Reconstituting past flood events: the contribution of citizen science

Bocar Sy[1,*], Corine Frischknecht[1], Hy Dao[2,3], David Consuegra[1,4], Gregory Giuliani[3]

[1] Department of Earth Sciences, Faculty of Science, University of Geneva, 13 rue des Maraîchers, Geneva, 1205, Switzerland
[2] Department of Geography and Environment, Geneva School of Social Sciences, University of Geneva, 66 boulevard Carl Vogt, Geneva, 1205, Switzerland
[3] Institute for Environmental Sciences, University of Geneva, 66 Boulevard Carl Vogt, Geneva, 1205, Switzerland
[4] Institute of Territorial Engineering, School of Management and Engineering Vaud, 1 route de Cheseaux, Yverdon-les-Bains, 1401, Switzerland

Correspondence to: Bocar Sy (Bocar.Sy@unige.ch)

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, particularly 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~~ all 3 flood events.

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 loss (EM-DAT, 2018). West African countries, such as Burkina Faso or Senegal, appear to be experiencing an increase in flood disasters due to population growth and the urbanization of flood-prone areas (Di Baldassarre et al., 2010). Between 1990 and 2014, floods were responsible for 86% of the economic loss from natural disasters in Senegal alone (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).

The government and local authorities of Senegal have tried several strategies to mitigate urban floods, such as developing emergency plans, relocating inhabitants, and building water retention basins. However, two key aspects, required for these measures to work, have not yet been considered. Firstly, it is necessary to understand the causes and characteristics of floods and, secondly, the local population must be involved in the process of risk management. Information on the 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 temporal 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 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 advancements in various modern technologies - internet, web 2.0, virtual globe, location-based services, social media, mobile devices, interactive geo-visualization interfaces such as OpenStreetMap; Google Earth, Geo Wiki (Fritz et al 2009; Mooney and Minghini 2017; Yu and Gong 2012) - as well as the rise of participatory research characterized by greater user interactivity and collaboration, increase the number of studies and the subjects investigated by citizen science projects. The use of citizen science has also emerged in flood analysis in recent years. The existing works can be classified according to which phase of flood risk management they are dealing with i.e. before, during or after the flood event. For example, Sy et al. (2019) reviewed the use of citizen science in flood hazard assessment, discussing its potential to gather information needed to develop realistic scenarios and provide flood hazard parameters, such as extent and water depth, that could help understanding the hazard level at site. Assumpção et al. (2018) focused on the role citizen science could play in flood modelling and demonstrated its value to provide data for informing, calibrating and validating flood models, particularly where data are scare. It is notable that most of the existing studies dealt with fluvial flooding; fewer studies consider pluvial or groundwater flooding (See, 2019). Moreover, none of those citizen science projects studied the reconstruction of past events using the citizen memory, unlike the field of wildlife conservation where Zhang et al. (2017) demonstrated the value of citizen data for mapping past phenomena that were not otherwise recorded.

The objective of this work is twofold: 1) retrieve flood extents and water depths for different past events and, 2) determine whether citizens can clarify the causal chain of flood events. We also assessed the reliability of these data with by comparing 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 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 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 these, 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 neighbourhood and at least 35 years old. One of the delegate's tasks is to inform the neighbourhood inhabitants about how to face disasters. In this paper, we will referred to with delegate as a neighbourhood chief (Tall, 1986), appellation employed by the local population.

Flooding in this area is mainly due to runoff and rainwater, which are not absorbed by impermeable surfaces, made worse by rapid urbanization and the ineffective drainage network, combined with the rise of groundwater at some locations. Therefore, our area is characterized by multiple types of floods. Flooding occurs during the rainy season, which usually starts in July and ends in October. The 3 events considered here 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 combining different participatory approaches together 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) have witnessed the 3 flood events; 2) have a good spatial knowledge of both the study and flooded areas; 3) their social standing. Therefore, the first group consisted of the chiefs of the 82 neighbourhoods in the municipal district of Yeumbeul North. A chief is the qualification given to an official delegate (Tall, 1986) representing the municipal administration (GDS, 1986) and is therefore the focal point for the inhabitants, also in case of disasters. The majority of this group were male (98%) and their ages varied from 40 to 90 years, with an average of 66

years. The second group was composed of 182 people, 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 was not by 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

For this group of citizens, we used a two-stage approach to optimize the validity, reliability and utility of the collected data, and to transform memories of past floods into temporal and spatial information. The first stage is based on the use of episodic memory through in-person interviews conducted in the chief's house. Episodic memory is the process by which humans remember events in 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 involves 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 oldest inhabitants of the neighbourhood. Each interview was expected to last between 45 and 60 minutes, but it varied according to the history told and no time limit was imposed. Ultimately, interviews lasted from 30 to 60 minutes. In some cases it was possible to record the narrative digitally using a smartphone. The information obtained from the narrative allowed the neighbourhoods that were flooded to be identified. 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), putting pins on the map, handheld 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 investigations (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 relaxed state, allowing them to focus their thoughts and cognitive and emotional states 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 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 that could act as time indicators (e.g. proximity to a presidential election, football game); c) notable flood-related measures taken by the authorities enabling the event to be dated; d) spatial indicators such as place

and street names allowing reconstruction of the flooded areas, and e) the event itself, including information allowing deduction of the water depth (e.g. "the water reached our knees").

Following the narrative, only chiefs who indicated having been confronted with floods went through participatory mapping using maps at the scale of the neighbourhood (62 out of 82 chiefs, see supplementary material 2). This phase required 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 other features in 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 a 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

The objective of stage 2 was to corroborate the chiefs' responses from stage 1 by cross-checking the information leading to the map from stage 1 with 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 (Rubin 2005). We drew the polygon of the spatial extension using a mobile GIS, with GPS receiver automatically recording the site location. Furthermore, we measured the water level as indicated by 49 neighbourhood chiefs with a graduated ruler (supplementary material 3, 4 and 5) at 64 sites and took the GPS coordinates. Post-processing treatments include merging the contours of flooded areas obtained on the 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 quantitative water level measurements. The objective of the latter was to verify if the sites indicated as having had very high water levels on the paper map from stage 1 (red pin) corresponded to a high water level measured in the field. Since we assume that memory retrieval is facilitated when one is present at the site, we consider the field value to be more reliable.

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 people, selected by local associations (e.g. "Réseau d'Information d'Education de Communication", "Association des Relais Communautaires de Yeumbeul") that deal with development of the neighbourhood and awareness on health issues. The selection was based on the previously mentioned criteria. As these associations operate locally, they personally know residents and the choice of the inhabitants to be the representatives of the neighbourhood was based on a consensus among the associations. From here on, we use the term "local representatives" to refer to these selected people. The aim of involving local representatives is to integrate their information with that provided from 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

recall 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
160 techniques. For this, representatives were trained the same way as the chiefs. These maps were then digitized. Regarding water level, local representatives went to the same 64 sites as indicated by the chiefs, but without having any prior knowledge on the depths given by the chiefs, and depth information was given 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
165 fraction of body height, as defined in the field of physical anthropometry (Drillis and Contini, 1966, Winter, 2009). 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) and chin (0.870). Finally, the water depth was obtained by multiplying the value of the appropriate coefficient by the contributor's (local representative) height, as measured on site with a tape measure (supplementary material 3, 4, 5 and 6). As we used two different approaches
170 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), which determines 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 plots them against the average of the two
175 approaches.

