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DATA SERVICES ARTICLE

Towards adoption of mobile data collection for effective adaptation and climate risk management in Africa

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Abstract

The collection and use of data on climate change and its impacts are crucial for effective climate adaptation and climate risk management. The revolution in internet access, technology and costs has led to a shift from using traditional paper-based data collection to the use of Mobile Data Collection using Personal Digital Assistants (PDA) such as smartphones and tablets. In this paper, we report our experiences using both approaches for a household and business survey during a climate adaptation study in two Nigerian cities—Makurdi and Calabar. The focus of this paper is to evaluate and compare the effectiveness of using traditional paper-based data collection and PDAs as data collection tools for climate change study in African societies. In Calabar, data were collected using paper questionnaires, while in Makurdi the questionnaires were developed on Open Data Kit (ODK) and administered using PDAs. Results show that data collection using PDA was faster, cheaper, more accurate and resulted in fewer omissions than paper-based data collection. There was a time saving of four (4) minutes per

Registered repository where your dataset is located: Aggregate data available at UWE Bristol Research Data Repository (https://www.uwe.ac.uk/study/library/research-support/research-data-repository).

Metadata for the dataset: Jessica Lamond, Nigeria, URN Data.

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Dataset

Identifier: http://researchdata.uwe.ac.uk/659

Creator: Jessica Lamond

Data correspondence: jessica.lamond@uwe.ac.uk

Title: Adaptation of urban infrastructure to enhance climate resilience in Nigeria

Publisher: University of West of England (UWE)

Publication year: 2022

Resource type: The dataset for all the wards in Makurdi, Nigeria showing incidences of climate hazard and their geo-cordinates.

Version: 1.0

questionnaire and a 24% cost saving when using PDA. PDA provides additional benefits where platforms can collect images, videos and coordinates. This significantly improved the credibility of the data collection process and provided further data that allowed for the mapping of environmental phenomena by linking survey research with geo-referenced data in a geographic information systems platform to provide spatial representations of social and environmental system convergence. PDA offers a tool for collecting data that will make necessary socio-environmental data available in a faster, reliable and cheaper manner; future research can build on this study by discovering other possible but less highlighted benefits of PDA. Although, with great benefits, there are lessons to be learnt and issues to consider when deploying PDA in large-scale household surveys.

KEYWORDS

disaster risk mapping, household survey, methodological innovation, open data kit, personal digital assistants

1 | INTRODUCTION

The collection of data through climate-related studies is significant means to combat the effects of anthropogenic climate change and related hazards (Brönnimann et al., 2018; Sebestyén et al., 2021). This is especially the case in many parts of the African continent where anthropogenic climate change is causing increases in hydro-meteorological extremes (Ndehedehe et al., 2018; Tall et al., 2013). In Africa, climate change has led to a wide range of consequences that have led to climate hazards such as flooding causing physical damage to infrastructures such as power plants, roads and bringing economic activities to a standstill (Douglas, 2017). According to projections, many parts of the continent face profound challenges if global warming exceeds more than 1.5°C (Niang et al., 2014). This underscores the need for high-quality and continuous data sources for effective adaptation and climate risk management (Brönnimann et al., 2018; Wilby & Dessai, 2010).

In African societies, surveys such as Afrobarometer (Simpson et al., 2021) provide vital scientific data to inform climate change risk management. However, the use of climate data for research and applications in Africa has been scanty because the availability of and access to climate data is very limited (Dinku, 2019). Sultan et al. (2020) has called for the collection of more climate data in the region. A wide array of high-quality spatial climate data is needed if African countries are to develop responsive, proactive and robust policy-making and planning for climate adaptation. With this comes the need for a cheaper, faster and more rigorous approach to the collection of hydro-meteorological data, but also social data on timing, magnitude, locations and coping capacity of the people than that are currently available. Because of the growing need for data to support adaptation and climate risk research, there have been calls to leverage digital technology for data collection (Sarku et al., 2021).

While the use of PDAs for household surveys in developing societies has been reported (Thriemer et al., 2012) and their benefits over paper-based surveys highlighted (Lane et al., 2006; Missinou et al., 2005), the literature is scarce regarding its use in studies where spatial or geo-referenced data are also a priority. To professionals and practitioners interested in the built environment, the information produced through questionnaires may only tell a partial story. They can, however, be more useful when used together with geo-referenced data that actors in the built environment find more useful to inform policy-making. The few studies that have assessed the benefits of using GPS-enabled PDA to augment qualitative data collection (see Jones et al., 2011; Rasouli, 2014), have focused mainly on developed country contexts. Most of the existing studies that report the use of GPS-enabled PDA devices have been transportation or health-related applications (Tan et al., 2015; Zhu & Gonder, 2018; Zhu et al., 2017). These studies have focused on comparisons and assessing the advantages of PDAs for data collection in circumstances pertinent to Africa and have not considered the benefits (or lack of them) of both methods in situations where there is a need for spatial mapping. This paper goes further by assessing other possible lessons that may be inherent in both methods for studies interested in collecting climate hazard management-related household data usable for spatial planning. The focus of this paper was to evaluate and compare the effectiveness of using traditional paper-based data collection and PDAs for climate change studies where geo-referenced data are a priority.

The paper (among other things) reports a comparison of our experiences, emphasize the challenges encountered, assess the acceptability, document the lessons learnt, and consider the possible additional benefits of PDAs for data collection and management in a climate study interested in spatial mapping. In addition, we will reflect on the process and make suggestions on key issues to consider when adopting PDAs for large-scale projects.

