



Capturing social sensing of farming activities for policymaking in fragile contexts

Nadir Ahmed Elagib^{a,*}, Bashir M. Ahmed^b, Hussein M. Sulieman^c, Abbas E. Rahma^{d,e},
Marwan M.A. Ali^a, Karl Schneider^a

^a Institute of Geography, Faculty of Mathematics and Natural Sciences, University of Cologne, Cologne, Germany

^b Digital Agriculture Research Program, Agricultural Research Corporation (ARC), Wad Medani, Sudan

^c Centre for Remote Sensing & GIS, University of Gadarif, Gadarif, Sudan

^d Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology, Khartoum North, Sudan

^e Department of Environment and Agricultural Natural Resources, College of Agricultural and Food Sciences, King Faisal University, Saudi Arabia

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ABSTRACT

Social sensing data are lacking particularly in fragile and conflict-affected communities (FACAC). Stakeholder specific data are however needed to identify vulnerabilities and exposure to hazards. Climate vagaries, environmental degradation, high political pressure, shrinking economy predominantly dependent on agricultural production, and violent conflict characterize challenges of many developing countries. Based upon our experience in collecting geospatial datasets on farm management practices in the African Sahel, we address key questions: Which approach to comprehensive social data acquisition is suitable and promising particularly in FACAC? Can such an approach mitigate shortages in data availability arising from insufficient or failing government structures? To this end, we present challenges encountered, opportunities and key lessons. We aim to offer a guiding blueprint for researchers and practitioners to organize farm-level surveys in fragile and conflict-affected states. A survey was developed and used in Sudan by means of a smartphone app and in traditional paper form. The survey took place during the period spanning July 2022 to April 2024. Challenges such as sampling under non-updated census, lack of logistics, technology, financial limitation, distrust, low women representation, remoteness and vastness of localities, lacking infrastructure, and dialect often limit the access to different groups of farmers. Using international cooperation of Sudanese and German researchers, involving official staff and locals, and a balanced use of traditional as well as Information and Communication Technology (ICT) approaches facilitated a successful data collection campaign. The survey resulted in >1800 interviews with over 70 questions pertaining to three different farming systems, namely traditional and mechanized rainfed as well as irrigated systems. Our results and recommendations show that conducting social sensing at the farm level in challenging situations can be effectively achieved as a basis for research and policy intervention.

1. Introduction

Availability of social science data, such as those related to farming practices, is necessary to analyze, understand and address major societal problems and to facilitate change management (King, 2011). Comprehensive data on farming practices for different farm types help identify actual or perceived risks to food production. Incorporating indigenous knowledge and practices into climate change policies is essential to facilitate transformation towards effective and sustainable farming strategies (Iniguez-Gallardo et al., 2023). A substantial heterogeneity in

farming practices, farmers' socioeconomic characteristics, and farm performance exists across geographical areas and scales from plot to agro-ecological zone (Gollin, 2014; Wahab, 2020). Farming practices strongly depend on experience and tradition. These practices often do not keep up with the pace of environmental or societal change. However, the lack of integrative assessment of social, natural, and geographical information (Rindfuss et al., 2004) often hinders developing the needed comprehensive perspective. Thus, a global recognition of the need for big social data (social sensing) on coupled human and natural systems has recently grown strongly (Li et al., 2023).

* Corresponding author.

E-mail addresses: nelagib@uni-koeln.de, elagib@hotmail.com (N.A. Elagib).

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Geospatial data collected by, from or on behalf of humans, are referred to as social sensing. It can capture socioeconomic features of the environment and allows to understand these features (Liu et al., 2015). Human social sensing is increasingly attracting the scientific interest of academia. This interest stems from the paramount implications of social sensing for the generation of new knowledge, improved quality of subsequent decisions making (Li et al., 2016; Boo et al., 2022) and usefulness for policy interventions (Galesic et al., 2021). Difficulties in gathering socioeconomic information limit the progress in addressing major human behavior theories and policies (Liverman and Cuesta, 2008). Social sensing on farming practices in fragile communities, particularly those living in abject poverty and/or whose livelihood is dependent on farming, is of utmost importance due to escalating demand for securing food in a changing world. The problem of developing a practicable, acceptable, resilient and timely new policy is compounded by higher costs of data collection and pronounced political economy dynamics (Hamilton, 2017).

For natural sciences, automated sensor systems (on ground or remote) provide a wealth of environmental data. Conversely, social sensing with high spatial resolution and timeliness on essential domains, such as farming operations, is particularly challenging due to the limited usability of technology, the large effort in personnel, funding issues and the low return rate of questionnaires. Today, modern and ubiquitously available information and communications technology (ICT) provides opportunities to address this data gap. The term “big geospatial data” frequently used in this context implies both large volume and

comprehensiveness of the data set. However, ICT presents challenges and opportunities associated with technical and conceptual perspectives (Li et al., 2016). Collection of such data has been largely transformed from traditional methods of questionnaires and interviews into fast and powerful methods (Liu et al., 2016), based on the ubiquitous availability of devices such as smartphones (Aggarwal and Abdelzaher, 2013; Li et al., 2016; Galesic et al., 2021). Data acquisition can go beyond a limited campaign. ICT provides the opportunity for a continuous technology-supported stakeholder dialogue.

Here we present our first experience in establishing a comprehensive dataset on farm management practices for different farming types in a fragile context, which is herein represented by the case of Sudan (Supplementary Material). Against the background of the given situation of limited and even failure of governance in this Sahelian country, we discuss our data collection approach and present our experience. It is implied that the blended approach of personally addressing the respondents combined with the use of ICT not only led to a large number of respondents but also supported reliability, quality and timeliness of the data. The potential of this approach is not fully utilized yet, as a continued ICT-mitigated stakeholder dialogue to support adaptation and transformation offers additional opportunities. Employing direct communication between scientist, policymakers and practitioners through an ongoing stakeholder dialogue can help fill the void of lack of governance. We address challenges and opportunities encountered and offer recommendations towards utilizing the full potentials of this approach. Herein we focus on the approach developed for the survey

