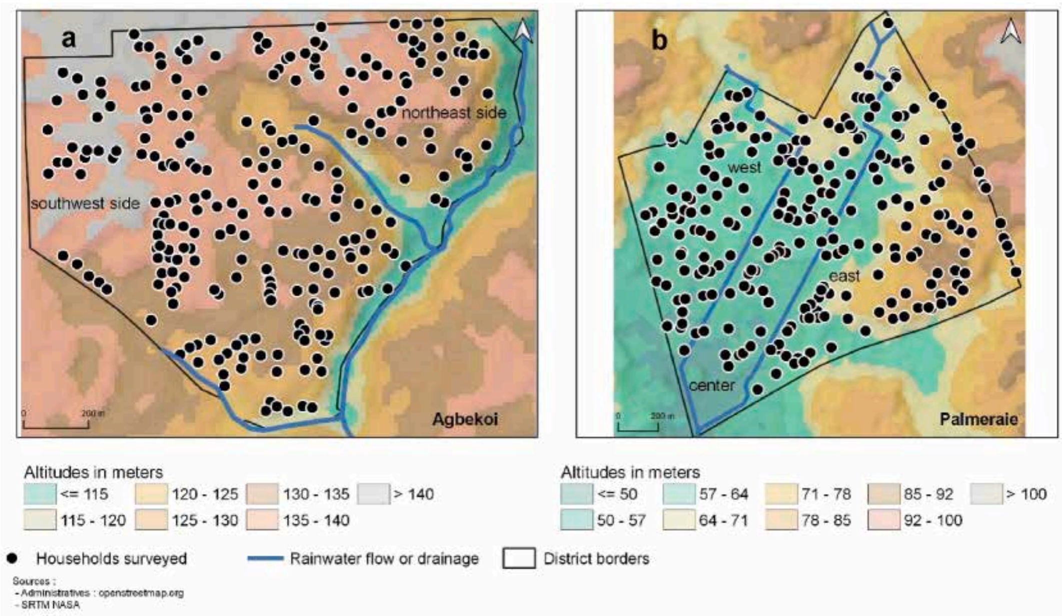

Fig. 1. Topographical profiles of the districts and localisation of the individuals surveyed.

Table 1
Definition of climate indices chosen to calculate trends.

Perception questions	Climate indices	Definition	Unit
Rainfall quantity	PRCPTOT	Annual total precipitation in wet days	mm
	PRCPTOT ≥ 50	Annual total precipitation when the daily precipitation ≥ 50 mm	mm
Precipitation intensity	SDII	Simple precipitation intensity index	mm/day
Extreme rainfall	R95pTOT	Annual total precipitation when the daily precipitation > 95 th percentile	mm
	R99pTOT	Annual total precipitation when daily precipitation > 99 th percentile	mm
Rainiest year	R20mm	Annual count of days when the daily precipitation ≥ 20 mm	day
	R50mm	Annual count of days when the daily precipitation ≥ 50 mm	day
Long rainy season	Onset	Starting day of raining	day
	End	Ending day of raining	day
	Length	Number of days between starting and ending of raining	day

To justify this choice of sites for the study, we undertook a comparison of the spatial data with the available ground data. This first concerns the precipitation data from the synoptic station at Félix Houphouët-Boigny International airport (DIAP). For this station, the monthly precipitation data cover a very long historical period from 1960 to 2012. We also made use of the data from the automatic station at Ste Foi in the municipality of Abobo less than 2 km from the neighbourhood of Agbekoi, a station installed under the ÉVIDENCE project. For this station, the data are daily for a very recent period, from 2016 to 2019. This comparison with the two data sources was carried out to validate the use of CHIRPS satellite data at the scale of two districts to study rainfall trend between 1984 and 2018.

The Pearson correlation coefficient, the RMSE (Root Mean Square Error) and the bias are the three metric indices that we have used, and that are generally used, to validate the spatial climatic data relative to the ground data [56–59].

We observed a good correlation between the CHIRPS data and the ground data. For the period from 1984 to 2012, there is good agreement of the monthly accumulated precipitation data between the DIAP station and CHIRPS with a Pearson correlation coefficient of 0.86 and a p-value « 0.05 (see Fig. 2 in annex). The consistency is all the more remarkable with the mean monthly precipitation for the period from 2016 to 2019 at the Ste Foi station where the Pearson correlation coefficient is 0.90 with a p-value « 0.05 (see Fig. 3 in annex).

It may be noted, however, that the precipitation is slightly underestimated by the satellite data. In particular, at the Ste Foi station, the bias is 1.02 mm per day. For the recent period from 2016 to 2019, a difference may be observed of 50 mm during the rainiest months (May, June and October) between the CHIRPS and Ste Foi data (see Fig. 4 in annex). It is lower during the remaining months.

These analyses show that the CHIRPS data are of good quality to study past trends in climatic indicators in the two study districts.

