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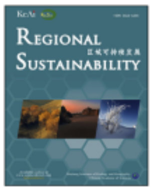

Knowledge flow analysis of knowledge co-production-based climate change adaptation for lowland rice farmers in Bulukumba Regency, Indonesia

Arifah [a], Darmawan Salman [b], Amir Yassi [b], Eymal Bahsar Demmallino [b,*]

[a] *Pangkep State Polytechnic of Agriculture, Pangkep, 90652, Indonesia*
[b] *Faculty of Agriculture, Hasanuddin University, Makassar, 90245, Indonesia*

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ABSTRACT

To increase the resilience of farmers' livelihood systems, detailed knowledge of adaptation strategies for dealing with the impacts of climate change is required. Knowledge co-production approach is an adaptation strategy that is considered appropriate in the context of the increasing frequency of disasters caused by climate change. Previous research of knowledge co-production on climate change adaptation in Indonesia is insufficient, particularly at local level, so we examined the flow of climate change adaptation knowledge in the knowledge co-production process through climate field school (CFS) activities in this study. We interviewed 120 people living in Bulukumba Regency, South Sulawesi Province, Indonesia, involving 12 crowds including male and female farmers participated in CFS and not participated in CFS, local government officials, agriculture extension workers, agricultural traders, farmers' family members and neighbors, etc. In brief, the 12 groups of people mainly include two categories of people, i.e., people involved in CFS activities and outside CFS. We applied descriptive method and Social Network Analysis (SNA) to determine how knowledge flow in the community network and which groups of actors are important for knowledge flow. The findings of this study reveal that participants in CFS activities convey the knowledge they acquired formally (i.e., from TV, radio, government, etc.) and informally (i.e., from market, friends, relatives, etc.) to other actors, especially to their families and neighbors. The results also show that the acquisition and sharing of knowledge facilitate the flow of climate change adaptation knowledge based on knowledge co-operation. In addition, the findings highlight the key role of actors in the knowledge transfer process, and key actors involved in disseminating information about climate change adaptation. To be specific, among all the actors, family member and neighbor of CFS actor are the most common actors in disseminating climate knowledge information and closest to other actors in the network; agricultural trader and family member of CFS actor collaborate most with other actors in the community network; and farmers participated in CFS, including those heads of farmer groups, agricultural extension workers, and local government officials are more willing to contact with other actors in the network. To facilitate the flow of knowledge on climate change adaptation, CFS activities should be conducted regularly and CFS models that fit the situation of farmers' vulnerability to climate change should be developed.

* Corresponding author.
E-mail address: demmallino2022@gmail.com (E. Bahsar Demmallino).

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1. Introduction

Climate change is a significant challenge to farmers, particularly in developing countries such as Indonesia, where major farms are small and have limited adaptive capacity (Yoseph-Paulus, 2014; Handayani et al., 2017; Jusup et al., 2022). Farmers, as decision-makers at local level, play an important role in climate change adaptation (Sabzevar et al., 2021). Much of research on climate change adaptation strategies is generally based on local knowledge derived from experience and passed down from generation to generation. Previous research on lowland rice farmers in Bulukumba Regency, South Sulawesi, Indonesia conducted by Arifah et al. (2022), revealed that farmers use their local knowledge to deal with drought, pest outbreaks, and rising temperatures caused by climate change. Farmers respond to climate change by implementing a variety of adaptation measures, including non-agricultural activities (Ali et al., 2021), seed variety improvement (Dendir and Simane, 2021), crop diversification (Ricart et al., 2022), etc.

The adaptation efforts made by smallholder farmers are considered inadequate, especially when climate change becomes more frequent and the impacts of climate change increase in magnitude. Farmers create seasonal markers based on long-term observations of repeated events or behaviors in plants or animals. However, according to scientific knowledge, the behavior of plants and animals is linked to casual mechanisms such as temperature, humidity, rainfall, radiation, wind direction, etc. Therefore, smallholder farmers need an effective climate change adaptation approach to adopt scientific knowledge without ignoring their local knowledge (World Bank Group and Asian Development Bank, 2021). Scientists and practitioners have incorporated local knowledge into scientific research, policy-making, and planning to increase society's resilience to climate change (Hiwasaki et al., 2014; Colloff et al., 2017; Fazey et al., 2018; Zarei et al., 2020; Singh et al., 2021). Hiwasaki et al. (2014) verified that the integration of local knowledge and scientific knowledge assist villagers in Vanuatu and Solomon islands, in surviving from tsunami events. During the initial data collection in Bulukumba Regency, it is discovered that farmers implement climate change adaptation strategies not only based on their local knowledge, but also scientific knowledge from third parties in dealing with natural disasters. Farmers arrange their planting schedules based on star calculations and the advice of agricultural extension workers. Some farmers also begin to participate in agricultural insurance programs introduced by third parties. However, not all farmers have easy access to information and knowledge about climate change adaptation from outsiders.

