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Reconstituting past flood events: the contribution of citizen science

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Abstract. Information gathered on past flood events is essential for understanding and assessing flood hazard. In this study, we present how citizen science can help retrieving this information, in particular in areas with scarce or no instrumental measurements on past events. The case study is located in Yeumbeul North (YN), Senegal, where flood impacts represent a growing concern for the local community. This area lacks instrumental records on flood extent and water depth as well as information on the chain of causative factors. We developed a framework using two techniques to retrieve information on past flood events by involving two groups of citizens who were present during the floods. The first technique targeted the part of the citizens' memory, which records information on events, recalled through narratives, whereas the second technique focused on scaling past flood event intensities using different parts of the witnesses' body. These techniques were used for 3 events, which occurred in 2005, 2009 and 2012. They proved complementary by providing quantitative information on flood extents and water depths, and by revealing factors that may have contributed in aggravating floods for 3 events which occurred in 2005, 2009 and 2012.

1 Introduction

Together with Asia, Africa is the continent most affected by floods (UNISDR-CRED, 2015). Between 2000 and 2018, there were 698 flood disasters in Africa, killing more than 14,250, affecting 45 million people, and causing 6.8 million USD of economic losses (EM-DAT, 2018). West African countries, such as Burkina Faso or Senegal, appear to experience an increase in flood disasters due to the population growth and to the urbanization of flood-prone areas (Di Baldassarre et al., 2010). Between 1990 and 2014, floods were responsible for 86% of the economic losses from natural disasters in Senegal only (Preventionweb, 2018). During that period, years 2005, 2009, and 2012 were marked by severe urban floods, particularly affecting the capital of Senegal, Dakar, causing human casualties and impairing socio-economic conditions (GFDRR, 2014). The country is facing enormous challenges in flood risk management, exacerbated by climate change (Douglas et al., 2008; Urama and Ozor, 2010), rapid and uncontrolled urbanization, lack of drainage infrastructure, and rapid changes in land-use that worsen drainage patterns (Chen et al., 2015; Ahiablame and Shakya, 2016).

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The government and local authorities of Senegal have tried several strategies to mitigate urban floods, such as developing emergency plan, relocating inhabitants, and building water retention basins. However, two key aspects have not yet considered that are needed for these measures to work. On the one hand, it is necessary to understand the causes and characteristics of floods and, on the other hand, the population must be involved in the process of risk management. Information on magnitude and intensity of flood events, as well as on processes controlling the flood, is at the core of flood hazard assessment and zoning (EXCIMAP, 2007). This fundamental information is scarcely available in the region (GFDRR, 2014; Sy et al., 2016). The absence of an organized data acquisition system during floods leads to the absence of a comprehensive catalogue on past flood events and consequently on flood hazard maps.

Without records of past events and without the possibility of capturing the time dimension in terms of frequency of occurrence, accurate flood hazard assessment is impossible to achieve. Moreover, floods are not only triggered by natural factors, but are frequently influenced by man-made processes (WMO, 2012; DAEC, 2016), which are not easily recorded by ground-based instruments (Townsend and Walsh, 1998) or remote sensing (Sanyal and Lu, 2004).

Consequently, new alternatives must be explored. Citizen science is a form of collaborative research involving citizens from the community in scientific projects (Wiggins and Crowston, 2011). Citizen science has attracted much attention from scientists in many fields such as ecology (Dickinson et al., 2010; Silvertown, 2009), astronomy (Raddick et al., 2007), and more recently hydrology (Buytaert et al., 2014; Paul et al., 2018). Rapid advancement in various modern technologies - internet, web 2.0, virtual globe, location-based services, social media, mobile, smartphones, interactive geo-visualization interfaces such as Open Street Map; Google Earth, Geo Wiki (Goodchild, 2007; Silvertown, 2009) - as well as the rise of participatory research characterized by greater user interactivity and collaboration, increase the number and the subjects investigated by citizen science projects. The use of citizen science has also emerged in flood analysis for multiple purposes (Sy et al., 2019) including near real time mapping of flooding, crisis mapping, and other modelling projects (Cervone et al., 2016; Starkey et al., 2017;Rosser et al., 2017) in which the volume of data to interpret increases significantly. However, none of those citizen science projects explicitly studied the reconstruction of past events, and the use of citizen memory.

The objective of this work is twofold: 1. retrieve flood extents and water depths for different past events and, 2. determine whether citizen can clarify the causal chain of flood events. We also assessed the reliability of these data with cross comparisons and against independent methods, such as remote sensing.

2 Characteristics of the study area

Our citizen science approach was applied to the suburbs of Yeumbeul North (YN), one of the municipal districts of Pikine in Dakar city, Senegal, West of Africa (Fig. 1). YN covers an area about 9 km^2. It is one of the most populated districts of Senegal, with 168’379 inhabitants (ANDS, 2015), and a population density of approximately 18,700 inhabitants/km^2. YN is characterized by lowlands with elevation less than 20 m above sea level and is highly urbanized with more than 80% of its territory covered with buildings, critical facilities and roads (Sy et al 2016). It is one of the suburbs most affected by flooding.

Figure 1 displays the state of the permanent water bodies (Lakes Warouwaye and Wouye), which existed before the retention basins were implemented as mitigation measures after the 2012 floods (GFDRR, 2014; Sy et al 2016).

Administratively, YN is divided into 82 major neighbourhoods. In each of them, a delegate, chosen among the inhabitants of the neighbourhoods, represents the municipal administration (decree N 86-761 Republic of Senegal) (GDS, 1986). The delegate should be from the site and at least 35 years old. One of the delegate's tasks is to sensitize the neighbourhood inhabitants on how to face disasters. In this paper, the delegate will be designated under the qualification of neighbourhood chief (Tall, 1986), appellation employed by the local population.

Flooding occurs during the rainy season, which usually starts in July and ends in October. The 3 events under investigation occurred in 2005, 2009 and 2012. Their timeframe and the peak rainfall intensity are provided in table 1. The timeframe was retrieved from the Emergency Events Database (EM-DAT) database (EM.DAT, 2018), whereas the rainfall intensity values were registered at the station of Dakar-Yoff located 20 km away from the study area.