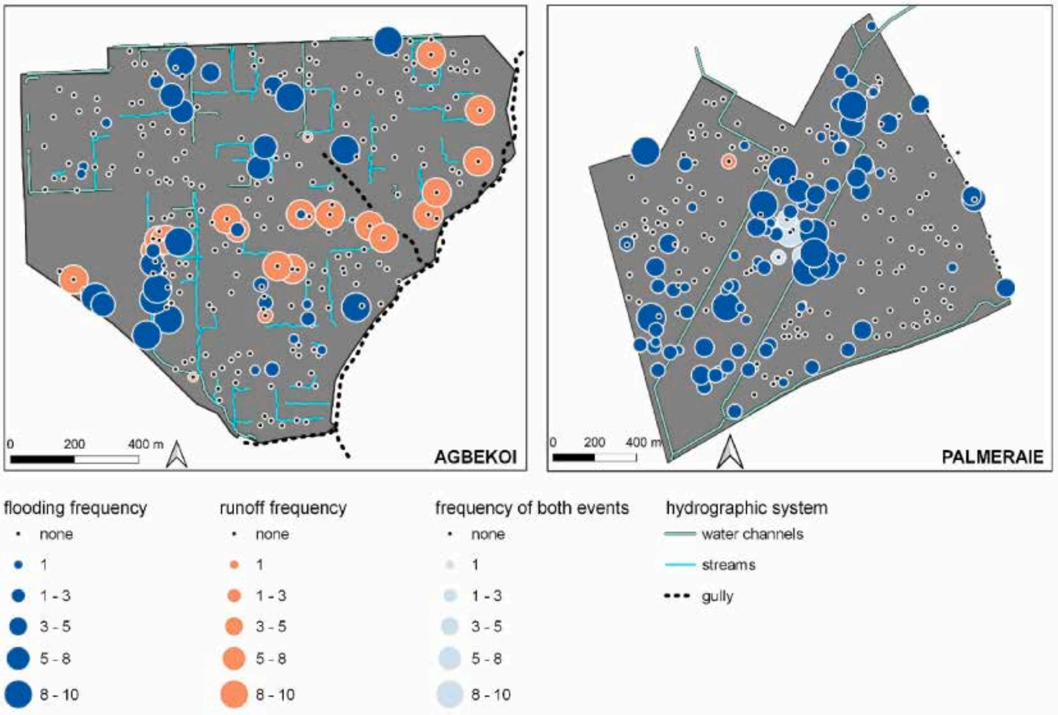

Fig. 2. Map showing the frequency of flooding and runoff at the scale of the households of individuals surveyed.

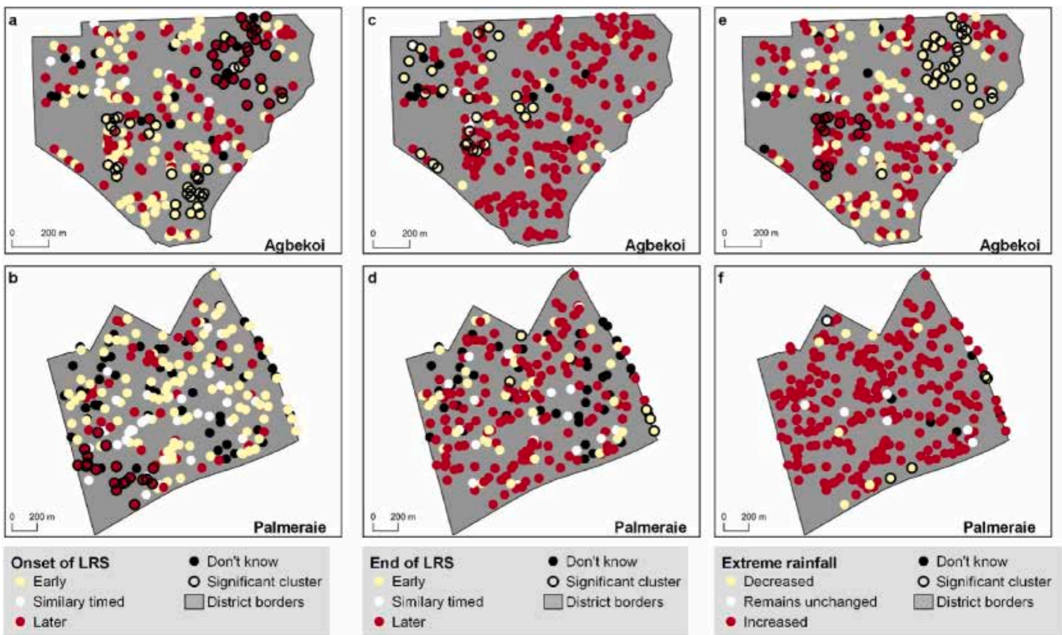

Fig. 3. Spatial representation of the perception of individuals surveyed and of clusters regarding the question of the beginning and the end of the long rainy season and intensity of precipitation and of extreme rainfall.

2.4. Statistical analyses

2.4.1. Descriptive analyses of socio-economic variables and of flooding phenomena

In our survey, we have collected information which describes the socio-economic conditions of the individuals interviewed regarding their habitat, in particular the type of dwelling, the occupation status of the dwelling, the monthly rent and the number of years of residence in the neighbourhood. In order to analyse these variables, we have translated the qualitative responses into percentage proportions in each neighbourhood. A chi-squared test was applied to analyse the contingence of the qualitative responses.

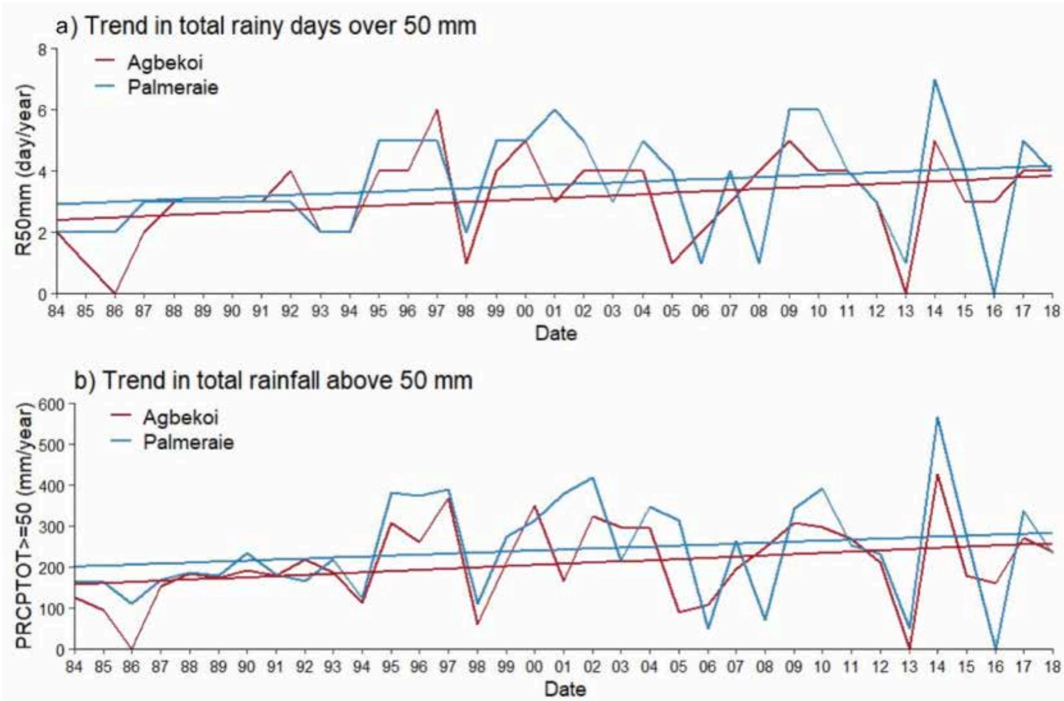

Fig. 4. Patterns of change in trends in R50mm and PRCPTOT ≥ 50 from 1984 to 2018 between the two districts.