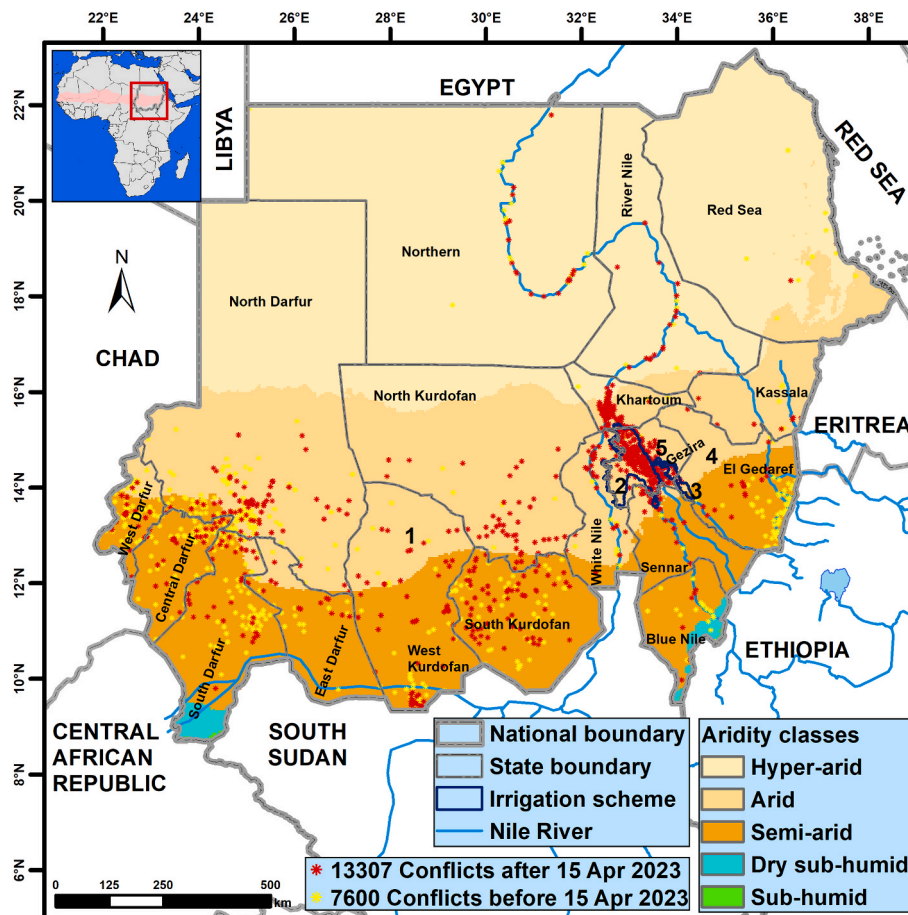


Fig. 1. Sudan as a fragile and conflict-affected Sahel country. The source of armed conflict location and event dataset (ACLED) for the period spanning January 1, 2019–May 31, 2024 is Raleigh et al. (2010). Demarcation of the aridity zones was based on the aridity index of the United Nations Environment Programme (UNEP, 1997) defined as the ratio of annual rainfall to annual reference evapotranspiration using data from TerraClimate (Abatzoglou et al., 2018). The numbers 1 to 5 refer to the five study areas covered by the survey, namely 1. West Kurdofoan State (traditional rainfed system), 2. Gezira Irrigation Scheme, 3. Rahad Irrigation Scheme, 4. El Gedaref State (traditional and mechanized rainfed systems) and 5. Gezira State (traditional rainfed system).

rather than on the surveys content as this approach is transferable also to other lines of research beyond farm management research.

2. Methods

2.1. Representation of farming systems

The arable land cultivated in Sudan encompasses a large area (Supplementary Material), most of which lies within the Sahel zone of Sudan (Elagib et al., 2024) with predominantly arid and semi-arid conditions (Fig. 1). This zone accommodates four agricultural farming systems, namely rainfed traditional, rainfed (semi-)mechanized, gravity-irrigated and spate-irrigated systems (Elagib et al., 2023). These farming systems are defined based on the techniques applied which are determined largely by the economic conditions and level of sophistication of farm managers (Carter, 1963). As covering the full cultivated area is not feasible within this study, we applied a selection and sampling strategy that was guided by eight factors.

1. Climatic and agro-ecological zones representing arid and semi-arid conditions.
2. Geographical location to ensure cross-Sahel regional representation.
3. Soil types, which are generally speaking clayey soil in the eastern part of the zone but sandy in the western part.
4. Water availability defining the supply resources of irrigation whether being rainfall or surface from river.
5. Diversity in system management and/or farm size (large-scale irrigation schemes; smallholder, medium holder, large-holding household).
6. Significance of economic contribution to Sudan's gross domestic product (GDP), food security, and/or exports (e.g., production of cotton, sorghum, sesame, groundnut, gum Arabic, etc).

7. Challenges and opportunities manifested by climate hazards (e.g. droughts and floods), land fertility or degradation, resource depletion, salinity, high agricultural potential, etc.
8. Insecurity situation in the wake of violent conflicts.

Most of the above factors match the guidelines revealed in the household survey literature on the Sahel countries (e.g. Mertz et al., 2009; Di Falco and Veronesi, 2013; Ujunwa et al., 2019; Marie et al., 2020; Assefa and Gebrehiwot, 2023; Abay et al., 2023; Coly et al., 2024; Kirui et al., 2024). Accordingly, the farming systems across the Sahel zone of Sudan were selected from eastern Sudan, central Sudan and Kurdofan Region (Fig. 1). More information on Sudan as a fragile state can be found in the Supplementary Material.

2.2. Scope of the survey

The present survey is characterized by six main attributes (Fig. 2). We considered extensively cultivated areas to represent three farming systems, namely traditional rainfed, (semi-)mechanized rainfed and irrigated systems. The survey was conducted using two formats: a) traditional paper format and b) smartphone apps. The questions of both formats are identical though 72 and 73 questions were asked in the paper and app format, respectively. The additional question in the app addresses a technical issue. The app-based questionnaire facilitates data transfer in near-real time if internet access is available, thus facilitating seamless cooperation of the participating researchers.

As shown in Fig. 2, the structured survey comprised seven key sections/themes (apart from the general questionnaire identifier that consisted of 3 questions). The sections were respectively used to collect detailed data on: i) household characteristics (17 questions); ii) farming systems (23 questions); iii) crop productivity (11 questions); iv) climate change perception (9 questions); v) seasonal weather forecast (2 questions); vi) adaptation measures against climate change (6 questions); vii)

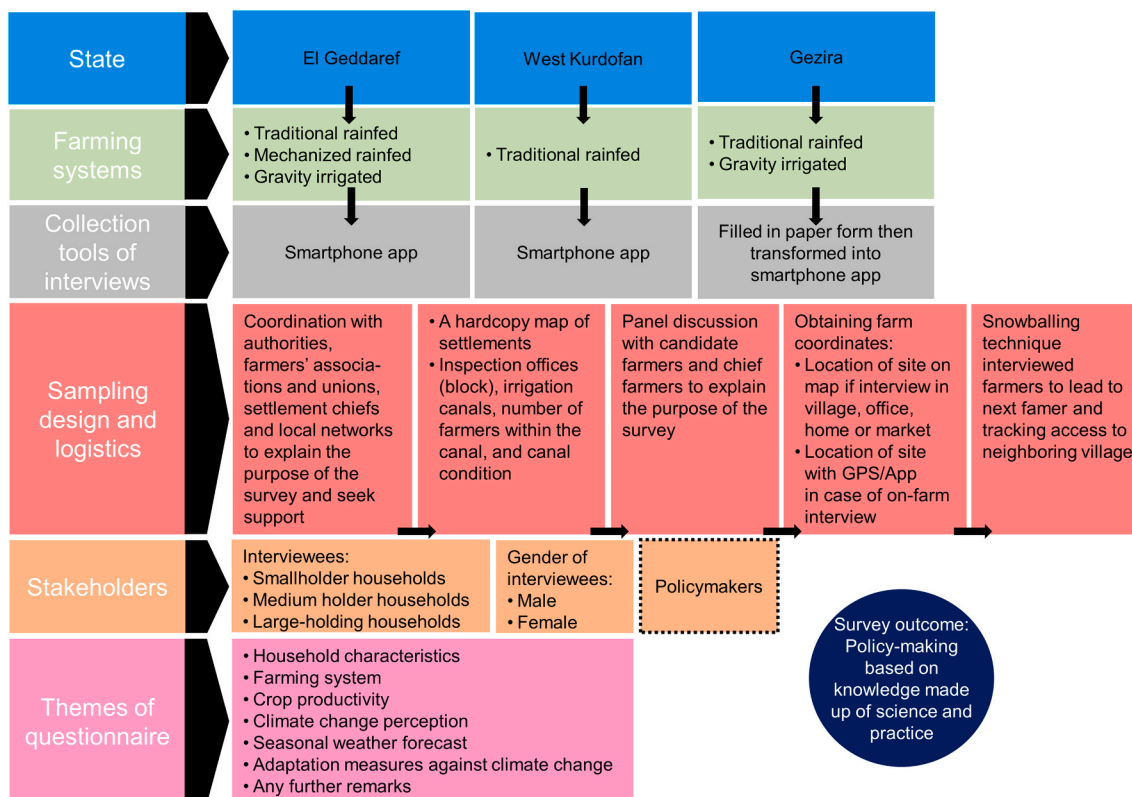


Fig. 2. Framework of the geospatial survey attributes in the farming systems covered in the survey.

any further remarks (1 question). The farms are categorized as small-holder, medium holder and large-holding farmers.