2 | STATE OF CLIMATE DATA COLLECTION IN AFRICA

The need for information to underpin actions on climate hazard management is widely accepted. It has been emphasized, for example in the *Sendai Framework for Disaster Risk Reduction 2015–2030* that the collection, analysis, management and use of relevant data and practical information should be a top local and national priority for action (United Nations Office for Disaster Risk Reduction, 2015). Besides the need for socio-economic and cultural data (Hanger et al., 2013; Moser & Ekstrom, 2010), studies have also emphasized the importance of spatial data because of climate variability and extremes, the sensitivity of populations and systems to climatic stressors and adaptive capacities are all spatially differentiated (Arouri et al., 2015; de Sherbinin et al., 2015). However, the provision of such climate services which involves the 'timely production, translation and delivery of useful climate data, information and knowledge for societal decision-making' (Vaughan et al., 2016:65) is often not available for many societies. As a result, researchers and policy-makers have been engaged in intensive and frequent studies to monitor and understand hazard-related events. This is especially relevant in Africa (The World Bank, 2014; Wood et al., 2015) where the availability and accuracy of data for climate hazard-related studies is a major challenge in a region where synoptic and continuous data archiving is yet to be prioritized. In these contexts, data collected through surveys are of critical importance (Randall & Coast, 2015). Most of these efforts have typically adopted the traditional paper-based data collection, which has been critiqued for being prone to errors, with high and prohibitive data entry and storage costs (Siegfried et al., 2005; Tomlinson et al., 2009). Furthermore, any spatial or geo-referenced data collection using this approach will require additional tools, that is, handheld GPS, which introduces further costs and complexities.

To leverage some of the shortcomings of the paper-based data collection method, electronic field data collection is being encouraged in Africa (Nakalembe et al., 2016; Thriemer et al., 2012) and other parts of the developing world (Caviglia-Harris et al., 2012). The rise of the Information and Communication Technology (ICT) era in Africa (Bollou, 2014) and explosive growth in the availability of mobile devices (Comer & Wikle, 2017) have brought about innovation and a gradual shift in data collection processes from paper-based to mobile-based data collection, even within some remote communities with poor/limited access to internet infrastructure. Mobile Data Collection (MDC)—sometimes referred to as Computer Assisted Personal Interviewing (CAPI)—is the utilization of mobile devices (also called Personal Digital Assistants (PDA)) such as phones, smartphones and tablets with the aid of data collection client programs (software) installed on these devices for data gathering. Instead of the traditional method of recording information on paper and manually entering it into a database for analysis, data is collected using a client program running on a mobile device, which can be exported immediately once the data have been transmitted to the server program (database).

3 | METHODS AND ANALYSIS

3.1 | Study setting

The study reported here is based on a project that contributed to the evidence base for better urbanization strategy, urban policy and urban programming and management in Nigeria. The data collection for the project focused on the 'adaptation of urban infrastructure to enhance climate resilience in Nigeria' to contribute to the development of guidelines and tools to assist decision-making regarding sustainable urban infrastructural development in the face of climatic hazards in Nigeria.

The data collection reported in this paper took place in two Nigerian cities—Makurdi and Calabar. The two study sites represent cities with differing climate risk profiles and urban planning histories in Nigeria. They represent two ecological zones (one each from the two broad belts of vegetation types—forest zone and savannah zone—in Nigeria) and cities at risk from coastal and fluvial flood risks. The two cities are similar in that they are both medium-sized when compared to cities like Lagos and Kano with a population of more than 10 million (National Population Commission, 2006). According to the National Population Commission (2006), based on an annual population growth rate of 3.2%, Calabar is with a population of about 525,000 and Makurdi's population of 420,000.

Calabar is the capital city of Cross River State, Nigeria. It is made up of two local government areas (Calabar Municipal and Calabar South) and extends between latitudes 04°15′ and 5° north of the equator and is 8°25′ east of the Greenwich meridian Odum and Aloba, (2014).

Calabar Municipal is made up of 10 administrative wards, while Calabar South is made up of 12 administrative wards (Figure 1). Calabar has an area of approximately 328 square kilometres and a population of 525,000 (National Population Commission, 2006). The city which hosts TINAPA, one of the key tourist attractions, is a popular tourist destination in Nigeria.

Makurdi, the capital of Benue state, is located along the Benue River. Unlike Calabar, Makurdi is predominantly an agricultural catchment and there are sections of the city that are not linked by paved roads. However, the city hosts critical infrastructures such as the Nigeria Air Force Base and an airport. Makurdi has 11 administrative wards (Figure 2) and, with a land area of 835 square kilometres, the population density stands at 502 persons per square kilometre.

3.2 | Data analysis and ethics

The thematic themes around which to compare methods of data collection were based on themes emerging from literature, discussions with RA's, and project team reflections. RAs and project team members kept a note that records their field activities (such as the time it took to complete each questionnaire), daily reflections on the effectiveness of the data collection process, and lessons learnt. The informal conversations with RAs about the strengths and weaknesses of both data collection approaches served as further opportunities to add 'context' and 'authenticity' (Swain & Spire, 2020) to the data used for this paper. The quantitative information collected was analysed using Microsoft Excel while qualitative data were analysed using the manual method of coding.