Where chi-squared is significant, we performed a post-hoc analysis based on the residues, by adjusting the p-values with the method of correction of multiple tests of Bonferroni [60]. There is a significant difference if the p-value is lower than 0.05.

We also collected the testimony of the same people surveyed regarding the frequency of flooding or runoff impacting their dwellings during the period 2009–2018. Household flooding is considered as the submersion and stagnation of rainwater in significant amounts in the household environment. In contrast, household runoff is the runoff of a significant amount of rainwater into the households' environment without stagnation. Therefore, individuals interviewed were asked to indicate which phenomenon occurred in their residence between flooding and runoff (none, runoff, flooding, or both) and after the investigator has explained the difference between the two phenomena. To measure the severity of these phenomena, the individuals surveyed were required to give an estimation of the maximum water level ("below ankle level", "ankle level", "calf level", "knee level", "above knee level") reached during the most spectacular event (flooding or runoff) and to specify the average duration ("less than 1 h", "less than half a day", " one day" and "more than one day"). A variance test was used to show the existence of a difference in the frequency of flooding or runoff between the two districts. A difference is significant if the probability value is below 0.05 [61,62]. These statistical tests were done using the 'stats' package of R software [63]. A map showing the frequency of flooding and runoff was made at the scale of persons surveyed with QGIS software [64]. This map is used to superimpose the perception of persons surveyed on the changes in precipitation and their experience of flooding.

2.4.2. Description and determination of clusters of perception of individuals

To describe the perception of individuals surveyed regarding the changes in precipitation during the last ten years (2009–2018), we first attributed a score on a scale of three points to questions relative to the amount of water, the intensity of the rain, extreme rainfall, the beginning, end and duration of the long rainy season. The 'much decreased' and 'somewhat decreased' responses were grouped into a single 'decreased' modality with a weight of 1. The responses 'much increased' and 'a little increased' were grouped into 'increased' with a weight of 3. The responses 'much stronger' and 'a little stronger' were grouped into 'stronger' with a weight of 3. These groupings are justified because individuals do not base their responses on a specific measure, but on a perception of the general change [65]. A weighting of 2 was attributed to the intermediate responses 'remained the same' and 'remained unchanged'. This scale was applied to the responses for the long rainy season. The response 'don't know' was not included in the analysis, but solely represented on the map.[4] A score from 1 to 10 (from the earliest to the most recent year) was attributed to the question on the perception of the rainiest year. We then calculated the mean of the responses to the questions, and applied a Mann-Whitney non-parametric *U* test [66] using the 'stats' package of R software [63].

In a second stage, we calculated the Moran's I global index to determine the nature of the spatial distribution of these perceptions at the scale of the districts. Our assumption is that the spatial distribution of the weight of each response is independent across individuals surveyed. This method tests this hypothesis by measuring whether the persons surveyed have a perception that is close to that

[4] Over the full set of questions asked, the response 'don't know' represented on average 6% at Agbekoi and 10% at Palmeraie.

of their neighbours. There is a similarity of perception of the closest individuals surveyed if the index is positive, and it is dispersed in the contrary case. The distribution of the perception of individuals surveyed is random if the index is null. We also calculated the Anselin Local Moran's I index for each localisation in order to determine the clusters of households having a similar perception [67]. The Moran's I global index gives a single value for the similarity of all the individuals surveyed of the neighbourhood whereas the local index provides a value of similarity of each individual and their neighbours. The local index thus enables us to determine the neighbouring individuals surveyed who form a cluster by the similarity of their perception. We used the package 'spdep' developed under R [68] to calculate these two indicators. The values of the two indices are significant if $z < -1.96$ or $z > 1.96$ with a p-value below 0.05. By using the geographical data of the households, the perception and the clusters were mapped using the software QGIS [64].

2.4.3. Calculation of the climate indices trends

Indices of climate variability for precipitation, established by the Expert Team on Climate Change Detection and Indices (ETCCDI) [69], were calculated and used for comparison with the perception of persons surveyed (Table 1).

These climate variability indices were calculated using the package 'climdex.pcic' under R [70]. The software R-Instat.0.6.2 (Copyright [C] 2015–2018 African Maths Initiative [AMI]) was used to calculate the dates of the beginning and the end of the long rainy season. These dates were determined using the method of Sivakumar [71]. The duration of the long rainy season corresponds to the difference between the two dates.

The climate indices trends were determined using the test of Mann-Kendall [72]. Before using the test of Mann-Kendall, the test for autocorrelation of rainfall series was analysed using the Durbin-Watson test [73]. This test, carried out in R using the 'lmtest' package [74], exhibit no autocorrelation in the rainfall series as the Dubrin-Watson coefficients are greater than 0 (DW = 1.80 at Agbekoi and DW = 1.79 at Palmeraie) and not significant (p-value > 0.05). Therefore, the Mann Kandall test can be used without correction of the rainfall series. It is assumed initially that there was no stationarity in the series of each index. The non-parametric Mann-Kendall test can be used to examine whether there is stationarity in the series or not. The details of the calculations using this approach have been extensively described by Libiseller [75]. The identification of the trend in the couple series is done by observing the value z and the rate. A positive value for these two indices indicates a rising trend (increase) in the series, and a falling trend (decrease) the opposite. These indices are significant if the p-value is below 0.05. This test was applied using the package 'trend' under R [76].