3 Methods

3.1 Investigation on past flood events

Since there is currently no catalogue on past flood events available for the Dakar region, we decided to investigate the potentiality of citizen science in the retrieval of this information. We developed a framework applying novel methods in the field of citizen science (Fig. 2).

The field campaign was carried out from July to August 2017. Our approach involved two different groups of citizens. Participants were selected based on three criteria: 1) to have witnessed the 3 flood events; 2) to have a good spatial knowledge of the study area and the flooded areas; 3) their social credibility. Therefore, the first group consisted of the chiefs of the 82 neighbourhoods of the municipal district of Yeumbeul North. The majority of this group were male (98%) and the age varied from 40 to 90 years, with an average of 66 years. The second group was composed of 182 local representatives, 2 or 3 per neighbourhood. 72% were men, with ages varying between 35 and 60. The average was 38 years old. The under-representation of women in the study is not our choice, but instead due to the socio-cultural context of the country (Creevey, 1996).

3.1.1 Neighbourhood chiefs: from episodic memory into flood information

This group of citizens was involved in a two-stage approach set up to optimize the validity, reliability and utility of the collected data, and to transform memory of past floods into temporal and spatial information. The first stage is based on the use of episodic memory through in-person interviews in the chief's house. Episodic memory designates the process by which the human being remembers events with their context: date, place and emotional state (Tulving, 1972, 1993, 2002), and is part of the long-term memory (Zack et al 2000). The second stage relies on participatory mapping (IFAD, 2009) and on-site visits.

Face-to-face interviews were conducted with each chief of the 82 neighbourhoods. These persons are nominated by the local population because of their reputation, as they are considered senior and among the first inhabitants of the neighbourhood. The

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in-person interview was forecast to last between 45 to 60 minutes but it depended on the history told and no time limit was imposed. At the end, interviews lasted from 30 to 60 minutes. In some cases it was possible to register the narrative. The information obtained from the narrative allowed identifying which neighbourhoods were flooded. Then the chiefs of flooded neighbourhoods were involved in a participatory mapping in the house and in the field, together with hand/GIS mapping for the latter case. The purpose of this second step was to formalize and express the chiefs' memories of the floods (as witnesses or victims) in explicit form in order to obtain past information useable for flood hazard assessment, such as flood extent and water depth. Tools such as land-use paper maps of the area with footprint of houses and different land-use categories (see figure 1), fixing pins, handled GPS and mobile GIS were used.

Stage 1: Investigation on past flood information in neighbourhood chief's house

The methodology of this stage was derived from techniques used in police investigation (Fisher, 2010, Perfect et al 2008). Compared to other forms of interviews, it allows the witness (here the neighbourhood chief) to play a more active role, by expressing freely his history without being interrupted or influenced by questions, which could distort the memory (Loftus and Palmer, 1974). First, neighbourhood chiefs were put into a mental condition allowing them to focus their thoughts, cognitive and emotional state by closing their eyes (Perfect, 2008) and avoiding physical and psychological distraction (e.g. telephone calls) during this phase, as it requires intense concentration (Fisher, 2010). Some neighbourhood chiefs felt uncomfortable when closing their eyes. In such cases, they were told to focus on a blank surface, like a table or the floor. Once ready, they expressed their memories of the event in the form of descriptive stories, as they came to their mind, using their own words and language, Wolof in that case, in order to avoid misunderstanding. They were instructed to describe in detail anything that may be related to the event, such as a) processes that accompanied the flood (e.g. the rupture of a water drainage pipe, manmade obstacles); b) important political or public events as time indicators (e.g. proximity to a presidential election, football game); c) peculiar flood-related measures taken by the authorities enabling the event to be dated; d) spatial indicators such as place names, street names allowing to reconstruct the flooded areas, and, e) the event itself, with information making it possible to deduce the height of water reached (e.g. "water reached our knees").

Following the narrative, only chiefs who indicated having been confronted with floods went through participatory mapping using scale mapping (62 chiefs out of 82, see supplementary material 2). This phase required a training on how to read and use a map. Therefore, the concerned neighbourhood chiefs were first familiarized with a land-use map of their neighbourhood locating their house and details about their area including main and secondary roads as well as houses. After this introductory explanation, the neighbourhood chiefs used the map to describe their spatial perception of the different flood events, using a distinctive colour pencil to draw the flood contours of each year. Coloured pins were used for indicating the water depth at different locations on the map; red for high level of water, green for medium and yellow for low. This method allows obtaining a qualitative indication of the water depth as well as its spatial distribution.

Stage 2: Investigation on past flood information with neighbourhood chiefs in the field

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The objective of stage 2 was to consolidate the response by confronting the story leading to the first map to the on-site mapping. To do this, neighbourhood chiefs brought us to the places they previously described. This is important because memory retrieval is facilitated when the context of the event is recreated, and neighbourhood chiefs can also use their other senses (sight, hearing, smell) to better remember the event. We drew the polygon of the spatial extension using a mobile GIS, with GPS receiver automatically recording the site location. Furthermore, we measured 64 sites for the water level indicated by 49 neighbourhood chiefs with a graduated ruler (supplementary material 3, 4 and 5) and took the GPS coordinates. Post-processing treatments include merging the contours of flooded areas obtained on paper map with the ones obtained in the field as well as checking the correspondence between qualitative water levels obtained with the coloured pins to the water level measurements.