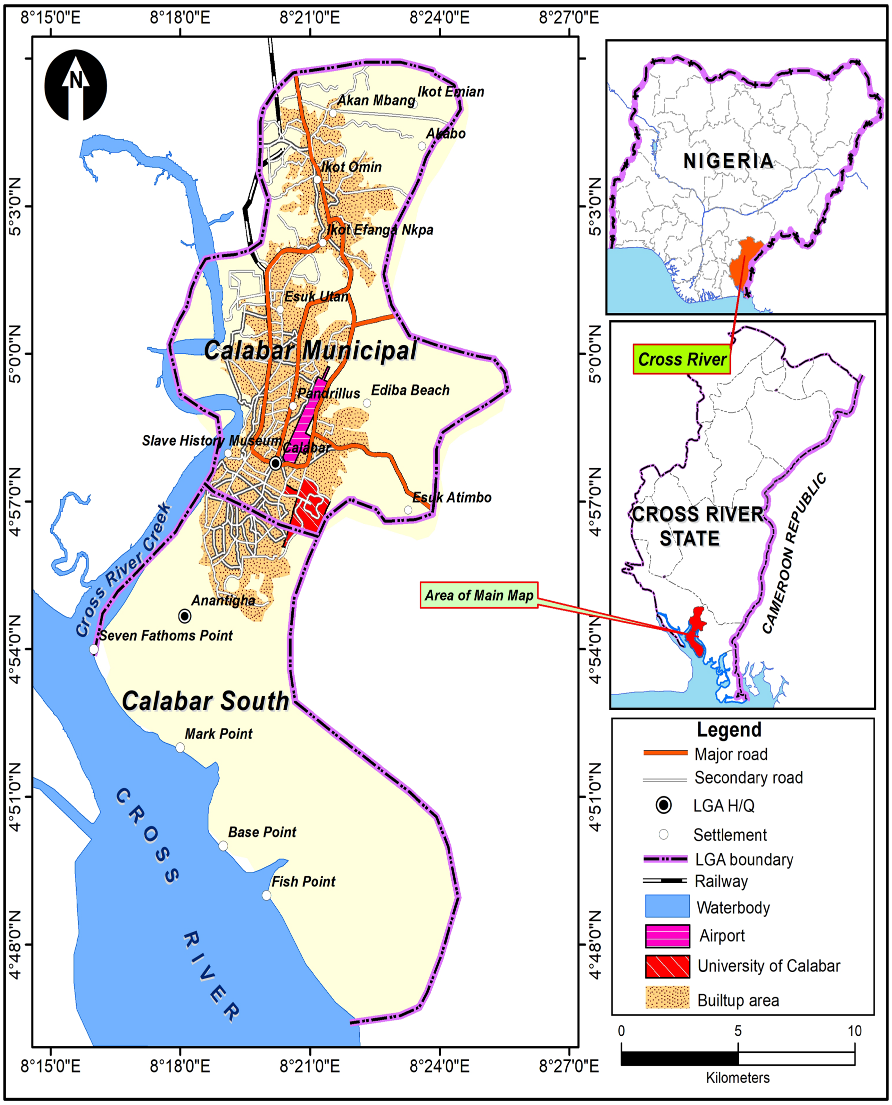

FIGURE 1 Map of Calabar (Calabar South LGA and Calabar Municipal LGA)

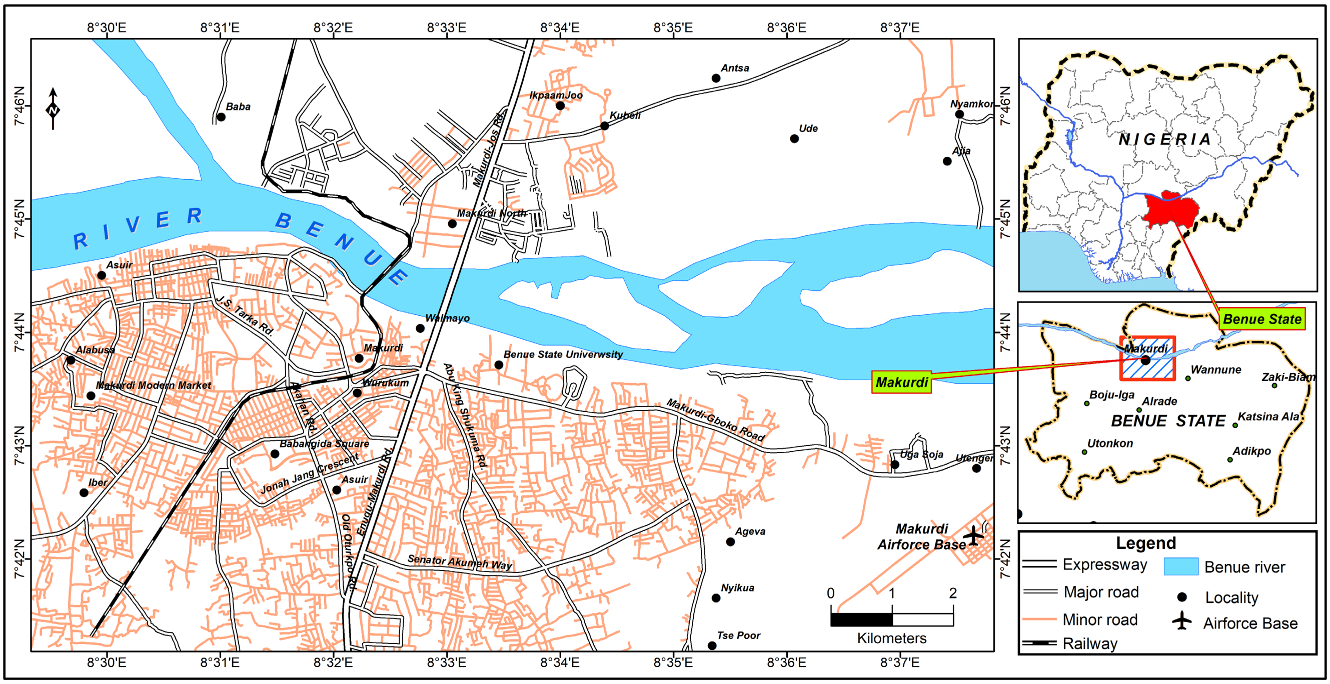

FIGURE 2 Map of Makurdi

Full ethics approval was sought and granted for this study. In line with the research ethics review process of UWE, Bristol, an outline of the research protocol and all research documents—that is, information sheet, consent form, questionnaires, etc.—were scrutinized before the field visit. Participants were notified that they could withdraw at any point in the study. No personal information was collected therefore no data protection issues arose. Where necessary, we also sought consent locally through recognized authorities (traditional rulers and local government councils) in each of the case study cities.

4 | RESEARCH INSTRUMENT FOR CLIMATE ADAPTATION AND CLIMATE RISK DATA COLLECTION

4.1 | Questionnaire design

The need to continually invest in climate-related data through surveys has been severally highlighted in the climate science community (Vaughan et al., 2016). In line with the objective of the research, and based on the outcome of the initial literature review and stakeholder workshops, two sets of structured surveys to be circulated to (a) households and (b) small-scale businesses were designed. The front matter of the questionnaire was to collect information on the research assistant (RA) completing the questionnaire, the ward, the questionnaire number and the date and time the questionnaire was administered. The questionnaire itself consisted mainly of closed-ended questions. The first section of the questionnaire collected some of the general background information about the respondents (such as age, gender, income and household size). The second section focused on the respondents' views on climate hazards. The third section examined the actions adopted by respondents to each of the identified climate hazards (i.e. flood, urban heat and windstorm). The questionnaire was piloted in terms of question clarity and length. After the pilot, to reduce the length of the survey, the number of questions each respondent needed to complete was reduced using a multi-questionnaire strategy. Once the final questionnaire was agreed upon, paper-based surveys were printed. The paper-based questionnaire was administered in Calabar, the data form was then coded and entered using the mobile-based survey tool called Open Data Kit (ODK; https://opendatakit.org/)—an online open-source tool that helps manage field data collection using mobile devices. The process adopted in Makurdi was purely the electronic (non paper-based) data collection method using handheld devices (smartphones and tablets). The choice of the study site for the adoption of ODK and PDA is purposive and based mainly on logistics. Both sites have a similar level of internet penetration and accessibility. The paper research instrument was converted to an equivalent mobile form using ODK (Figure 3). A test-driven approach was adopted for