3. Results

3.1. Two sites with contrasted socio-economic conditions and flooding phenomena

In this study, we have identified certain socio-economic characteristics which show the contrast between the two districts with regard to the conditions of the habitat of the individuals interviewed (Table 2). At Palmeraie, the people surveyed reside for the most

Table 2
Socio-economic variables characteristic of the habitat of the individuals surveyed.

Variables	Agbekoi n = 252	Palmeraie n = 251	X^2	p-value
Residential status				
Owner	37.70[31.75–44.03]	54.58[48.20–60.82]	7.60	< 0.01
Tenant	53.17[46.82–59.44]	27.89[22.52–33.95]	20.08	< 0.001
Free accommodation	2.38[0.97–5.36]	17.13[12.80–22.50]	27.94	< 0.001
Family home	6.75[4.10–10.77]	0.40[0.02–2.55]	14.22	< 0.01
Type of dwelling				
Villa	2.38[0.97–5.36]	59.76[53.39–65.83]	132.92	< 0.001
Hut	0.40[0.02–2.54]	16.33[12.10–21.63]	38.10	< 0.001
Apartment in an apartment block	1.98[0.73–4.83]	14.74[10.72–19.88]	24.38	< 0.001
Communal courtyard/concession	64.68[58.40–70.51]	2.39[0.98–5.38]	145.85	< 0.001
Individual communal courtyard	22.62[17.71–28.38]	3.19[1.49–6.42]	36.94	< 0.001
Terrace housing	6.75[4.10–10.77]	–	–	–
Detached housing	1.19[0.31–3.73]	3.59[1.76–6.93]	3.00	1
Rent				
Less than 30 000	37.70[31.75–44.03]	5.98[3.50–9.86]	58.18	< 0.001
[31 000–50 000]	13.49[9.65–18.48]	1.99[0.74–4.85]	21.56	< 0.001
[51 000–100 000]	1.59[0.51–4.29]	7.57[4.74–11.75]	9.78	< 0.01
[101 000–150 000]	0.40[0.02–2.54]	1.99[0.74–4.85]	2.67	0.741
[151 000–200 000]	–	3.984[2.04–7.43]	–	–
[201 000–300 000]	–	3.586[1.76–6.93]	–	–
More than 300 000	–	2.789[1.23–5.90]	–	–
Non-tenant	46.83[40.56–53.18]	72.112[66.05–77.48]	13.27	< 0.001
Length of residence				
Less than 5 years	4.76[2.60–8.38]	15.94[11.75–21.19]	15.08	< 0.001
[5–9] years	16.27[12.05–21.54]	23.11[18.14–28.92]	2.92	0.538
[10–19] years	18.25[13.80–23.70]	45.02[38.79–51.40]	28.23	< 0.001
[20–29] years	22.62[17.71–28.38]	14.74[10.72–19.88]	4.26	0.234
More than 30 years	38.10[32.13–44.43]	1.20[0.31–3.74]	87.36	< 0.001

part in villas (60%), huts (16%) and apartments (15%), habitat conditions ranked as of high or intermediate standing.[3] Furthermore, they are mostly owners of their dwelling (54%), and those who are tenants (28%) pay monthly rent of 51 000 to 100 000 CFA francs (or 78 to 153 euros). This sum is a considerable financial burden in a country where the gross domestic income (GDI) per inhabitant was close to 1 200 000 CFA francs per year in 2018 [77]. It should be pointed out too that most people surveyed have been resident in the neighbourhood for less than 20 years. Palmeraie is thus a fairly recent neighbourhood where people with high socio-economic conditions reside.

At Agbekoi, people surveyed mostly reside in a communal courtyard (65%). A communal courtyard is a group of houses with brick walls and a corrugated iron roof giving onto a central courtyard, a type of habitat classified as economically mobile.[3] The residents in this type of habitation are for the most part tenants (53%) who pay monthly rent below 30 000 CFA francs (less than 50 euros) in the case of 38% of the individuals surveyed at Agbekoi. In this neighbourhood, the majority of people surveyed have been resident for more than 30 years in the case of 38% of them. Overall, Agbekoi is an older neighbourhood than Palmeraie and one where individuals with lower socio-economic conditions reside.

Fig. 2 shows the types of flooding phenomena that the people surveyed in the two districts are exposed to. At Agbekoi, the households of the individuals surveyed are subjected both to flooding (14% of households) and rainwater runoff (9% of households). In this neighbourhood, the households frequently flooded between 2009 and 2018 are located in proximity (less than 20 m) to the streams and/or drainage gutters, and those that are impacted by the rainwater runoff are situated on average less than 280 from the ravine. At Palmeraie, flooding has more impact on the households of people surveyed (37% of households) in comparison to runoff which affects very few households (less than 3% of households). The households at Palmeraie affected by flooding are located in the 'Centre' area of the neighbourhood, in proximity to the main drainage gutters (less than 110 m). During the period 2009 — 2018, the households of the people surveyed at Palmeraie were more often impacted by flooding than those at Agbekoi, a statistically significant difference with a probability threshold of difference 5 ($F = 4.563$, p-value « 0.05). In contrast, Agbekoi households are more affected by rainwater runoff than Palmeraie households, with a statistically significant difference ($F = 19.56$, p-value « 0.001). Individuals surveyed estimated that, during the most spectacular event, the water had reached 'ankle level' for 48% of flooding or runoff households at Agbekoi and 'above the knee' for 45% of flooding or runoff households at Palmeraie(Artadji et al., forthcoming). In addition, they estimated that the duration of this spectacular event was 'less than 1 h' for 67% of flooding or runoff households at Agbekoi and 'less than half a day' for 32% of flooding or runoff households at Palmeraie (Artadji et al., forthcoming).