3.1.3 Remote sensing analysis

We used data from ~~remote~~ sensing analysis to assess the reliability of the extents of flooded areas provided by the two citizens~~~~ groups. Our requirements were: 1) availability of images for the years considered, 2) free access of data, 3) sufficient resolution for the size of our study area (9km^2), and 4) minimum cloud cover. Radar images such as TerraSAR-X, Radarsat-2 or COSMO-
180 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 they are not free of charge and, most importantly for our case, no images were available for the periods of interest. Consequently, we only used available optical satellite images from different sensors. The main characteristics of these products are given in ~~table~~ 2. Flooded areal extents were obtained following the process chain ~~describes on~~ Fig. 3.
185 For ~~2005~~ event, we used two SPOT images (23/10) and (07/09) provided by the applied Remote Sensing Laboratory (LTA) of the Institute of Earth Sciences (IST) of the University Cheikh Anta Diop (UCAD) (~~table~~ 2). It should be noted that we did not find an image from before the flooding and hence we used an image obtained during a dry period. These two multispectral SPOT 5 images of 10 m resolution were merged with a SPOT 5 panchromatic image ~~of~~ a spatial resolution of 2.5 m to increase ~~their~~ spatial accuracy. We then applied the normalized difference water index (NDWI; Khajuria et al., 2017) to ~~~~the water

signature from other land-use types. The NDWI is calculated following the method of McFetters (1996), using the green and the near-infrared bands:

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

An unsupervised classification was then performed to cluster pixels having similar NDWI values, using the ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering algorithm provided through the software Erdas Imagine 2014©. The classes are then coded to highlight only the water areas. These areas were then digitized on both images. Finally, both layers are compared and only areas corresponding to flooded areas are kept. An area is considered as flooded if water can be detected only on the image after the flood.

For the 2009 and 2012 events, we used images available from Google Earth. Google launched Google Earth in 2005 (Cha and Pak, 2007), and it provides free online aerial and satellite images covering many parts of the world, with various resolutions and sensors. The highest resolution, about 0.5 m, is provided by Worldwide and QuickBird satellite imagery operated by Digital Globe. For each flood event, we examined the historical true colour composite imagery from Google Earth using the time slider bar of Google to find one image as close as possible to the flood event and another one in a dry period after the event. These images were then photo-interpreted to identify areas of water. These areas were digitized and then compared to extract only areas considered as flooded.

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 identified rainfall as the primary factor. 29 chiefs (neighbourhood numbers 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 pointed out the rise of the water table, substantiated by wet ground, greening of walls due to the water infiltration, and removal of paint from walls.

The neighbourhood chiefs identified different processes that worsened the flood, by either increasing the quantity of water or obstructing the typical flow, for both different locations and events. For example, for the 2005 event, 4 neighbourhood chiefs (13, 36, 46, and 67) mentioned the failure of the pipeline in the road of Malika, used for water drainage, as 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 performed by the local population, such as emptying of household septic tanks, which aggravated this event and also had direct consequences on health (e.g. cholera epidemics) (Wade et al., 2009). Pipeline failure and emptying of septic tanks also 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 did not 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. 4).

~~The citizen science~~ revealed that the 2005 event was the most widespread whereas the 2012 event was the smallest (~~table~~ 3).

225 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 between the extents identified by the two citizen groups (Fig. 4), but the areas overlap reasonably well (Fig. 5).

~~Remote~~ sensing analysis confirms that the main flooded areas were in the central part of the study area (Fig. 4), but some discrepancies occur at the edges. The total surface area is smaller than that provided by citizen science for all years (~~table~~ 3),

230 but shows the same tendency of decreasing surfaces from 2005 to 2012. We also find that flood extents provided by neighbourhood chiefs agreed better with the remote sensing than those provided by local representatives for all events.

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.

235 Figure 6 displays scatter diagrams of depth values obtained from the two different groups of citizens using the techniques described in the methods (see Fig. 2) at 64 sites, sampled over 49 neighbourhoods. We have two measurement from each site. The maximum retrieved flood depth is 2.5 m for the 2005 event, 1.5 m for the 2009 event, and 1.2 m for the 2012 event.

Figure 7 shows the data obtained by applying the Bland-Altman method for the 2005, 2009 and 2012 events for the 64 sites of measurements. The value of the mean differences in water depth, indicated by the blue line, is 0.16 m for the 2005 event, 0.23

240 m for 2009 and 0.26 m for 2012. The limits of agreement, also displayed, are set at 95% confidence intervals. Assuming the differences to be normally distributed, these limits are defined by the mean difference +/- 1.96 multiplied by the standard deviation σ of the differences. For the 2005 event, this range is from 0.68m to -0.37m, with two values ~~out of~~ these limits. For 2009 and 2012, three values are outside the 95% confidence interval which is from 0.78m to -0.32m for 2009 and 0.62m to -0.11m for 2012.

5 Discussion and conclusion

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

Our methodology consisted of a set of techniques designed to gather the most complete spectrum of information. These

250 techniques are unusual in the field of flood hazard assessment and we had to resolve some challenges associated with the time ~~elapsed~~ since the events and participant's understanding of maps. One technique 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 memory distortion. The procedure was then completed by a ~~scene~~ visit with each neighbourhood chief involved in order to consolidate the verbally provided information. The ~~scene~~ visit is very important because the time elapsed between the oldest event and the

255   date of this study is about 12 years. As time goes by, memories can become vague (Lacy and Stark, 2013). However, people who have experienced traumatic and stressful events, like floods, tend to retain 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 understanding and locating themselves on a map.

260   Moreover, maps are usually constructed ~~applying by~~ standard rules of graphic semiology (Thomas, 2011) that does not necessary take into account the cultural background 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 on how to read a map and locate themselves to ensure they understood the map and we explained what they should be doing and how to do it.

265   Developing the quality and reliability of citizen science data is a growing research field (Crall et al., 2011; Flanagin and Metzger, 2008; 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 obtained from the two groups. If the same area is described as flooded by both groups, there is a good chance that the area was indeed flooded. Due to the social organisation of the Dakar region, we limited issues

270   regarding source credibility (Flanagin and Metzger, 2008) by involving neighbourhood chiefs. Indeed, these chiefs are appointed by local citizens, according to the trust placed in 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 on the chain of events. The second group was composed of local representatives, selected with the support of local and well-implemented associations.

275   Identifying the chain of processes generating flooding is very important for flood hazard assessment (DAEC, 2016) as it enables analysis of more realistic flood scenarios. Citizens living in flood affected areas are not frequently included in post-event or flood hazard assessments, even though they could provide useful insights as they have a good understanding of their surroundings (Tran et al., 2009) and an in-depth local knowledge. Our study demonstrates this as ~~neighbourhood chief's~~ identified both natural and man-made factors that contributed to flooding, such as the rise of ground water, the Warouwaye

280   lake overflow, and the emptying of septic tanks.

In terms of flooded areas, the results obtained from the two groups of citizens are similar for each event, although some spatial differences can be observed regarding the extent. Reasons for the differences could be related to a) a more in-depth knowledge of the neighbourhood and their surroundings by the chiefs, as they have the confidence (Tall, 1998) of the inhabitants and therefore have access to more detailed information; b) the techniques used in mapping the areas. With neighbourhood chiefs,

285   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.

A good spatial agreement exists between flood extents determined from remote sensing and citizen science, with better agreement from the data provided by the neighbourhood chiefs. However, areas provided by remote sensing are smaller. This discrepancy can be explained by various factors. One could be the different spatial resolution of the selected images, which

290   varied from 0.5 m to 2.5 m, the larger probably not being ~~probably~~ small enough to capture all flooded areas (Grimaldi et al., 2016) at the scale we worked. A second factor concerns the different time lapses between images. Post-event images from Google Earth were captured at intervals from 1 to 15 days and therefore may not have captured the maximum extent. Furthermore, for the 2005 event, one image was obtained during the flooding, with the second image taken one year after with the assumption it was captured during a dry period. A third factor is related to technical limitations of the capability of optical

295   satellites to detect flooded areas, which is reduced when clouds are present (Malinowski et al., 2017; Mallinis et al., 2013). Finally, the efficiency of the NDWI index used to detect water areas could be altered by noise (Xu, 2005).

One of the techniques used to retrieve water depths was inspired from studies expressing flood hazard levels on maps using a 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

300   (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 less than 0.3 m, which is within the range of other comparisons between observed and simulated methods (Kutija et al., 2014).

Both involvement and motivation from citizens are necessary for the success of citizen science projects (Rotman et al., 2012).