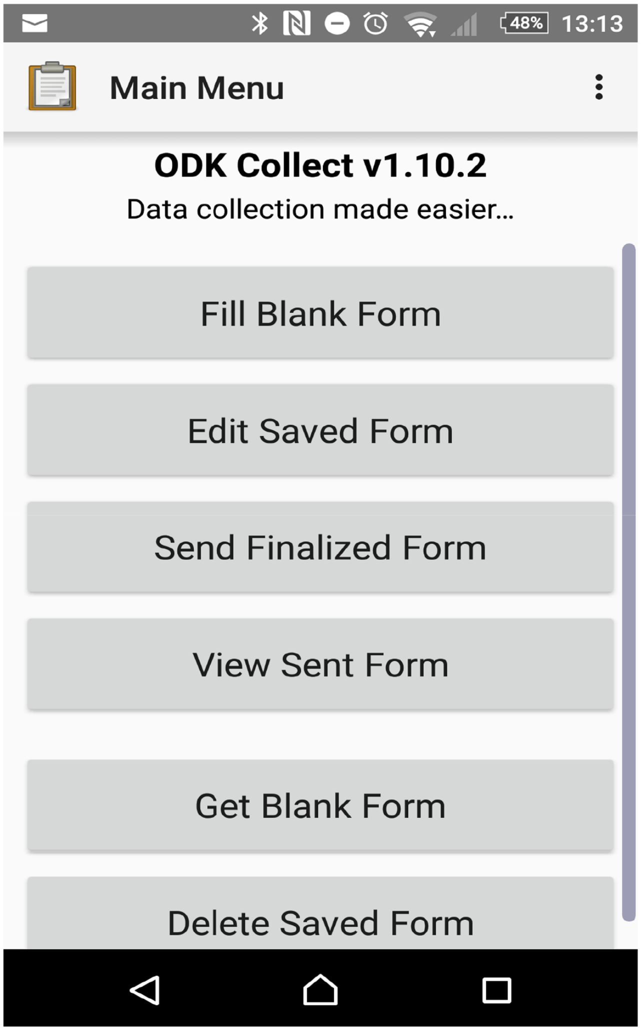

FIGURE 3 Image of Open Data Kit (ODK) platform

the development with incorporated skip logic and validation routine to ensure low veracity of data. Questionnaires were downloaded to each RA's PDA. The mobile form was hosted in *ODKAggregate* in the cloud using the Google Application Engine. This platform was chosen because it is popular and freely available. Alongside the questionnaire were consent forms and project information sheets (paper-based for both study sites).

4.2 | Questionnaire administration protocol

The survey was administered to households and small-scale businesses in the two case study cities. This occurred from 10th October–23rd October in Calabar and 24th October–6th November in Makurdi. The implementation of the structured questionnaires used a systematic sampling strategy stratified on a ward basis in both study sites. The aim was to administer a total of 330 business questionnaires (10 each per ward, 110 from the 11 wards in Makurdi and 220 from the 22 wards in Calabar) and 3,300 household questionnaires (100 each per ward, 1,100 from the 11 wards in Makurdi and 2,200 from the 22 wards in Calabar). A research assistant (chosen from university students and recent graduates) was employed to survey each ward, making 33 research assistants (22 in Calabar and 11 in Makurdi) each expected to administer 110 questionnaires within the period.

In both cities, the first day was dedicated to training the research assistants and for them to test the questionnaires. This was to ensure that the RAs fully understood what was expected from each question within the questionnaires, and could thus interpret them correctly for participants. Throughout the data collection, there was constant communication between the RAs and the project team to address any challenges arising in the field, and for the project team to check and monitor the activities of the RAs and check the questionnaires were administered daily. In Calabar, paper questionnaires were collected from RA daily, those in Makurdi were trained on the use of the mobile version of the survey instrument, and submitted daily to the cloud server for spot-checking. RAs were to provide their mobile device. This was done to ensure that they were using a device they were already conversant with, for introducing them to a new device could hamper their speed. In Calabar, additional staff was recruited to code the paper-based form using the ODK platform. Further information for this paper is based on the informal interactions/interviews of the project team with the RA's and an analysis of the project budget.

4.3 | Data interpolation

Interpolation is a common approximation method used to predict unknown values where adequate data are not available. Interpolation techniques are based on principles of spatial -auto-correlation which assumes that closer points are more similar compared to those at distance. To generate a Digital Elevation Model (DEM) of the area it was essential to generate a model for predicting the unmeasured locations which are normally done by using the mean elevation estimates. There are a number of interpolation methods available which are suitable for different purposes. Prominent local interpolation methods include Inverse distance weighting, Local polynomial, Nearest Neighbour and Radial bases functions. In this case, kriging is used for interpolation of point altitude data collected from the field using ODK. Kriging is grounded on a geostatistical foundation which uses its calculation based on known values and a semi-variogram model to predict values at unmeasured locations. The degree of spatial dependence between samples is measured by the semi-variance which is dependent on the separation distance between the points (Jarvis & Stuart, 2001). The semi-variogram model that best fits the data is used to produce the optimum weights for interpolation. In the present study, for example, kriging interpolations were modelled using ArcGIS spatial analyst tool is performed to develop the raster surface. For our specific application of utilizing GPS measurements from field operations which provided the optimum result for further interpretation of collected field data. The ground elevation data are extracted via GPS from 284 data points. The resolution of the DEM is set at 5 m during conversion.

5 | RESULTS

Both data collection methods were compared on several items, including the process of data collection and coding, the ease of training, the cost and time and the monitoring and acceptability to RAs and respondents. Based on themes emerging from literature, discussions with RA's and project team reflections, thematic themes around which to compare methods of data collection emerged. A summary of the thematic comparison of the paper-based form and the PDA for data collection during this study is presented in Table 1 below.