2.3. Fieldwork modalities including sampling

The survey was originally written in English; then, was translated into Arabic. The app facilitates a multi-language support. Three teams were involved in the survey. Each team consisted of four dedicated, educated and well-experienced members including the head or supervisor of the team. In order to obtain representative samples, some researchers used probability and non-probability sampling techniques and sampling formulae to determine the desirable sample size (e.g. [Assefa and Gebrehiwot, 2023](#); [Coly et al., 2024](#)). However, sampling design of a household survey in Sudan based on non-updated nationwide census as old as the year 2008 can be contested ([Raja et al., 2017](#)). Absence of up-to-date sampling frames due to population displacement or loss of records poses additional difficulties to the data collection process in fragile areas ([Hoogeveen and Pape, 2020](#)). Conversely, available censuses, lists of total households in agricultural offices or previous survey records constitute baseline data providing detailed characteristics of households, including Global Positioning System (GPS) coordinates of the household, for survey campaigns elsewhere ([Abay et al., 2023](#)). Each team therefore had to design a sampling plan to suite the given situation on ground and existing data.

In general, we learned substantive lessons from the sampling procedures as follows:

1. Sampling following rigid techniques is less efficient and less desirable in the present cases.
2. In mobile communities, interviewees in the field may not be available or may be unwilling to participate. Thus, reaching to interviewees becomes costly and time consuming.
3. Flexible adaptation of sampling strategies leads to more respondents and makes the stratified random samples highly representative.

Prior to the survey, each head of team examined the formulation of the questionnaire, and a feedback loop was ensured for enhancement before the survey was conducted. Similarly, all heads of teams trained the use of the app and provided feedback. They later trained the members of the teams prior to using the app in the field to interview the farmers. Briefing, training and testing is a necessary step prior to implementation of the survey to ensure clarity of and incorporate modifications and amendments to the questionnaire. Pre-testing of the questionnaires was run with a number of nearby farmers. The aim of pre-testing is usually to have an indication of: 1) the easiness or difficulty of the questions to the understanding of the farmers, 2) the best way to phrase and express the questions during the interview and 3) the average estimated duration of the interview ([Marie et al., 2020](#); [Coly et al., 2024](#)). All the questions were addressed directly to the farmers in person. Initial pilot studies help refine strategies of survey data collection ([Hoogeveen and Pape, 2020](#)). Trained surveyors ensure knowledge about survey administration techniques, ethical considerations, data collection protocols, minimization of interviewer bias and consistency of data collection ([Coly et al., 2024](#)). In all cases, the purpose and objectives of the study were clearly explained to each farmer and the farmer's consent was obtained before starting the interview. Communicating the objectives of the survey is part of the best practices in conducting survey-based research ([Coly et al., 2023](#); [Kirui et al., 2024](#)). Verbally consenting to conduct the interview is an ethical consideration showing willingness to answering the questions ([Assefa and Gebrehiwot, 2023](#); [Kirui et al., 2024](#)).

2.3.1. Rainfed farming systems in El Gedaref State

In order to have good coverage and well representative sample for the whole of El Gedaref State, the fieldwork was organized based on a campaign for each locality. Prior to the field campaign, a hardcopy map

showing the settlements in the locality was prepared. The team used the map as a reference database for farm geolocation in the state. In case of presence of a government office in the settlement (e.g. Locality Headquarter or Office of Agricultural Services), the team first met the authorities to explain the idea and the objectives of the study, the data collection techniques and the app. If no official governmental body existed, the team met the chiefs of the settlement, village or community to explain the purpose of the study and the app. Then, farmers were invited for the interview. After finishing the interview, the farmer was invited to locate the site of his/her farm on the map. The team avoided to interview farmers who were neighbours to allow for good distribution of the samples and independence of the data. In most cases, a snowballing technique was followed by asking the interviewed farmers to help the team find the next farmer to be interviewed. Literature shows that leveraging the characteristic social connectivity in rural areas, where everyone knows everyone, is common in survey sampling to find participants ([Pierce and Scherra, 2004](#)). When the work in a settlement/village has been completed, the team asked the chiefs for contacts and phone numbers of the chiefs of the neighboring village and about the accurate direction and best track to access that village. Asking locals to assist in giving directions in remote areas is common in data collection ([Pierce and Scherra, 2004](#)). Some of the interviews were conducted in the headquarter of the state where the majority of the large-holding farmers live or gather.

2.3.2. Rahad Irrigation Scheme

In this scheme, the field survey was organized based on a hardcopy map showing the scheme and the settlements/villages, where the farmers live. Before conducting the interview, the team met the village leader to introduce themselves and the aim of the survey. There were a few cases where the team met the agricultural inspectors of the scheme to explain the aim of the survey. Then, farmers were invited to participate in the interviews. Once the interview was completed, farmers were invited to mark the location of their farms on the hardcopy map. In most instances, a snowball sampling technique was used such that the interviewed farmers were asked to recommend the next farmer for the interview. Once the work in a particular settlement or village was completed, the team sought contact information and phone numbers of the chiefs of neighboring villages from the local chiefs of the surveyed village.

2.3.3. Rainfed farming system in West Kurdofan State

Preparatory coordination with governmental authorities, staff of the Ministry of Agriculture and colleagues in the state was rather important. These connections facilitated the fieldtrip in general by contacting leaderships of the agricultural associations, preparing for access to and locating the targeted areas, arranging the participation of representative number of farmers and conducting the interviews. Where there are farmers' associations, interviews were conducted directly on the farm, particularly with farmers who cultivate later summer crops and harvest during winter. Otherwise, maps were used to obtain the coordinates of the farms where rainy season farming was practiced. To avoid influence on responses, the interviews were conducted individually and personally away from the other respondents.

2.3.4. Gezira Irrigation Scheme

Extra coordination and administrative preparations were necessary in advance to conduct the surveys here due to the complexity and vastness of the scheme. The interviews were arranged according to the administrative groups of the scheme. The scheme is administratively divided into 18 groups, each containing a number of inspection offices (blocks). Care was taken to consider a sample of farmers representing the designated office. The sampling was also governed by the number of irrigation canals belonging to each office, their areas, number of farmers within the canal, and canal condition in terms of maintenance, intermediate bridges, and level of water supply. Thus, considering a number

of these canals highlights the problems and merits of each office. A panel discussion was held with the farmers to inform them of the purpose of and the benefit they may expect from the questionnaires and/or the research (Fig. 3a and b). To ensure confidence in answers and avoid interference of other farmers, filling out the questionnaire took place individually. Interviews were conducted either in the village, rarely on the farm (Fig. 3c), in house of chief farmers (Fig. 3d), on the market day (Fig. 3e) or in the “inspection” office. Each approach has advantages and disadvantages. For example, on the market day, a large number of farmers at the group level can be found but at the expense of ideal canal representation. Conversely, in the designated office, the guide or inspector can gather a number of farmers for interviews with appropriate representation and information about each canal. Interviews in the village ensure finding a number of farmers in the same office, but often within the same canal, so the spatial distribution is not ideal.