305   As Facebook was one of the most used social media in ~~Yeumbeul North~~ at the time of the study (Sy, 2019), we first created a page to interact with local citizens and motivate them to be part of the project. Secondly, we designed and presented the project in a way to convince contributors that their contribution will be beneficial for them and their neighbours. Thirdly, 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 can now also take advantage of the

310   free availability of radar images such as sentinel (Malenovský et al., 2012). However, at the scale we worked, these images do not offer the required spatial resolution (Twele et al., 2016), nor information on the depth of the flood, which is a critical datum for flood hazard assessment that we ~~was~~ 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, involving two

315   different groups of citizens, increases the reliability of the obtained data. Provided that the functioning of the society subject to floods is well understood, such an approach can be replicated in other parts of the world. Moreover, the citizens that have been involved in the various steps of this project have developed skills in flood data acquisition and an understanding of flood processes. They can thus better integrate into a decision-making process regarding flood risk.

Author contributions

320 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.

325 ## Acknowledgements

The authors are grateful to the Augustin Lombard from SPHN and plantamour-Prevost grants for their support for the field campaign, as well as Dr Wade for providing us the SPOT satellite images from Applied Remote Sensing Laboratory (LTA) of the Institute of Science of Earth (IST) of the University Cheikh Anta Diop of Dakar (UCAD).

References

330 Ahiablame, L. and Shakya, R.: Modeling flood reduction effects of low impact development at a watershed scale, Journal of environmental management, 171, 81-91, https://doi.org/10.1016/j.jenman.2016.01.036, 2016.

ANDS. Situation économique et sociale régionale 2013 : Agence Nationale de la Statistique et de la Démographie, 1-129, 2015.

Assumpção, T. H., Popescu, I., Jonoski, A., and Solomatine, D. P.: Citizen observations contributing to flood modelling: opportunities and challenges: Hydrology and Earth System Sciences, 22, no. 2, p. 1473-1489, http://www.hydrol-earth-syst-sci.net/22/1473/2018, 2018.

335 Bénit-Gbaffou, C. and Katsaura, O.: Community Leadership and the Construction of Political Legitimacy: Unpacking Bourdieu's 'Political Capital'in Post-Apartheid Johannesburg, International Journal of Urban and Regional Research, 38, 1807-1832, doi: 10.111/1468-2427.12166, 2014.

Bland, J. M. and Altman, D.: Statistical methods for assessing agreement between two methods of clinical measurement, The lancet, 307-310, 1986.

340 Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., Dewulf, A. Foggin, M., Hannah, D. M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., Van Hecken, G., and Zhumanova, M: Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development, Frontiers in Earth Science, 2, 26, 1-21, https://doi.org/10.3389/feart.2014.00026, 2014.

Cha, S.-Y., and Park, C.-H.: The utilization of Google Earth images as reference data for the multitemporal land cover classification with

345 MODIS data of North Korea: Korean Journal of Remote Sensing, 23, no. 5, p. 483-491, 2007.

Chen, Y., Zhou, H., Zhang, H., Du, G. and Zhou, J. Urban flood risk warning under rapid urbanization, Environmental research, 139, 3-10, http://dx.doi.org/10.1016/j.envred.2015.02.028 ,2015.

Contini, R. Body segment parameters, Part II, Artificial limbs, 16, 1-19, 1972.

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., and Waller, D. M.: Assessing citizen science data quality: an

350   invasive species case study, Conservation Letters, 4, 433-442, doi: 10.1111/j.1755-263X.2011.00196.x, 2011.

Creevey, L.: Islam, Women and the Role of the State in Senegal, Journal of Religion in Africa, 268-307, doi: 10.2307/1581646, 1996.

DAEC : Cartographie intégrale des dangers naturels liés aux crues sur le plateau fribourgeois, Direction de l'aménagement, de l'environnement et des constructions, 1-25, 2016.

Di Baldassarre, G., Montanari, A., Lins, H., Koutsoyiannis, D., Brandimarte, L., and Blöschl, G.: Flood fatalities in Africa: from diagnosis

355   to mitigation, Geophysical Research Letters, 37, L22402, doi: 10.1029/2010GL045467, 2010.

Dickinson, J. L., Zuckerberg, B., and Bonter, D. N.: Citizen science as an ecological research tool: challenges and benefits, Annual review of ecology, evolution, and systematics, 41, 149-172, 2010.

Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., and Campbell, J.: Unjust waters: climate change, flooding and the urban poor in Africa, Environment and urbanization, 20, 187-205, doi: 10.1177/0956247808089156, 2008.

360   Drillis, R., and Contini, R.: Body segment parameters. Office of Vocational Rehabilitation, Department of Health, Education and Welfare: New York, Scholl of Engineering and Science, New York University. Report No 1166-03, 1966.

EM-DAT: The OFDA/CRED International Disaster Database, Retrieved from <http://www.emdat.be/disaster_trends/index.html> [accessed 14 August 2018], 2018.

EXCIMAP: Handbook on good practices for flood mapping in Europe. (European exchange circle on flood mapping), 1-60, Retrieved from

365   <http//e.ceuropa.eu/environment/water/flood_risk/flood_atlas/pdf/handbook_goodpractice.pdf>. [accessed 14 August 2018], 2007.

Fisher, R. P.: Interviewing cooperative witnesses, Legal and Criminological Psychology, 15, 25-38, doi: 10.1348/ 135532509X441891, 2010.

Flanagin, A. J., and Metzger, M. J.: The credibility of volunteered geographic information, GeoJournal, 72, 137-148, doi: 10.1007/s10708-008-9188-y , 2008.

370   Fritz, S., McCallum, I., Schill, C., Perger, C., Grillmayer, R., Achard, F., Kraxner, F., and Obersteiner, M.: Geo-Wiki. Org: The use of crowdsourcing to improve global land cover: Remote Sensing, 1, no. 3, p. 345-354, 2009.

Fuchs, S., Spachinger, K., Dorner, W., Rochman, J., and Serrhini, K.: Evaluating cartographic design in flood risk mapping, Environmental Hazards, 8, 52-70, 2009.

Gouvernement Du Sénégal (GDS), Decret N 86-761 du 30 juin 1986, Retrieved from

375   <http://www.servicepublic.gouv.sn/assets/textes/deleg-quartier.pdf> [accessed 24 September 2018]., 1986.

GFDRR: Senegal: urban floods: recovery and reconstruction since 2009, World Bank's Global facility for Disaster Reduction and Recovery, 1-48, 2014.

Grimaldi, S., Li, Y., Pauwels, V. R., and Walker, J. P.: Remote sensing-derived water extent and level to constrain hydraulic flood forecasting models: opportunities and challenges, Surveys in Geophysics, 37, 977-1034, doi: 10.1007/s10712-016-9378-y, 2016.

380   Handmer, J.: Floodplain maps: uses and limitations as public information, in proceedings of the 13th New Zealand Geographical Society Conference, Hamilton, New Zealand, 1985.

IFAD. Good practices in participatory mapping: a review prepared for the International Fun for Agricultural Development (IFAD), 1-59, 2009. Retrieved from http://www.iapad.org/.../ifad_good_practice_in-participatory_mapping.p... [accessed 24 January 2019], 2009.

Khajuria, A., Farooq, M. and Prashar, P: Flood inundation mapping of Srinagar city using geospatial techniques, in: Proceeding of the

385   National Conference on Advances in Water Ressource and Environment Research, Tamilnadu, India 29-30 June 2017,1-236, 2017.

Kutija, V., Bertsch, R., Glenis, V., Alderson, D., Parkin, G., Walsh, C., Robinson, J., and Kilsby, C.: Model validation using crowd-sourced data from a large pluvial flood, in: Proceedinds of the 11th International conference on hydroinformatics, New York City, USA, 17-21 August 2014, 2014.

Lacy, J. W., and Stark, C. E.: The neuroscience of memory: implications for the courtroom, Nature Reviews Neuroscience, 14 (9), 649-658, doi: 10.1038/nrn3563, 2013.