3.1.2 Local representatives: participatory mapping on flood extent and water level of past flood events

The second group involved in investigating past flood events was composed of 182 local representatives selected by associations well implemented locally (e.g. "Réseau d'Information d'Education de Communication", "Association des Relais Communautaires de Yeumbeul") dealing with development of the neighbourhood and awareness on health issues. The aim for involving local representatives is to confront their information with the one provided by the neighbourhood chiefs in order to check the consistency between the two sources. 2 or 3 local representatives were selected per flooded neighbourhood, accounting for 130 out of 182 representatives, in order for them to confront their memories and reach a common agreement (Swanson et al., 2016) before providing information on flood extent and water depths for the different flood events. Data on flood extent were retrieved by participatory mapping using hands-on techniques. For this, representatives were trained the same way as the chiefs. These maps were then digitized. Regarding water level, information was retrieved on the same 64 sites indicated by the neighbourhood chiefs using the different parts of the human body, e.g., ankle, knee or shoulder. This strategy was proposed to provide local representatives with a visual resource to describe the water level more easily. Then, the pre-defined tags were converted into quantitative data by using average body segment lengths expressed as a fraction of body height defined in the field of physical anthropometry (Winter, 2009; Drillis and Contini, 1966). The bottom-up dimensionless coefficients applied for each anthropometric segment (supplementary material 6) are (Winter, 2009;Contini, 1972): ankle (0.039), knee (0. 285), wrist (0.485), elbow (0.63), chest (0.72), shoulder (0.818), chin (0.870). Finally, the water depth was obtained by multiplying the value of the appropriate coefficient by the contributor's (local representative) height, measured on site using tape measure (supplementary material 3, 4, 5 and 6).

As we used two different approaches to obtain the same information, we needed to assess the level of agreement instead of the correlation between the two datasets. We used the Bland-Altman method (1986) (Bland and Altman, 1986), which allows determining the level of agreement between data acquired with two different techniques, even if there is no information about the "true" values (Bland and Altman, 1986). In our case, we assessed depth values that could not be measured instrumentally during the flood events under study. The Bland-Altman method calculates the differences between the results obtained with two different approaches and plot them against the average of the two approaches.

3.1.3 Remote sensing analysis

In order to assess the reliability of flooded areas provided by the two citizens groups, we used remote sensing analysis. Our constrains were: 1) the availability of images for the years considered, 2) the availability of free access, 3) a resolution sufficient for the size of our study area ($9km^2$), and 4) a minimum cloud cover. Radar images such as TerraSAR-X, Radarsat-2 or COSMO-SkyMed, can provide information with high resolution (Schubert et al., 2012) and can capture flooded areas in cloudy conditions at day and at night (Mason et al., 2014; Schuman, 2017) but their costs were prohibitive and no images were available for the periods of interest. Consequently, we only used optical satellite images, available at the Applied Remote Sensing Laboratory (LTA) of the Institute of Earth Science (IST) of the University Cheikh Anta Diop (UCAD) and satellite images from Google Earth historical imagery as listed in table 2.

The flooded areas for the 2005 event were determined using available Spot 5 images i.e. one acquired during the 2005 flood event and one acquired in 2006 in the absence of flooding.

The multispectral Spot images of 10 m resolution were merged with a Spot panchromatic image with a spatial resolution of 2.5 m to increase their spatial accuracy. In order to detect water-covered areas, we applied the normalized difference water index (NDWI) (Khajuria et al., 2017) and supervised classification methods on both sharpened images. Finally, results from both images treatment were compared to extract the flooded areas.

For the events of 2009 and 2012, flooded areas have been obtained by comparing and photo-interpreting high-resolution true colour composite images from Google Earth historical imagery, about 0.5 m resolution, before and up to 3 weeks after the flood events.

4 Results

4.1 Identifying chain of events

The chain of events, which triggered floods in YN, was retrieved from the narrative obtained from 82 neighbourhood. For the 2005, 2009 and 2012 events, all the 82 chiefs of neighbourhoods identify rainfall as the primary factor. 29 chiefs (neighbourhood number 1, 2, 3, 7, 9, 17, 19, 20, 28, 29, 31, 32, 33, 34, 35, 36, 39, 40, 41, 44, 49, 50, 56, 57, 62, 67, 70, 72, 76; see Fig.1) also indicated the rise of the water table, substantiated by wet ground, greening of walls due to the water infiltration, and removal of the wall painting.

Regarding the aggravating processes, which worsen the flood by either increasing the quantity of water or obstructing the flow, they varied depending on the year of the event and the location. For example, for the 2005 event, 4 neighbourhood chiefs (13, 36, 46, and 67) mentioned the failure of the pipeline of the road of Malika, used for water drainage, as a cause of increasing the intensity of the flood event. 8 neighbourhood chiefs (7, 17, 18, 20, 21, 28; 45, 77) mentioned the overflow of the Warouwaye Lake. 15 neighbourhood chiefs (7, 13, 17, 18, 19, 20, 21, 28, 36, 45, 46, 67, 72, 76, 77) mentioned actions achieved by local population, such as emptying of septic tanks located in their house, which contributed in aggravating this event and had also direct consequences on health (e.g. cholera epidemics) (Wade et al., 2009). Pipeline failure and emptying of septic tanks occurred during the 2009 event, but at different locations, e.g. near the municipal hospital of Yeumbeul North for the pipeline failure. For the 2012 event, the 82 chiefs didn't recall any aggravating processes.

4.2 Flood extent mapping

Flood extents for the 2005, 2009, and 2012 events were obtained from the two citizen groups using the methodologies described in Figure 2 and then compared to the results derived from remote sensing analysis (Fig. 3).

As a first result, the citizen science revealed that the 2005 event was the most widespread whereas the 2012 event was the smallest (table 3). Flooded areas provided by local representatives are slightly smaller than those indicated by neighbourhood chiefs (table 3), showing variations from 1.8% in to 2005 to 0.6% in 2012 (table 3). In terms of mapping, slight differences appear on the extents identified between the two citizen groups (Fig. 3), but areas overlap reasonably well (Fig. 4).

Remote sensing analysis confirms the main flooded areas in the centre part of the study area (Fig. 3), but some discrepancies occur on the edges. The total surface area is smaller than the one provided by citizen science for all years (table 3).

4.3 Water depth information

Water depth is one of the key parameters considered in describing flood intensity and mapping hazard (Van Alphen et al., 2007), but difficult to record during flood events. Therefore, retrieving flood depths from past events is of prime interest. Figure 5 displays scatter diagrams of depth values obtained with the two different groups of citizens using the techniques described in the methods (see Fig. 2) on 64 sites, sampled over 49 neighbourhoods. Each site has paired observations. The maximum flood depth retrieved is 2.5 m for the 2005 event, 1.5 m for the 2009 event, and 1.2 m for the 2012 event.

