Building resilience through improving groundwater management for sustainable agricultural intensification in African Sahel

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Building resilience through improving groundwater management for sustainable agricultural intensification in African Sahel

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Abstract

Background: This paper examines the role of improved groundwater access and management in providing opportunities for sustainable agricultural intensification and building the resilience of community farmers in Southern Burkina Faso. The findings contribute to current debates about pathways of commercialisation and adaptation in the African Sahel, especially those seeking to find responses to managing the impacts of climate change and delivering on the Sustainable Development Goals.

Methods: This paper presents data that has been thematically analysed based on the Framework for Sustainable Intensification developed by Pretty and Bharucha (Ann Bot 114:1571–1596, 2014). The data used includes 144 Vulnerability Baseline Assessments which were conducted at the start of the project with the four target Burkinabe communities (Kado, Poa, Tomo, and Zhilivele), and 33 monitoring interviews and vulnerability assessments from the Burkinabe communities of Poa and Tomo to track progress and behaviour change resulting from the BRAVE project interventions.

Results: The data analysis showed that Burkinabe communities are already making some use of groundwater to support their agricultural livelihoods; most do this through accessing groundwater from shallow wells. It was also shown that there were improvements in the four main themes Identified by the Sustainable Intensification Framework. These included improved information sharing through increased peer-to-peer learning and improvements in confidence levels; improved social cohesion through reduction in community conflict over water resource management; asset improvements shown by tangible improvement of yields; and increased awareness exemplified by behaviour change.

Conclusions: Through using the Sustainable Intensification framework, this paper argues that such an approach improves essential aspects of resilience building such as information sharing, improved local governance and increased social capital and income. We argue that such changes provide essential pathways to reducing vulnerability and increasing resilience of at-risk communities in the Sahel, but that national policy alignment and investment is essential for long term change and sustainability.

Keywords: Sustainable intensification, Groundwater, Resilience, African Sahel, Groundwater, Burkina Faso, Sustainable agriculture

Background

Managing water scarcity in semi-arid regions such as African Sahel, remains a critical challenge (Jiménez Cisneros et al. 2014; Sanga et al. 2021; IPCC 2020; Boyd et al. 2013). Climate change is predicted to lead to increased variability in precipitation, with a greater frequency of

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extreme events such as droughts and floods (Bichet and Diedhiou 2018; Epule et al. 2018). This increased variability in rainfall is likely to cause greater irregularity in river flow and more unreliable surface water supplies (Jiménez Cisneros et al. 2014; Sanga et al. 2021). This reduced availability of water resources poses risks to livelihoods, food production (Stuch et al. 2021), sanitation, health, and freshwater ecosystems (IPCC 2020). Climate and hydrological models suggest that 15% of the global population will experience severe reductions in water resources with a 2 °C rise in global mean temperature compared to the 1990s, rising to 17% at 3 °C (Schewe et al. 2014).

One potential solution to the anticipated decline in reliability of surface water resources is to better utilise groundwater (Taylor et al. 2013; MacDonald et al. 2021; Foster et al. 2020; Wu et al. 2018; Bianchi et al. 2020). Groundwater resources are buffered from climatic variability and therefore have the potential to support the resilience of domestic, agricultural, and industrial water supplies. This is particularly the case in dry regions, such as the Sahel, where the deep-water table means the water supply is slow to respond to surface fluctuations in precipitation (Cuthbert et al. 2019a), although the local hydrology influences the recharge rates (Cuthbert et al. 2019b). This study focuses on the low-storage aquifers in Burkina Faso which, until recently, had limited understanding of recharging processes and the potential of these to support people's livelihoods.

In the long term however, whilst climate variability and land use affect groundwater supply, societal change affects demand (Ascott et al. 2020). A society dependent on groundwater is highly vulnerable to mismatches between supply and demand, especially for low storage aquifers. Careful water governance, including early warning of shortages is crucial to maintaining a stable supply, with recharge rates higher than abstraction rates. In the Volta River Basin of Ghana and Burkina Faso, recharge is estimated between 5 and 50 mm per year, but with local recharge estimated ranging up to 250 mm/year (UPGro 2020). Abstraction in the Volta Basin is estimated to be < 5% of the recharge rate (UPGro 2020; Martin and Giesen 2005) indicating that there is significant potential to expand groundwater use sustainably in this region, with careful monitoring and management (Taylor et al. 2013; Al-gamal 2020). By providing a reliable source of freshwater for domestic and agricultural use, groundwater resources could be key to enabling communities to enhance their resilience to climate variability and environmental change. In some areas, the available groundwater resources have the potential to go beyond meeting subsistence demand for water; improved groundwater management and planning can increase irrigation of agricultural lands and livestock supporting production throughout the dry season as well. Such uptake of sustainable agricultural intensification (SI) practices can build the resilience of community farmers to the recurring environmental crises they experience.

Gowing et al. (2016) suggest that most community farmers rely on accessing shallow groundwater due to power and technology limitations. Groundwater in the Sahel has historically been used as a local domestic water resource for community farmers rather than a strategic water resource that can support increased productive development for crop irrigation (ibid). In the Sahel, there have been concerns that using groundwater for irrigation could have negative impacts on domestic water supplies and groundwater-dependant ecosystems (MacDonald et al. 2009). Moreover, whilst groundwater yields could support small-scale garden irrigation, they may not be adequate to support large-scale agricultural use (Hydrogeological and Africa 1995; Macdonald et al. 2012). More recently, this view appears to be shifting with groundwater irrigation being increasingly promoted (Abric et al. 2011; Al-gamal 2021) as an important avenue to overcome poverty and improve food security by governments, donors and NGOs (Abric et al. 2011; Ngigi 2009). However, to realise this the outstanding social issues relating to groundwater use and management (Al-gamal 2020) need to be addressed, as much as the technical support required from external experts (Dessalegn and Merrey 2015). One option may be to enhance user participation in local resource management and support equitable platforms and communication channels to allow local users to navigate the social dynamics of community access and use.

In 2014, the BRAVE (Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa) project (https://upgro.org/consortium/brave2/) was established to build better ways to model and communicate the complex environmental changes in the Sahel region of West Africa and use that to provide early warnings of groundwater shortages so that the most vulnerable families and communities are more resilient to drought be being able to proactively engage in drought coping strategies such as water harvesting, crop planning, livestock management, and other water saving practices (Sharma and Smakhtin 2016). BRAVE not only improved understanding of how water moved through catchments representative of the Volta River Basin, but with output from land surface and groundwater models, used new scientific knowledge to support planning from basin-scale to seasonal community management of groundwater supplies and emergency planning.

In this paper, social science analyses from the BRAVE project are used to examine the role of improved groundwater management in providing new opportunities for sustainable agricultural intensification and enhancing livelihood outcomes for community farmers in Southern Burkina Faso. Structured around the key principles of sustainable agricultural which include integrated management, dynamic balance, regenerative design, and social development (FAO 2021), this study highlights the importance of four key aspects underpinning these principles which include: (a) information sharing (b) social cohesion (c) asset improvement and (d) increased awareness.

Groundwater, sustainable intensification (SI) and resilience.

Water is integral to all aspects of social and economic development—energy, food production, health, and the environment. Historically, a strong link has been demonstrated between water resources development and economic development that impacts upon social and environmental outcomes (Brown and Lall 2006). Secure access by rural poor people to both land and water is therefore central to the achievement of the Sustainable Development Goals (United Nations 2021) in particular the target of reducing by half the proportion of people living in extreme poverty and hunger by 2015. Over two-thirds of poor people in Africa depend on farming for their livelihoods (Pretty et al. 2011), and developing resilient agricultural water supplies is thus key to reducing poverty and maintaining food production to keep up with the growing population (IAASTD 2009; World Bank 2008; Godfray et al. 1979). This ultimately means that agriculture will need to be intensified (Pretty et al. 2011; Haggar et al. 2020), and therefore it is predicted that water abstraction demand will increase (Cobbing 2020).

The concept of SI (or sustainable intensification) has the potential to be seen as philosophical, somewhat ideological panacea and concept (Pretty 2007). However, the literature suggests that when considering the dynamic nature of the concept of sustainability itself, and the ever-changing environment we operate in, it is essential for sustainable agricultural practices to not be seen a one set of prescribed technologies (Thompson 1992), but rather as a process of innovation and adaptation itself, and that such adaptations are context specific (Pretty 1995). Of course, such a point of view is also underpinned by the 'context-specific' ideology which presents challenges for the global change required (Hansen 1996), however it is acknowledged that this more holistic, contextually responsive approach can be seen as a useful alternative guide for farmers to move towards change (Hansen 1996; Thompson 2007). This concept can also be related to contemporary concerns and presents the possibility of using sustainability as a criterion which can guide agricultural production to respond to the rapid changes it is presented with whilst also keeping long term durability and resilience at the forefront (Hansen 1996; Bockstaller et al. 2008). This connection between SI and resilience is a core aspect for this paper as it directly links sustainability with climate resilience, a key concept which can be defined as 'the ability to anticipate, prepare for, and respond to hazardous events, trends or disturbances related to climate' (C2ES 2022).

Because of the broad range of conceptualizations of sustainable agriculture or sustainable intensification, there are a plethora of frameworks which have been used to 'measure' such intervention, many of which are evaluations of sustainability and measurements (Hayati 2017; Hayati et al. 2010). There however, also attempts to look at the situation as a whole and outline a set of standardized reference points (Passel and Meul 2012), and then move to contextually relevant forms of measurement (Zhen and Routray 2003; Meul et al. 2008). If we examine frameworks which highlight such reference points, it is also clear that even these vary between authors. However, a recent literature review (Trigo et al. 2021) presents four universal principles which include integrated management; dynamic balance; regenerative design; and social development.

Given that this study has is positioned in the lens of resilience in the face of climate change, it was deemed important to identify a holistic framework which could be used to structure and systematize an analysis of the different attributes and outcomes of sustainable intensification in a contextually relevant way which capture elements of SI found in all four universal principles stated above.

Perhaps unsurprisingly given the conceptual debates found on SI, the literature assessing SI is vast, with a variety of assessment frameworks ranging from ones which focus solely on ecological systems (McCown 2001; Simmonds 1985; Bawden 1995) through to recent, more holistic systems-based frameworks such as the Social-Ecological Systems (SESs) framework (Mahon et al. 2018). Whilst such frameworks are undoubtedly useful for framing analyses, this paper has made use of the SI framework presented by Pretty and Bharucha (2014). This framework was chosen because it can be used as a lens to identify key attributes of SI including the universal principles outlined previously, as well as being able to connect the key attributes to the anticipated outcomes. This practical way of assessing the progress towards SI provides a clear basis and platform for a structured analysis and discussion, alongside situating these in the contemporary debates noted above.