3.2. Spatially heterogeneous perceptions

Table 3 presents the mean scores for the perception of individuals surveyed regarding the seven questions on the change in climate events relative to precipitation in the two districts of Abidjan studied. The individuals surveyed at Palmeraie perceived more a strong increase in the amount of rainwater falling in their neighbourhood during the period 2009–2018 (mean score = 2.74), in the intensity of rainfall (mean score = 2.92) and in extreme rainfall (mean score = 2.74) than individuals surveyed at Agbekoi (Table 3), a difference which is statistically significant ($p\text{-value} < 0.05$). With regard to the long rainy season, a greater proportion of individuals surveyed consider that it ends later than in the reference period at Agbekoi (mean score = 2.62) than at Palmeraie (mean score = 2.49), a slight difference which is statistically significant ($p\text{-value} < 0.05$). Between the two districts, there is also a difference in the mean scores of individuals' perception regarding the rainiest year over the period 2009–2018. Overall, they mostly cited the year 2017 at Agbekoi and the year 2018 at Palmeraie, a difference that is statistically significant ($p\text{-value} < 0.05$). These differences indicate that individuals' perceptions are heterogeneous across districts, a heterogeneity that can also be observed within districts.

The results of the Moran's I global index evidence the existence of a similarity of perception between the closest persons surveyed. These persons surveyed form a cluster which is identified by the Anselin Local Moran's I index. First, the Moran's I global index shows that there is a strong similarity of perception regarding the onset ($I = 0.13$, $z = 4.84$, $p\text{-value} < 0.05$), the end ($I = 0.14$, $z = 5.36$, $p\text{-value} < 0.05$) and the length (I = 0.,08, z = 3.,29, p-value < 0.,05) of the long rainy season at Agbekoi. The similarity of percep-

Table 3
Mean score for the perception of individuals surveyed on the variability of precipitation.

Perception **(score)**	Neighbourhood	Score range	Observation	Mean ± sd	Median	p-value
Quantity of water fallen	Agbekoi	1–3	246	2.46 ± 0.86	3	0.0003
	Palmeraie	1–3	243	2.74 ± 0.60	3	
Intensity of rains	Agbekoi	1–3	249	2.52 ± 0.84	3	0.0000
	Palmeraie	1–3	248	2.92 ± 0.35	3	
Extreme rainfall	Agbekoi	1–3	244	2.17 ± 0.96	3	0.0000
	Palmeraie	1–3	246	2.88 ± 0.44	3	
Rainiest year	Agbekoi	1–10	210	8.00 ± 2.43	9	0.0000
	Palmeraie	1–10	218	9.00 ± 2.02	10	
Beginning of long rainy season	Agbekoi	1–3	234	1.94 ± 0.97	1	0.1710
	Palmeraie	1–3	197	1.80 ± 0.88	1	
End of long rainy season	Agbekoi	1–3	242	2.62 ± 0.77	3	0.0431
	Palmeraie	1–3	205	2.49 ± 0.83	3	
Duration of long rainy season	Agbekoi	1–3	239	2.41 ± 0.91	3	0.8288
	Palmeraie	1–3	224	2.42 ± 0.85	3	

tion is different between the two sides of Agbekoi: in the 'north-east side' the individuals surveyed cited a later onset in contrast to those of the 'south-west side' who noted an earlier onset of the rainy season (Fig. 3. a). These individuals situated in the 'south-west side' form clusters and note an early end (Fig. 3. c) and a shorte duration of the long rainy season. Furthermore, the Moran's I global index shows that there is a similarity in the perception of extreme rainfall ($I = 0.22$, $z = 8.43$, $p\text{-value} < 0.05$) between the closest individuals surveyed at Agbekoi district. This similarity is in reality observed at local scale where a first cluster of individuals surveyed can be distinguished, in the 'north-east side', who report a decrease in extreme rainfall, and a second cluster in the 'south-west side' who think the opposite (Fig. 3. e).

In Palmeraie, people's perceptions are less contrasted than in Agbekoi. The Moran's I global index shows that there is a similarity of perception between the closest individuals surveyed regarding the beginning of the long rainy season at Palmeraie ($I = 0.11$, $z = 3.89$, $p\text{-value} < 0.05$). This similarity is observed between individuals surveyed who cited a late onset of the long rainy season and who form a cluster situated in the 'Centre' area, specifically at the outlet of the drainage channels (Fig. 3b).

3.3. Variations and trends in climate indices

Two CHIRPS data grids provide the values for precipitation at Agbekoi and Palmeraie. Between the two districts, we observe a good correlation for the daily precipitation between 1984 and 2018 ($corr = 0.99$, $p\text{-value} \ll 0.00001$). This good correlation for precipitation does not systematically reflect a similar trend in the climate indices between the two districts.

Table 4 presents the results for the trend in climate indices calculated by the Mann Kendall test in the two contrasted districts, Agbekoi and Palmeraie. Firstly, we analysed the trends for the beginning, end and duration of the long rainy season. The trend for the end of the long rainy season is negative in the two districts, but only significant at Agbekoi ($p\text{-value} < 0.05$) (Table 4). This confirms an early end to the long rainy season in this neighbourhood. This early end induces a decrease in the trend for the duration of the long rainy season with an almost significant probability ($p\text{-value} = 0.06$) at Agbekoi (Table 4).

Analysis of the trends in rainfall days shows a positive trend in the total number of days of rainfall more than 50 mm in both districts but is only significant at Agbekoi ($p\text{-value} < 0.05$) (Table 4). In this area, a positive trend is also observed with total annual quantity of precipitation higher than 50 mm, with an almost significant probability ($p\text{-value} = 0.06$). These results would appear to imply an increasing trend in the days and amount of rainfall higher than 50 mm in this neighbourhood. According to Konaté et al. [78], daily rainfall higher than 50 mm is heavy and would cause flooding in the Abidjan neighbourhood.

Fig. 5 shows the patterns of change in the Simple Precipitation Intensity Index (SDII) between 1984 and 2018 between the two districts. The SDII trend shows a significant increase in the rainfall intensity, statistically significant at Palmeraie ($p\text{-value} < 0.05$) and non-significant at Agbekoi ($p\text{-value} > 0.05$) (Table 3).

3.4. Similarities and divergences between individual perceptions and metric precipitation trends

An analysis of the meteorological data has enabled us to compare them with the individual perceptions regarding the beginning, the end and the duration of the long rainy season, the quantity of rainfall, the intensity of rainfall and extreme rainfall episodes with the climate indicators for the last ten years in the two districts.