Figure 6 shows the plots obtained applying the Bland-Altman method for the 2005, 2009 and 2012 events for the 64 sites of measurements. The value of the mean differences, expressed in meters and indicated by the blue line is 0.16 for the 2005 event, 0.23 for 2009 and 0.26 for 2012. The limits of agreement, also displayed, are set at 95% of confidence interval. The differences being normally distributed, these limits are defined by the mean difference +/- 1.96 the standard deviation σ of the differences. For the 2005 event, the range for the differences is from 0.68m to -0.37m, with two values out of these limits. For 2009 and 2012, three values are out of range, the interval being 0.78m to -0.32m for 2009 and 0.62m to -0.11m for 2012.

5 Discussion and conclusion

In this study, we used citizen science to retrieve information on three past flood events having impacted the region of Dakar during the past 10 years. Our approach provides quantitative information on water depth, helps retrieving the flood extents and provides insights on aggravating factors of the intensity of floods.

Our methodology consisted of a set of techniques to gather the most complete spectrum of information. Those techniques are unusual in the field of flood hazard assessment and we had to resolve some challenges related to the time elapsed and the

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understanding of maps. One of the techniques is based on people's episodic memory. We used face-to-face interviews with neighbourhood chiefs, applying specific tools in order to limit external influence and distortion of memory. Moreover, the procedure was completed with a scene visit with each neighbourhood chief involved in order to consolidate the information provided verbally. The scene visit is very important because the time elapsed between the oldest event and the date of the study is about 12 years. As time goes by, memories can become vague (Lacy and Stark, 2013). However, people having faced traumatic and stressful events, like floods in our case, tend to keep a more accurate, detailed, and time persistent memory of the event (Sotgiu and Galati, 2007).

Another technique involved participatory hands-on mapping. Mapping can represent a challenging task for laypersons (Handmer, 1985; Żyszkowska, 2015, 2017) as they may have difficulties to understand and to locate themselves on a map. Moreover, maps are usually composed of a graphic semiology applying standard rules and recommendations that rarely take into account the culture or knowledge of the citizen (Fuchs et al., 2009). Therefore, if a citizen has no experience in reading or producing maps, information can be incorrectly reported. To overcome this problem, we trained people to ensure they understood the map; we explained what they should be doing and how to do it.

Quality and reliability of citizen science data is a growing research field (Flanagin and Metzger, 2008; Crall et al., 2011; Silvertown et al., 2015). In our study, we developed different strategies in order to improve these two aspects. We decided to work with two different target groups according to the context and the purpose of the study. The objective was to check the consistency of information between the two groups. If the same flooded area is mentioned by the two groups, there is a good chance that the area was effectively flooded. Due to the social organisation of the Dakar region, one way to limit issues about source credibility (Flanagin and Metzger, 2008) was to involve neighbourhood chiefs. Indeed, these chiefs are appointed by local citizens, based on the trust placed on them and on their long-lasting presence in the area. Usually, they have a good memory and good verbal abilities. Moreover, as a witness or sometimes as a victim, they were at the forefront of the flood scene, therefore representing a valuable source of information to describe the chain of events. The second group was composed of local representatives. The selection was made with the support of local and well-implemented associations.

Identifying the chain of processes generating flooding is very important for flood hazard assessment (DAEC, 2016) as it enables considering more realistic flood scenarios. Citizens living in flood affected areas are not often included in post-event or flood hazard assessments, although they could provide accurate insights as they have a good understanding of their surroundings (Tran et al., 2009), and an in-depth knowledge on the specific realities. Our study demonstrates this as neighbourhood chiefs allowed identifying additional natural and man-made factors that contributed to flooding, such as the rise of ground water, the Warouwaye lake overflow, and the emptying of septic tanks.

In terms of flooded areas, the results obtained per event with the two groups of citizens are similar. Some spatial differences can be observed regarding the extent. Reasons for the differences could be related to a) a more in-deep knowledge of the neighbourhood and their surroundings by the chiefs, as they have the confidence (Tall, 1998) of the inhabitants, therefore having access to more detailed information; b) the techniques used in mapping the areas: with neighbourhood chiefs, we used a two-stage procedure to retrieve the flood extent, involving hands-on mapping and GIS mapping in the field, whilst the local representatives only produced hands-on maps that were then digitized.

When compared to remote sensing analysis, spatial differences can also be noticed which can be explained by a) the resolution of the selected images varies from 0.5 to 2.5 m, probably not accurate enough to capture all flooded areas (Grimaldi et al., 2016); b) the acquisition time as the post-event images were taken up to one year after the flood; c) the technical limitation as satellites cannot capture floods inside a structure that are solid like buildings or under vegetation canopies (Wilson et al., 2007; Mallinis et al 2013);d) the efficiency of the algorithm used for the remote sensing analysis (Bates et al., 1997; Schumann et al., 2009).

Concerning water depth retrieval, one of the techniques was inspired from studies expressing flood hazard levels on maps using body scale (e.g. EXCIMAP, 2007; Luke et al., 2018). Therefore, quantitative data on water depth were retrieved using a proportion of the size of the human body borrowed from physiology field (Winter, 2009). These values represent an average (Drillis and Contini, 1966), since the length of human body segments depend on body structure (Contini, 1972), gender and racial origin, and therefore could be a source of uncertainties. However, when comparing the two approaches used for water depth investigation, we find a fairly good agreement, with an average differences below 0.3m, which is in the range of other comparisons done for example between observed and simulated methods (Kutija et al., 2014).

Both implication and motivation from citizens are necessary for the success of citizen science projects (Rotman et al., 2012). To ensure people implication in our project, we first created a Facebook page (http://www.facebook.com/xeexmeude.com) in order to interact with the local citizens. Second, we designed and presented the project in a way to convince contributors that their contribution will be beneficial for them and their neighbours. Third, we worked with community leaders (Bénit-Gbaffou and Katsaura, 2014) and local associations to ensure a better acceptance of the project.

Citizen science requires involvement and time, compared to remote sensing analysis, which could now also take advantage of the free availability of radar images such as sentinel (Malenovský et al., 2012). However, at the scale we worked, these images don't offer the required spatial resolution (Twele et al., 2016), and they don't provide information on depth of flood, which is one of the critical information for flood hazard assessment that we were able to obtain with citizen science.