5.1 | Training needs

The training session focused on the entire protocol of the project, introducing the aim of the research project, and providing a detailed explanation of the data collection protocol. The training of the 22 RAs in Calabar, where paper-based data collection was used, took about 5 hr to complete (Table 2). There was, therefore, time for the RAs to interact and pilot/test the questionnaires among themselves before the actual data collection began. This also provided them with the opportunity to ask further questions before embarking on the actual field data collection. However, in Makurdi where the PDA approach was deployed, it was necessary to first train the RAs on the paper version to ensure that they understood the questionnaire before then taking them through the PDA interface. The training time in Makurdi took almost eight hours and, while the RAs had the opportunity to interact and ask further questions, it was not as much time as was available to those in Calabar. This meant the duration of the training on the use of PDAs took longer by about three hours. There were hardly any challenges that arose before the commencement of the paper-based training; however, with the training on the use of PDAs, there were some challenges that needed to be resolved before the training could commence. These related to the fact that some of the mobile devices (seven of the 11) provided by the RAs were not compatible with the ODK platform. Although the affected RAs were subsequently able to access compatible devices, this might have affected the training process as they had to pair up at some point in the training. While the training for the RAs using PDA took more time than training those using the paper-based form, this was balanced by the additional training time required in Calabar, where the paper-based method was used, to train the data entry assistants. This data entry training took about an hour and thirty minutes.

5.2 | Ease of data collection, entry and checking

During data entry from the fieldwork conducted in Calabar, which used the paper-based data collection format, it was observed that some forms were not fully/properly completed. It became imperative for the data entry assistants to spend more time on their work, and for them to employ a detailed data quality check for quality assurance. Incomplete paper-based questionnaires, when identified, were returned to the responsible RAs for proper completion before entering the final/completed questionnaire into the template designed for data entry. Amid the high check, data entry personnel, whenever confronted with poorly completed forms, could not proceed with that particular form entry. The implication was that all re-administered forms had to be re-entered after queries were fully resolved on the form. This affected so much of the amount of time estimated to complete the data entry process.

Conversely, with the PDA approach adopted in Makurdi, the experience was different. The ODK Collect platform made it possible to collect surveys offline and submit them at some point in time to a central server (database) for export and swift analysis. This platform also equipped the data collectors with a powerful tool that was used to improve data collection speed due to some skip logic introduced with the mobile forms and also increases data quality as most fields were marked as required. Hence, a response must be entered to move to the next question. This, therefore, completely eradicated cases of uncompleted questionnaire items, and also elevated the time and cost the study would have incurred if it were the paper-based data collection process. Individual questions were presented one at a time, moving forward to the next screen on completion by entering data after a validated data type was entered. Filter logic introduced in the mobile data collection process also enhanced data quality by

TABLE 1 Thematic comparison of the paper-based and electronic platform surveys

Themes	Paper-based survey	Electronic survey platform
Recruitment & Training of the RAs	The recruitment of the RAs was easier and required basic field experience, while training was done on the delivery of the questionnaire	The recruitment and training of the RAs typically took a longer time since they were trained firstly on understanding the delivery of the questionnaire and secondly, on the use of the electronic platform on their mobile devices
Cost	The cost was, overall, higher due to printing the questionnaires and additional costs were incurred for data entry such as hiring and training data entry personnel. There was a 14% extra cost when compared to the PDA	Given that the handheld devices used were owned by the RAs, there was no cost for procuring them. The cost was limited to renting a server to host the completed questionnaires during the data collection process
Weather (Rain) Problems	Rain could drench the papers and damage the data already collected	Devices could use rainproof covers while data collection was happening during rain
Convenience	Inconveniences included: carrying large amounts of papers and having to be careful not to mix the different completed questionnaires	The RAs could collect multiple forms with the handheld mobile devices conveniently. There was no need to carry a large number of the paper questionnaire
Speed & Quality of Data	The average time for completing a questionnaire, uploading the data and analysing it was high. Also, the risk of fake data collection was higher without a geo-referenced platform	Allowing for good network connectivity, the average amount of time for collection, upload and analysis was significantly reduced. The geo-referenced feature also improved data integrity
Monitoring	Monitoring would require multiple persons in the field with the RAs. Completed questionnaires could only be fully assessed at the end of the day	Effective, as even one person in a remote location could do the monitoring. Questionnaires could be assessed on the spot (in real-time) and corrections communicated to the RAs. Improved data transfer to the central office allowed for easier monitoring of study progress. Real-time monitoring also makes it easier to see if there were any problems with the questionnaire if the survey was taking longer than planned, or to check if data collectors were covering their assigned areas properly
Other benefits	Could not collect images, location data or video. Mapping the data collection locations was impossible, except with the use of a GPS which could incur further costs in purchase and training	Mapping the locations of data collection was in-built and easily achievable. Respondents were able to take pictures of key features that the study was interested in, and upload them to the server

TABLE 2 Summary of major activities and average time requirements

Activities		Calabar (paper-based survey)	Makurdi (PDA)
Training	Training	5 hr	8 hr
	Training data entry	1 hr 30 min	0
	Retraining Assistants	2 hr 30 min	6 hr
Coding/data entry		15 min per questionnaire	N/A
Monitoring and supervision		4 hr 15 min	1 hr

eliminating possible confusion arising from questionnaire instructions. The efficiency of the mobile data collection tool allowed both the survey supervisor and enumerators to keep better track of the number of questionnaire forms completed daily during the process of data collection, which in turn enhanced performance.

5.3 | Time and cost

At the outset, (i.e. the first 3 days of data collection), the completion rate using the paper-based format was higher than using PDA (Figure 4). The results showed that this was up to five times a higher completion rate than that of mobile-based data collection. This, however, should be considered as data collection only as it does not include the time that will be needed to code the data into a usable format. As data collection progressed to the peak period, the completion rate using PDA become higher than that of the paper-based. For those using the PDA, the first RA to