Pretty and Bharucha (2014) suggests that SI can be measured by a series of attributes (Fig. 1) including the use of more productive crop and livestock varieties,

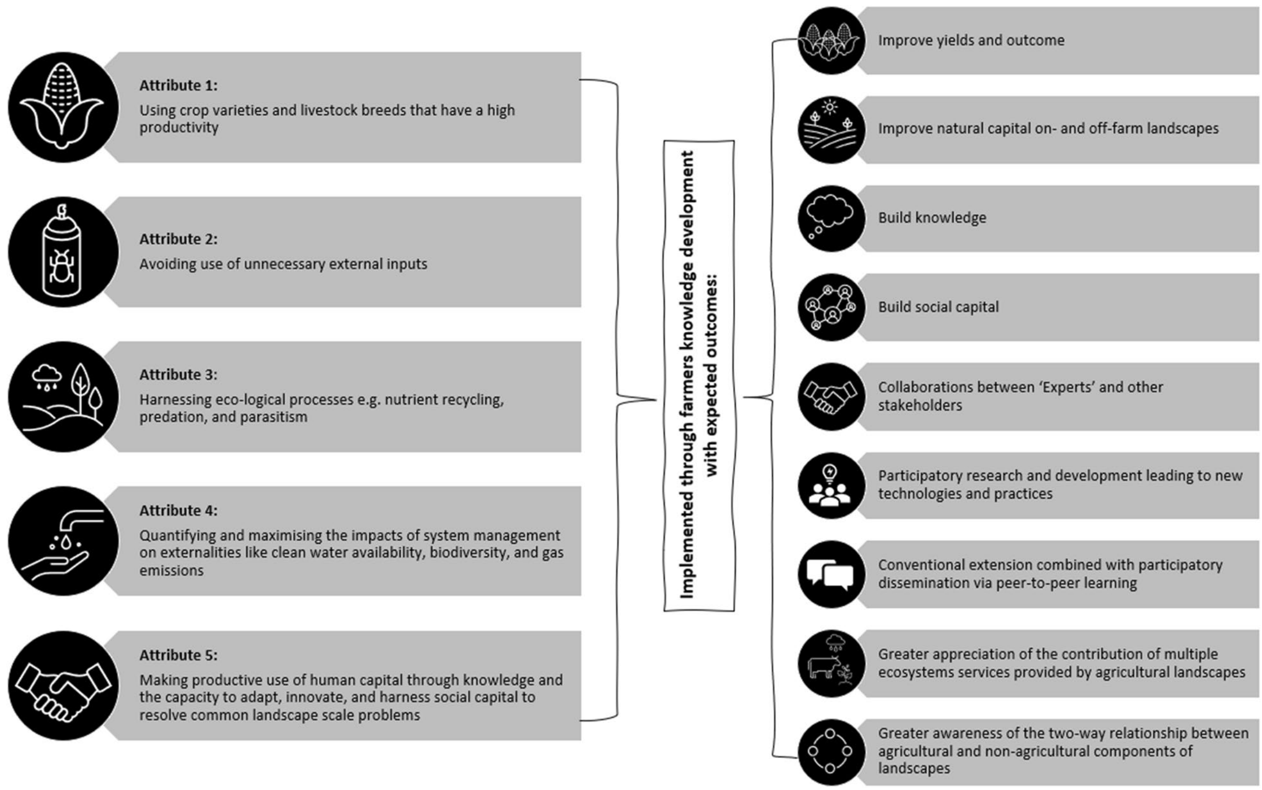

Fig. 1 Attributes and outcomes of Sustainable Intensification (based on Pretty and Bharucha 2014)

avoiding unnecessary external inputs by making use of natural ecological processes, effect natural resource system management, and making use of human capital by increasing adaptation, innovation, and social capital (Pretty 2007). SI places an explicit emphasis on a set of drivers, priorities, and goals which go beyond solely increasing production (Pretty and Bharucha 2014). These are based around farmers' knowledge development and include a range of outcomes identified in Fig. 1 (ibid). The outcomes are used to structure and evaluate the data presented by this paper.

To enable these attributes to develop, there is also the need for supportive policy to enable free-flowing information that can increase adaptation between agencies and individuals to be accessible and trusted (Pretty et al. 2011).

Macdonald et al. (2012) and Bianchi et al. (2020) suggest that groundwater could provide the opportunity for more smallholder intensive irrigation and improved drinking water. However, they do also indicate that there is a clear link between wealth and use of water because more wealthy groups use more water for all purposes across all livelihood zones because of multiple factors such as wealthy groups having better access to labour, water storage and transport assets (MacDonald et al. 2011). Such differences are especially pronounced in the dry season (ibid). Linked to this, poor households are less likely to be able to meet minimum water needs for livelihood activities especially during the dry season. This is compounded by needing to travel further to reach water sources, with less time available for other vital livelihood activities. In answer to this, it is suggested that boreholes offer the most consistently high-quality water (MacDonald et al. 2011; Lapworth et al. 2015), and, unlike surface water points, the collection time for groundwater points do not change throughout the seasons (MacDonald et al. 2011). This clearly indicates that groundwater investment and usage should be central to adaptation strategies, but also illustrates the challenges different wealth groups face relating to access and use of groundwater resources. This lack of access is further undermined by low levels of political support and limited information on food production technologies and strategies (ibid).

Such combinations of complex factors that exacerbate people's vulnerability, is often interpreted as an indication that semi-arid areas such as African Sahel, have limited potential for SI. However, it remains vital to challenge the levels of vulnerability found in these areas (Robinson et al. 2015), and it has been found that activities such as water harvesting can support sustainable intensification

(Taddele et al. 2013) and that SI has the potential to reduce vulnerability of some households by improving production and associated food security, (Ritzema et al. 2017) although this is dependant shift is not necessarily feasible for the most poor households (Ritzema et al. 2017; Sietz et al. 2017).

Overview of community farming in Burkina Faso

Generally, this region has limited water resources due to its dependency on a single rainy season (the West African Monsoon; May–October) and the localised nature of groundwater resources in areas underlain by weathered and fractured hard rock (weathered basement aquifers). In south-eastern Burkina Faso, the groundwater table reduces on average 0.6 mm per day in the cropping season thus the water withdrawal (76 l per capita per day, l.c.d) largely exceeds the provision of 20 l/c/d. Given this, it is predicted that demand will overtake supply by 2030 (Sandwidi 2007). It must also be recognised that community groundwater abstraction is highly variable in Burkina Faso with groundwater resources having different recharge rates correlated with anthropogenic influences, hydrological properties and structure controls (Ascott et al. 2020). Groundwater is also generally not considered in the national water management policy strategies (Basson et al. 2020). Given this, there is a vital need to ensure that sustainable water management strategies are recognised as a vital consideration for future policies, but also that any agricultural intensification processes within such policies and future development are actively considering sustainable intensification approaches.

Annual rainfall in Burkina Faso ranges from 600 to 1200 mm from north to south and has high levels of spatial and temporal variability (The World Bank 2021). Evaporation generally exceeds rainfall during the rainy season when the basin is recharged (Sandwidi 2007; Ouédraogo 2004). In addition to this, it is also noted that annual rainfall across the Sahel has generally not translated into improved rainfall for agricultural production (Porkka et al. 2021) and an increase of higher intensity rainfall events (Kowal and Kassam 1978). The increase in higher rainfall events is consistent with the projections from the Coupled Model Intercomparison Project (CMIP5) models (Dunning et al. 2018). By the end of the century, the majority of these CMIP5 models agree that most of West Africa–and Burkina Faso specifically—will have a wetter climate with the increased rainfall resulting in an increase in surface runoff. However, although the average daily rainfall is projected to increase, and the number of rainy days to decline, the distribution of the rainfall is key to the groundwater recharge. Monitoring in the BRAVE study catchments of the weathered basement aquifers, has shown the key requirement for substantial recharge is not just a single high intensity rainfall event, but a series of high frequency intense rainfall events (Ascott et al. 2020).

Several measures can and are being taken by the farmers to overcome the vulnerability risk posed by groundwater variability. Interventions relevant to this paper include the improvement of the efficiency of irrigation, encouragement of the use of groundwater, and the promotion of better community water management to limit resource overuse (Sandwidi 2007; Eguavoen 2013; Whaley and Cleaver 2017).

In Burkina Faso, 86% of the workforce are reliant on agriculture (Callo-Concha et al. 2012). Many of the households are led by senior men who represent community meetings. The household heads oversee assigning land use and decision making. This means that many decisions are gender biased with men making most agricultural decisions (Callo-Concha et al. 2012). Men are responsible for larger, income generating livestock e.g., cattle and sheep, crop growing, rearing livestock, and cultivating cereals (González et al. 2011). Men also participate in seasonal paid work, so often migrate (González et al. 2011). Women, on the other hand, whilst they do play roles in the everyday management of larger livestock, cereal management, and cultivation, are mainly responsible for small poultry livestock, and vegetable horticulture (González et al. 2011). Women also manage other 'off the farm' livelihood activities, such as sales of food and drinks, and the processing and sale of forest products such as shea, honey, and baobab leaves. Women are also responsible for collecting water and gathering wood, as well as caring for the family and home (González et al. 2011).

In West Africa, small scale community farming follows a 'concentric ring' pattern in which three different types of land are used for agricultural production (Fig. 2). The compound land is used for permanent cultivation and is the most intensive farming land (Prudencio 1993). The community land is used for shifting cultivation and intercropping, and the bushland areas are primarily used for livestock rearing and grazing (Ouédraogo 2004).

Methods

This paper uses data collected through the social science components of the BRAVE project. To explain the methodological approach, it is important to identify the overarching research approach taken by the project, as this conceptual framework shaped the data collection procedures. This has been summarised in Fig. 2.

The localised nature of groundwater resources in areas underlain by weathered and fractured hard rock such as in the areas studied by BRAVE, is a key factor in its management. In these environments, community-based

Fig. 2 Concentric farming in Tomo, Burkina Faso. Photo credit; BRAVE project team; BRAVE 2016

management is more appropriate than top-down approach in these environments. In alignment with this, the BRAVE social scientific conceptual approach focused on information sharing processes which would support the establishment and local ownership of vertical communication channels. Such channels are vital to support the information flows necessary for improving the attributes identified in the Sustainable Intensification framework. The framework was built on the understanding that successful information sharing, and increased information and communication technology (ICT) use can reduce poverty (Ali and Watt 2017; Wu et al. 2018; Ruhyana and Essa 2020). Figure 2 shows what attributes of SI this approach supports.

Figure 2 shows that the BRAVE social science fieldwork was largely based on sharing information generated through the physical science aspects of the projects.

The manner in how this process was administrated is where it first connects the SI framework.