Dealing with the impacts of climate change necessitates a strong knowledge connection, involving not only farmers but also agricultural extension workers, agricultural researchers, and other stakeholders. Since connections between actors are essential to improve the utilization of and access to climate change adaptation knowledge, research on the connections between actors in knowledge transfer has become a research hotspot. Helbing et al. (2015) stated that efficient communication system, reliable information flow, and good coordination between stakeholders are key components to minimize the impacts of climate change. Wang et al. (2020) and Jusup et al. (2022) also pointed out that the adaptation to climate change and the mitigation of climate change risk on agriculture can be achieved with cooperation and communication between related stakeholders.

In the context of climate change adaptation, connections between actors must be addressed at every level to achieve appropriate knowledge sharing, thus ensuring a reliable and efficient knowledge flow. Farmers need to develop methods to enhance the framework and dissemination of climate change knowledge, as knowledge transfer in agriculture is a matter of providing and understanding sufficient information (Adger et al., 2016), which is relevant with social circumstances where ordinary people and professionals have different opinions on climate change (Whitmarsh and Capstick, 2018). Howarth et al. (2022) believed that the flow of knowledge among different stakeholders is an emerging challenge in knowledge integration. Furthermore, a substantial body of research has conducted on how knowledge transfer motivates farmers to participate in initiatives that encourage them to use improved farming techniques to adapt climate change (Nonaka, 1994; Zarei et al., 2020). Both the sharing or dissemination of knowledge and the provision of inputs for issue-solving are considered forms of knowledge transfer.

Knowledge co-production refers to adaptation actions that combines scientific knowledge and local knowledge that comes from professional experience with social construction knowledge (Urquhart et al., 2014; Bremer and Meisch, 2017; Schneider et al., 2021). Sharing knowledge among stakeholders can foster and maintain relationships and provide information to ensure that policies benefit society, particularly for those people who are most vulnerable to the impacts of climate change (Singh et al., 2021). The concept of knowledge co-production in the field of climate change has emerged in the literature as the climate knowledge increases among governments, scientists, and the public (Zarei et al., 2020); but it is still not widely used in developing countries, particularly in the field of knowledge flow for climate change adaptation at local level. Several studies have been conducted on the topic of knowledge co-production on the impacts of climate change on agricultural sector in developing countries, such as the co-production of knowledge on climate information services for farmers in Bangladesh (Kumar et al., 2021b), as well as the social, economic, and environmental impacts of farmers on knowledge co-production in Iran (Zarei et al., 2020). However, studies on the flow and co-production of knowledge on climate change adaptation with farmers are few, particularly in Indonesia.

Contributors to adaptation knowledge from various disciplines can play a role and take responsibility, so that appropriate knowledge co-production is easily accessible to all actors, especially smallholder farmers. Thus, beneficiaries can integrate natural science, local knowledge, and social sciences to develop appropriate climate change adaptation strategies for farming. Local government officials, agricultural extension workers, and other stakeholders interact at local level to ensure that sufficient information is compiled through policies and actions and integrated into effective responses to support adaptation in a variety of contexts. The successful development of adaptation strategies ensures that global policies respond to local priorities and that the political support gained through adaptation mainstreaming is effective at local level. Climate Field School (CFS) is an implementation type of knowledge co-production that aims to improve farmers' knowledge systems by combining local knowledge with scientific knowledge to predict the impacts of certain climate phenomena on farming such as droughts and floods (Hasan and Kumar, 2019). As field school, CFS empowers farmers by providing the knowledge and skills they need to understand climatic conditions and to carry out location-specific agricultural cultivation to reduce production declines caused by climate phenomena. The objectives of CFS are to increase farmers' knowledge and skills about climate change adaptation based on both scientific knowledge and local knowledge, to assist farmers in observing climate elements and applying them to agriculture, and to translate forecast climate information into local language. In brief, CFS activities take a non-formal education approach, such as hands-on and experience-based learning to incorporate scientific insights into local knowledge systems. In CFS, farmers can learn topics such as weather and climate knowledge, extreme climate, weather measuring tools, planting calendars, the local wisdom in managing their farming operations, etc. (Nur, 2020). The ability of farmers to understand the knowledge and skills acquired through CFS is an indicator of the success of CFS program.