At times of conflicts, it is essential to implement security regulations and, as much as possible, seek other tools to exclusively conduct the interviews remotely (Coly et al., 2024). Only in one group of the Gezira Scheme, an internal conflict led to insecurity issue that prevented the enumerators from visiting the farmers in their places. The head of the group advised the team to conduct the interviews by phone calls. Thus, interviewees were then selected in collaboration with leaders of farmers. The sample of this group was composed of 40 farmers. Determining the coordinates of each farm was not difficult. Once the farmer informed the team of certain description of the area, the location of each farm was readily identifiable on the detailed map of the scheme.

2.3.5. Rainfed farming system in Gezira State

In this traditional rainfed sector, the questionnaire was conducted based on the administrative localities of the state, where there is an

office for agriculture in each locality. Coordination with these offices was made through the Director General of the Ministry of Production and Economic Resources in the state. Villages and local markets were targeted to meet the largest possible number of farmers of the designated locality. Different groups were targeted such as smallholder farmers, large-holding farmers, chief farmers, farmers who were former officials as well as farmers who are members of the Farmers Union and various organizations. The interviews were usually conducted in the villages, either at the homes of the chief farmers or in the market. Usually, gathering of a large number of farmers attached to the different offices in the same division takes place in the market. The questionnaire was filled out individually.

2.4. Validation of the high resolution

As indicated earlier, some of the teams had to use printed maps to obtain the approximate location of farms. Analysis of land use and land cover (LULC) classification represents an appropriate source for validation/cross-checking of the survey sampling. In the present survey, satellite data on LULC was useful particularly in rainfed agricultural systems. Here the distribution of farms is dispersed such that the farm location (coordination) is not well-known like in the irrigated sector. In this study, a comprehensive methodology was employed to analyze LULC in the study areas. The detailed methodology is described in the [Supplementary Materials](#). The classified image was visualized on the map using a distinct color palette for each land use class (Fig. 4).

3. Challenges and how they were overcome

A suite of challenges can be exemplified and discussed in relation to



Fig. 3. Features of the survey process as conducted for irrigated and rainfed farming systems. a) and b) Discussion between survey team and farmers prior to interviews to inform them about the purpose of and benefit from the questionnaire; c) On-farm interview; d) Interview with a chief of farmers at home; e) Interview in the market; f) Interview with woman farmers at home; g) Interview using smartphone app; h) Re-entering the questionnaire answers from the paper version to the app using a smartphone or a laptop; i) Villagers inviting the survey team to take early morning tea.

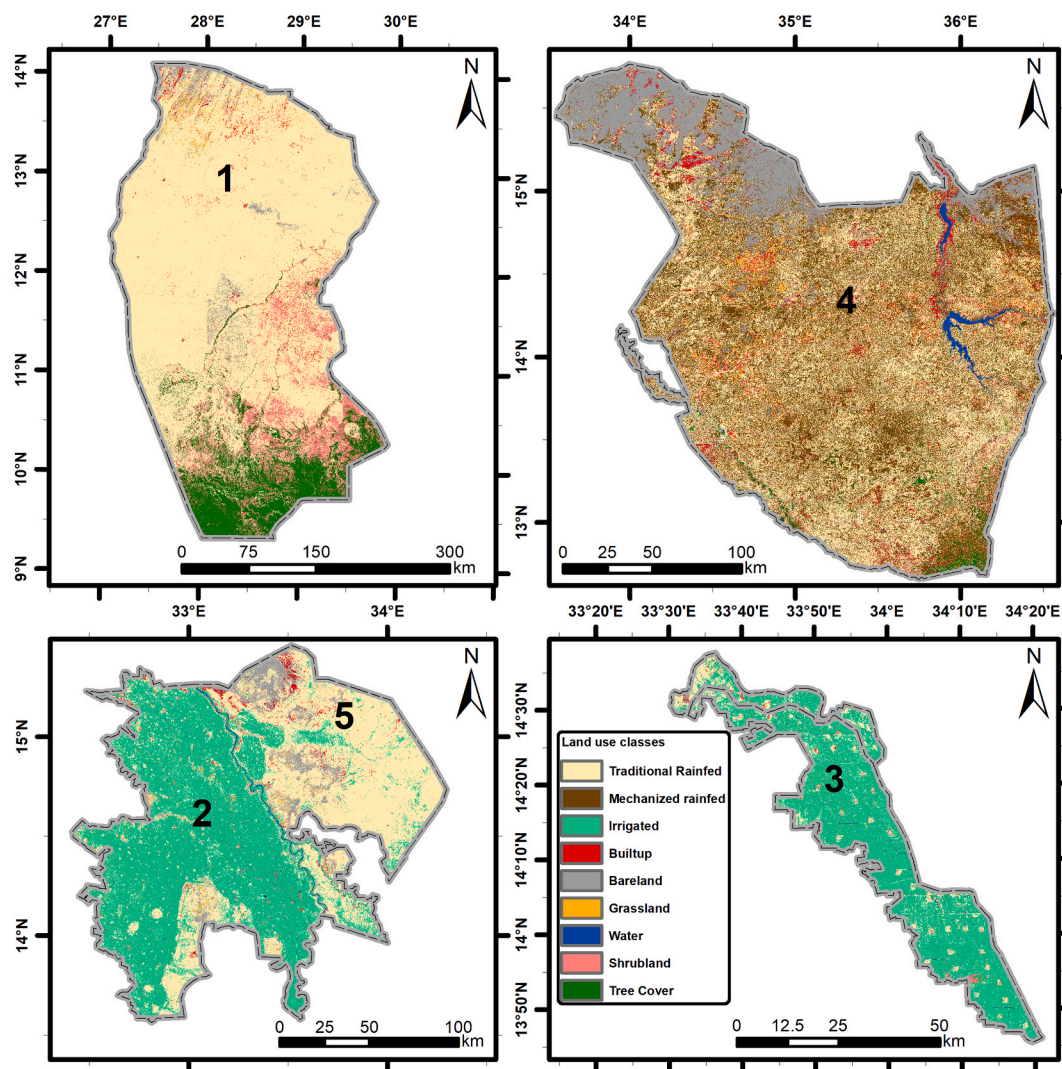


Fig. 4. Land use classes in the areas covered by the survey.

collecting large-scale datasets on farming operations in such fragile regions.

3.1. Timing of the survey

While taking the agricultural cycle into consideration, key issues in planning the data collection were accessibility to the study area, availability of the interviewees and security issues. The first fieldwork was carried out in July 2022 for a couple of days in El Gedaref State, but was stopped due to limited trafficability resulting from heavy rains and difficult road conditions. The rainy season in Sudan normally starts in June, peaks in August and diminishes in around mid-October. Therefore, the bulk of the fieldwork covering the rainfed sector in El Gedaref State and the Rahad Irrigated Scheme was conducted after the rainy season during the period from October 2022 to April 2023. Organizing the fieldwork during the dry season is marked by absence of the farmers in their fields, thus hindering direct registration of the field coordinates without the need for approximation using the map. Nevertheless, 172 out of the 622 interviews related to the rainfed farming system in El Gedaref State were successfully implemented during two dry months (March and April 2024). The interviews took place in the farmers' villages, and the coordinates of the farms were geolocated using the printed map. The survey in the large-scale Gezira Irrigation Scheme took place in October 2022. A small-scale survey in West Kurdoan State was

conducted in October 2022 whereas the bulk of survey in February 2023, i.e. during the dry season of the year and just one and half months before the eruption of the civil war in the country in mid-April 2023. Contrary to the case of El Gedaref State, the team noted the dry season as the best time to catch a large number of farmers for the interview. During this dead season, i.e. non-growing season farmers gather to discuss the problems they faced during the past growing season. However, the survey of the rainfed system in Gezira State was conducted in July 2023, just a few months before the expansion of the violent conflict to the state.