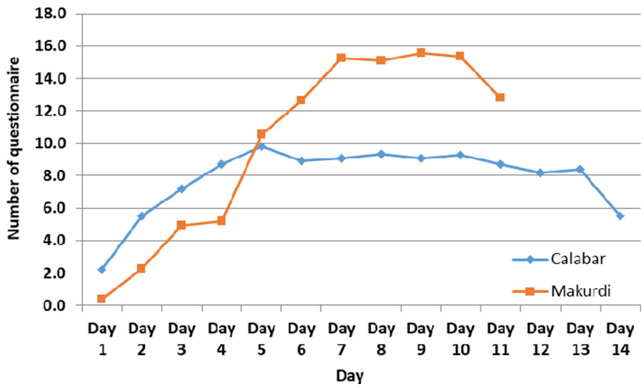

FIGURE 4 Daily completion data from paper-based and personal digital assistants (PDA) approach

complete their allocated number of questionnaires (110) took 7 days (an average of 15 questionnaires a day) compared to 9 days (an average of 12 questionnaires a day) for those using the paper-based form. For those using PDA, it took 11 days for all data collection to be completed, however, data collection for the Calabar case study using paper-based questionnaires took 15 days. The average time it took to complete a questionnaire was 18 min for those using PDA, while it took an average of 22 min for those using the paper-based format to complete the questionnaire. In addition, the project office had to spend more time re-training some of the RAs. Overall, six (55% of RAs) of the 11 RAs using the PDA required further re-training, compared to just five (22% of RAs) of those using the paper-based form requiring re-training. While we acknowledge that the RAs are different and may be working at different speeds, these results are consistent and indicative. In addition to the time difference displayed in questionnaire administration, while the PDA approach does not require further time for data entry, the paper-based form required an additional 9 days for the data entry (double the number administered using PDA, thus about 4.5 days more) to be completely coded. This translates to about 15 min to code one questionnaire.

The cost associated with both approaches was also analysed. The cost of designing the ODK platform and using the ODA approach was compared to the paper-based approach; in addition, there were extra costs needed to host the ODK platform. Additional costs were incurred when using the paper-based form due to the printing and photocopying of questionnaires and the recruitment of data entry assistants. The total cost for conducting the research using the paper-based (for the same number of questionnaires administered in Makurdi) format totalled at N2, 540,000 (US$7,055), while that of the PDA totalled at N2, 220,000 (US$6,166). This translates to US$5 per questionnaire while using the PDA in Makurdi and US$ 6 per questionnaire using the paper-based questionnaire in Calabar. This indicates a 14% extra cost incurred when using the paper-based form.

5.4 | Acceptability, convenience and monitoring—the perspective of the RAs and project office

All the RAs involved in the paper-based survey indicated that the process was stressful from the beginning to the end; those using the PDA felt that, although the data collection was stressful at the outset, it gradually became less stressful and more interesting as the data collection continued. The RAs using the PDA were all new to this approach and all indicated an interest in using the approach in their future research. There was a report of two instances where respondents showed some reservations about being interviewed using the PDA. This was because the respondents were used to paper-based interviews and felt that there could be a security risk were their responses taken on mobile devices. To resolve this, they demanded to see the entire questionnaire. While this was possible, it could be time-consuming—compared to if it was a paper-based survey. The situation was, however, resolved because the RAs were able to present the respondents with a paper version which they always had with them. However, overall, the RAs believed that in most cases respondents were generally interested in being interviewed using the PDA. However, the project office also observed that RA's using the paper-based approach had a lot more to say about their interaction and discussions with respondents than those using the PDA. For example, some RAs using paper-based described how respondents choose to sit close to them and fill in the questionnaire and in the process, they engaged in more discussion. While this could be partly responsible for more time spent in completing paper-based questionnaires, it could also be an indication that the paper-based approach provides a better opportunity to build rapport with respondents.

Managing the RAs, monitoring and checking the data collection was found to be easier when using the PDA compared to using the paper-based form. During the paper-based survey, the project office staff had to frequently visit the field to ensure smooth data collection and on the spot inspection/checking of completed questionnaires. The data entry assistants also carried out further checking. With the PDA, field travel for the field staff was less expedient and data monitoring and checking could be done remotely and in real-time. As the data could be downloaded in excel format, using the sorting function made it possible to easily identify missing/incomplete fields, and the RA were notified immediately while still in the field. With the paper-based approach, this would not have been possible. At the end of the data collection, we found that there were more sections of the paper-based responses that were missing compared to the PDA which showed almost no instances of missing data.

5.5 | Other benefits

Notably, there were additional benefits to using the ODK powered PDA for this study to use the paper-based. With the PDA, at the end of the questionnaire, the platform can record the geographically referenced data (i.e. coordinates, altitude) of where the questionnaire was submitted. Which, based on the study protocol, will be the residence (or business premises) of the respondent. This provided two important benefits. First, the recorded coordinates can be assessed to monitor RAs, checking that they are in the field and conducting the data collection according to protocol. Second, the geo-referenced data are useful in mapping. The maps produced using the DEM surface (see Figure 5) interpolates the altitude of the area and illustrates the spatial distribution of households affected by floods, windstorms and extreme temperature. Furthermore, the PDA platform has the functionality to take pictures and videos, hence why the RAs found interesting and exceptional images useful to the study—they were able to capture such and submitted them alongside the completed questionnaire. This provided additional data for the study. Equally, the online-based data collection platform empowered data collectors to speedily get to the field, even without setting up a scalable web service. As such, the data upload was through a data network with platform encryption: thus, increasing the security of the data. PDA is also more environmentally friendly because of reduced paper use. In Calabar, where paper-based form of data collection was deployed it was estimated that we have used close to 22,000, A4 papers. An average of 10 papers per respondent. While in Makurdi it was about one paper for five respondents.

5.6 | Designing and hosting the platform

The paper-based questionnaires were translated to mobile equivalence for the ease of data entry by data entry assistants (DEA) using the ODK Aggregate that was deployed on a local web server running Tomcat with MySQL databases. We deliberately chose to use the ODK for data entry for ease (compared to excel), and so that the final datasets would be compatible during data analysis. The ODK mobile form used for data entry in the Calabar study was adapted and slightly modified (to take note of the location, ward names, the name of RA, etc) for the PDA data collection in Makurdi. While no challenge was faced in designing the questionnaire in ODK Build construct (which produces the XML file that describes the mobile form) hosting the form proved to be a major challenge for the PDA data collection since IT infrastructure to host the form locally was unavailable. KoBoToolbox was selected because of its cloud-free hosting opportunity coupled with its compatibility with other popular tools for form export and import from/to Excel for advanced purposes. However, attempts to host on the Kobo platform (http://www.kobotoolbox.org/) failed because of a