The results evidence a divergence between perceptions of individuals surveyed regarding the end of the long rainy season and the precipitation data trends at Agbekoi. In fact 76% of individuals surveyed (Fig. 6b) in this neighbourhood report a later end which is in contradiction with the negative trend in the meteorological data which reflects an earlier end to the long rainy season. Similarly, in the same neighbourhood, 66% of individuals surveyed (Fig. 6c) report a longer duration of the long rainy season. Yet the trend in the precipitation data shows a shorter duration of the long rainy season.

In terms of the quantity of precipitation falling in a given year, the year 2018 was not the rainiest year in the past 35 years and not even in the past ten years. The individuals surveyed nonetheless designated 2018 as being the rainiest for 34% at Agbekoi and 62% at Palmeraie (Fig. 7d). Considering the total number of rainy days, the year 2018 was among the years where R50mm is considerably higher than the interannual mean at Agbekoi (3 days) and at Palmeraie (3.5 days). Furthermore, the trend in R50mm confirms a significant increase at Agbekoi. The perception of individuals surveyed regarding this question is thus more consistent with the number of days of extreme rainfall.

Table 4
Results of the Mann Kendall test for analysis of the climate indices trends between the two districts.

		Agbekoi			Palmeraie		
Perceptions	**Indicators**	**Z**	**tau**	**p-value**	**Z**	**tau**	**p-value**
Amount of rainfall	PRCPTOT	0.738	0.089	0.460	0.028	0.005	0.977
	PRCPTOT ≥ 50	**1.832**	**0.219**	**0.066**	1.363	0.163	0.172
Intensity of rainfall	SDII	1.675	0.2	0.093	**1.988**	**0.237**	**0.046**
Extreme rainfall	R95pTot	1.619	0.193	0.105	0.937	0.113	0.348
	R99pTot	0.929	0.116	0.352	0.087	0.012	0.930
Rainiest year	R20mm	0.457	0.057	0.647	0.385	0.048	0.699
	R50mm	**2.072**	**0.267**	**0.038**	1.548	0.196	0.121
Long rainy season	Beginning	0.014	0.003	0.988	0.799	0.098	0.424
	End	**−2.559**	**−0.317**	**0.010**	−1.325	−0.168	0.185
	Duration	**−1.862**	**−0.224**	**0.062**	−1.436	−0.173	0.150

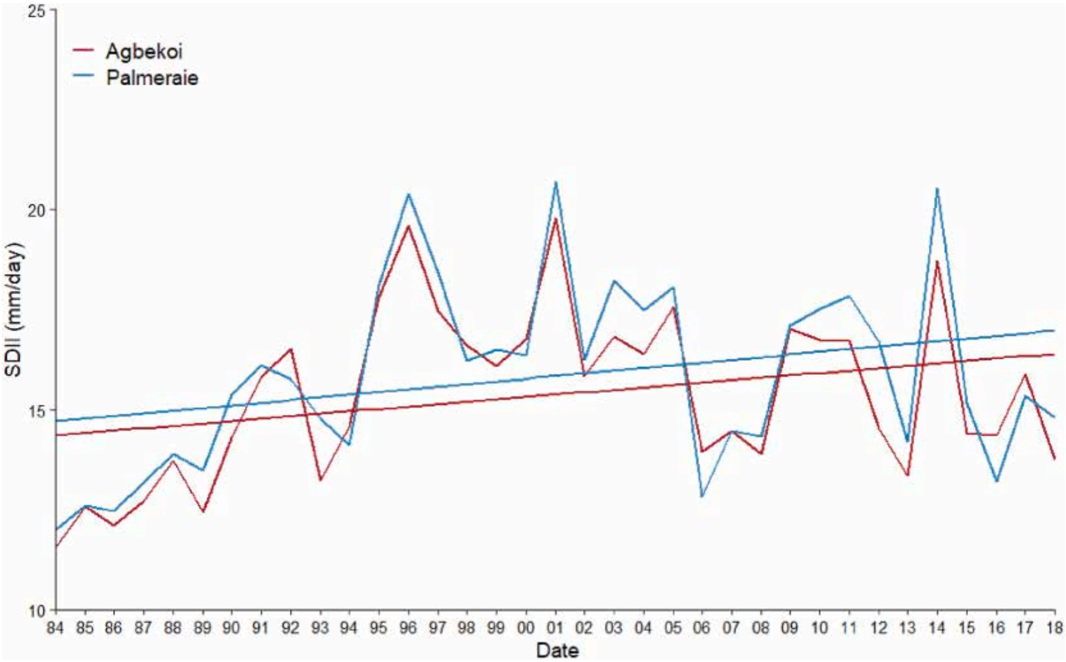

Fig. 5. Patterns of change in the trend in the SDII from 1984 to 2018 between the two districts.