3.2. Logistics

As indicated earlier, sampling design of household survey for a country as large as Sudan, with several farming systems that spread across vast croplands, is challenged by an out-of-date national census. Therefore, designing a sampling plan had to consider the farming systems in a case-by-case, state-by-state or scheme-by-scheme basis. Endeavoring different modalities to guide the interview was imperative (Fig. 2). A coordination with the government authorities or chiefs of the settlement, the village or the community was made. This coordination served several purposes in the present survey, as explained in Section 2. Informing the town halls or municipalities of the targeted districts in advance can also facilitate deployment of the questionnaire or even the

surveyors' visit (Coly et al., 2024). Rural residents' knowledge of most people in the area is useful in finding participants in a survey (Pierce and Scherra, 2004), thus saving efforts and time. Difficulty in locating households for interviews is a logistic constraint that can even limit the completion of the originally sampled number of questionnaires (Bryan et al., 2013).

3.3. Security issues

Dangers from conflicts or diseases are problematic to enumerators in fragile contexts. In such cases, literature suggests hiring local individuals and collaborators as enumerators or sponsors to navigate the survey protocols after training and under supervision (Reichman et al., 2001; Hoozeveen and Pape, 2020; Kirui et al., 2024). Leveraging local networks improves safety and feasibility of surveys (Driscoll and Lidow, 2014). The survey campaign took place during the period spanning from July 2022 to April 2024. This period was characterized by fragile conditions due to political unrest, economic difficulties and violent conflict in the country. In October 2022, a few-day conflict typified by gunfire exchange was reported in Al Lagowa locality in West Kurdoan following escalating contestation between two tribes over land (OCHA, 2022a). It is worth mentioning that we originally planned to conduct surveys in parts of Darfur Region and Khartoum State. However, those plans were cancelled due to security reasons. Outbreak of inter-communal clashes and localized conflict and armed attacks were reported across Darfur Region in October 2022 (OCHA, 2022b). Armed conflict broke out in the country mid-April 2023 between the Sudanese Armed Forces (SAF) and the paramilitary Rapid Support Forces (RSF). The war overwhelmed the capital Khartoum and spread countrywide. Hence, in lieu of these two regions, the surveys were shifted to the rainfed sector of the Gezira State and the Rahad Irrigation Scheme. Luckily, the part of the survey that covered the rainfed sector in Gezira State endured the turmoil of the armed conflict. This state was relatively in peace at the time compared to others. However, a few months later, the war stormed into the state.

3.4. Mistrust

As most of the interviews took place in rural areas, there was clear fear and reluctance to participate exhibited by the interviewees. Many farmers believe that such interviews and questionnaires have never brought about benefit to them. Fear of government officials, authorities and strangers from the area engenders an atmosphere of mistrust. Thus, farmers do not deal easily with the interviewers. This challenge can reflect significantly into intentional or unintentional untruthful responses (Hamilton, 2017). Risks associated with trust gap in the science-policy-practice interface need to be managed (Lacey et al., 2018). In the present case, contacting and involving a circle of acquaintances of the social associations and natives from those areas helped breaking this wall of mistrust. For instance, this acquaintance helped explaining the purpose of the interview to the farmers that it was only to conduct scientific studies and nothing else. Such community dialogues facilitated by researchers and community leaders to explain the purpose and importance of surveys help mitigating resistance and suspicion (Hoozeveen and Pape, 2020). In many cases, scientists among the team of interviewers offered some scientific products (e.g., books, bulletins, technical package, etc.) to the chief farmer to be shared with others. This challenge can thus be considered interrelated with the logistic type of challenges.

3.5. Cultural matters

Cultural matters precipitated somewhat a form of challenge to the survey. For instance, the women segment of the farming society was poorly represented in the data. Reasons behind underrepresentation of women and prevention to them from participating in surveys could be men-ownership of land since women do not normally inherit farmlands,

labor roles played by women, cultural norm, access to resources and social barriers. Social barriers can include time constraints due to women in-house responsibilities, lack of mobility and reluctance to speak to enumerators (outsiders) due to cultural norms (Al Subeh and Alzoubi, 2020; Grindstaff, 2022; Gbenga et al., 2023; Podreka et al., 2024). Although women contribute significantly in agriculture in developing countries, there is evidence of differences between them and men with regards to payment and access to land, capital, assets, human capital, and other productive resources (SOFA Team and Doss, 2011). It is also reported elsewhere that rural women do not think their participation or the information they would share is important (Pierce and Scherra, 2004). In Sub-Saharan African countries, female labor tends to share highly in households where women own a larger share of the land and when they are better educated (Palacios-Lopez et al., 2017). Females in West Kurdoan State work as labors rather than farm owners. Thus, there were only very few female interviewees. In central and eastern Sudan, the prevailing customs and traditions hindered thorough investigations attempting to understand the role of women in the agricultural production process. This observation aligns with reports describing the matter in other parts of the Sahel. Female labor shares and input to Africa's agricultural activities differ starkly between north and south, revealing low contribution of women in the Sahel countries, such as northern Nigeria (32 %), Ethiopia (29 %) and Niger (24 %) (Palacios-Lopez et al., 2017). In the present survey, women in the farming systems were represented by only 63 households (3.5 %). However, women participation in the survey was noticeably more effective in the rainfed agriculture in Gezira State (Fig. 3f). Here, they supervise and carry out all farming operations themselves.

In spite of ensuring full coordination with local authorities or people, cancellations may be made for various reasons, including social circumstances (deaths in the village, illness among family members, etc.). Moreover, respect for customs and traditions revealing hospitality of the community entails accepting an invitation to a meal, drinking a cup of tea or coffee, etc. (Fig. 3i). This stray from the questionnaire path is unavoidable, leading to a bit of prolonged duration of the planned daily production of questionnaires.

3.6. Disruptable survey timeframe

The planned timeframe in which the survey is to be completed can be challenged by several factors. On top is the insecurity issues in hotspot states and localities as explained earlier. The nature of some areas makes them time-consuming and hard to access due to bumpy roads and long distances between the areas. In the Gezira Irrigation Scheme, a day was allocated for each group to survey most of the offices in the group. Some localities in El Gedaref State were covered by the team in one working day whereas others took two or three days, depending on the area of the locality, accessibility and spatial distribution of the settlements. In general, given the already high cost of conducting surveys of this large scale, any accidental interruption to the original plan may incur unexpected additional costs. Lack of funding and support systems has recently been confirmed, leading to existence of research gaps and challenges in the African social sciences (Ogega et al., 2023).