In this qualitative study, we researched two scientific questions: (1) the knowledge flow of knowledge co-production-based climate change adaptation strategy in paddy rice farming communities; and (2) the role of actors in the process of sharing and transferring knowledge on adaptation to climate change impacts. We examined the flow of climate change adaptation knowledge in the knowledge co-production process in CFS activities and analyzed the knowledge flow of knowledge co-production-based climate change adaptation strategy using Social Network Analysis (SNA). SNA, which can help describe the reality of social actors controlling over information and provide insights for improving information systems, has been used in a variety of disciplines such as marketing (Simon et al., 2021), education (Chang et al., 2022), and agriculture research (Cadger et al., 2016). According to Adger et al. (2003), social networks can help rural communities adapt to climate change by facilitating the flow of information. This study provides an effective climate change adaptation strategy for smallholder farmers by integrating local knowledge and scientific knowledge, as well as information for actors in generating and disseminating adaptation knowledge and policy, particularly at local level.

2. Literature review

This section includes a literature review of knowledge flow of climate change adaptation based on knowledge co-production. This section also identifies the gaps that this research aims to fill.

2.1. Knowledge co-production

Knowledge co-production has been extensively researched in various contexts and at various levels, particularly in the field of climate change adaptation and decision-making. Formulating climate change adaptation strategies require interaction and collaboration between sectors and community stakeholders, including practitioners, academics, and politicians with expertise and knowledge who can contribute to the development of climate action (Kumar et al., 2021a). Adopting knowledge co-production approach provides participants with a good understanding of adaptation strategies, allowing them to adopt knowledge from other actors to better shape climate policy. The power relations between actors involved in a knowledge co-production process must be addressed, the interconnections of issues and interests at stake and the implications these may have must be considered, and the common goals of knowledge co-production process must be identified (Eikebrokk et al., 2021).

Knowledge co-production can be defined as the collaborative process of bringing together a wide range of knowledge sources to address a defined problem and build an integrated or systems-oriented understanding of that problem (Armitage et al., 2011). Knowledge co-production is considered successful when there is a robust, reflective, and collaborative joint learning process (Bremer and Meisch, 2017). It has been recognized that the "process" is more important than the "results" in knowledge co-production (Vincent et al., 2018). The success of knowledge co-production is determined by the level of active participation between actors (e.g., farmers and research institutions), or the level of involvement of various stakeholders (e.g., policymakers and farmers). Knowledge co-production serves two purposes: (1) serving as a bridge organization at the intersection of science and politics, and (2) associating with the interactive and dynamic endeavor of multiple actors (Pohl et al., 2010). Hill et al. (2020) defined know co-production as "the simultaneous production of knowledge and social order", emphasizing the constant reworking of understandings, norms, beliefs, practices, and the openness to uncertainty and messiness of knowledge co-production, which can serve as sources of learning.

2.2. Knowledge flow

The availability of information used for decision-making determines the success of knowledge transfer process (Pandey et al., 2018). Information is divided into two categories: supply (knowledge) and demand (the need for knowledge). In addition to information availability, information infrastructure also plays an important role in the dissemination of adaptation knowledge to various actors. Foundations or frameworks that support the technology used for communicative interactions among the local communities, stakeholders, policymakers, and government, are referred to as information infrastructure (Kumar et al., 2021b).

Farmers in the Philippines are encouraged to share their knowledge with people related by blood or friendship. Farmers' motivations to share knowledge are based on an assessment of the reciprocal benefits of information obtained from knowledge sharing (Malabayabas and Baconguis, 2020). Isolated communities in Sri Lanka have developed a unique local knowledge sharing mechanism in response to landslide disasters. Local knowledge sharing has great influence on the social capital dimension of knowledge-sharing network. The communities have a highly centralized social network configuration, with a few community members dominating the structural dimension. Community members play an important role in the evolution and transfer of knowledge. Furthermore, cognitive and relational dimensions such as unique culture, social trust, unique social relationships, and respect for the hierarchy of human social, facilitate smooth knowledge transfer among network members (Dasanayaka and Matsuda, 2022).