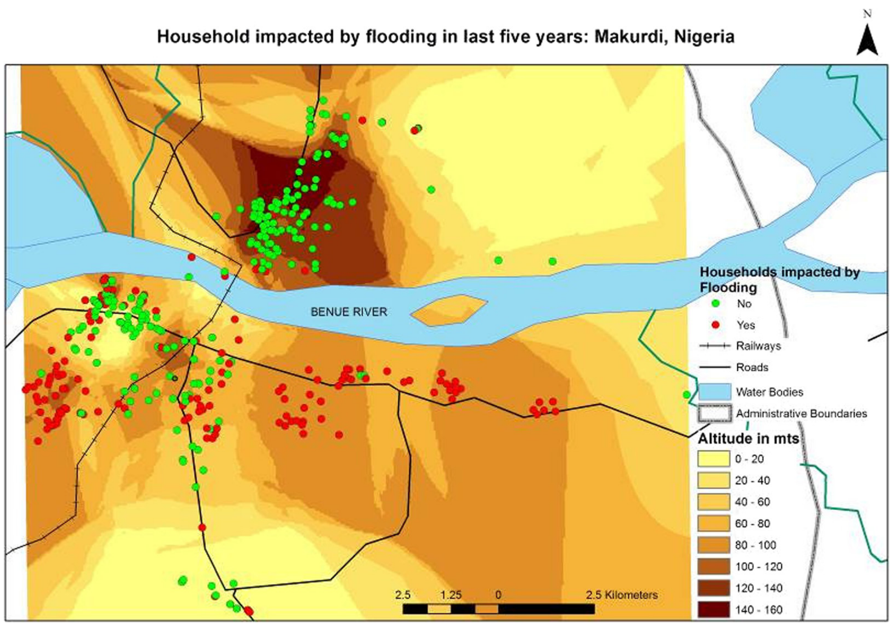

FIGURE 5 Spatial map using georeferenced data from Open Data Kit (ODK)

few incompatibilities in the syntax rule during conversion from ODK Build (XML) and KoboToolbox Build (XLSX: Excel spreadsheet). This was despite both systems internally compiling this form definition to an XML file, which is then downloaded to the mobile device. Efforts to resolve this (including contacting the hosting company) were unsuccessful and nearly threatened the start of the PDA data collection because of the timeline for the commencement of data collection.

Several other hosting options that would involve extra costs were considered, including hosting on a local web server in Makurdi. However, the equipment and expertise to set this up were not readily available. This prompted the hosting of ODK form in the cloud by deploying ODK Aggregate on Google's App Engine (idealgroup1980.appspot.com/Aggregate).

The Google Cloud Platform project (under which the ODK Application was deployed) hosts projects under certain conditions. Although there was no cost to set up the projects, App Engine projects that are lightly used incur no charges; exceeding the free daily quota allowed by Google Cloud Platform causes the Application Engine server to stop accepting new submissions and download requests for up to 24 hr until a reset at midnight. This was another phase of challenges associated with the PDA, as data collectors could sometimes not submit all completed forms for the day. As such, there was the risk of losing collected data if the phone or tablet crashed or was stolen. However, this challenge was minimized by restricting regular access to visualizing and exporting collected data on the ODK Aggregate hosted on the Google cloud. The project team members who have access to the site were advised to limit frequent daily download of submitted forms to preserve the daily allocated quota. Another major challenge was the fact that the Google Cloud Application setup and consequent activity chain (deployment of ODK on Google Engine, uploading, downloading, submission and visualization of forms) required constant internet access. Given the somewhat fluctuating internet connectivity, especially around the fringes of Makurdi's urban area, this hampered the smooth and swift process of data collection.

6 | DISCUSSION: TOWARDS RAPID ADOPTION OF MOBILE DATA COLLECTION FOR CLIMATE DATA IN AFRICA

Earlier studies comparing the use of PDA against the paper-based form of data collection (see Seebregts et al., 2009; Thriemer et al., 2012) have emphasized the suitability of PDA data collection over paper-based surveys in a variety of researches in developing countries, based on a number of criteria. Our study found similar results; however, it also discovered other benefits and highlighted the possible challenges inherent in PDA. We found that data collection using the PDAs was more accurate and complete than paper-based data collection. There were several instances of omitted information among questionnaires administered through the paper-based form, compared to none in the PDA. With the PDA, software applications helped to circumvent input errors through data type and range checking at the time of capture, and by use of selection lists which restricted entry data to predefined options and thus prevented typing and data format errors—a similar finding to that reported by Seebregts et al. (2009). We also found out that the digital data capture platform can make data available rapidly enough to allow for error detection at the data collation point with immediate feedback to RAs for correction (Seebregts et al., 2009). These systems may improve data transfer to the central server making it easier to monitor study progress (Pace & Staton, 2005). The in-built geo-referencing provides both a tracking system and an opportunity for mapping. For a study like ours—where we are interested in the links between socio-economic, socio-cultural and spatial phenomenon and their mapping—a platform such as ODK Collect used in line with PDA allows the mapping of responses by linking survey research with geographic information systems (GIS) to provide spatial representations. This enabled us to visualize and identify geographical areas which may be prone to climate hazards (Figure 5). The exploratory spatial analysis presented in this paper is a first step in identifying and describing a spatial trend which the PDA revealed to us at no extra cost. The PDA is also more environmentally friendly. The paper-based platform was better for building a rapport with respondents, as the respondents could look at the paper-based questionnaire, flip through it and see the questions. In this study, the RAs were required to always have a paper-based copy of the questionnaire.

In this study, similar to that by Thriemer et al. (2012), we found that the duration of the required training on the use of PDAs was longer than that for the paper-based survey. However, while Thriemer et al. (2012) found that there was no need for re-training of data collection staff when using the PDA, in our study the need for re-training was higher for the PDA (Table 2), while only a handful of the RAs using the paper form needed re-training. This perhaps is attributable to the relatively low knowledge of research assistants working with research-based applications, such as the ODK adopted for the Makurdi part of this study. The need for training should, however, be considered alongside the training for data entry staff which Thriemer et al. (2012) did not emphasize.