Of course, the time required to cover an area of a locality is also governed by the duration of the interview. This duration varied from one study area to another, from a farmer to another and from an interviewer to interviewer. In El Gedaref State, for instance, the time needed for each interview was approximately 20–30 min. Interviews carried out in the rainfed and irrigated sectors of the Gezira State revealed an average duration of interview of 15–20 min. As many farmers took advantage of this opportunity to obtain additional information or technical guidance related to the agricultural operations, those farmers caused derailing of the interview from the main theme and usually took longer to interview. The team covering West Kurdoan noted in some areas the requirement to repeat the question to the farmer being interviewed more than once. This way allowed the farmer to understand the intent of the question in a

simplified manner. In such a case, longer time was taken to complete the interview. However, in general, the time taken in the interview ranged from 20 to 35 minutes per farmer.

3.7. Technological versus traditional approach

Tailoring mixed methods in data collection in fragile and conflict-affected settings is found to allow flexibility in accessing and documenting data (Khan Mohmand et al., 2017). We hypothesized that comprehensive social datasets require integration of new technological approaches with traditional approaches utilizing networks to provide quality-controlled big data. In general, use of an app is preferable to the paper version. The app allows immediate checks for consistency of the responses. Moreover, the app ensures answering all questions unlike the paper version, which may cause omission of some conditional questions. Unlike the app, the paper approach entails manual transformation of the questionnaire data again into a digital format for analysis. However, despite the growing digital tools and when using the app, attention should be paid to the following guidelines: a) Availability of paper and digital maps that enable easy determination of the farm coordinates if the questionnaire is not taking place on the farm; b) A tablet should be used, if possible, instead of the phone for clearer sight and ease of data entry; c) Questions and answers should be as short and direct as possible; d) Digital surveys may encounter data loss due to technical faulty before submission, e) Most of the remote or under-developed areas lack sustained power supply or are utterly unconnected with electricity; thus, digital surveys can be disrupted by power outages or lack of internet access, resulting in data loss; f) Cost of and resource constraints to digital platform surveys.

In this survey, collection of the answers from the respondents was carried out using either the smartphone app (Fig. 3g) or the paper version followed by the app (Fig. 3c–f and 3h). The smartphone app was produced using ONA open data kit (ODK) (Hartung et al., 2010). To survey the rainfed and irrigation sectors in Gezira, the paper version was adopted first instead of the smartphone app version due to the absence of some important information such as the coordinates of the farm. Therefore, a paper map (sketch) of the designated office was taken from the Headquarter of Gezira Scheme. It was used to identify the location of each farmer with the help of the office inspectors. These maps were later converted into shapefiles and the coordinates of each farm were determined with the help of some basic maps, such as Google Earth Base Map. Later, the data in the paper forms were entered in the app using a smartphone or a laptop in order to send them to the questionnaire repository (Fig. 3h). Despite this double work, it was easy to communicate any later quality checks between the team in Sudan and the team in Germany since the former still had the paper copy. As per the team based in El Gedaref State, the app was user-friendly, efficient and saved time. Moreover, the app stores all data on the local device and transmits the data once internet access is available. Thus, the app works without phone network coverage, storing the responses in the smartphone browser for later upload. This feature is advantageous, particularly as the internet network is usually weak. The team who covered West Kurdofan State reported some pros and cons of both the app and the paper copy versions of the questionnaire. The app eliminated the need for making a number of paper copies that must be carried with the interviewers, taken care of, and retained undamaged during the fieldtrips. Moreover, the hardcopy needs to be entered into the computer after the interview, and this is a time-consuming double work (see Fig. 3h). While the app enables saving and sending the data instantly, it needs a smartphone with special specifications and reasonable capabilities. Furthermore, weak internet connection was a problem particularly in the remote areas. In this case, sending the data was sometimes only possible in the city.

Most of the advantages and disadvantages listed above agree well with those common in surveys and data collection efforts (Mutepfa and Taper, 2019; Real World, 2024).

3.8. Use of local dialect

Literature indicates that some survey campaigns may necessitate recruiting locals with language proficiency in collaboration with local authorities or agencies (Coly et al., 2024). It was also sometimes hard to understand the responses when a farmer used words in the local dialect. Dialect is spoken principally in rural areas. Therefore, having a local accompanying the team was helpful in explaining the local dialect. Conducting the surveys in local languages ensures better understanding among households (Assefa and Gebrehiwot, 2023; Coly et al., 2024).

The above challenges concord with those arising generally from inability to reach people living in certain regions lacking infrastructure, characterized by social fragmentation caused by diverse cultures and religions or affected by internal displacement of people due to conflicts (Raja et al., 2017).

4. Results and discussion

4.1. How dense is the survey?

In the present survey, a total of 1815 interviews - spatially distributed over a cropland area of ~6.48 million hectares - were conducted (Fig. 5). Thus, the survey covers one household per ~3570 ha on average. An unusually large database of farmers' practices in the different farming systems was built. Covering sub-national farming systems in Sudan within ~64800 km², i.e. with a density of 1 interview per 35.70 km², can be considered quite dense. For example, the large Sudan rural household survey conducted by Kirui et al. (2024) during the ongoing conflict in Sudan shows a density of 1 household per 418.74 km² (Table S1). On the scale of a state (Table S1 and Fig. 5), the density of the present survey still outweighs that of Kirui et al. (2024). It is noteworthy that their survey was phone-based and did not involve farm visit nor farm coordinates record. Moreover, to reflect the stratification of the population based on gender and state in the whole of Sudan, the household survey data used in the analysis by the Department for International Development (DFID) consisted of 2365 households (Raja et al., 2017). Even in comparison to other large-scale social surveys conducted in Africa, Asia or Europe (see Table S1), our survey is an impetus striving towards future more extensive surveys.

Furthermore, the LULC classification analysis of the surveyed croplands as described in the methods shows promising results too (Table 1). The accuracy of classification is highest for the irrigated croplands, followed by rainfed croplands where traditional rainfed farming system is dominant in the given region (e.g. Gezira State and West Kurdofan State). However, distinguishing the difference between traditional and mechanized rainfed land uses is expectedly difficult. This limitation manifests in El Gedaref State, where the rainfed farming is largely a mixture of both systems, i.e. traditional and mechanized. It is therefore recommended to merge both cropland types and consider them in one land-use class, i.e. rainfed, an approach normally used in land use products.

Limited representation of woman in the surveys as reported herein has a dire policy implication. Darfur Region in western Sudan is famous for large women farmer community. Unfortunately, the exclusion of this region in the coverage of the survey due to insecurity limited this valuable participation.