Loftus, E. F., and Palmer, J. C.: Reconstruction of automobile destruction: An example of the interaction between language and memory, Journal of verbal learning and verbal behavior, 13, 585-589, 1974.

Luke, A., Sanders, B. F., Goodrich, K. A., Feldman, D. L., Boudreau, D., Eguiarte, A., Serrano, K., Reyes, A., Schubert, J. E., and AghaKouchak, A.: Going beyond the flood insurance rate map: insights from flood hazard map co-production, Natural Hazards and Earth System Sciences. 18, 1097-1120, https://doi.org/10.5194/nhess-18-1097-2018, 2018.

Malenovský, Z., Rott, H., Cihlar, J., Schaepman, M. E., García-Santos, G., Fernandes, R., and Berger, M.: Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land, Remote Sensing of Environment, 120, 91-101, https://doi.org/10.1016/j.rse.2011.09.026, 2012.

Malinowski, R., Groom, G. B., Heckrath, G., and Schwanghart, W.: Do Remote Sensing Mapping Practices Adequately Address Localized Flooding? A Critical Overview: Springer Science Reviews, 5, no. 1-2, p. 1-17, doi: 10.1007/s40362-017-0043-8, 2017.

Mallinis, G., Gitas, I. Z., Giannakopoulos, V., Maris, F., and Tsakiri-Strati, M.: An object-based approach for flood area delineation in a transboundary area using ENVISAT ASAR and LANDSAT TM data, International Journal of Digital Earth, 6, 124-136, doi: 10.1080/17538947.2011.641601, 2013.

Mason, D. C., Giustarini, L., Garcia-Pintado, J., and Cloke, H. L.: Detection of flooded urban areas in high resolution Synthetic Aperture Radar images using double scattering, International Journal of Applied Earth Observation and Geoinformation, 28, 150-159, http://dx.doi.org/10.1016/j.jag.2013.12.002, 2014.

McFeeters, S. K.: The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features: International journal of remote sensing, 17, no. 7, p. 1425-1432, doi: 10.1080/01431169608948714, 1996.

Mooney, P., and Minghini, M.: A review of OpenStreetMap data, In Foody, G, See, L, Fritz, S, Mooney, p, Olteanu-Raimond, A-M, Fonte, C C and Antoniou, V (Eds.), Mapping and the Citizen Sensor, 37-59, London: Ubiquity Press, https://doi.org/10.5334/bbf.c., 2017.

Paul, J. D., Buytaert, W., Allen, S., Ballesteros-Cánovas, J. A., Bhusal, J., Cieslik, K., Clark, J., Dugar, S., Hannah, D. M., and Stoffel, M.: Citizen science for hydrological risk reduction and resilience building, Wiley Interdisciplinary Reviews: Water, 5, e1262, https://doi: 10.1002/wat2.1262, 2018.

Perfect, T. J., Wagstaff, G. F., Moore, D., Andrews, B., Cleveland, V., Newcombe, S., Brisbane, K.-A., and Brown, L.: How can we help witnesses to remember more? It's an (eyes) open and shut case, Law and Human Behavior, 32, 314-324, 2008.

Preventionweb. Disaster and Risk Profile, Africa, Senegal, Nationally Reported Losses 1990-2014. (2018). Retrieved from < http://www.preventionweb.net/countries/sen/data/> [accessed 14 August 2018], 2018.

Raddick, J., Lintott, C., Schawinski, K., Thomas, D., Nichol, R., Andreescu, D., Bamford, S., Land, K., Murray, P., and Slosar, A.: Galaxy Zoo: an experiment in public science participation, Bulletin of the American Astronomical Society, 39, 892, 2007.

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., Lewis, D., and Jacobs, D.: Dynamic changes in motivation in collaborative citizen-science projects, in: Proceedings of the ACM 2012 conference on computer supported cooperative work, Washington, USA, 11-15 February 2012, 217-226 (2012). Retrieved from https://dl.acm.org/citation.cfm?id=2145238 [accessed 25 January 2019], 2012.

Rubin, D. C.: A basic-systems approach to autobiographical memory: Current Directions in Psychological Science, 14, no. 2, p. 79-83, 2005.

Sanyal, J., and Lu, X.: Application of remote sensing in flood management with special reference to monsoon Asia: a review, Natural Hazards, 33, 283-301, 2004.

Schubert, A., Small, D., Jehle, M., and Meier, E.: COSMO-SkyMed, TerraSAR-X, and RADARSAT-2 geolocation accuracy after compensation for earth-system effects, Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International, 3301-3304, https://doi.org/10.1109/IGARSS.2012.6350598, 2012.

Schumann, G., Bates, P. D., Horritt, M. S., Matgen, P., and Pappenberger, F.: Progress in integration of remote sensing–derived flood extent and stage data and hydraulic models, Reviews of Geophysics, 47, RG4001, doi: 10.1029/2008RG000274, 2009.

See, L. M.: A Review of Citizen Science and Crowdsourcing in Applications of Pluvial Flooding: Frontiers in Earth Science, 7, p. 44, 2019.

Silvertown, J.: A new dawn for citizen science, Trends in ecology & evolution, 24, 467-471, 2009.

Silvertown, J., Harvey, M., Greenwood, R., Dodd, M., Rosewell, J., Rebelo, T., Ansine, J., and McConway, K.: Crowdsourcing the identification of organisms: A case-study of iSpot, ZooKeys, 480, 125-146, doi: 10.3897/zookeys.480.8803, 2015.

Sotgiu, I., and Galati, D.: Long-term memory for traumatic events: experiences and emotional reactions during the 2000 flood in Italy, The Journal of Psychology, 141, 91-108, 2007.

Swanson, A., Kosmala, M., Lintott, C., and Packer, C.: A generalized approach for producing, quantifying, and validating citizen science data from wildlife images, Conservation Biology, 30, 520-531, doi: 10.1111/cobi.12695, 2016.

Sy, B., Frischknecht, C., Dao, H., Consuegra, D., and Giuliani, G.: Flood hazard assessment and the role of citizen science, Journal of Flood Risk Management, e12519, https://doi.org/10.1111/jfr3.12519, 2019.

Sy, B.: Approche multidisciplinaire de l'évaluation de l'aléa d'inondation à Yeumbeul Nord, Dakar, Sénégal: la Contribution de la science citoyenne. (Thèse de Doctorat). Department de Sciences de la Terre, Université de Genève, p. 187, 2019.

Sy, B., Frischknecht, C., Dao, H., Giuliani, G., Consuegra, D., Wade, S., and Kêdowidé, C.: Participatory approach for flood risk assessment: the case of Yeumbeul Nord (YN), Dakar, Senegal, WIT Transactions on The Built Environment, 165, 331-342, doi: 10.2495/UW160291, 2016.

Tall, S. M.: La Décentralisation et le Destin des Délégués de Quartier à Dakar (Sénégal). Plaidoyer pour les délégués de quartier de Dakar après la loi de décentralisation de 1996, Bulletin de l'APAD, 15, 1-13 (1998). Retrieved from http://journals.openedition.org/apad/567 [accessed 28 November 2018],1998.

Thomas, I.: Cartographie d'aujourd'hui et de demain: rappels et perspectives: Cybergeo: Revue européenne de géographie, 7, 2001.

Townsend, P. A., and Walsh, S. J.: Modeling floodplain inundation using an integrated GIS with radar and optical remote sensing, Geomorphology, 21, 295-312, 1998.

Tran, P., Shaw, R., Chantry, G., and Norton, J.: GIS and local knowledge in disaster management: a case study of flood risk mapping in Viet Nam, Disasters, 33, 152-169, 2009.

Tulving, E.: Episodic and semantic memory, Organization of memory, 1, 381-403, 1972.

Tulving, E.: What is episodic memory?, Current Directions in Psychological Science, 2, 67-70, 1993.

Tulving, E.: Episodic memory: From mind to brain, Annual review of psychology, 53, 1-25, 2002.