By using an approach that shared information with multiple stakeholders essential to groundwater use and management, this approach also supported the development of a system change that improved knowledge to resolve large scale problems at a policy level, build human capacity through knowledge sharing at the science interpreters' level, and build knowledge sharing mechanisms that also improved social cohesion at the community level through participatory farmers voice radio. The content of the radio programmes was carefully aligned and generated by farmers identified previously in the baseline vulnerability assessments. The radio programmes suggested strategies to farmers that could support SI through providing information about hydrological processes, natural inputs, clean water, alternative varieties, and intensification processes. Through this dialogue process, the increased production was hoped to not only improve sustainable resource management that is supported by policy and therefore potentially bolstering long-term resilience (Adger et al. 2011; Boyd and Cornforth 2013) but also that through increased production, communities would have more capacity to adapt and cope in the face of climate change (see Fig. 3).

This approach was implemented with 4 communities in central Burkina Faso (Fig. 4), guided by local partners Christian Aid and Reseau Marp. The selected communities were chosen because although initial modelling showed significant groundwater potential, the communities low productivity, characterised these communities located within the transboundary catchment of the White Volta Basin.

Initially there were a larger number of study communities, but these were scaled back due to conflict and security issues.

Whilst the groundwater modelling and policy engagement activities are ongoing (Cornforth et al. 2019; Myers and Cornforth 2020), this paper will focus on the community-level activities conducted through local NGO partners to explore behaviour change around groundwater access and use, and livelihood effects. By working alongside a local NGO, Reseau Marp, already undertaking work connecting community farmers to information sources to improve household income, the BRAVE

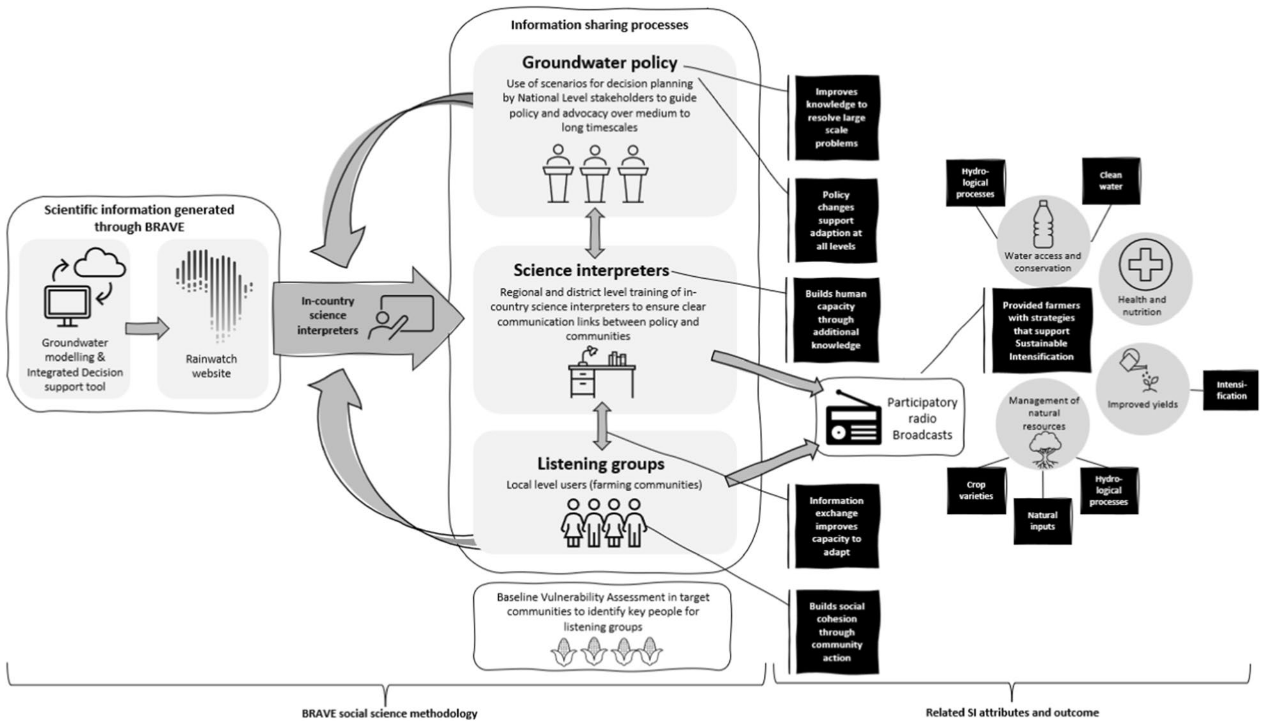

Fig. 3 BRAVE Social Science and associated Sustainable Intensification attributes and outcomes (Adapted from Pretty and Bharucha 2014) methodology (Adapted from https://upgro.org/consortium/brave2/)

project helped to build the communities' capacity to understand, monitor and better manage their existing groundwater resources.

Within the target communities, the role of groundwater in livelihoods and the potential of the resource as an adaptive strategy was explored. At the start of the project in 2015, 144 Vulnerability Baseline Assessments were conducted within the target communities (see Fig. 6 for details). Following this, a series of community level training sessions on monitoring rainfall and well water point levels were delivered to provide data for the hydrological modelling component in BRAVE. Using rain gauges, 77 Burkinabe community members (44 men and 33 women) participated in the training and data collection processes. This training consisted of well management training carried out by the BRAVE project team who provided community members with practical methods to measure well water levels, quality, and strategies to conserve water and make it safer for human and livestock to consume.

Alongside this, and what this paper focuses on, the same communities participated in implementing the Farmer Voice Radio (FVR). Based on the understanding that the Radio is one of the most affordable, accessible, and sustainable ICTs (Komodromos 2020; Richa and Kirti 2016), FVR is a participatory process to create and broadcast radio programmes through local radio stations. The content of these broadcasts is identified, defined, and recorded by the community through Listening Groups; a group of community members selected on their community engagement, role, and gender to ensure a wide range of community representation. Importantly, the radio programmes include discussions and input from local experts such as agricultural extension officers. This aspect of the FVR connects directly with the SI approach aspect and BRAVE project design of improving information exchange channels and supporting community action (see Fig. 2). The radio programmes are broadcasted in time with the local crop calendar to ensure timeliness and relevant. The FVR approach is summarised in Fig. 5.

Based on the initial vulnerability data collection and working alongside the well management training, the Lorna Young Foundation (LYF) established listening groups in 2017 within the Burkinabe communities to develop the FVR Programmes. Through this participatory model of communication, 48 programmes were recorded and broadcast on the local radio La Voix du Sanguié, covering an area with a population of 20,390 (9616 males, 10,774 females) at least 32 times in local language with the support of the agricultural technical. The thematic areas were defined by the target communities, and included improved yields, access and conservation of

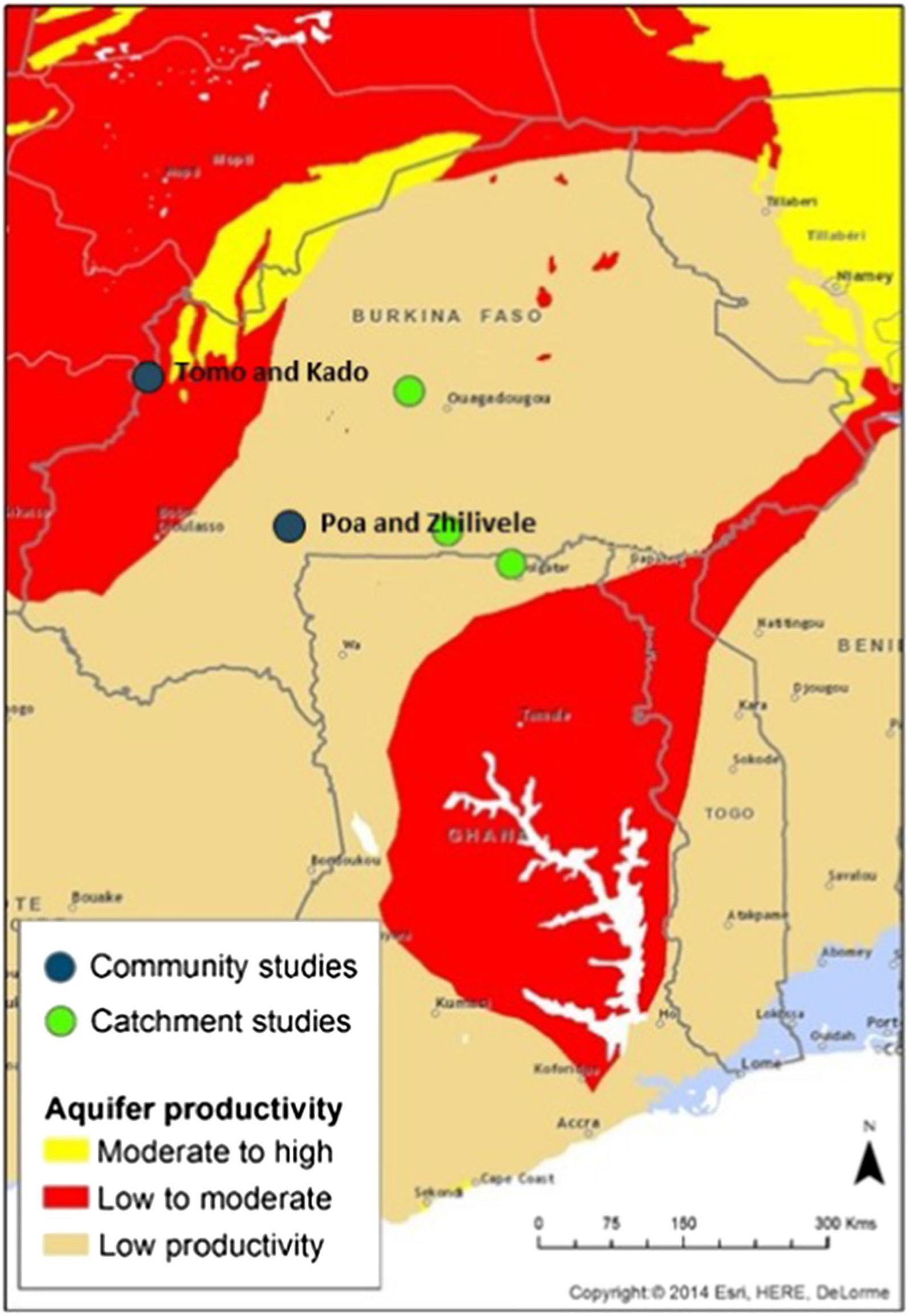

Fig. 4 Map of community studies conducted in Burkina Faso in relation to aquifer productivity (Taken from Esri. HERE, DeLome, 2014)

water, nutrition and health, and management of natural resources. As identified in Fig. 2, the radio content generated through these programmes straddles multiple areas of the SI approach including use of crop varieties and natural input, harnessing hydrological models, and maintaining clean water sources, and intensifying production.