4.2. Duration of the survey

Timely surveys are important to capture the event and/or practice to formulate appropriate response to be taken. Although the teams collecting the data was composed of same number of data collectors, it is worth-noting that each team had different strategies to conduct data (refer to fieldwork modality). These prior plans and on-site conditions of course governed the number of days spent in each survey. Each strategy was cost-effectively designed depending on the logistics, vastness of

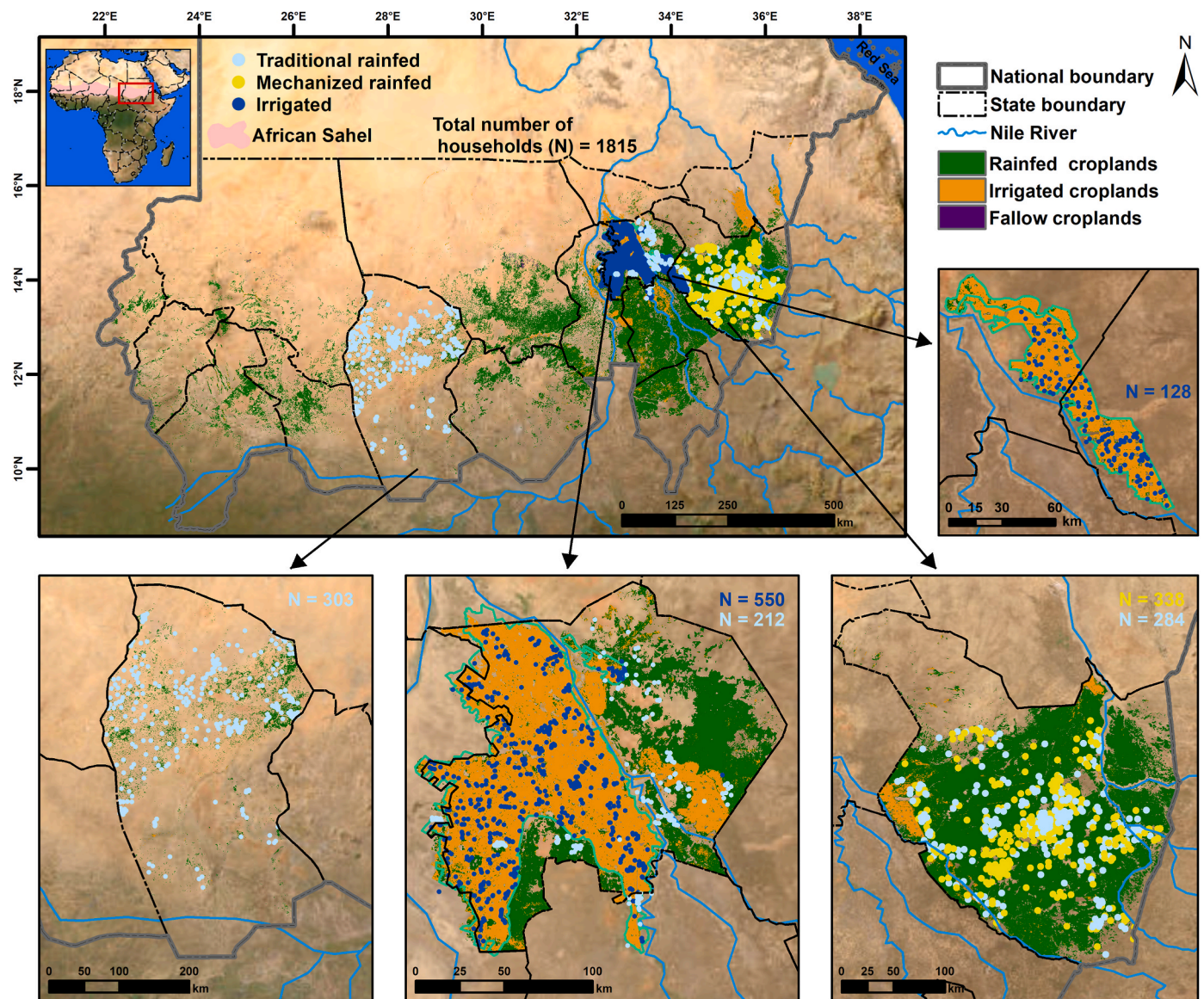


Fig. 5. Spatial distribution of the farm-level survey conducted in three farming systems in the five study areas indicated in Fig. 1 during the period spanning July 2022 to April 2024. The land use shown on the map represents the 2022 croplands based on WaPOR database methodology (FAO, 2020).

Table 1
Accuracy of the land cover and land use classification.

Surveyed area/ region	Calibration			Validation			Overall accuracy
	TR	MR	IR	TR	MR	IR	
	Producers Accuracy			Consumers Accuracy			
Rahad Scheme	0.87	0.33	0.90	0.71	1.00	0.78	0.71
Gezira	<u>0.73</u>	NA	<u>0.94</u>	<u>0.67</u>	NA	<u>0.87</u>	0.78
El Gedaref	<u>0.48</u>	<u>0.40</u>	NA	<u>0.36</u>	0.49	NA	0.43
West Kurdofan	<u>0.99</u>	NA	NA	<u>0.93</u>	NA	NA	0.88

TR = Traditional rainfed; MR = Mechanized rainfed; IR = Irrigated; NA = Not applicable.

Underlined entries are the accuracies relevant to the system under consideration.

each surveyed system, cost of living, transportation, etc. The enumerators took all possible measures to ensure integrity and reliability of the surveys. These variations indeed reflected in variations encountered in the cost from survey to another. Despite the multitude of challenges

encountered in a fragile context like Sudan, this quality-controlled survey was remarkably accomplished in a record time.

4.3. Opportunities

Strengthening the dialogue between science, policy and society is increasingly seen critical for advancing the adaptation to climate change in view of the foreseen global food crisis (Arnott et al., 2020; Serrao-Neumann et al., 2021). Notwithstanding the practical challenges arising out of the attempts aiming at collecting large-scale datasets, enormous opportunities can be offered through capturing this type of data. Farmers are principal actors in the agriculture sector. They are holders of important farming knowledge to be shared through such a dense database. Engagement of these indigenous and local knowledge systems provides a useable knowledge to inaugurate a science-for-policy dialogue (Mertz et al., 2009; Tengö et al., 2017) relating to these farming systems. Sahelian farmers' perception of long-term climate or extreme phenomena (e.g. drought) and adaptation experience can suggest lessons to be learnt of wider utility for climate change policy in the future

(Mortimore, 2010). Furthermore, this survey has established extensive networking with chiefs of farmers. The value of this widespread networking can be exploited in the implementation of any research activities in the future. Despite somewhat technical matters relating to slowness of receipt, transportation and delivery in fragile countries, collection of farming information has become easier with popularity of smartphones and internet communication than with the traditional paper approach. The result is an endorsement of our multiple survey approaches rather than a limitation. Therefore, graduates, pupils and sons of farmers can be trained in different villages, schools, universities and offices to help filling out the questionnaire and reach the largest number of farmers possible in different regions. A wider spatial coverage is thereby achievable.

5. Conclusions and recommendations

This work supports the argument raised by Fast (2017). Firstly, collection of both big data and evidence-based decision-making in fragile situations (e.g. conflict) can be facilitated through collaborative efforts made by researchers/scholars and practitioners/operational actors as well as policymakers. Secondly, a deepening chasm between theory and practice can be prevented. The present experience has enabled designing guidelines and a number of key lessons for researchers and practitioners who intend to conduct similar surveys elsewhere in the future. A succinct overview of the lessons learned from the present experience can be designed below. Considering these lessons will undoubtedly improve the collection process of comprehensive and high geospatial resolution datasets.

Use of LULC maps. Satellite LULC data help identify the approximate locations of farms, especially in cases of rainfed farms like ours. Satellite data analysis can significantly reduce the cost of data collection. Thus, sampling frames can be derived from these LULC maps.

Funding. To turn out the state of farming practices data from scarcity to abundance, adequate grants and funding are imperative to enable such surveys. As the ability of fragile countries to invest in data capturing is unlikely, international funding plays a key role here. This vantage point is corroborated by the fact that developing trans-disciplinary research and practice in the global South needs to be supported by national and international funding agencies (Serrao-Neumann et al., 2021). Limited budgetary is likely to restrain achieving the targeted sample size of the survey (Bryan et al., 2013).