In conclusion, our study shows the potential of citizen science in retrieving quantitative and reliable information on past flood events, especially in areas where no or few records of past events are available. Our investigation strategy, by involving two different groups of citizens, increases the reliability on the data obtained. Provided the functioning of the society subject to floods is well understood, such approach can be replicated in other parts of the world. Moreover, considering the fact that citizens have been involved in the various steps of this project, they have developed skills in flood data acquisition and understanding of flood processes. They can thus better integrate a decision-making process around flood risk.

Author contributions

BS conceived the study and carried out citizen science project in the field. BS analysed the results and compiled the figures with input from CF. The outline of the manuscript was drafted by BS, HD, DC, GG, CF. BS and CF prepared the manuscript with contributions from all co-authors. All the authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

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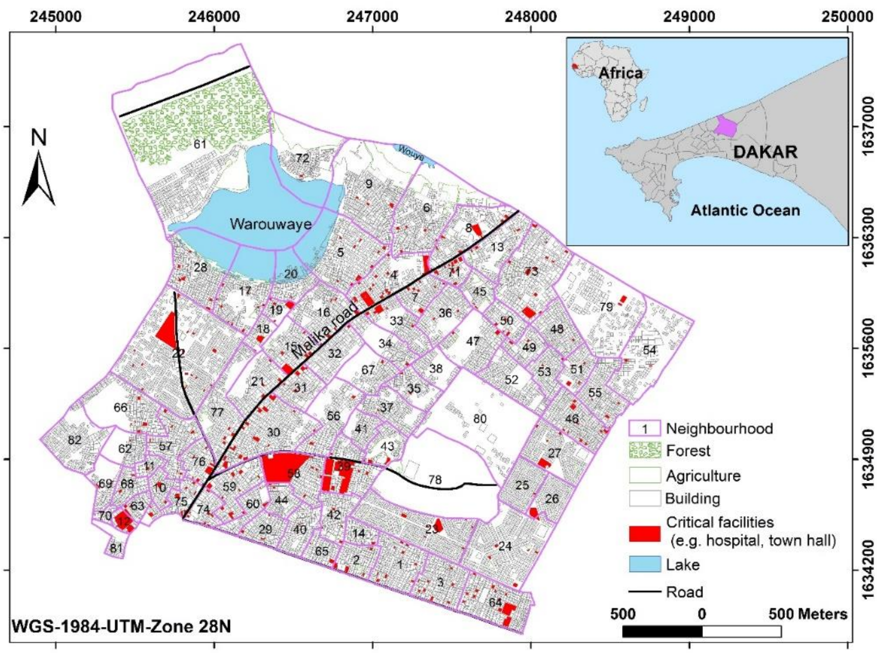

Figure 1: Location of the study area. The insert on the right corner locates our study area in the city of Dakar in Senegal. The central map represents our study area Yeumbeul North, without the retention basins that were constructed after the 2012 flood. The 82 neighbourhoods are designated by a number from 1 to 82. The corresponding names are provided in the supplementary material 1 (SM1).

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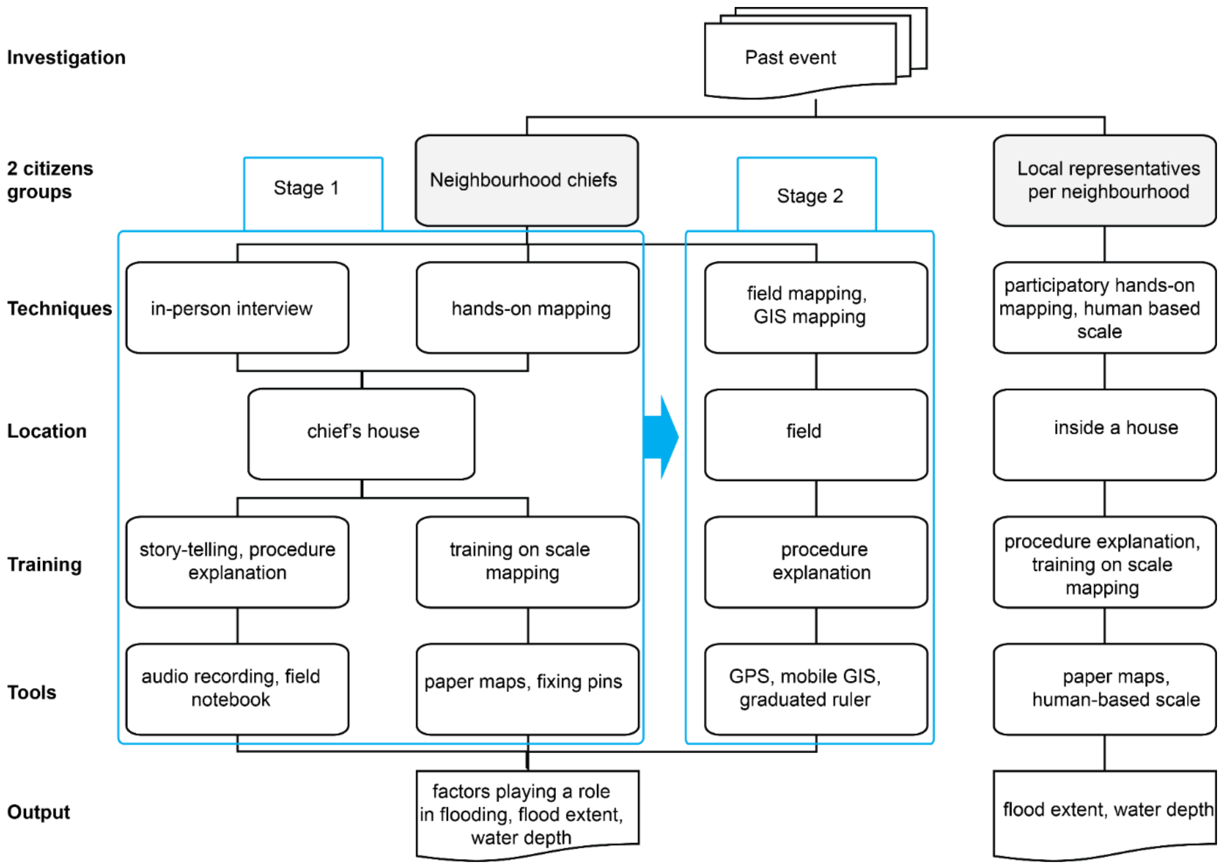