Twele, A., Cao, W., Plank, S., and Martinis, S.: Sentinel-1-based flood mapping: a fully automated processing chain, International Journal of Remote Sensing, 37, 2990-3004, 2016.

UNISDR-CRED: The human cost of weather-related disasters 1995-2015

United Nations office for Disaster Risk Reduction (UNISDR) and Centre for Research on the Epidemiology Disaster (CRED), 1-30, 2015.

Urama, K. C., and Ozor, N.: Impacts of climate change on water resources in Africa: the role of adaptation, African Technology Policy Studies Network, 29, 1-29, 2010.

Van Alphen, J., Passchier, R., and Martini, F.: Atlas of Flood Maps: Examples from 19 European Countries, USA and Japan, Retrieved from <http:// www.mko.gov.si/.../atlas_primerov__kartiranja_poplavne_nevarn...> [accessed 1 December 2018], 2007.

465   Wade, S., Faye, S., Dieng, M., Kaba, M., and Kane, N.: Télédétection des catastrophes d'inondation urbaine: le cas de la région de Dakar (Sénégal), Journées dÁnimation Scientifique (JAS09) de lAUF Alger, 2009.

Wiggins, A., and Crowston, K.: From conservation to crowdsourcing: A typology of citizen science, in: Proceedings of the 44th Hawaii International Conference on System Science (HICSS). 1-10, 2011.

Winter, D. A.: Biomechanics and motor control of human movement, fourth edition, John Wiley & Sons, Inc., 82-106, ISBN: 978-0-470-
470   39818-0, 2009.

WMO: Integrated flood management tools series: Urban flood management in a changing climate, World Meteorological Organization. 14, 1-54. Retrieved from https://library.wmo.int/pmb_ged/ifmts_14.pdf [accessed 14 August 2018], 2012.

Xu, H.: Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery: International Journal of Remote Sensing, 27, no. 14, p. 3025-3033, doi: 10.1080/01431160600589179, 2006.

475   Yu, L., and Gong, P.: Google Earth as a virtual globe tool for Earth science applications at the global scale: progress and perspectives: International Journal of Remote Sensing, 33, no. 12, p. 3966-3986, 2012.

Zacks, R. T., Hasher, L., and Li, K. Z.: Human memory, . In F.I.M Craik & T.A Salthouse (Eds.), the handbook of aging and cognition, Mahwah, NJ: Erlbaum, 293-357 , 2000.

Zhang, G., Zhu, A. X., Huang, Z. P., Ren, G., Qin, C. Z., and Xiao, W.: Validity of historical volunteered geographic information: Evaluating
480   citizen data for mapping historical geographic phenomena: Transactions in GIS, v. 22, no. 1, p. 149-164, 2018.

Żyszkowska, W.: Map perception: theories and research in the second half of the twentieth century, Polish Cartographical Review, 47, 179-190, doi: 10.1515/pcr-2015-0017, 2015.

Żyszkowska, W.: Levels and properties of map perception, Polish Cartographical Review. 49, 17-26 (2017).Retrieved from https://www yadda.icm.edu.pl/yadda/.../c/zyszkowska_levels_1_2017.pdf [accessed 25 January 2018], 2017.

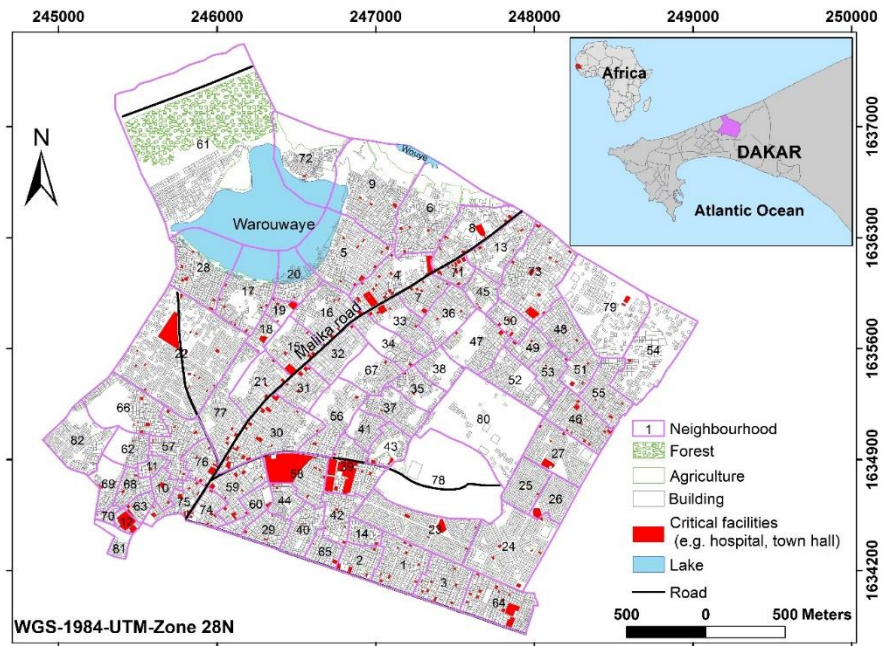
485

490

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).

495

500

505

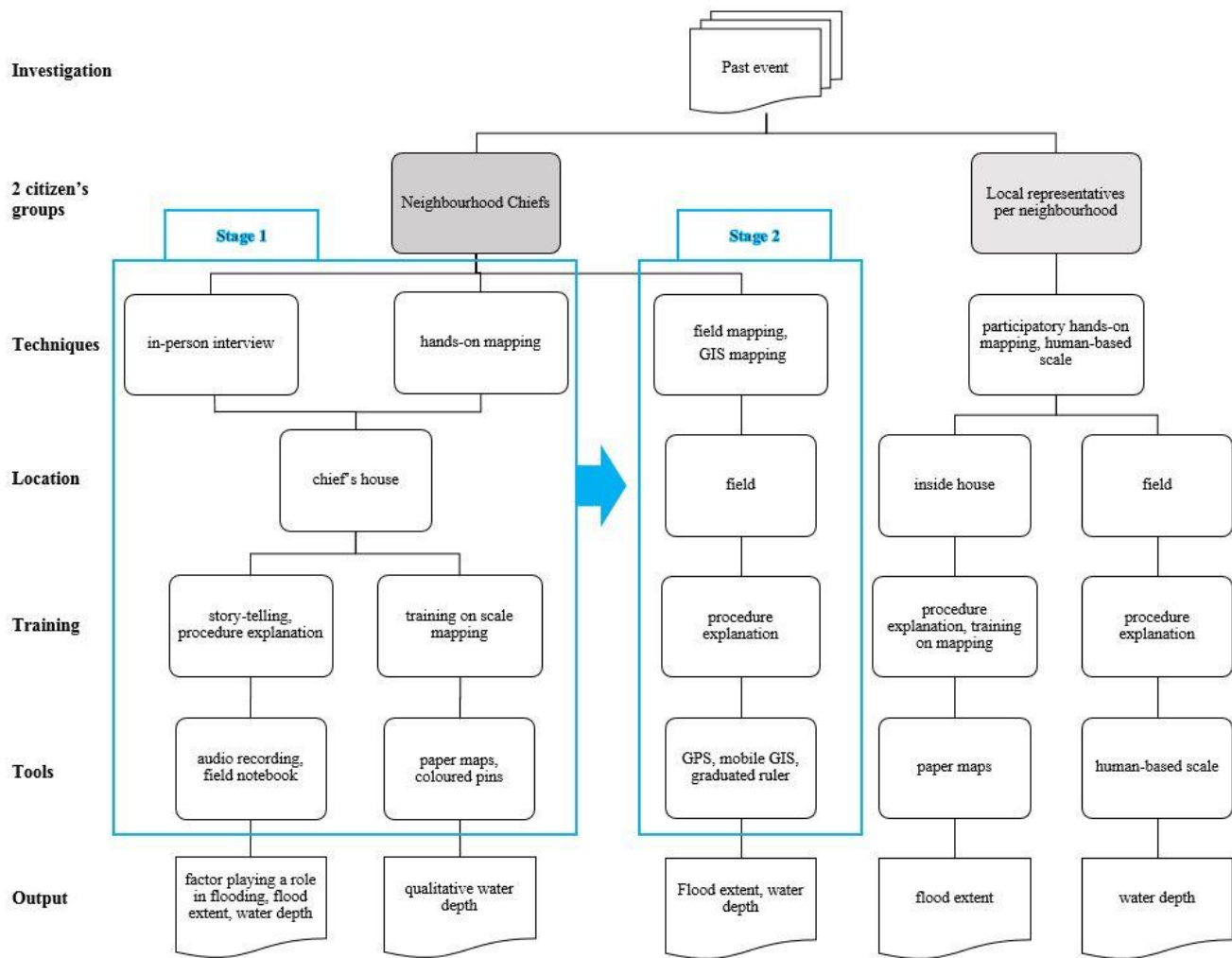



Figure 2. Framework for retrieving past flood information by citizen-based methodology