Coordination. To facilitate the personal interview procedures when conducting any surveys in rural areas, agricultural supervisors, chiefs of farmers or villages, educated people of those areas and village elders should be contacted for assistance. Such a coordination can help overcome the constraint of using a local dialect if enumerators, who could speak the local language, are selected to carry out the survey (Bryan et al., 2013). Coordination also facilitates reaching out to remote interviewees and enlarging the sample size.

Well timing. Choosing the right time (e.g. season of the year) to conduct the survey is a fundamental step to ensuring quicker achievement of the survey goals. Well timing also means selection of best location to conduct interviews as discussed below.

Suitable venue. Sampling of the farmers, sound representation of them and selection of best location of interviews are challenges facing large-scale irrigation schemes in particular. Therefore, a reasonable compromise between the three challenges should be devised. Here, well timing of the survey is also relevant since the survey is guided by availability of respondents and access to location. Any opportunity of farmers gathering is a benefit to meet as large number of the farmers as possible. In our case, gatherings in social events, inspection office, market or village were perfectly leveraged.

Trust building. In order to ensure successful campaigns and to obtain reliable information, the interviewer must carefully address trust building with the farmers. Selecting members of the survey team who are familiar with the local customs is particularly useful (Bryan et al.,

2013). Engaging local researchers and community members as co-researchers helps establish rapport, enhance cooperation and increase data reliability (Khan Mohmand et al., 2017; Hoogeveen and Pape, 2020). Neighborly relationships are also a factor in reaching respondents in the process of social data collection (Pierce and Scherra, 2004).

Inauguration meeting. It is useful to hold an introductory session with farmers prior to conducting the interviews to inform them of the positive outcomes of the research or interviews. In case of on-farm interview, the farmer may expect a kind of technical support. If the interviewer is only a research entity, this session is the right time to provide a convincing explanation that the purpose of the survey has nothing to do with production inputs or crop marketing.

Flexibly tooled survey. To reduce effort, time and cost, the survey should use readily available tools. We recommend integrating different approaches subsequent to judging the upsides and downside of each approach based on a small-scale field trial. In our experience, employing paper-based approach, app-based approach or a mixture of them did the job, depending on each particular situation. Reaching farmers in their villages takes long time and becomes costly due to multiplicity of villages and ruggedness and, occasionally, similarity of the roads. An innovative solution for this challenge is possible through mobile phone interviews if telephone number database is available (Driscoll and Lidow, 2014; Kirui et al., 2024). The advantage here is that data can be collected rapidly, at no risk and at low-cost. However, the implementation of this research method is not without challenges. Such a method may not ensure well geospatial coverage or collection of farm coordinates. Obtaining the exact location (coordinates) of the farm is only guaranteed by app/GPS instead of using the approximate map-based approach. Moreover, studies in Africa, including Sudan, reported a number of challenges: disruption of sampling in mobile phone surveys as a result of population mobility or high displacement rates among rural populations or from conflict zones; high rates of non-response; difficulty in reaching respondents in remote areas, leading to unplanned prolonged data collection period and to increasing the call frequencies; dropouts over time; suspension of telecommunication and transport services; need for incentivizing respondents with a gratuity of additional mobile telephone airtime (Hoogeveen and Pape, 2020; Abay et al., 2023; Kirui et al., 2024).

Dealing with insecurity. In insecure regions, limited access to some neighborhoods constrains survey implementation (Driscoll and Lidow, 2014). It is extremely difficult if not impossible to deploy enumerators to the field to collect information from farmers through face-to-face interview. Researchers should prepare for security issues through consulting local authorities and institutions as implemented in the present survey. This way, access permissions to and recommendations of secure locations and paths can be obtained. The survey should otherwise be postponed until insecurity issues are resolved as, for example, the cases faced in Western Kurdoan. Alternatively, interviews via telephone calls can be arranged, especially if farm coordinates are not sought.

Tolerance. In spite of full coordination with all relevant authorities ahead of time, social circumstances, customs and traditions may end in cancellation or postponement. Exercising a kind of respect, acceptance and tolerance to these social and cultural values is important. If tackled prudently, cultural matters can contrarily ease efficient conduction of the survey, thus yielding good results. Assistants used to carry out the interviews should undergo training on how to deal with cultural challenges (Assefa and Gebrehiwot, 2023), especially if the data collectors are outsiders.

Woman representation. Women farmers are important players in the decision-making process that affects the economic farming activities in fragile countries. Therefore, they should make their voice heard in such surveys. The reported experience evidenced the need for ensuring the building, stability, progress and development of the woman community to play a central role and leadership in the farming systems. The difficulty of reaching a woman farmer due to the prevailing customs and

traditions “should not be taken to mean that investment in raising female labor productivity in agriculture cannot be a high return activity” (Palacios-Lopez et al., 2017). ICT-mediated communication in this case may help tap into this important perspective and source of information.

Validation. There are ways to somewhat validate the answers of the questionnaires. Those collected with acquaintances around are more truthful compared to those without. The questionnaire was designed such that some answers can be verified by counterfactual answers to other questions. Additionally, checking existence of discrepancies in answers between respondents in similar context can offer cross-validation from the collected dataset itself. For example, in the Gezira Scheme, the sampling strategy resulted in each block being represented by ~5 samples, thus ensuring a way of validation. Truthing or falsification of the data was also ensured during the quality control of the submitted data. Verification was attained by scrutinizing the answers with the data collectors and occasional recommunication with farmers. This process triaged only 84 cases of the whole sample, and the data were amended. Unlike large-scale irrigation schemes, rainfed systems are not governed by one management, and farms are dispersed. Variations in answers between respondents are expected, and are more related to decisions made by the farmer and household characteristics, etc. One can validate certain aspects if the same crop is grown by different farmers. Generally, cross-checking with responses to the same questions across years and regions can mitigate the inaccuracy of the datasets (Raja et al., 2017).

Replication and establishing community dialogue. Although we did not invoke a continuous stakeholder dialogue yet through ICT-based questionnaire using smartphones, employing this feature offers the opportunity to provide context specific feedback and information. Ways of doing so include: 1) community engagement, i.e. through involvement of local scholars and practitioners and disseminating findings through reports, policy briefs, and public lectures (Reichman et al., 2001) and 2) iterative learning that allows researchers to adapt their methodologies based on feedback and lessons learned to improve data quality and response rates (Pierce and Scherra, 2004). Augmenting the app this way strengthens the notion of benefit to the interviewee.

CRediT authorship contribution statement

Nadir Ahmed Elagib: Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization. **Bashir M. Ahmed:** Writing – review & editing, Methodology, Investigation. **Hussein M. Sulieman:** Writing – review & editing, Methodology, Investigation. **Abbas E. Rahma:** Writing – review & editing, Methodology, Investigation. **Marwan M.A. Ali:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation. **Karl Schneider:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jrurstud.2025.103638>.

Data availability

Data originating from public archives are as follows: Fig. 1: The aridity zones were demarcated based on the aridity index of the United Nations Environment Programme (UNEP, 1997) defined as the ratio of annual rainfall to annual reference evapotranspiration using data from TerraClimate (Abatzoglou et al., 2018) and downloaded from: <https://www.climatologylab.org/terraclimate.html>; ACLED data were downloaded from <https://acleddata.com/data-export-tool/>. Fig. 4: The land use (cropland) data were obtained from Water Productivity Open-access portal (WaPOR) (FAO, 2020) and downloaded from (https://wapor.apps.fao.org/home/WAPOR_2/1). Sentinel-2 data are available from: <https://developers.google.com/earth-engine/datasets/catalog/sentinel-2>.

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