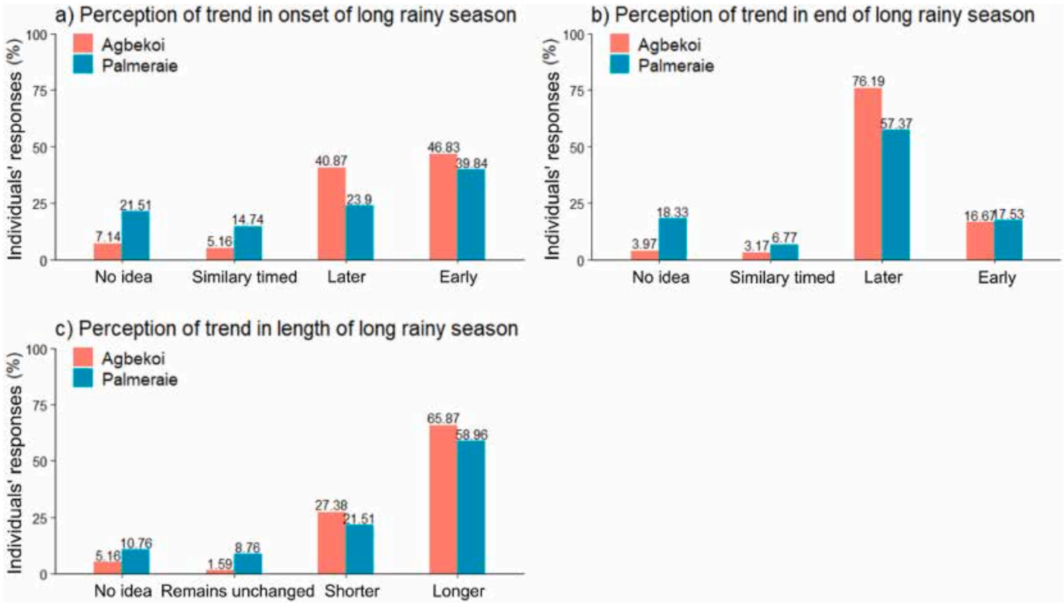

Fig. 6. Perception of individuals surveyed regarding the variation of the long rainy season in their neighbourhood.

Overall, the individuals surveyed perceive an increase in the total quantity of rainfall (in the period 2009 — 2018) both at Agbekoi (69%) and even more at Palmeraie (80%) (Fig. 7a). In the light of the precipitation data, we cannot confirm a similarity between the perception of individuals surveyed and the trend in the total quantity of precipitation (PRCPTOT) in the two districts, since it is not significant. On the other hand, the trend in the quantity of precipitation higher than 50 mm would appear to converge with the perception of individuals surveyed at Agbekoi.

Regarding the intensity of precipitation, the individuals surveyed perceive an increase in the rainfall intensity in the case of most of them at Agbekoi (73%) and at Palmeraie (93%) (Fig. 7b). This perception converges with the trend in the intensity indicator (SDII) which is significant at Palmeraie with a slope of 23%. This slope reflects the increase in intensity of precipitation greater than 20% at Agbekoi and would appear to be convergent with the perception of individuals surveyed.

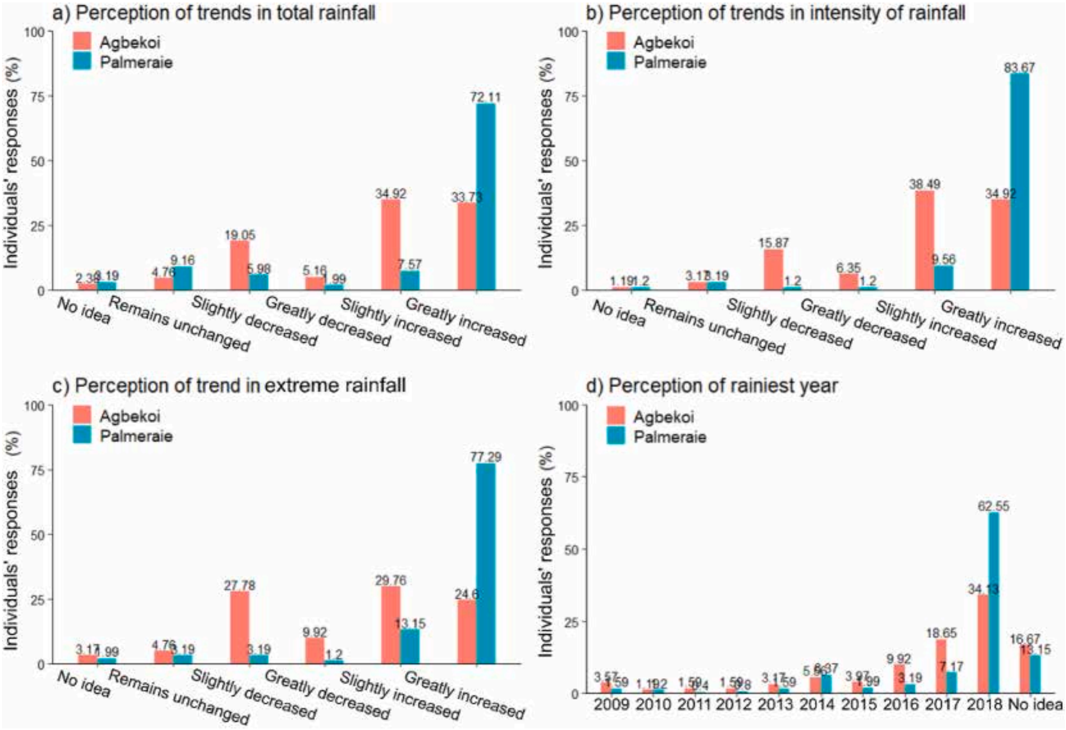

Fig. 7. Perception of individuals surveyed on the variation of precipitation in their neighbourhood.

Finally, concerning the extreme rainfall episodes, the individuals surveyed consider that extreme rainfall is increasing, a majority at Agbekoi (54%) and above all at Palmeraie (90%). In parallel, for these two districts, the trends in these climate indicators (R95pTot and R99pTot) certainly show an increasing trend, but are not particularly significant (Fig. 7c). At this stage, it is thus particularly difficult to draw any conclusion, one way or another,[5] regarding the convergence between the perception of individuals surveyed and the trends in the indicators of extreme rainfall in the districts studied.

4. Discussion

This study has revealed certain points of divergence and other points of convergence between the perceptions of those surveyed and the pluviometric measurements. Firstly, there is a divergence between the perception of people surveyed and the meteorological data concerning the variations in the beginning, the end and the duration of the long rainy season. The individuals surveyed perceive a later end and a longer duration of the long rainy season in the period 2009 to 2018, whereas the measured trends show an earlier end and a shorter duration of the long rainy season. According to Kouassi et al. [47], the variability of these dates, calculated on the basis of meteorological data, of the onset and the end of the long rainy season is high. This might explain the difficulty for persons surveyed to perceive exactly the changes in the dates of the beginning and end of the long rainy season. It should be noted that the majority of persons surveyed practice a profession in urban environment in the public or private sector, professions that are relatively little dependent on the variability of precipitation. In contrast, studies show that farmers seem to perceive the changes in the variability of the climate with a certain precision, since their activity is dependent on the precipitation and the temperatures [26,28,79]. Less connected to ‘nature’ than farmers, urban people may also be more influenced by the media, and its climate change discourse [80]. Their perception that something is changing in the climate may be also related to a greater exposure to the media. Research on the impact of media discourses on perceptions of natural disasters and climate change in West African cities is still scarce. Yet it is essential for understanding pro-environmental and prevention behaviours.