At the outset of the survey, our study witnessed a faster completion rate in favour of the paper-based survey. The initial slower completion rate recorded by the RAs using the PDA was due to challenges in understanding the platform and difficulty with the compatibility of mobile devices with the ODK platform. This slowed down their speed of data collection in the first 3 days. The completion rate of the PDA was only higher after the fourth day when the RAs had a better understanding of the application, and all issues were resolved. This could, however, imply that for short studies requiring data to be collected within a short period lasting about 3 days, it might be faster to use the paper-based form than the PDA. However, this should be considered in the context that it only involves data collection and, if the additional time needed for data entry (15 min per questionnaire) is considered, it probably is not saving much time. If there is a project that is short term (less than 3 days) required for data collection, and for which there may be no need to code the data, then the paper-based approach may still be best in terms of time saving. However, it is difficult to envisage any such occasion. If it is considered that the time needed for data collection in Calabar (with the denser population (1,600/sq km) and easier transport system, since most of the streets are paved) was more than for Makurdi (with less density (500/sq km) and with poorer paved streets), then there is strong evidence to suggest that, overall, the PDA takes less time than the paper-based survey.

There were a number of challenges encountered in the use of PDAs, which were mainly related to design, the hosting of the electronic form and the compatibility of some mobile devices for the forms. These should be a major consideration before commencing any large-scale project using the PDA approach. In addition to the skilled data manager needed to create and install the software at the beginning of the study (Thriemer et al., 2012), it should be a requirement that manpower is provided to monitor the platform during data collection to address any unforeseen issues that may arise and could potentially threaten the data collection process. Although the skills necessary to manipulate devices such as PDAs are spreading rapidly, there may still be limited expertise in some societies.

Considering that the study was conducted in a developing society with poor resources, we have envisaged during the pre-data collection that the RAs using the PDA would be challenged with the battery life and internet access necessary for such large-scale survey research. However, this was not the case as there was no incidence of an inability to charge phones, nor a loss of signal, although the platform allowed for the offline submission of questionnaires. This could, however, be because our study was based wholly in the urban centre where facilities are ordinarily better. However, it may be the case that, if a similar study were to be conducted in rural parts, there would be a need to consider networks' coverage and power. Overall, our experience with PDA in Makurdi confirms prior findings (see Caviglia-Harris et al., 2012) and shows that the use of PDA can result in gains in data quality, reducing on-site oversight of the survey teams, reduced cost. This is an opportunity for African countries to address the lack of climate data (Sultan et al., 2020) by developing state-of-the-art methods for data collection for addressing climate-related impacts around cities and regions.

Based on our findings, we make further suggestions as to what researchers using the PDA approach should consider. Consideration should be given to how the relevant mobile device will be sourced, and the cost implication discussed. Along with this, it is important to consider and decide upon the platform on which the questionnaire will be hosted. This should be evaluated to be sure it has the relevant features (i.e. allows for geo-coordinates, pictures and videos) that may be needed for the project, as well as compatibility with data collection devices. Although, in this study, we had requested the RAs to come with their own devices because we felt it would be easier for them to use a device they were used to, as opposed to being introduced to a new device on their first day. While our assumption was found to be correct, we also found that this was also a problem as some of the RAs came with devices that were not compatible with the platform. Although ODK will run on most Android form factors (including tablets and netbooks) from version 1.6, in general, we will recommend devices that run the latest Android OS (4.0+ and higher). Adequate attention should be paid to this in the case of a large-scale study looking to use mobile/handheld devices. Supplying the RAs with new devices is an option, but would also come with additional costs.

7 | CONCLUSION

Developments in information and communication technology have created exciting platforms for a change in the approach to conducting research and data collection, with huge benefits. PDA data collection is an appropriate platform for improving data collection speed, reducing cost and environmental impacts, increasing quality, providing convenience, enhancing monitoring and evaluation. It also proves to be a convenient technology for socio-environmental data collection, in diverse settings where there is a need for spatial mapping. Our study shows that there is strong potential for practitioners interested in the built environment to use GPS technology-enabled in mobile computing to augment qualitative data in developing country contexts. However, despite the many benefits of using PDA, researchers should be aware of and should address the potential problems associated with electronic methods of collection, as highlighted in this case study.

Our study demonstrates that utilizing PDAs for data collection will benefit practitioners, policymakers and decision-makers and all those with an interest in climate change in Africa are often called on to use evidence-based research to inform decisions. This will especially be useful for studies that require large-scale data collection; mapping studies requiring coordinates data and that require photographs/videos/audio clips to add value to the research. This approach will go a long way in helping African researchers overcome the dearth of data and addressing climate data challenges facing African countries and demonstrates the potential to adopt mobile phone surveys in other contexts.

However, attention needs to be paid to the ease of use and appropriateness of the platforms and applications used for the projects as well as appropriate internet connectivity that will aid the smooth and swift process of data collection. While internet access and strength are expanding in most African communities, an effort is still needed to ensure broader coverage, especially in rural communities. This calls for more investments to be made by African countries to create national or African-based platforms that facilitate the ease of hosting PDA. This may need to be backed up by national policies to enable strong data collection for diverse purposes and enhance the decision-making process.

AUTHOR CONTRIBUTIONS

Olalekan Adekola: Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (equal); Project administration (equal); Resources (equal); Supervision (equal); Validation (equal); Writing – original draft (equal); Writing – review & editing (equal). **Jessica Lamond:** Conceptualization (equal); Data curation (equal); Funding acquisition (equal); Methodology (equal); Project administration (equal); Supervision (equal); Validation (equal); Writing – original draft (equal); Writing – review & editing (equal). **Ibidun Adelekan:** Investigation (equal); Methodology (equal); Supervision (equal); Writing – original draft (equal); Writing – review & editing (equal). **Namrata Bhattacharya-Mis:** Conceptualization (equal); Formal analysis (equal); Funding acquisition (equal); Validation (equal); Visualization (equal); Writing – original draft (equal). **Mboto Ekinya:** Data curation (equal); Formal analysis (equal); Methodology (equal); Resources (equal); Software (equal); Writing – original draft (equal). **Eze Bassey Eze:** Investigation (equal); Project administration (equal); Supervision (equal); Writing – review & editing (equal). **Fanan Ujoh:** Investigation (equal); Methodology (equal); Project administration (equal); Software (equal); Validation (equal); Writing – original draft (equal).

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OPEN PRACTICES STATEMENT

This article has earned an Open Data badge for making publicly available the digitally shareable data necessary to reproduce the reported results. The data is available at https://doi.org/10.1002/gdj3.156. Learn more about the Open Practices badge from the Centre for Open Science: httos://osf.io/tvyxz/wiki.

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