Understanding context is especially important for local-level knowledge sharing in Bangladesh. Face-to-face communication techniques require a level of trust between the knowledge recipients and the knowledge providers. Climate change adaptation mainstreaming can be made more effectively by improving the flow of relevant knowledge. To achieve appropriate knowledge sharing and thus ensure smooth and effective flows of knowledge, communicative connections must be addressed at each communication link. Climate change adaptation knowledge contributors from a variety of disciplinary backgrounds can take responsibility for making appropriate knowledge accessible. As a result, knowledge recipients would be able to integrate nature science, politics, and social science to learn adaptation policies and strategies (Zarei et al., 2020).

2.3. Climate field school (CFS)

CFS is a non-formal education program developed by the Ministry of Agriculture, Indonesia in collaboration with the Meteorology, Climatology, and Geophysics Agency (MCGA), aiming at reducing the losses in agricultural production caused by climate change by providing knowledge and skills for analyzing agro-climates (Nur, 2020). Through the program, farmers learn together how to understand and use climate information and forecast effectively in their farming activities. The aim of implementing CFS is to build the capacity of society, especially the farming communities in particular to anticipate and adapt to climate change, as well as mitigate the impacts of climate change (Chandra et al., 2017; Kumar et al., 2021b). Several studies show that through CFS, farmers increase their ability to improve livelihoods when affected by climate change (Siregar and Crane, 2011; Chandra et al., 2017; Adiyoga and Basuki, 2019). In addition, CFS can strengthen farmers' critical attitude in making climate change adaptation and mitigation decisions, and motivate them to rebuild local wisdom and community values of self-reliance, including the creativity needed to solve problems. An important finding from relevant literature is that participatory and collaborative processes of knowledge construction (i.e., knowledge co-production) take place in CFSs (Chandra et al., 2017; Charatsari et al., 2020).

As above mentioned, integrating local knowledge with meteorological information, which is provided by meteorological agency on climate, is useful for farmers. Local knowledge is formed by how individuals and communities observe, discuss, and comprehend their surroundings. Farmers are more likely to perceive climate and agricultural science knowledge applicable to their farms if this science knowledge can be compatible with their knowledge, rituals, and skills (Heaton et al., 2016; Borquez et al., 2017). CFS stages include preparation, identification of prospective participants, provision of necessary facilities, and curriculum. A few weeks before activity, preparations are made through meetings with the target farmer groups. Farmers and agricultural extension workers discuss curriculum materials, participant selection, and the time and place of learning at meetings. There are usually 25 participants (male and female farmers) in a CFS who actively attempt to learn agriculture knowledge in one same village area. Learning activities are carried out every ten days. The curriculum is learning area curriculum, which is created and compiled independently by a CFS group under the guidance of agricultural extension workers based on the conditions of farmers' paddy fields.

Farmers obtain information on climate, weather measuring instruments, the effects of climate change on plants, local climate wisdom, and planting calendar in CFS. CFS provides a platform for designing climate change adaptation strategies that combine scientific and traditional ecological knowledge (Biskupska and Salamanca, 2020; Charatsari et al., 2020). MCGA explains to CFS how farmers' local knowledge corresponds to data of MCGA; farmers share stories about how they use local knowledge in farming. The compatibility of MCGA information with local knowledge gives new legitimacy to farmers' technical information. As MCGA recognizes the validity of farmers' knowledge system, farmers' trust in MCGA grows, resulting in more productive relationships.

3. Methodology

3.1. Study area

Bulukumba Regency (05°20′–05°40′S, 119°58′–120°28′E) locates in the southern part of South Sulawesi Province, Indonesia, with an area of 1154.58 km^2 and a population of 4.37×10^5 (BPS-Statistics of Bulukumba Regency, 2021). Bulukumba Regency has a humid or slightly wet climate, with average temperature ranging from 23.82 °C to 27.68 °C, making it suitable for crops planting. The main food crop in Bulukumba Regency is rice, with a cultivated area of over 229.58 km^2 and yield of approximately 2.30×10^5 t/a (BPS-Statistics for Bulukumba Regency, 2021).