The perception of increased intensity of heavy rains has been demonstrated elsewhere in previous research conducted in West African countries [37,81]. The people surveyed in our study also perceive an increase in days with rainfall higher than 50 mm and the intensity of precipitation in the period 2009 to 2018. Furthermore, the trends in measured climate indicators show similarities with the perception of individuals surveyed on these questions at Agbekoi and at Palmeraie. The analysis of the climate indicator trends based on the CHIRPS data at the Adiaké station, situated more than 85 km from the city of Abidjan, confirm a non-significant increasing trend in rainfall intensity [55]. This same study confirms an increase in precipitation intensity in Benin and Burkina Faso. Recent studies have simulated a strong increase in precipitation intensity (SDII) in Côte d’Ivoire in the coming centuries [18]. Daily rainfall higher than 50 mm is considered as heavy rainfall and is likely one of the factors causing flooding in the district of Abidjan [78].

[5] Unless we accept a margin of 10.5% of risk of error in the case of the indicator R95pTOT.

The experience of flooding or runoff would also explain the clusters observed at Agbekoi which show a divergence of perception between the individuals surveyed on the two sides of the neighbourhood. In the 'north-east side' of Agbekoi, a first cluster formed around individuals surveyed who perceive a later start to the long rainy season whereas another cluster of individuals who have an opposite perception may be observed in the 'south-west side'. These two clusters of individuals also have divergent perceptions concerning the extreme rainfall trends; in the 'north-east side', the individuals surveyed report a decrease whereas those of the 'south-west side' report an increase. Results obtained in the United States have shown that perceptions regarding climate variation may be expressed differently from one neighbourhood to another according to whether the residents live in a flood zone or a non-flood zone [82]. Other studies have shown that the experience of flooding results in an overestimation of changes in climatic conditions, of the perception of risk and of vulnerability [83,84]. The spatial superimposition between the perception of individuals surveyed and their experience of flooding or runoff shows that the 'north-east side' cluster at Agbekoi includes individuals surveyed less impacted by flooding or runoff in their households (Fig. 2). In contrast, those of the 'south-west side' are often impacted by flooding or runoff or rainwater in their households (Fig. 2). The absence of a cluster at Palmeraie shows that there is less divergence of perception between the individuals surveyed. The neighbourhood of Palmeraie figures among the zones at high risk of flooding in the municipality of Cocody [46,49]. Furthermore, we have observed a fairly broad spatial distribution of households impacted by flooding at Palmeraie (Fig. 2). In addition, perceptions do not diverge, since the floods extensively impact the households of individuals throughout this neighbourhood.

The people surveyed perceive certain intensive events in the variability of precipitation in the light of their experience of flooding or runoff. In this context, the perception of individuals surveyed does not systematically reflect a change in the climatic variability. Marin and Berkes [85] maintain that the populations do not observe the same variables as the scientists. Leclerc et al. [86] showed that indigenous farmers from Mount Kenya have a perception of climate variation associated with their experiences of extreme weather events such as droughts or heavy rainfall. Furthermore, farmers and livestock breeders perceive the changes in climate variables which have a strong impact on their activities such as pockets of drought [26,87]. Our results reach the same conclusions that the year 2018 is the one that is most often cited at Palmeraie as being the rainiest over the past ten years. This perception must certainly be seen in relation with their most recent experience of flooding, on June 18th and 19th 2018, a few months earlier. It is therefore relevant to think that climatic knowledge, which stems from individual perceptions, built on experiences particularly those of extreme climatic events, and associated behaviours, must be considered with scientific knowledge in order to better respond at the city level to hazards and their sometimes dramatic consequences.

5. Conclusion

Of the three components of climate risk conceptualized by the Intergovernmental Panel on Climate Change (IPCC), one focuses on reducing the vulnerability of human and natural systems to these hazards. Reducing vulnerability to climate variations poses major challenges, due to the strong uncertainties concerning the nature, the magnitude and the temporality of these changes. One of the first steps is to have a good knowledge of the phenomenon itself. It is therefore important to strengthen the data collection system at the fine level, over the current period, by setting up meteorological terminals skilfully placed at the city scale to be able to measure the inter-neighbourhood variability. The Evidence project has strengthened this collection system by setting up 20 new stations. But efforts must continue to continue the collection, and even set up more stations. Knowledge of the phenomenon also requires support for forecasting, and a project like the Raincell project [88,89] provides low-cost solutions, if the public authorities and the private cell phone sector are committed.

A second step is to understand people's perceptions of these climate changes. In recent years, research has often focused on the rural environment, as we know, climate perceptions are more sensitive there, since the daily activities of the inhabitants of these areas depend in part on weather conditions. However, as our results show, the consequences of extreme rainfall can have major impacts on the living conditions of urban populations. Research on perceptions in cities is all the more important because the environments are very unequal in the face of these climatic extremes, in terms of exposure, effects, adaptive response (anticipation, repair, etc.) And these responses will depend on the understanding of the phenomena.

The implementation of an early warning system requires accurate researches on these different knowledge and data, accurate in terms of precise scales. For example, we see in our research how the choice of two contrasting districts was judicious. Indeed, it has been shown that local management of adaptation to the effects of climate variations could accentuate some of the disparities already observed between the different territories of the same urban complex [90].

Finally, this study highlights the understanding of the phenomenon of rainfall variation by populations that are exposed to hydroclimatic hazards. This knowledge could help government to reform climate policies and could enable all stakeholders to minimize the consequences of hydroclimatic threats.

Ethical concern

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional review boards.

Consent to participate Informed consent was obtained from all individuals for whom identifying information is included in this article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ijdrr.2022.103285.

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