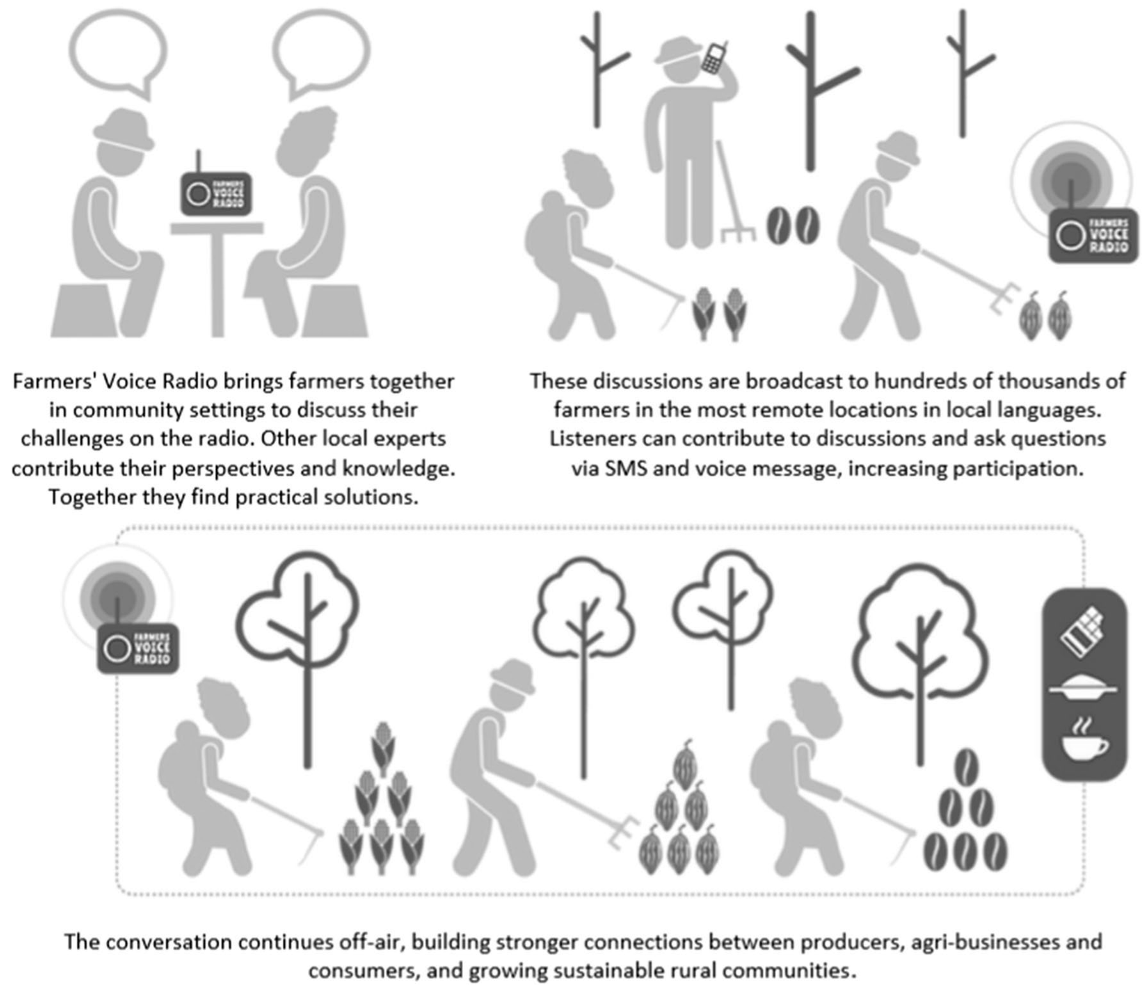

Fig. 5 Farmer Voice Radio process summary (Source: https://www.farmersvoiceradio.org/)

Following the implementation of these community activities, two sets of monitoring data were collected in January 2020 to identify behaviour and livelihood change. This data consisted of interviews with 33 community listening group members of two of the target communities in Burkina Faso—Poa and Tomo. The interview questions aimed to understand how and why community members had altered their crop and livestock production processes, with particular focus on groundwater and well management strategies. Most of the participants also undertook a second vulnerability assessment (very similar to the initial one) to allow thematic comparative analysis. The vulnerability analysis process is summarised in Fig. 6.

This paper presents the data analysis of the Vulnerability Monitoring Assessment which included a follow up vulnerability assessment to track progress made against the initial vulnerability indicators determines through the Baseline Vulnerability Assessment, and complimentary interviews to understand the reasons for the changes in the metric indicators. It also presents relevant aspects of the Vulnerability Baseline Assessment data to enable contextual outlining and progress analysis. This data has been used to evaluate the potential that improved groundwater use could have on sustainable intensification for these communities.

Results

The results section comprises of two parts. The first makes use of relevant aspects of the Vulnerability Baseline Assessments [a total of 144 vulnerability assessment (36 per community)] to identify primary agricultural activities, and primary sources and use of water within these activities. This aspect of the results supports the following section which presents changes in behaviour and practice that align with SI outcomes (identified in Fig. 1). This section is organised and presented around four themes that have grouped similar outcomes identified by

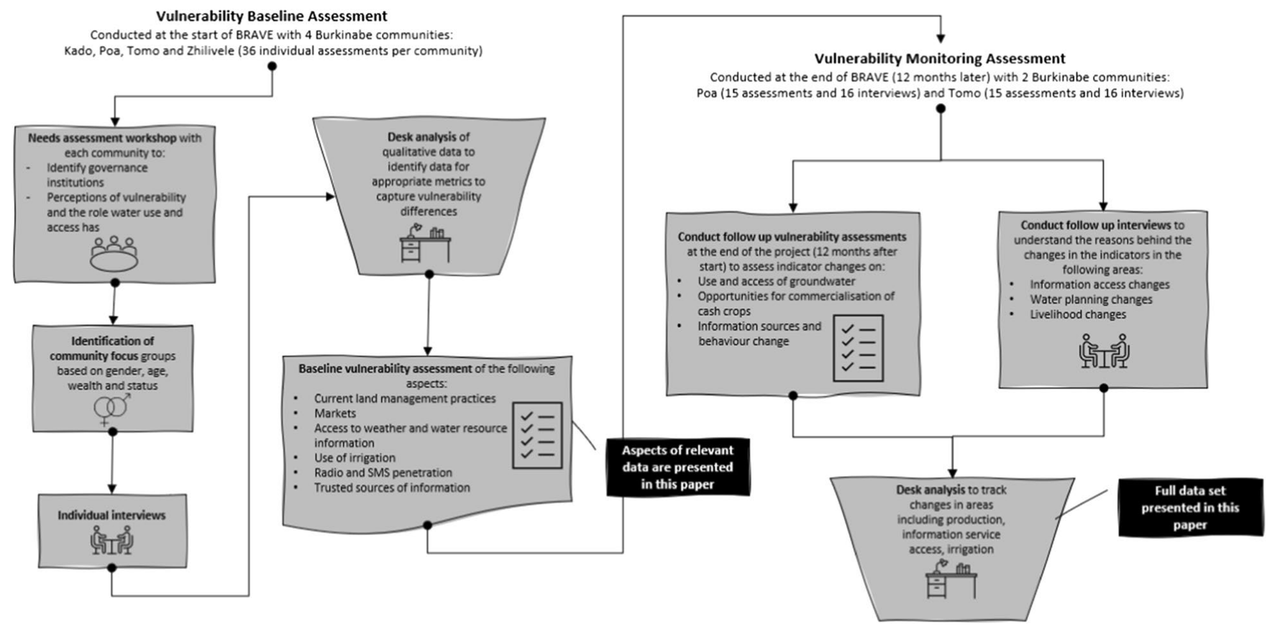

Fig. 6 BRAVE vulnerability data collection processes and data quantity summary

Pretty and Bharucha (2014) together. The themes include information sharing, social cohesion, asset improvement, and increased awareness, and the outcomes underneath each theme are identified in Fig. 7.

The data presented is based on 15 Vulnerability Monitoring Assessments and 16 follow up interviews with community members in Poa and 15 Vulnerability Monitoring Assessments and 16 follow up interviews with community members in Tomo; a total of 30 Vulnerability Monitoring Assessments and 32 follow up interviews.

Primary agricultural activities and water sources and use

The primary agricultural activities of the Burkinabe communities we worked with in BRAVE, included farming subsistence crops that were drought resistant such as sorghum and millet, intercropped with groundnuts (Net 2017). This farming practice supported households' nutritional needs of carbohydrates and protein (Callo-Concha et al. 2012). Alongside this, cash crops, such as tomatoes which required more water, were grown, and largely by women (Callo-Concha et al. 2012). This range of consumable crops is often more profitable than traditional crops (Callo-Concha et al. 2012) such as cotton and sesame (Fig. 8), which are also grown in Burkinabe communities.

These patterns were supported by the baseline vulnerability data (Fig. 9). Surplus vegetables are also often sold for cash. The cash income generated by these crops are important for other wellbeing services such as health care and school fees.

The presence of crop diversity here, some of which relies on irrigation, shows that supporting the sustainable intensification of these crops through improved water management strategies will not only have improve nutritional welfare, but will also improve income from the sale of surplus vegetables and cash crops. Although not shown in Fig. 9, livestock are also an important part of a suite of livelihood coping strategies of rural households in Burkina. However, whether people have livestock or not, varies considerably across and within communities (Callo-Concha et al. 2012).

Current use of groundwater

To identify the potential role that groundwater could play in SI, we evaluated the current role that groundwater played in agricultural and livestock production for Burkinabe communities.

Analysis of the baseline vulnerability data (a total of 144 vulnerability assessments) showed that the most frequently used water source for household drinking and domestic use is from unprotected dug wells with 90% of the community members identifying with this water source (Table 1), and that between 85 and 100% of farmers use irrigation in their agricultural practices (Fig. 10).

Unsurprisingly, most of the Burkinabe community members (92% respondents) irrigate their crops using groundwater from shallow hand-dug wells. Only 6% of respondents report using deeper groundwater wells for irrigation, and only 2% reported using other sources. This is illustrated in Fig. 11. Those with deeper wells

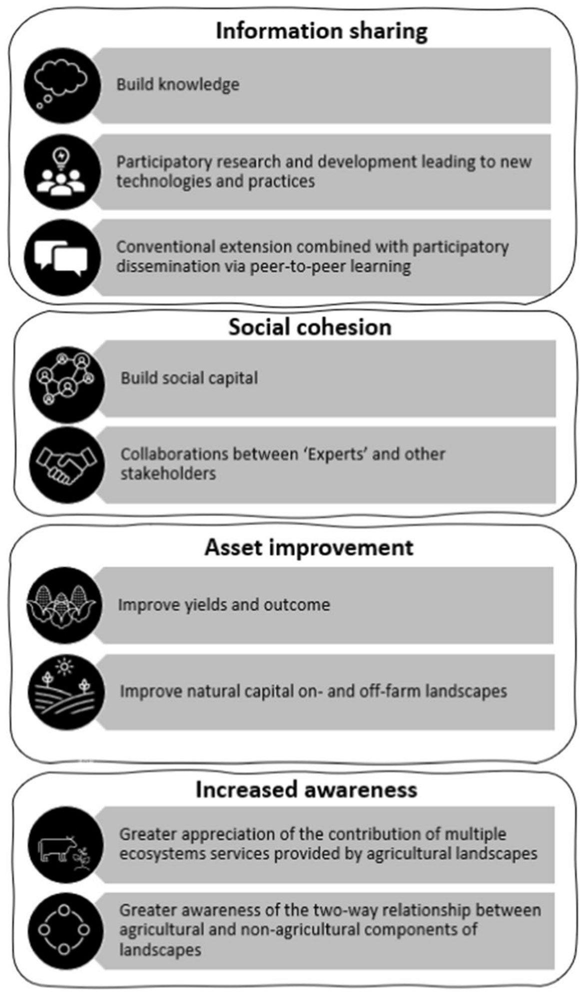

Fig. 7 Themes and relevant outcomes to assess the contribution towards Sustainable Intensification

indicated that they received technical help in establishing such wells, and that these are primarily used for watering livestock.