We carried out this study in Gantarang District, the largest sub-district and also the largest rice producer of Bulukumba Regency, with 1.54×10^4 hm^2 of paddy fields and a population of 8.12×10^4 of which 40.00% are farmers (BPS-Statistics of Bulukumba Regency, 2021). Farming paddy rice is the main livelihood of the farmers in study area, most of whom are sharecroppers who assist owners in managing their paddy fields under a profit-sharing system. Gantarang District was chosen because it is located in an ecological zone that is vulnerable to the impacts of climate change, and people living in here adopt climate change adaptation strategies based on local knowledge and scientific evidence and participate in CFS. Extreme weather events such as drought, are common in Gantarang District, influencing the livelihood of farmers. Farmers living in Gantarang District often practice local knowledge from the Bugis and Makassar tribes in farming, particularly when dealing with natural disasters caused by climate change.

3.2. Sampling and data collection

The selection of the participants sample was carried out on purpose. The sample size was 120 people and consisted of 12 groups of actors, including farmers participated in CFS and their family members and neighbors, farmers had not participated in CFS, agricultural extension workers, traders, local government officials, and MCGA staff.

This study used a semi-structured questionnaire with open and closed questions. Open-ended questions allow respondents to provide detailed opinions about their personal experience in acquiring and imparting climate knowledge. The questionnaire includes questions about the demographics of respondents and how they receive, respond to, and share knowledge about climate change adaptation. We also conducted in-depth interviews, which lasted a maximum of 30–45 min, and all interview results were recorded and transcribed.

All participants gave consent to share information, and interviews were conducted in accordance with ethical principles for research involving human participants. The objectives, benefits, and potential risks of interview were explained adequately to all participants. Participants were entirely voluntary and anonymous to attend interview, and provided written informed consent before conducting interviews. All data and information obtained from participants are strictly confidential and no one can access to the identities or opinions of participants. The data collection was carried out during the Covid-19 pandemic, which severely limited the interview, so in addition to face-to-face interviews, we also conducted telephone interviews with farmers, local government officials, agricultural extension workers, and other stakeholders.

3.3. Data analysis

This qualitative study explained farmers' experience in acquiring, responding to, and sharing knowledge in the context of knowledge co-production. Because knowledge co-production is a complex process, this study was thought to be appropriate for using a variety of methodologies, including literature studies, interviews, observations, and focus group discussions.

This study employed the qualitative analysis introduced by Miles and Huberman (1999), which consists of three processes: data simplification, data presentation, and conclusions or verification. The collected data are simplified before further processing. After all of the data are simplified, the next step is to present data as fixed data. Data are presented in narrative form in which researchers can record the facts in detail based on the theme of study. Following data presentation, researchers usually utilize triangulation method to interpret and verify the data. In this study, we used SNA to describe the flow of knowledge in the knowledge co-production process of climate change adaptation.

SNA is a method for identifying the type of shared knowledge and mapping the flow of knowledge from one actor to another (Malabayabas and Baconguis, 2020). Kirchhoff et al. (2008) defined SNA as mapping and measuring relationships and processes between individuals, groups, or organizations. SNA can map the number of relationships received by each actor (density), find the central actor (eigenvector), and depict the actor's role in the knowledge flow (centrality and power). The density of a network describes the flow of knowledge in the network and defines which actors play significant roles (Chang et al., 2022). Reciprocity is a concept used to determine whether actors in the knowledge flow have reciprocal relationships (Petzold and Ratten, 2015).

The degree centrality can be viewed as a measurement of person's social activity. High degree or a high number of direct contacts, indicates a high level of social activity within the network. To calculate the degree, betweenness, and closeness centrality of the knowledge flow in a network, we used UCINET software (Analytic Tech, Harvard, USA). The formula of degree centrality is as follows (Luo and Zor, 2023):

$$Di = \sum_{j} xij, \tag{1}$$

where D_i is the degree centrality of knowledge flow network; and x_{ij} is the number of direct linkages between actor i and actor j.

The betweenness centrality describes which actor takes the role of knowledge transfer in a community network (Nabiafjadi et al., 2021). The formula is as follows:

$$Bi = \sum_{k<k} \frac{Gjk(ni)}{Gjk}, \tag{2}$$

where B_i is the betweenness centrality of actor i; G_{jk} is the number of the shortest paths between actor j and actor k; and G_{jk} (n_i) is the number of the shortest paths between actor j and actor k through actor i.