510

515

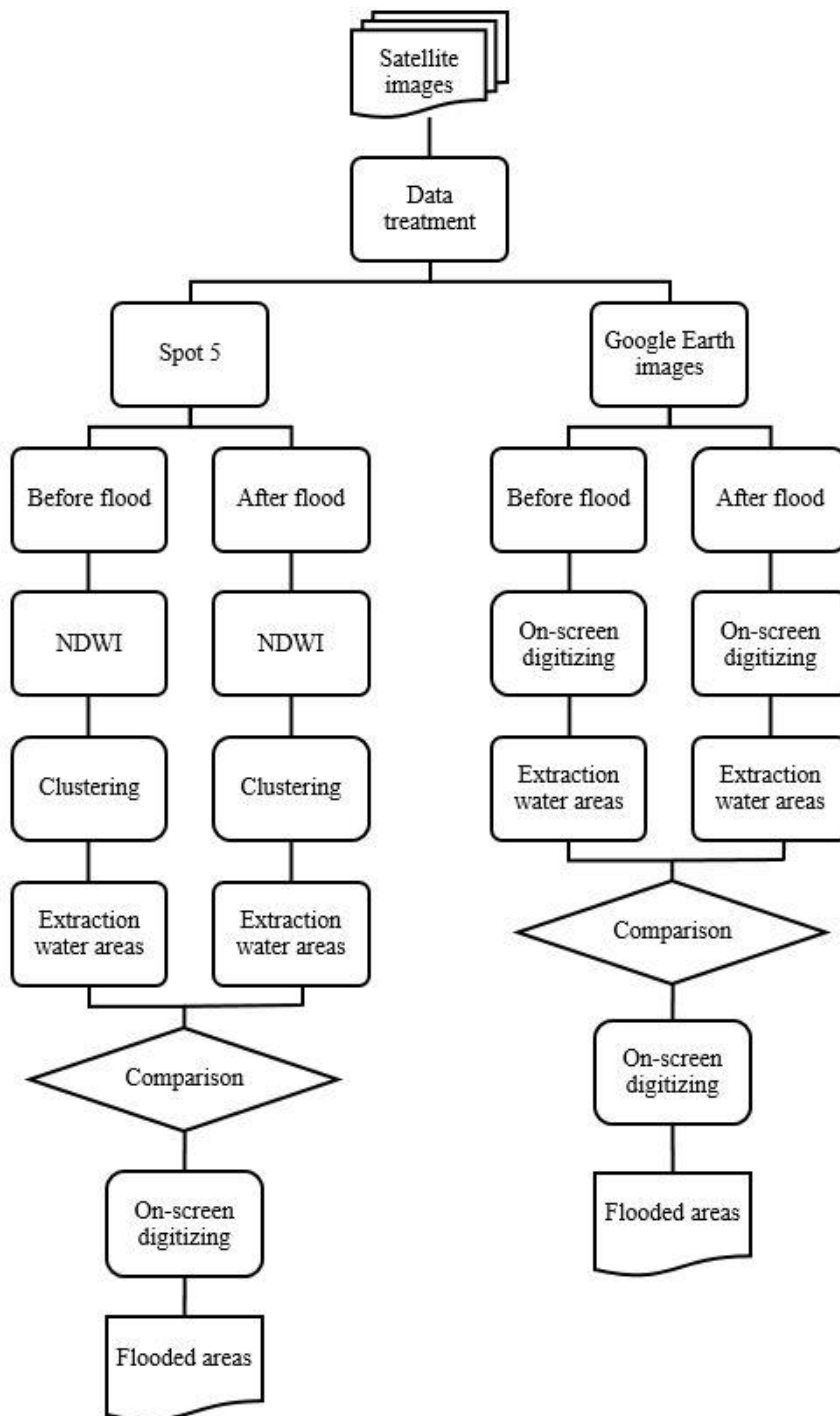



Figure 3. Framework for retrieving flooded areas by remote sensing analysis

520

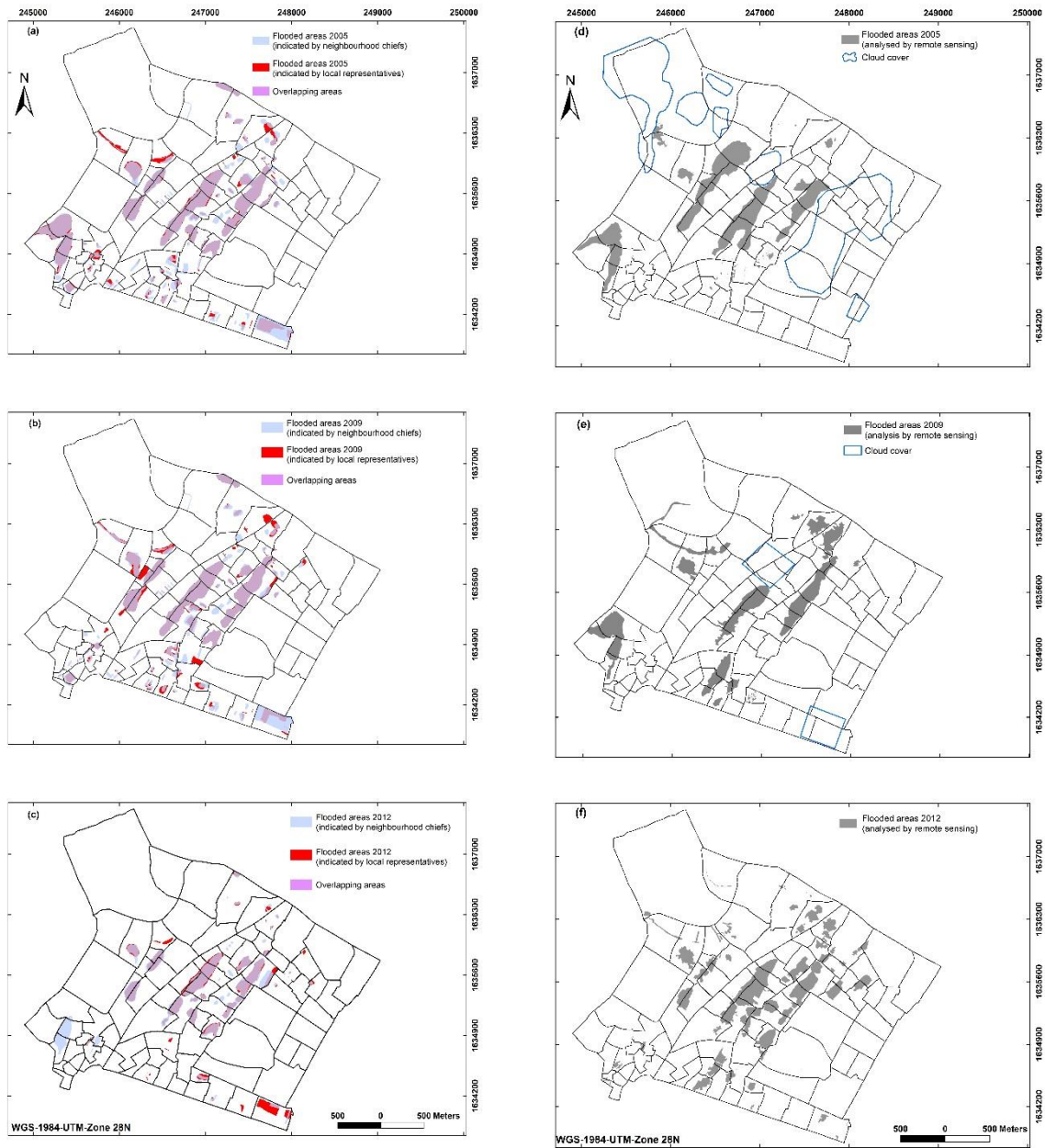



Figure 4. Left side: Spatial distribution of flooded areas based on citizen science techniques, (a) 2005, (b) 2009, and (c) 2012. Right side: flooded areas based on remote sensing data (d) 2005, (e) 2009, and (f) 2012.