The widespread use of shallow wells is likely due to infrastructure limitations. Shallow wells pose higher risks of failing during the dry season than deep wells, leaving the people who rely on this water source more vulnerable to water shortages. Despite this risk of failure, people are still having to construct and use these wells because of the cost of investing into groundwater aids such as digging deeper wells and building of handpumps, and, during the dry season, there are very alternative surface water options. It is recognised that systematic data on hand-dug wells is very limited (Martin and Giesen 2005), but given the prevalence of such wells, introducing strategies that align with SI might provide better water resource management and increased income for future investments. This could lead to sustainable behaviour

Fig. 8 Woman farmer growing sesame in Burkina Faso. Photo credit; RJ Cornforth, BRAVE 2016

changes that increases adaptive capacity and reduce vulnerability.

These findings indicate that Burkinabe communities are already making some use of groundwater to support their agricultural livelihoods, and most do this through accessing groundwater from shallow wells. This highlights the importance of local and national-scale monitoring data to support investment in small-scale irrigation should SI be implemented as a development pathway in the future.

Having identified that the basic infrastructure for small scale groundwater irrigation is already in place in Burkinabe communities, the next section will present data from the Vulnerability Monitoring data sets (a total of 30 vulnerability assessments and 32 follow up interviews from community members in Poa and Tomo) that show how the BRAVE project contributed to the four themes of Sustainable Intensification; information sharing, social cohesion, asset improvement and increased awareness.

Theme 1: information sharing

The three main outcomes in this theme including building knowledge, conducting participatory research and development leading to new technologies and/or practices, and implementing conventional extension combined with participatory dissemination via peer-to-peer learning. Whist the latter of these two outcomes are identifiable by the research making use of the participatory FVR, which supported conventional extension by community led radio programmes, it is important to explore

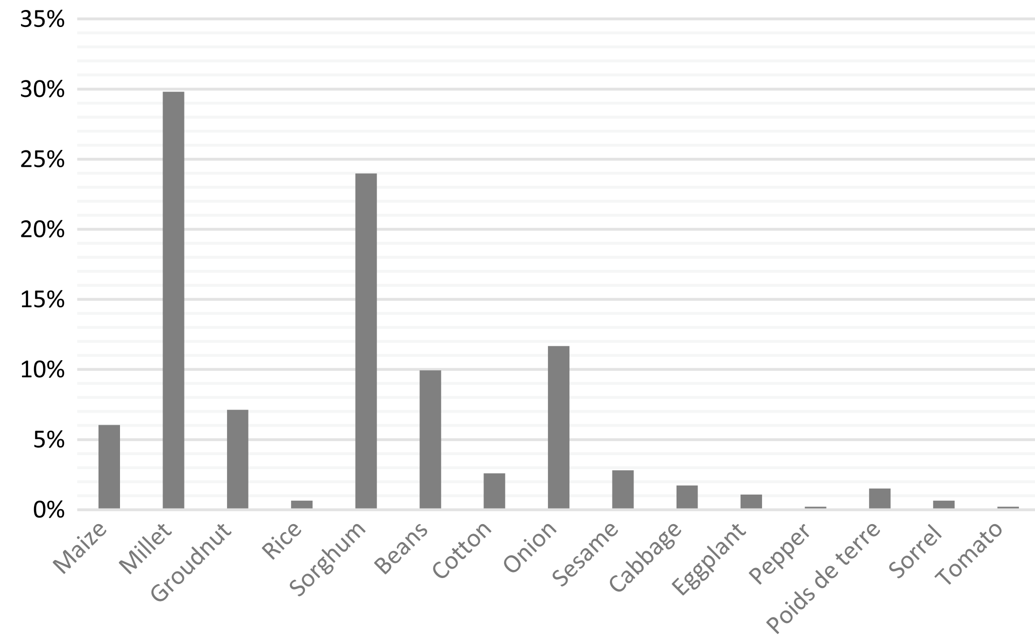

Fig. 9 Main crops farmed in Burkinabe communities from the baseline vulnerability data sets

Table 1 Table showing the main source of water for household and domestic uses across the four target communities in Burkina Faso

Water source	Percentage (%) of responses
Unprotected—hand dug well	90
Protected hand—dug well	4
Borehole	0
Unprotected spring	1
Protected spring	0
Public standpipe	4

what effect this approach had on community members in terms of building knowledge through peer-to-peer information sharing.

12 community members reported increased sharing of information between one another. 9 of these interviewees specifically say that information sharing between neighbours, friends and the wider community has also improved as illustrated by 112, 204 and 206:

> *"There has been a real change for us because we can mix our neighbours. We talk together. Everyone shows how to maintain and improve the way they*

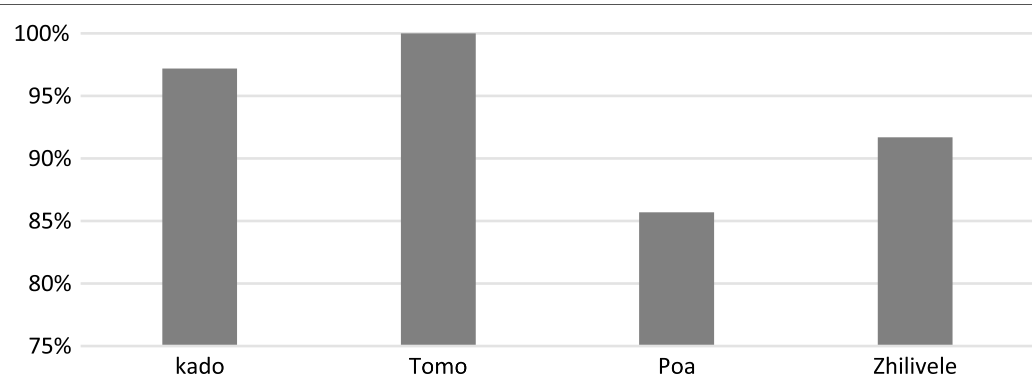

Fig. 10 Percentage of community members using irrigation

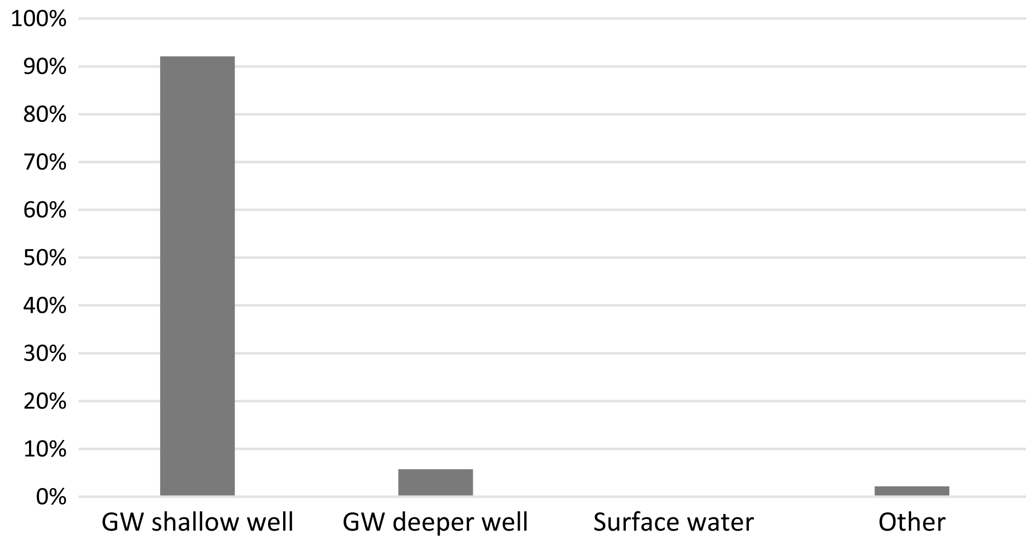

Fig. 11 Total percentage of all communities' members water source for irrigation

*generate their income." (***112, Poa, Female Farmer)**

*"We who have easy access to the association, in return we are the ones who will have to give advice to the other members of the community so that at least by next year the objective set by BRAVE or by the other associations can be achieved." **(215, Tomo, Male Farmer)***

*"Since BRAVE has often come even in public or at the market or in meetings I can advise even people, my neighbours in gardens or fields. I give them advice and I don't shy away, even at home those who misuse water I tell them that it can do this and that." **(204, Tomo, Female Farmer)***

*"The project has really changed us, why I say the project has really changed us, for example if you take our field work even the advice we give to our comrades and husbands, they apply. There are others who do not even come for meetings for, how to work in the fields, the techniques of the fields but the latter with our advice, we give them advice and he goes to his field he applied, or she applies to work in his field; we see that today they manage like us by earning a good return at the end." **(206, Tomo, Female Farmer)***

These quotations illustrate that those individuals who were engaged in the project activities have gained confidence to discuss new knowledge and practices within their communities (112 and 215), and to provide advice to fellow community members (204 and 206). This shows that this project supported SI by not only building knowledge but creating and disseminating it in a way that encouraged peer-to-peer learning.

Theme 2: social cohesion

The two SI outcome identified under this theme are to build social capital and to increase collaborations between 'experts' and other stakeholders. The information sharing identified above points to improved social capital and social cohesion because information sharing illustrates mutual respect. However, the data also shows more nuanced aspects of social cohesion. One dimension illustrated through the data is that of community governance. Given that social capital infers trust, concern for peers and a willingness to live within a given set of norms (Bowles and Gintis 2002), improved social capital can affect governance processes. Community governance can be defined at the 'set of small group interaction that, with market and state, determine economic outcomes' (Bowles and Gintis 2002). Community governance has an important link to social capital because it is connected to the capacity of communities to solve problems [directly linked to SI attribute 5(Fig. 1)], but that such capacity can be impeded by hierarchies and inequalities between members (Bowles and Gintis 2002).