The closeness centrality reflects the actor's independence in knowledge sharing network (Luo and Zor, 2023). The formula is as follows:

$$Ci = \frac{m-1}{\sum d(i,j)}, \tag{3}$$

where C_i is the closeness centrality of actor i; m is the total number of actors within network; and $d(i, j)$ is the length of the shortest path from actor i to actor j.

4. Results and discussion

4.1. Knowledge co-production

4.1.1. Acquisition of knowledge

Farmers make climate observation based on their experience. Observations are the basis of knowledge in managing farming business. Knowledge obtained by observation is classified as tacit knowledge, which is based on experience, actions, and involvement in a specific context (Polanyi, 1966; Nonaka, 1994). Notably, the results of observations about climate change become a topic of discussion of farmers' gathering in the field or elsewhere. Aside from discussions with other farmers, the interaction between farmers and traders when purchasing production inputs or selling crops is also used to obtain information on strategies for dealing with the impacts of climate change.

Social interactions between farmers and other stakeholders create and legitimize knowledge (Nonaka, 1994; Armitage et al., 2011). These informal social interaction communities provide a direct forum for the development of new ideas and the cultivation of emerging knowledge at all levels (Nonaka, 1994; Tran and Rodela, 2019). The potential contribution of informal communities to organizational knowledge creation can be linked to the more formal concept of hierarchical structure. As a result, active interactions are created through group discussions in CFS activities. If CFS activities are carried out effectively, new knowledge related to climate change adaptation can be obtained.

Gathering knowledge about climate change impacts and adaptation strategies from farmers requires a high level of trust and partnership among activity participants. During the discussion, agricultural extension workers act as activity facilitators, encouraging farmers to identify problems based on their respective perspectives and priorities. Highly experienced farmers are more likely to have more knowledge and awareness of both climate change and other management techniques (Pandey et al., 2015). We founded that farmers understand the value of sharing their knowledge and experience in dealing with the impacts of climate change. After the meet and trust-building session, the next step is to learn about rice farming. Farmers discuss the problems they are experiencing with their farming on the meetings, including droughts, pest attacks, and floods. Farmers with more experience share solutions based on their observations and knowledge. These findings are consistent with previous research by Hein et al. (2019) that experienced and educated farmers have more accurate perceptions and knowledge of climate change adaptation.

In terms of information access, farmers obtain climate information via both formal and informal channels. Formal information channels include climate information services such as public media (TV, radio, and government). Informal information channels include market, neighborhoods, and friends. The elderly farmers explain that they get climate information from parents who more rely on natural signs than other sources. The finding of this study is consistent with previous research conducted in Vietnam (Sen et al., 2021) that information availability is one of the barriers to local community to access and use climate information. The main barriers of information availability include the quality of information and the language of information. Most farmers speak their native language (Bugis and Konjo). As a result, it is difficult for them to understand the information provided by the Indonesian media. Direct communication through CFS activities appears to be the best approach for community.

The socio-economic conditions and characteristics of farmers influence the communication media used to gain climate information. Farmers with a high level of education have broad agricultural mindset, insight, and knowledge. Education and the use of communication media are linked. Some respondents state that communication media such as interpersonal media and the Internet, are used as sources of information in CFS. The more educated a person is, the more frequently he interacts with family members and other people in his context (Stott and Huq, 2014). A farmer's willingness to interact interpersonally, in groups, and through media is reflected by communication frequency. Farmers usually communicate with close relatives or friends, and also receive information from agricultural extension workers, traders, and community organizations. We found that when farmers trust one information channel, they are more willing to pay attention to the information, more supportive of the information, and more motivated to access and use the information. This is in line with the finding of Sen et al. (2021) that farmers lack of trust in formal climate information services, due to a lack of socialized awareness of the importance of climate information. In addition, there is a lack of programs to develop farmers' ability to understand and apply climate information in practices. The lack of detailed guidance and communication leads to many difficulties for farmers to access, understand, and use climate information.

The increasing severity of extreme weather events has raised farmers' awareness of the need for more climate information. Before CFS activities, farmers rarely receive climate information from agricultural extension services or agriculture department. Television and the Internet provide information of scientific climate change adaptation strategies for young farmers. Most farmers have television or smartphone now. The more frequently farmers communicate, the more intensely they use information sources.