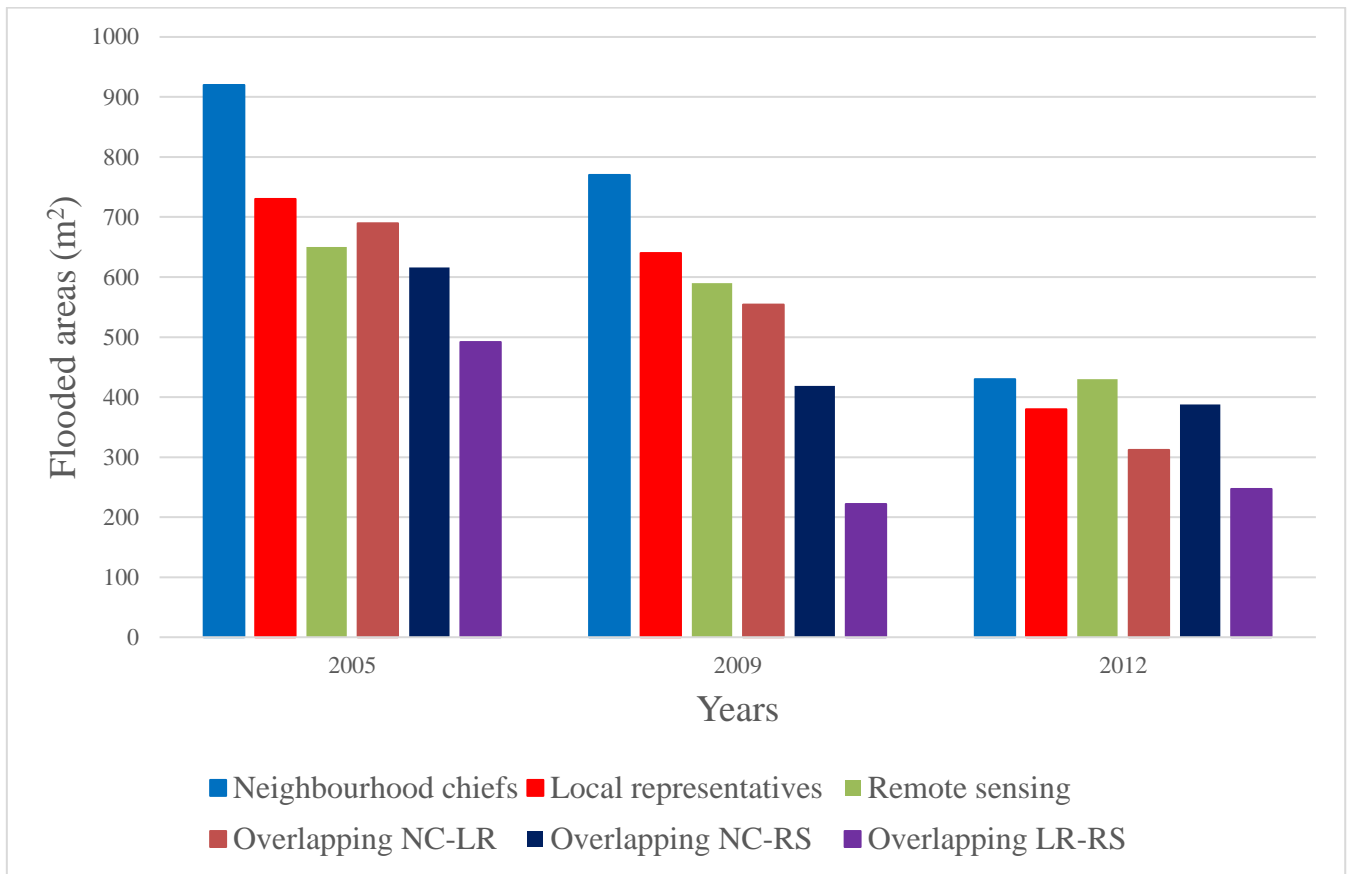
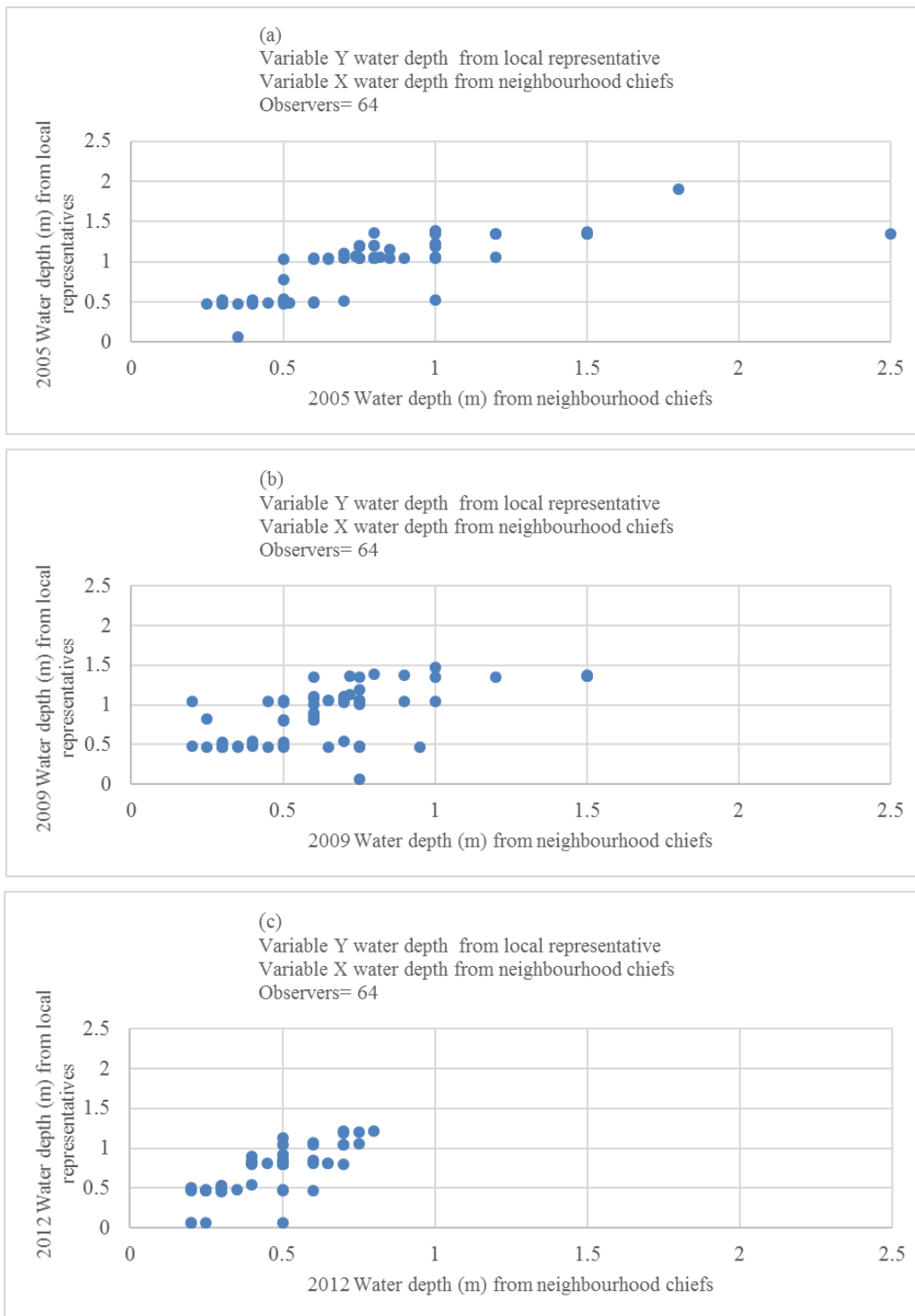
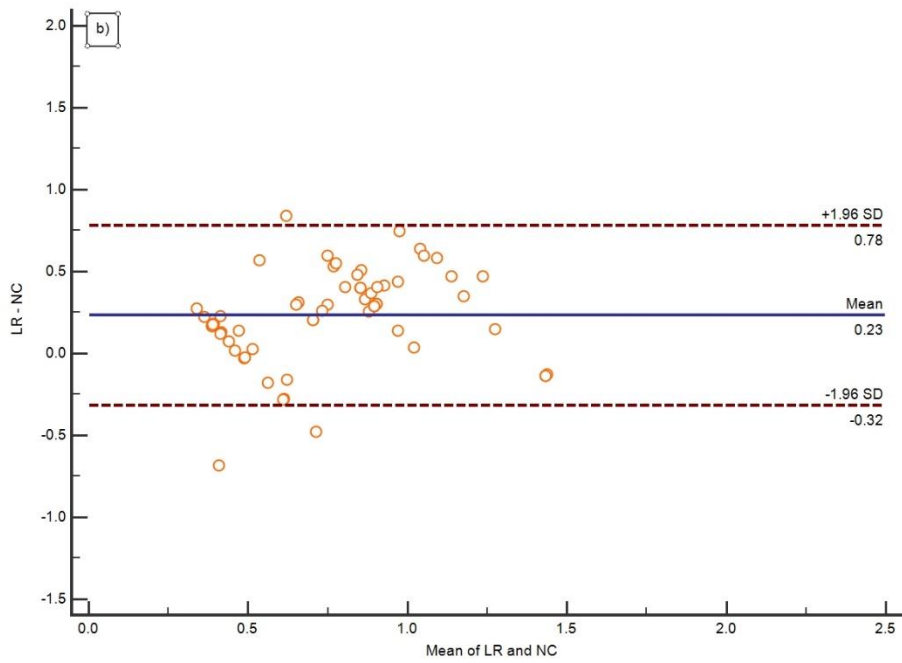
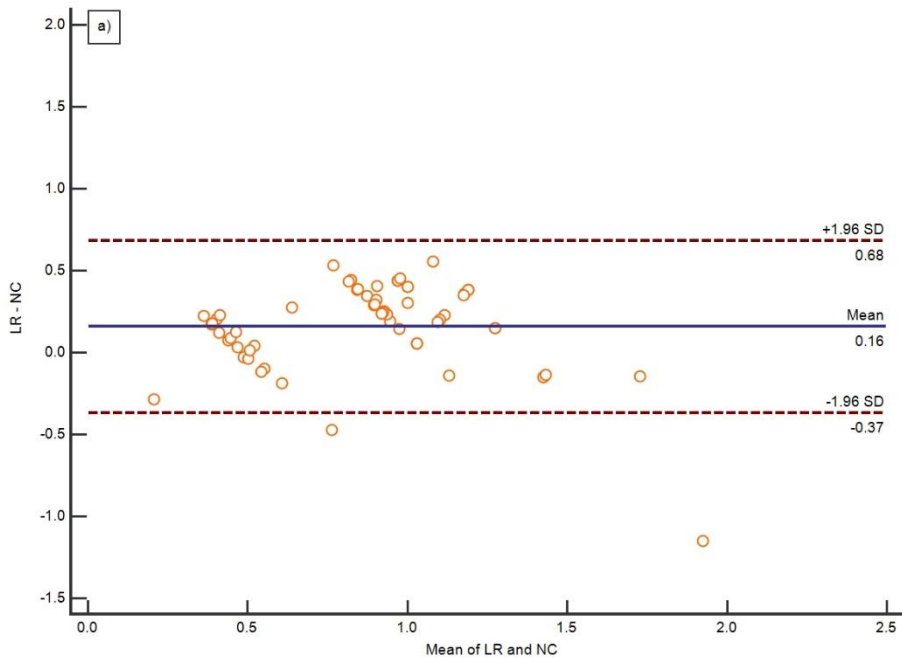
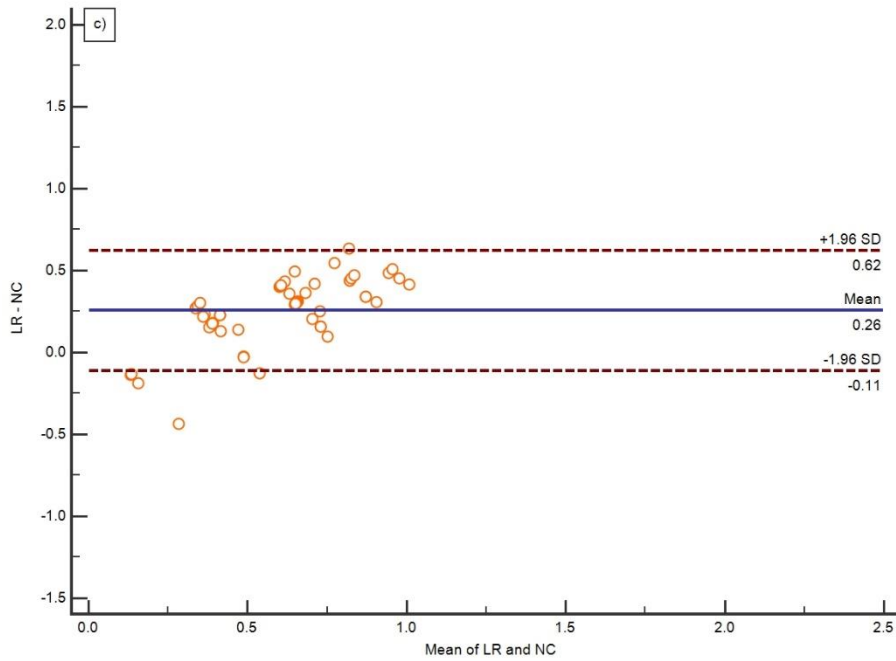