Figure 2. Framework for retrieving past flood information

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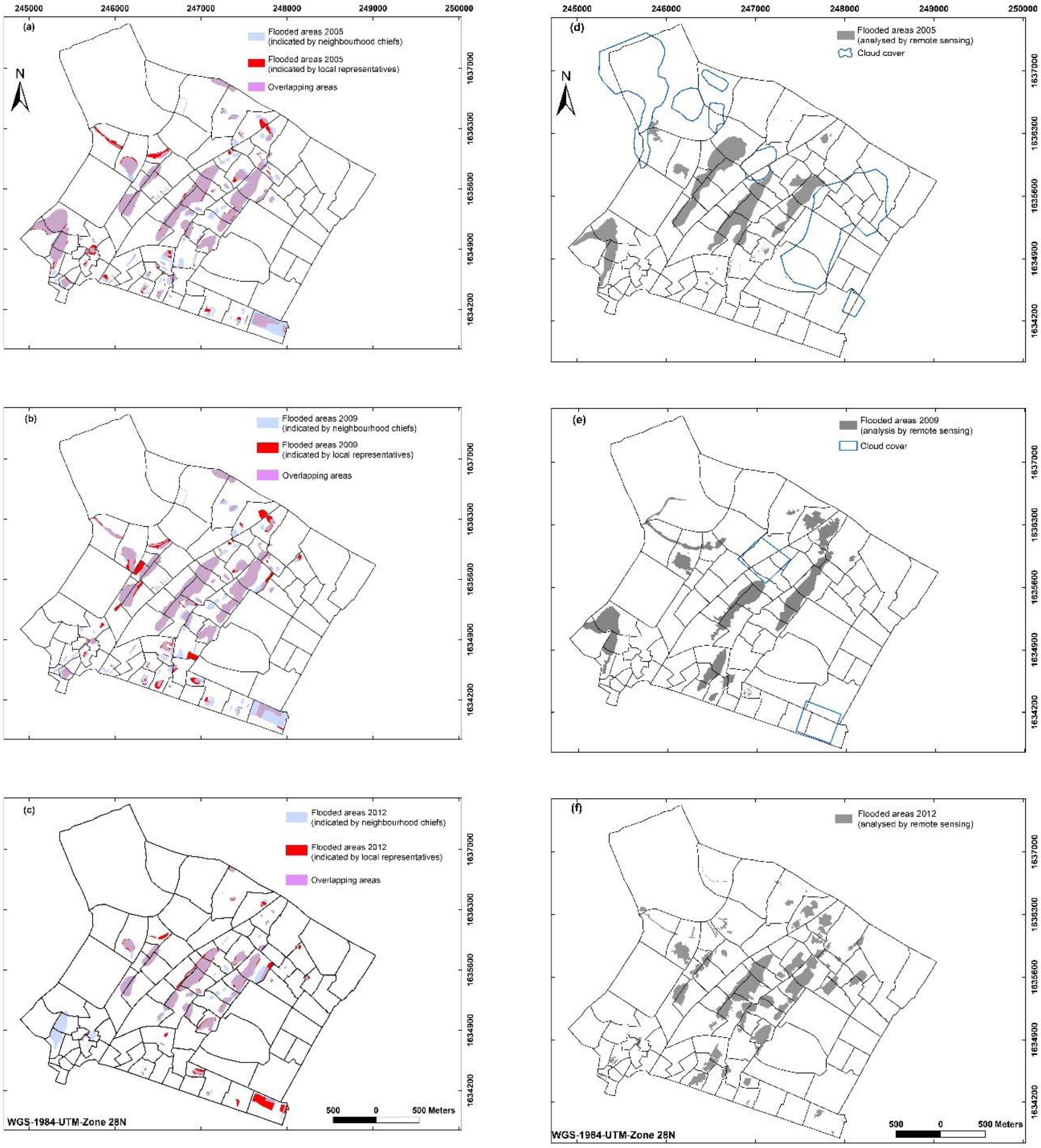

485 **Figure 3: Left side: Spatial distribution of flooded areas based on citizen science techniques, (a) 2005, (b) 2009, and (c) 2012. Right side: flooded areas based on remote sensing data (d) 2005, (e) 2009, and (f) 2012.**

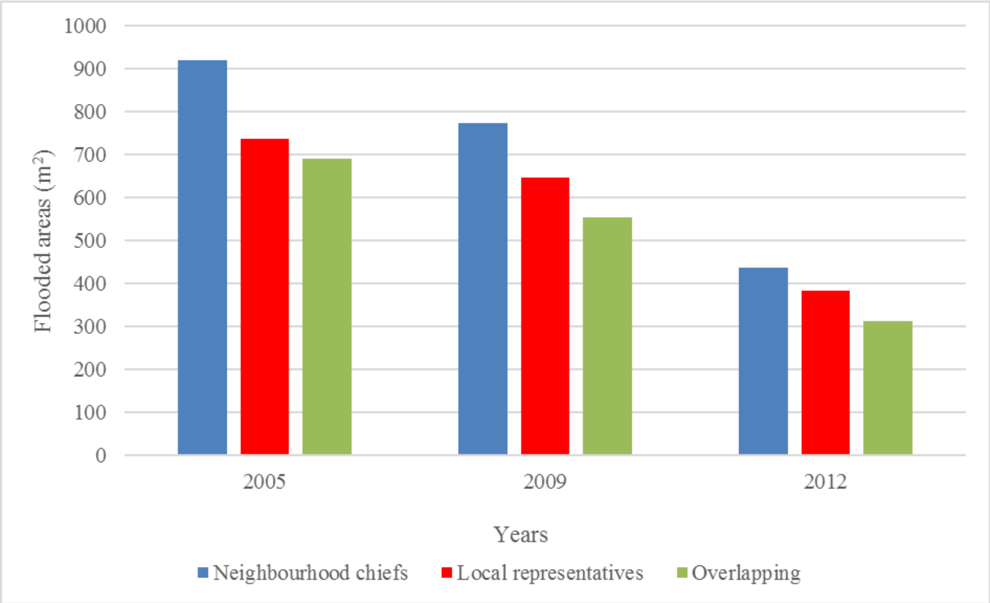

Figure 4: Flooded areas obtained by the two citizen groups and the surface of overlapping areas between the two results