The improved community governance is illustrated by the quote by 105:

"When we have started the group, at the beginning, there were the traditional chiefs, there were the CVDs, there were some representatives from the neighbourhoods. In any case, it's the same, that's why we have, there are the 3 counsellors in the group. It's to share information and when they to see these kinds of people, they see that it's right. Because it is the village leaders themselves who are in front. They will even think that it is normal, that it is good. So

*that's the information, it doesn't just remain for us. We share with the village leaders and even the whole population. From there, everyone decides what to do." **(105, Poa, Male Farmer)***

105 identifies that, through improved information sharing both from peer-to-peer but also sharing information upwards into local governance structure, decision making has become more inclusive. This process of improving community decision making directly support the fifth attribute of SI which is 'harnessing social capital to resolve common landscape-scale problems. The successful management and governance of groundwater in this manner is important in terms of SI attribute four which is focuses on 'quantifying and maximising the impacts of system management on externalities like clean water availability'.

109 explains that the LGs have supported strengthening of relationships between the members, and this has limited community conflict:

*"Now between us (LG members) ..., there is really solidarity between us. We're really working. We are in solidarity. It's like now in our concessions between husband and wife, there are no problems, we get along very well." **(109, Poa, Female Farmer)***

113 adds to this by explaining that decisions are now made through the mechanism that the BRAVE project has established:

"Since the project came along, decision-making has become firm and everyone, during meetings, people, we give each other advice and make firm decisions." **(113, Poa, Female Farmer)**

Another important avenue of improved social cohesion is the aspects of community conflict. 20/32 interviewees reported that community conflict over water management and use had been reduced due to the interventions implemented. The primary reason identified for this change was the reduced tension between community members due to increased water availability through better management activities. These activities included well monitoring, water conservation, water harvesting and disease control through covering the wells and maintaining a clean environment around them. These findings are illustrated by several quotes in Table 2.

The FVR provided community members with the opportunity to engage with guest experts. Unfortunately, the benefit of these interactions was not assessed, however, participants were asked about the level of contact they had with national extension experts. The analysis of the 32 vulnerability monitoring assessment interviews show that most respondents (55%) reported that national extension officers visited the communities 2–3 times per year (Fig. 12a). and provided information mainly about crop production and inputs, mostly in the forms of seeds (Fig. 12b).

This information shows that, whilst conventional extension services are an important information source to the communities, there is space for long term activities such as the FVR approach to complement conventional extension services. These provide additional information services that focus on SI content such as resource management and harnessing natural ecological and hydrological processes; information which the data and other studies (Ortiz-crespo et al. 2020; Kassie et al. 2015) suggest that conventional extension services are not covering.

The improved community cohesion and governance was an important outcome for the BRAVE project and is vital for adoption of SI as this approach requires responsible, shared resource management and governance that includes community level decision making structures

Table 2 Example quotes of reduced community conflict due to improved water management and availability

Reason for reduced conflict	Exemplary quote
Increased water availability	*As water is getting scarce there are disagreements because of the water and people are pulling at each other because of the water… As a result of the different advice given by the BRAVE project, misunderstandings have been reduced. **(107, Poa, Female farmer)***
Reduced water waste and allocated use	*They have small disagreements because there are fewer boreholes. Often there are many people on the same borehole, so for a while there are misunderstandings and people get a little tug of war. A small dispute. With the arrival of BRAVE, misunderstandings have decreased a little because villagers no longer waste water. Before, we used to see our women fetching water and using it at random now with the project we have been told that we must not use water just anyhow, anytime and that we must use it when we need it. **(114, Poa, Male farmer)***
Improvement of water quality and reduced water-related disease	*Yes, the use of water causes misunderstandings. We have two pumps and access to the springs causes these disagreements… Yes, the BRAVE project was able to reduce misunderstandings and water-related diseases with the water sources that last and thus reduced misunderstandings. **(116, Pao, Female farmer)***
Improved water governance	*There is no misunderstanding in my community because there is water now. With the implementation of the different councils, there is no lack of water, so everyone has the water they want, so there are no misunderstandings. **(212, Tomo, Female farmer)***

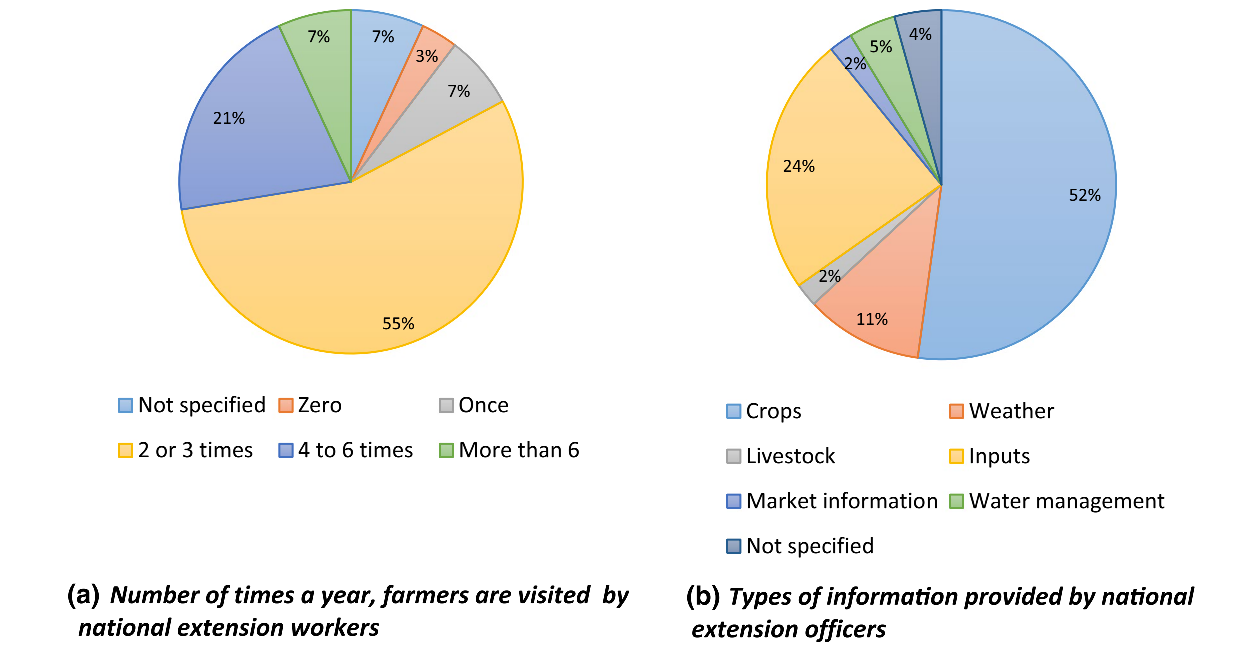

Fig. 12 **a** Number of times a year, farmers are visited by national extension workers. **b** Types of information provided by national extension officers

(Vanlauwe et al. 2014). Clearly aligning with multiple attributes and outcomes identified by the SI approach, this dynamic of community development needs to be nurtured and supported alongside the improved production strategies discussed earlier.

Theme 3: asset improvement

The two outcomes positioned underneath this theme include improvements of yields and outcome, and improvement of natural capital on- and off-farm landscapes.

In terms of improved yields, one of the major findings of this study was that agricultural production improved. Figure 12 shows that 100% of male farmers and 95% of female farmers interviewed reported livelihood improvements. These improvements were specified as either crop production improvement or livestock production improvement. Livestock pertained to any farming of live animals to cater to differences in livestock between men and women. 100% of male farmers and 95% of female farmers reported improvements in crop production, which was reported more frequently as being improved than livestock. However, it can be noted that 85% of males reported livestock production improvements and only 50% of female reported livestock improvement. The discrepancy between men and women is likely due to gendered activities. This indicates that there is potential tension over water resources due to competing livelihoods, and thus gender is a vital consideration for any water management interventions and policies to ensure equitable access; a notion which is well established in the literature (Imburgia et al. 2020; Rao et al. 2019; Khandker et al. 2020).

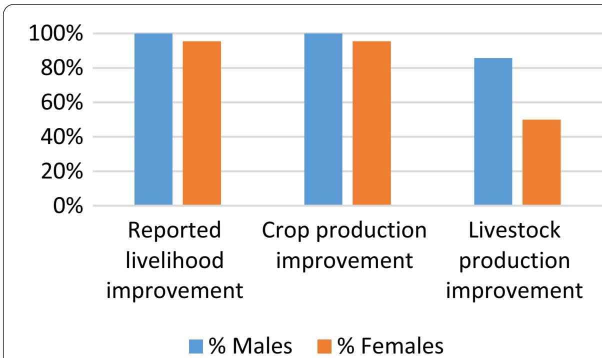

Fig. 13 Livelihood improvements noted by community members in Poa and Tomo

The quantification of these improvements was identified by six of the farmers who reported livelihood improvements reported tangible changes in income due to behaviour changes. The reported income increases ranged from 20,000 CFA to as much as 70,000 CFA:

> *"The changes in water management helped us to increase our income and especially at the livestock level there was an increase in income. Thanks to the project, people who had nothing have had an income of more than 20,000 F CFA." **(108, Poa, Female Farmer)***
>
> *"When we started to manage our water well, it allowed us to improve our crops, especially our onion crops ... For example, before, we could sell these onions and we earned 25,000 to 30,000CFA but now with the advice we received, we can water the onions and the crops are doing well and we can earn up to 50,000 or more." **(202, Tomo, Female Farmer)***

Of these six respondents, five reported a tangible change because of increased crop production, and one a tangible change due to increased livestock production. All of them assigned the change directly to improved water management strategies that had been communicated through the BRAVE initiative:

> *"With water management there has been a lot of production. These changes have led to an increase in income thanks to the gardens. Some people earn up to 100,000 CFA francs while they did not earn more than 30,000 CFA francs." **(116, Tomo, Female Farmer)***
>
> *"We have managed to make a difference in the use of water so we no longer consume water from our wells, so we can say that this has allowed us to have a lot of water to devote it essentially to our market gardening. When we had a lot of water, it allowed us to enlarge the surface of our gardens and thus we increased our production and thus our income. For someone who used to earn 30,000 to 35,000, today we earn 60,000 to 70,000." **(201, Tomo, Female Farmer)***
>
> *"It has really helped us to increase our income mainly in market gardening, for example, at home before receiving advice our production has increased considerably. Before, we couldn't have 35.000 FCFA but now we can have 100.000 FCFA per season." **(216, Tomo, Female Farmer)***

Having established that almost all farmers interviewed reported improvements to their livelihoods, the reasons for such improvements were analysed in more detail to understand what practices had changed to enable such improvements.

The two primary reasons identified for the crop production improvement were firstly, adjusting their water management strategies, and secondly, adjusting their agricultural practices because of information received through the BRAVE projects. 8 participants identified water management strategies (example quotes in Table 3), and 9 identified agricultural information. The main agricultural practices identified by the participants were based around the chosen thematic of the radio programmes (see previous section) with selected examples identified in Table 3 including pest management and sowing practices.