Figure 5. Flooded areas obtained by the two citizen groups and remote sensing with the surface of overlapping areas between the 525 two results citizen groups (1), neighbourhood chiefs and remote sensing (2), and local representatives and remote sensing (3)

530 **Figure 6. Scatter diagram of water depth information provided by neighbourhood chiefs and local representative's techniques for 3 different flooding events (a) 2005, (b) 2009, and (c) 2012**

535   **Figure 7. Bland-Altman plots for different flooding events (a) 2005, (b) 2009 and (c) 2012. These graphs show 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**

540

545

550

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)

560

565

570

575

580

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©

585

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

| Years | Citizen science | | | | Remote sensing | | Overlapping | | |
| | Neighbourhood chiefs (NC) | | Local representatives (LR) | | | | NC / LR | NC / remote sensing | LR / remote sensing |
	Flooded areas (km^2)	% of the study area	Flooded areas (km^2)	% of study area	Flooded areas (km^2)	% of study area	area (km^2)	area (km^2)	area (km^2)
2005	0.92	10	0.73	8.2	0.65	7.3	0.69	0.62 (95%)	0.49 (75%)
2009	0.77	8.6	0.64	7.2	0.59	6.6	0.55	0.42 (71%)	0.22 (37%)
2012	0.43	4.8	0.38	4.3	0.43	4.8	0.31	0.39 (91%)	0.25 (58%)