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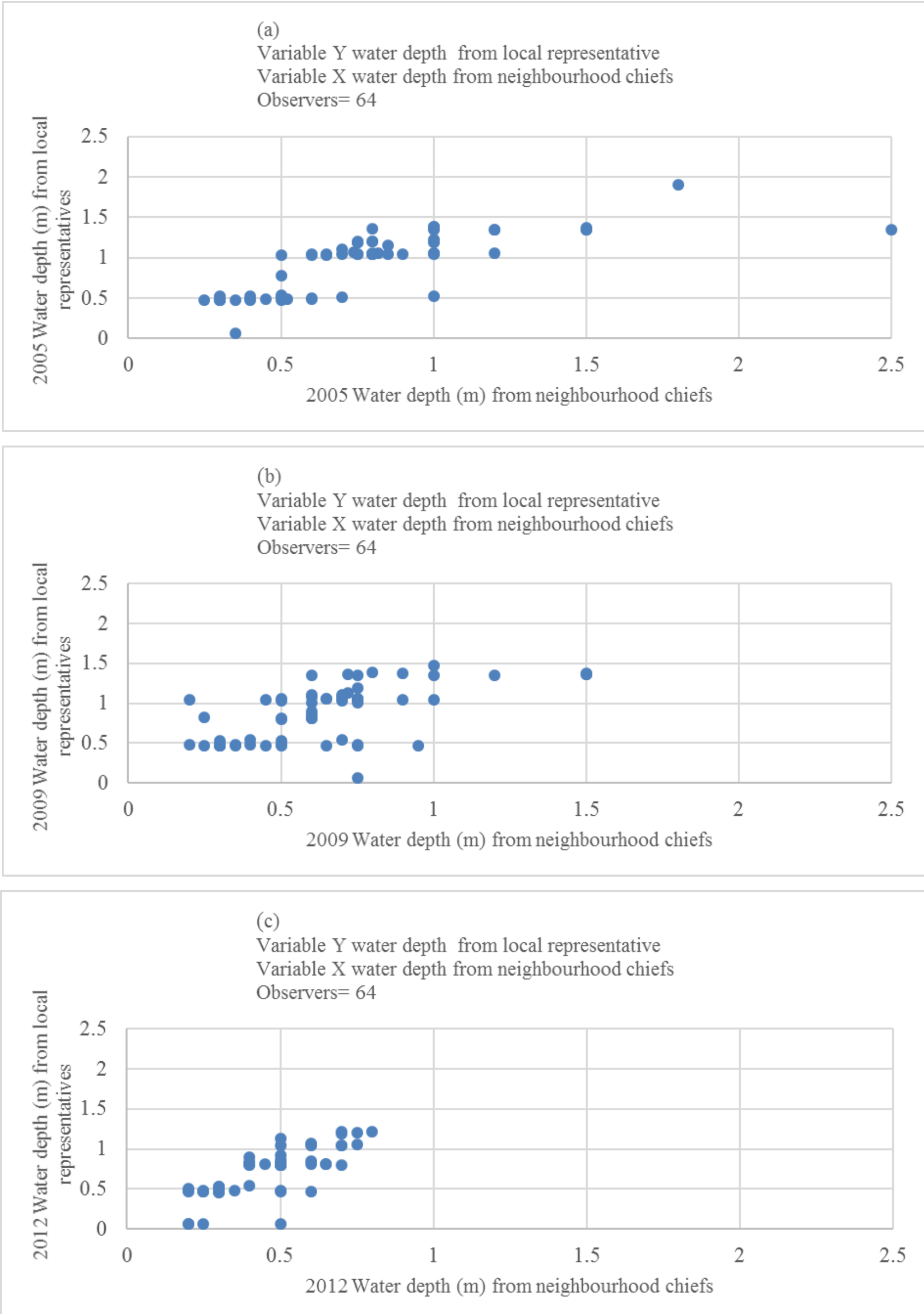

Figure 5: Scatter diagram of water depth information provided by neighbourhood chiefs and local representatives techniques for 3 different flooding events (a) 2005, (b) 2009, and (c) 2012