The main water management strategies (see Table 4) that were identified that supported agricultural production improvement were measuring borehole water levels (identified by 7 participants), limiting irrigation (identified by 4 participants) and borehole improvement strategies (identified by 4 of the participants) such as removal of mud, keeping the area clear of debris and rubbish and covering the wells to prevent contamination. These strategies were communicated through

Table 3 Illustrative quotations of reasons identified for improved crop production

Water management strategies	Agricultural information
"At the community level it can be said that the advice received for well water management has really helped a lot. It has allowed us to improve the production of our gardens and also to improve our own health and thus increase our income." ***(203, Tomo, Female Farmer)*** *"The changes in water management have enabled the community members, myself personally, to increase my income from agriculture and livestock."* ***(215, Tomo, Male Farmer)***	*"Before, others worked all season without any income at the end but now at the end of the season, we have a lot for consumption and the rest is sold to provide for the different needs of the family. The other change I have seen is in the plants; before the plants were dying but now, we have the techniques to avoid all these diseases thanks to the advice of the BRAVE project."* ***(211, Tomo, Female Farmer)*** *"Whether in the fields or on the farm, production has increased, the most significant change is in agriculture because long before the project came along, we were sowing randomly. But the project has taught us that we have to sow in rows, we have to dig holes to put manure even in our gardens before we made squares in a messy way, but the project has taught us that we have to make squares a little wider with planks."* ***(212, Tomo, Female Farmer)***

Table 4 Illustrative quotes of water management strategies used by the communities

Water measurement	Limiting irrigation	Well improvement strategies
"Through these trainings and information, I learned how to work with well water. Even if there is a water level in the well, I know how to work with that water level. Even though the water level has decreased I know how to work, now I take the increased water level. If I take the increased water level, I know how to work so that the water reaches February–March with my condiments in my garden." ***(203, Tomo, Female Farmer)*** *"We see the water levels in the wells ourselves, otherwise there was not someone who really measures the amount of water in the wells."* ***(210, Tomo, Female Farmer)***	*"The project has come to tell us to stop using machines in the gardens to water our gardens. In the past we have been using the machines, so the water is drying up fast. Now since then we have left with the advice of the BRAVE project, so since that day we water manually but now there is no more water."* ***(202, Tomo, Female Farmer)*** *"In the past we used water at random. We were drawing water from our gardens, and they came to tell us how to arrange your garden, so that the garden would not waste water. But they came to show how to make a little figure on soils and do it in such a way that, even if you water with, little water, it be enough."* ***(208, Tomo. Male Farmer)***	*"It is also possible to get in and remove the mud that is at the bottom of the well to allow the water to rise again."* ***(101, Poa, Female Farmer)*** *"With the support of the BRAVE formation, we started to cement, to maintain our wells well. Also, we put concrete on the surroundings of the well and sometimes we even look for slabs to cover the well… regarding well water, they showed us how to arrange our wells with the covers or either build the edge of the well to prevent runoff water from entering the well."* ***(104, Poa, Female Farmer)***

the FVR programmes and through the well management training and have direct links to key SI attributes including Harnessing eco-logical processes, avoiding the use of unnecessary inputs (e.g., using manure as natural fertiliser), and maximising the management of natural resources such as groundwater.

17 interviewees (11 females and 6 males) reported improvements in livestock production. The reasons for this improvement were less clear than those stated for agricultural improvement, but it was indicated that the radio programmes about livestock feed helped (205).

> *"Through the advice received, the whole community has seen its income increase in agricultural production and also in livestock production. Thanks to the feed recommended to the animals, they gain more weight than before. Among these changes, the most significant is animal husbandry, because at any given time you raise livestock while other activities are carried out at specific periods of time." **(205, Tomo, Female Farmer)***

Another factor contributing this improvement is likely to have been the reported decrease in livestock deaths due the increased availability of clean water:

> *"There are fewer diseases and fewer animal diseases, there are fewer problems than before."* **(102, Poa, Male Farmer)**
>
> *"We also knew that all the diseases that were there before because of the misuse of our wells, we saw that all these diseases are leaving, and we feel that there has been a real change with the input, the advice of BRAVE." **(111, Poa, Female Farmer)***
>
> *"There are not more serious diseases that come from malaria, stomach aches, fever, even diarrhoea. So, we see that a lot has changed in this village." **(205, Tomo, Female Farmer)***

It can be seen from the data presented under this theme that not only has the agricultural production of the Burkinabe communities increased which has provided additional incomes, but, perhaps more importantly, that the reasons underneath these improvements come down to success management of the natural resource of groundwater and improved agricultural information provided to communities through the participatory FVR approach. It must also be recognised that the information provided enabled people to make alterations to their farming practices that made use of ecological and natural processes, and therefore benefited the long-term sustainability of such intensification.

Theme 4: increased awareness

Increased awareness has been showcased by behaviour changes that have improved agricultural production identified in theme 3. Whilst there is limited data that specifically showcases the greater appreciation for the contribution of multiple natural ecosystems services, it can be observed that the data shown so far has illustrated multiple benefits that have been identified by interviewees including avenues of increased production and multiple improvements within community cohesion. Additionally, the data also shows increased awareness of other, equally important, aspects of community life resulting from the additional investment of time, information, and support into groundwater resource management for the Burkinabe communities. These included additional behaviour changes such as: increased awareness around improved health due to better understanding of well water quality and maintenance; and improved understanding of water borne diseases.

> *"Before the other wells, we used to remove water from the wells, which gave us diseases and consorts. But since then, we started drinking the drinking water from the boreholes. So, since that day I think there are no more diseases like that. We don't go to the hospital like we used to." **(103, Poa, Female Farmer)***
>
> *"Before at any time, I would go to the hospital with my children, even myself. There were prescriptions for prescriptions. But during all these two years, I can do even a year without getting into the hospital. It is because hygiene is there." **(108, Poa, Female Farmer)***
>
> *"I think that since the project had not yet arrived here, the usual methods used in previous years were still being used. So, it was the same problems, we worked with dirty water. You could have stomach aches, diarrhoea, even malaria. Since the project came to make us aware of these things, I think it's going very well." **(213, Tomo, Female Farmer)***

Discussion

Before reflecting on the implications of the data presented, it is prudent to reflect on the SI framework used to structure this analysis. As discussed previously, SI involves a vast range of varying aspects which need to be examined, and the literature has shifted over time to a more holistic, systems-based understanding. Using a framework adapted from Pretty and Bharucha (2014) has helped to enable a tangible and structured analysis of some of the more subtle aspects surrounding behaviour change and knowledge sharing identified in the SI concept and position the findings into areas which can speak directly to sub-outcomes found within the 'universal' principles of SI (Trigo et al. 2021). By making use of a framework which can flex to evaluate a systems-based, and interdisciplinary project such as the BRAVE project, this study has shown that framing a critical evaluation and discussion on the social aspects of SI can be helpful in adding to the data on evaluating SI.

Whilst we recognise that such an approach also has limitations, Sustainable intensification is an approach to agricultural intensification promoted in international policy, for example by the FAO as a route to achieving the SDGs (FAO 2021) and by the Convention on Biological Diversity as part of an action plan on conservation and sustainable use of ecosystem services (CBD 2018). Often there is little clear information about how to achieve it, or whether it is cost effective from a producer's perspective. Whilst the approach used here provides some quantifiable measurements such as increased crop and livestock production, it also includes an analysis of the social aspects of SI, which draws on qualitative data.

This exemplifies the challenges of conducting and synthesising interdisciplinary research (Pedersen 2016; Brown et al. 2019; Duerr and Herkommer 2019) which sits at the core of this project. Whilst there is much work still to do to harness interdisciplinary research effectively, hope that BRAVE offers an example of how to structure interdisciplinary research and in this case, apply it to bridge the multi-disciplinary aspects of SI.

When reflecting on the data presented in the study, it shows improvements in four main areas which align directly to the SI approach. The first of these areas is increased information sharing with peers. Through the information provided by the FVR programmes, the benefits to farmers making use of inputs, such as organic fertilisers, and implementing water management techniques such as water harvesting, increases their social networks, agricultural production and therefore income. These improvements reduce their dependency on external social protection measures and illustrate the sustainable benefits of harnessing ecological processes.

The second area of improvement is that of social cohesion and governance. The area shows initial indications of such improvements due to increased ability to successfully share information both with peers and with local councils. Such information sharing encourages and enables vertical dialogue processes which can directly influence community participation in governance councils and decisions; an aspect clearly identified in the SI attribute of using social capital to resolve common landscape scale problems.

The third, and perhaps most tangible area is that of increased agricultural and non-agricultural assets (presented in Fig. 13). The data illustrates that community members attribute these changes to improved water management strategies and information provision. Whilst this is likely, it must be acknowledged that are potentially a multitude of external factors that may also have contributed to such improvements such as weather, and local value chain shifts for example, and that external factors such as market absorption of additional produce can limit the exponential success of increased production. The data collected did not directly consider these aspects, so this is an area for future research which would strengthen the argument that SI processes directly support production improvements. It must also be noted that the data presented did not systemically examine income changes by different demographic groups such as groups by wealth levels and gender. This is another area which would strengthen the findings and therefore arguments presented by this paper, as these additional categories would provide a more nuanced insight into who in the community had better or worse access to aspects such as land quality, seed inputs, information channels and labour. One mechanism that could be employed to explore this in more detail is the Household Economy Approach (HEA) which has successfully been used to identify such differences in a multitude of studies (Barad et al. 2020; Boubacar et al. 2017; Lankouandé and Nfon-Dibié 2020).

The final area of improvement is that of increased awareness which also resulted improved community health (due to cleaner drinking water and likely improved nutrition).

These four areas support one another resulting in a cyclical system of change involving the community members in participatory research approaches as the FVR and capacity building activities such as well monitoring, well monitoring and in a participatory information generation and sharing process such as the FVR which are aligned to the SI approach results in improved confidence and awareness of individuals. This supports their capacity to share information with wither resulting in increased social capital and improved community cohesion. This results in the ability for communities to make landscape decisions to harness SI approaches, resulting in increased production and income. The illustration of these benefits supports aspects of human capacity to further participate in and lead participatory capacity building activities (see Fig. 14).

The relationship between SI and commercialisation remains a subject for debate however (Newsham et al. 2018). Having presented the contextual data collected in the Burkinabe communities through BRAVE, this type of improvement in agricultural and water management

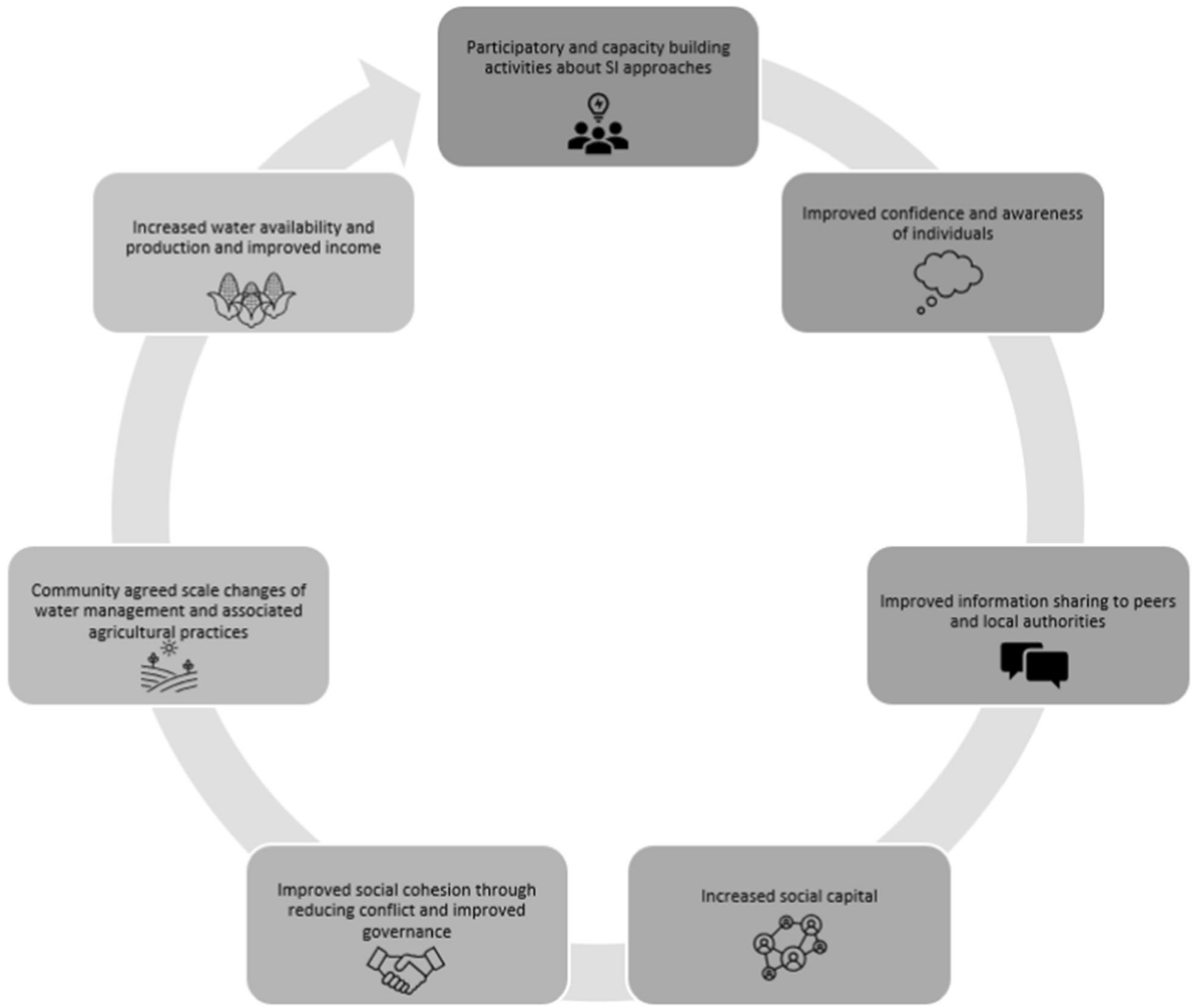

Fig. 14 Cyclical system of change resulting from an SI intervention

practice has an advantage over adopting a more commercialised route.

Overall, the data shows that communities living in African Sahel, a semi-arid region, have the capacity to use groundwater for small-scale irrigation. Given that climate models predict a wetter future, and therefore an increased likelihood of better groundwater status linked to increased precipitation (Ascott et al. 2020), this finding has important implications for supporting climate resilient communities. With the right information and support provided to seasonal community management of groundwater supplies and longer-term planning, these communities can improve their irrigation strategies to build their resilience and reduce their own vulnerability during dry periods. It also shows that, by harnessing the SI framework to support the research design and project implementation, the development of adaptive resilience of individuals becomes a clear priority. By focusing on a holistic concept of resilience, the opportunity for people to make informed choices is improved. As this process is embedded people's capacity to access and process information which they can interpret themselves is increased. This results in improved agency as individuals can choose their pathways to development, rather than being driven by market demand.

There are several caveats to adopting this approach. A systems-based approach is a requisite for supporting SI in Burkina Faso. The livelihood improvements seen above, are a result of providing information about managing groundwater, and alternative cropping techniques whilst taking account of the social dimension and communication processes. A key and often overlooked component of this approach is the consideration and inclusion of social and contextual structures. The design of the intervention enabled individuals to engage with local governance processes and feel empowered to share information widely. Taking account of the social dimension is vital for supporting SI effectively. Enabling local governance, enables sustainable resource access and use in turn.

There are also several limitations of this approach which must be recognised.

(1) The communities need to have access to groundwater resources—these are dependent on a wide range of factors spanning the hydrogeology, climate variability and environmental change and land management, to the political, economic, and social constraints. Improved understanding of how water moves through local catchments depends on long term monitoring to evaluate complex coupled modelling generating output from climate, land surface and groundwater models. Social exploration is imperative to understanding the social and geo-political factors. It is such an interdisciplinary approach that will enable communities to truly improve their use of groundwater resources and management to support SI.
(2) The communities must have suitable infrastructure to access groundwater resources and knowledge to support long term planning. Uniquely across Africa, the Burkina Faso government has prioritised groundwater infrastructure and invested in continued and extended monitoring of groundwater resources. The historical and season-to-date groundwater data from Burkina Faso is thus very good and enabled reconstructions to contextualise current and future groundwater resource status.
(3) There is a need for policies which can start, lead, and support the SI approach, but also so that natural resources such as groundwater remains equitably accessible. This requires both improved community governance and policy/higher level governance to enforce this.

The combination of these improvements in multiple areas of community life have provided people with the ability to make more choices. This increased capability is directly linked to the concept of improving resilience and overcoming vulnerability (Lindbom et al. 2015) and is particularly connected to the attributes of the model of SI including the assessment of the impacts of sustainable intensification on clean water, and the improvement of human capital and capacity to adapt and harness social capital to overcome resource issues such as water scarcity (Bianchi et al. 2020; Macdonald et al. 2012).

A vital part of this process is allowing people the opportunity to interpret information and advice and translate this into something that can help them make their own decisions. The provision of choice and opportunity for individuals to convert this into contextually relevant decisions also supports the process of agency [people's involvement in a course of action (Drydyk 2013)], as well as the broader aspects of well-being, through empowerment by the outcome (Drydyk 2008) of being able to better shape one's own life (Narayan 2006). Empowerment is a vital component to supporting improved governance (Nath 2001), as it improves people ability to engage in and influence community level decision making processes. This is particularly important for the involvement of women in governance processes (Nath 2001). Community decision making is linked to essential processes of governance that is needed to support SI (Cuthbert et al. 2019b; Ascott et al. 2020; Campbell et al. 2014; Fish et al. 2014).

These additional elements of behaviour change are important because, as identified by Sharaunga et al. (2015), improved access to water resources and irrigation alone do not significantly influence household vulnerability to food security. However, improved economic agency and physical capital empowerment, do significantly improve household vulnerability.

Implications for policy

The findings of this paper suggests that with suitable investment from a national level, the agriculture extension service working together with the community water and sanitation engineers could be a strong vehicle to support long term, nationally owned SI initiatives. However, these services would need to be increased or supplemented to provide farmers with the information that aligns with SI practices which can support overcoming vulnerability (Nath 2001), and be supported by appropriate communication/media platforms (such as the FVR), to create contextually relevant and scale information widely.

Sustaining such an approach, would require a number of deliberate policy interventions such as:

(1) Improving policies and local job mandates (such as agricultural extension workers') to support the developmental aspect of SI and ensure that relevant information is available. This would require investment in capacity building and improved information services (such as the use of local radio).

(2) Investment in long-term monitoring of groundwater resources and infrastructure.
(3) Appropriate governance policies so that the less wealthy can benefit equally from SI, with effective decision-making processes in place at household, community and national levels (Vanlauwe et al. 2014).
(4) Advisories need to be accompanied by other techniques presented by the SI approach to ensure that groundwater investment is a mechanism the enables SI expansion to ensure that the resource is sustainability used.

Conclusions

Using a framework generated around the concepts and outcomes of SI, this study has presented how groundwater has the potential to support at-risk communities in the Sahel in the face of increased rainfall variability due to climate change. The study has presented an approach that has been built on the fundamental understandings of SI and has presented resulting improvements in the study communities in four key areas.

The first theme of information sharing showed that most community members reported sharing information generated through the participatory research approaches with their peer groups resulting in improved social capital. Data presented in the second theme of social cohesion showed improved governance processes through community members sharing information with local councils, and significant reduction in community conflict over water resources due to practice and behaviour changes instigated by the BRAVE project. The third theme of asset improvement showed tangible increases in both agricultural and livestock production of community members through implementing SI approaches which harness natural hydrological and ecological processes. The final theme of increased awareness illustrated the additional benefit of using this approach which was improved community health.

Based on these findings it can be concluded that applying the SI approach to supporting the increased use and management of groundwater can not only ensure that that the resources is used sustainably, but also that famers can increase their resilience and reduce their vulnerability and reliance on social protection measures by improving their access to assets such as social capital and income. However, the implementation of such approaches needed national support in policy and job mandates to ensure the continuity of such information and support services needed by communities. It is also vital that governance policies ensure equitable access for all wealth groups so that those most vulnerable can also benefit.

Given the size of this study, it would be beneficial for additional studies to be implemented to strengthen the findings presented here. It would also be useful to examine differences between communities, which was out of the scope of this paper. Future work should also make use of approaches that can examine the access and effect of this approach on different wealth groups through using approaches such the Household Economy Approach. Finally, adopting newer SI frameworks such the SES framework by Mahon et al. (2018) or the Global Farm Metric (2022), to improve on the framework used in this study could be a useful line of future work.

Abbreviations

BRAVE: Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa; FVR: Farmer Voice Radio; HEA: Household Economy Approach; SI: Sustainable Intensification; ICT: Information and Communication Technology.

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Author contributions

LC, and HO originated the idea with support from RC as the Principal Investigator of the NERC/FDCO-funded BRAVE project; LC analysed the data and wrote the paper with input from all co-authors. All the authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The data presented in this paper was subject to the ethical clearance processes outlined by the University of Reading, School of Agriculture, Policy and Development: reference 1012D. In line with these processes, all individuals who participated in this study where fully informed of the studies aims, selection criteria and scope, have given their consent to participate in this study and have all been fully anonymised.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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