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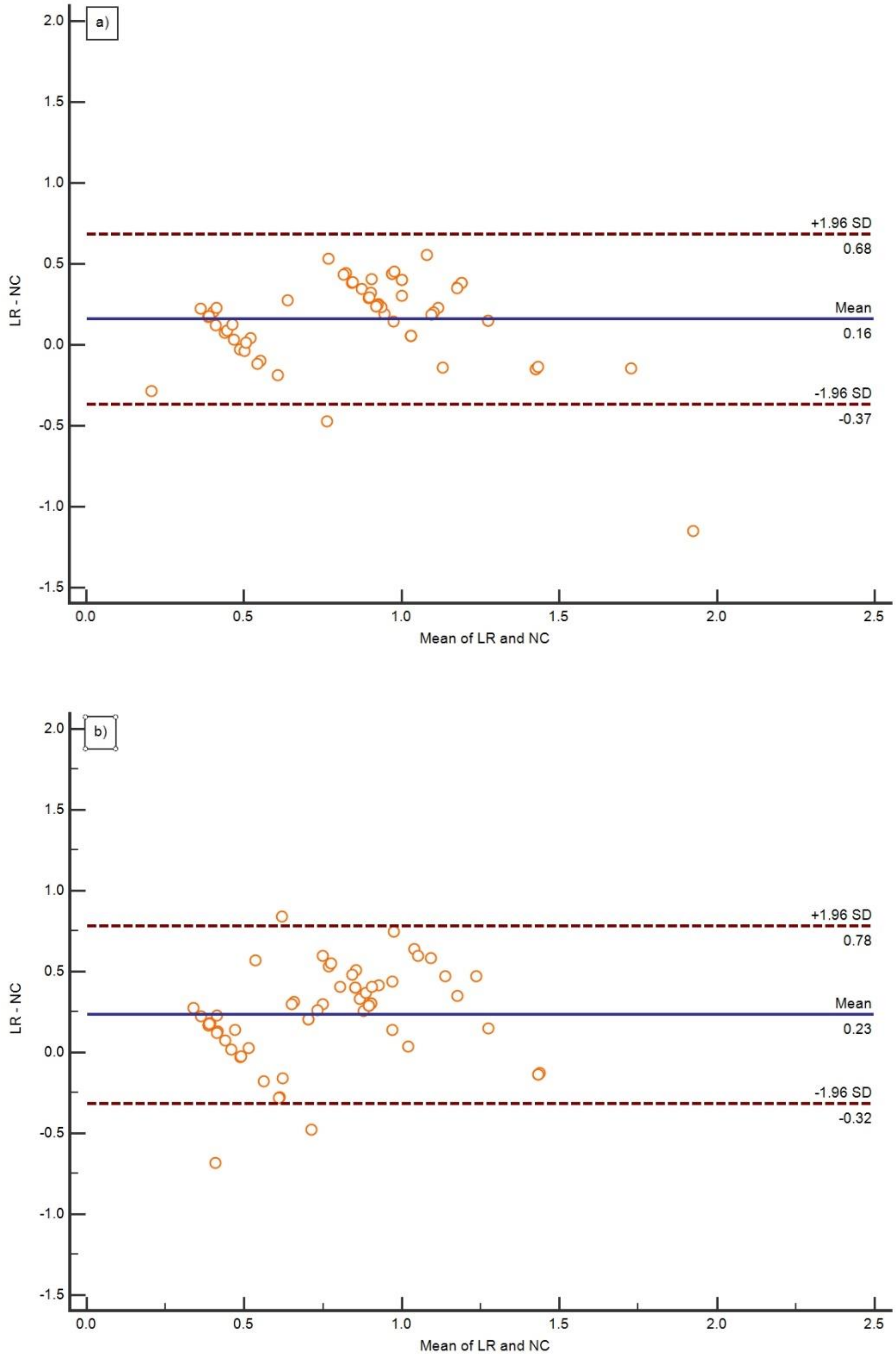

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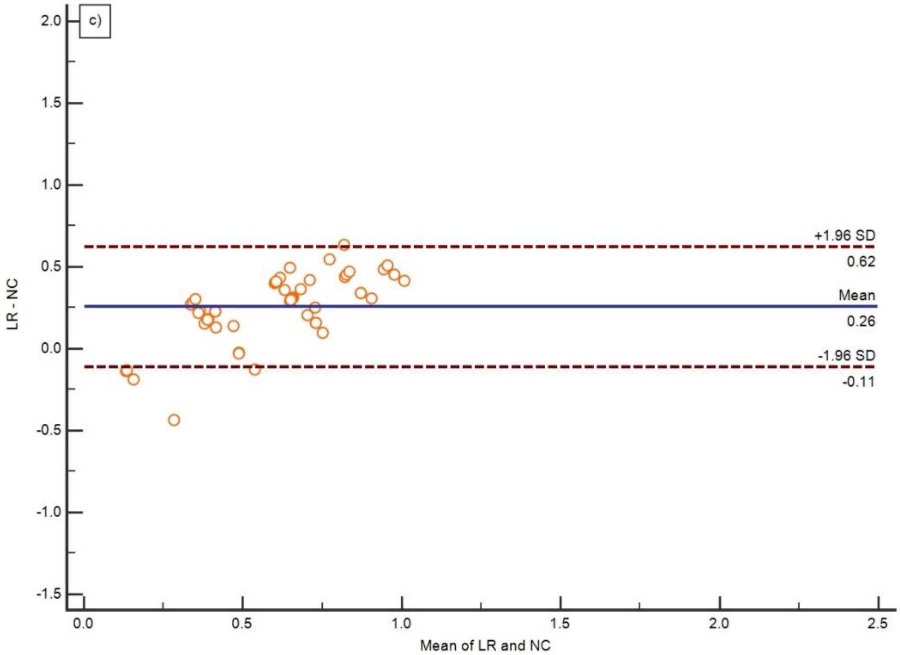

Figure 6. Bland-Altman plots of differences between water depth provided by neighbourhood chiefs (NC) and local representatives (LR) in meters against averaged values of NC and LR. Blue line is the mean difference value and the red dotted lines show the +/- 1.96 standard deviation (SD) water depth differences for all observations.

Table 1 The beginning and the end of the 3 flood events according to the Emergency Events Database (EM-DAT), as well as rainfall intensity peak of each event in Dakar-Yoff station coming from the National Agency for Civil Aviation and Meteorology (ANACIM) database in Senegal

Flood events	2005	2009	2012
start	20.08	09.08	15.08
end	10.09	20.09	31.08
Peak rainfall intensity	50 mm/h (04.09)	40 mm/h (24.08)	145.5 mm/h (26.08)

Table 2 Remote sensing data

Data/images	Date	Satellite / sensor	Resolution	Source
Mutispectral color	07/09/2005	Spot-5/HRV	10 m	UCAD
Mutispectral color	23/10/2006	Spot-5/HRV	10 m	UCAD
Panchromatic	23/10/2006	Spot-5/HRV	2.5 m	UCAD
Digital Globe©	11/03/2009	Worldview / QuickBird…	0.5 m	Google Earth©
Digital Globe©	14/10/2009	Worldview / QuickBird…	0.5 m	Google Earth©
Digital Globe©	08/03/2012	Worldview / QuickBird…	0.5 m	Google Earth©
Digital Globe©	31/08/2012	Worldview / QuickBird…	0.5 m	Google Earth©

Table 3 Comparison of flooding areas coming from citizen science techniques deployed in Yeumbeul Nord (neighbourhood chiefs and local representatives) and remote sensing analyses

	Citizen science				Remote sensing	
	Neighbourhood chiefs		Local representatives			
Years	Flooded areas (km^2)	% of the study area	Flooded areas (km^2)	% of study area	Flooded areas (km^2)	% of study area
2005	0.92	10	0.73	8.2	0.65	7.3
2009	0.77	8.6	0.64	7.2	0.59	6.6
2012	0.43	4.8	0.38	4.3	0.43	4.8