4.1.2. Sharing knowledge

Sharing knowledge in a management context is faced with challenges of language and knowledge documentation (Sen et al., 2021). Local knowledge is transmitted orally, while scientific knowledge is obtained textually. Farmers don't have documents related to their local knowledge, so the process of sharing knowledge in CFS activities encounters obstacles, especially when share with scientists who don't understand the local language. Scientists need translators to convey information or, otherwise, convey information directly by themselves with limited native language skills. Sharing knowledge is not optimal when farmers convey information in Indonesian. Knowledge is embedded in language, so efforts to share knowledge are complicated when there is a language barrier (Hill et al., 2020).

Farmers are highly motivated to participate in CFS activities as they gain farming knowledge form the activities. They are proud to share the local knowledge they acquired and practiced over decades while obtain more scientific knowledge. Farmers' awareness of the impacts of climate change increases their desire to find collective solutions or strategies. This is consistent with the findings of Thomas et al. (2020) that although farmers tend to stick to local knowledge, they are open to new information about climate change adaptation practices, particularly when discuss in groups.

Farmers who acquire knowledge through CFS activities share their knowledge with relatives, neighbors, traders, or other farmers through informal small discussions in the fields, markets, mosques, or in front of their homes. Female participants share their knowledge with family members, neighbors, and other women they meet at markets, mosques, or meetings of other women's organizations such as Family Welfare Empowerment. Local government officials, agricultural extension workers, and leaders of farmer groups participated in CFS activities transfer their knowledge on official meetings such as farmer group meetings and village office meetings. Farmers are willing to share their knowledge with other actors who have good working relationships with them. This finding is consistent with the previous research of Hill et al. (2020) that the desire to share knowledge is motivated by reciprocity and positive relationships with recipients; in other words, a person is motivated to help others if something is received in return. Similarly, the existing familiarity contributes to the motivation of other parties to share their knowledge. The relationship is based on trust, which influences how they share knowledge (Stott and Huq, 2014).

Non-CFS actors who have received knowledge from CFS participants also share their knowledge with other actors. Farmers are highly motivated to share their climate knowledge, indicating that they hope other farmers to have the same knowledge in dealing with climate pressures. Farmers typically adhere to experiential farming practices, but they also collectively discuss new information and technologies that affect their farming such as those related to adaptation practices to changing weather conditions. This is supported by the findings of Dasanayaka and Matsuda (2022) that farmers emphasize the need to collectively handle and share information on climate change mitigation and adaptation.

Besides, we found that traders convey the most information. Traders have many opportunities to meet with various parties when they carry out business activities, including farmers, fellow traders, and the government officials, both inside and outside their territory. Facilitated formal group discussion is an important space for interaction, but farmers are more likely to choose informal meetings to share knowledge because no one would be intimidated when discussing issues and information related to agriculture. Dasanayaka and Matsuda (2022) found that interaction space is an important component of knowledge exchange.

4.2. Social network configuration

This study maps the flow of knowledge and information related to climate change adaptation obtained in CFS activities. The degree, closeness, and betweenness centrality of the knowledge flow process and the roles of actors in the process were calculated (Table 1).

The concept of degree centrality aims to determine an actor's incoming (in-degree) and outgoing (out-degree) relationships with other actors. According to the value of out-degree centrality, the most active actors in conveying information about climate change adaptation in the knowledge co-production process are farmers participated in CFS including male and female farmers, local government officials, heads of farmer group in CFS, and agricultural extension workers (Table 1).

The betweenness centrality describes which actor takes the role of knowledge transfer in a community network (Nabiafjadi et al., 2021). The betweenness centrality values of trader and family member of CFS actor are 34.00 and 31.45, respectively (Table 1), indicating that these two are the main actors of the community network due to their ability to function as a liaison between other actors in the process of disseminating knowledge on climate change adaptation. Actors with a high betweenness centrality value, according to Chang et al. (2022), may hold authority, control social collaborations and networks, or be the center of many clusters.

The concept of closeness centrality quantifies the speed of information transmitted from an actor to other actors in the network. In-closeness represents the distance of dissemination between actors, whereas out-closeness represents an actor's proximity to other actors in the network (Dasanayaka and Matsuda, 2022). Family members and neighbors of CFS actors have the highest in-closeness values as they are closest to other actors and their roles and positions are accessible to other actors in the network, also it is convenient for other actors to communicate climate information with them. Farmers in CFS including male and female farmers, heads of farmer group in CFS, agricultural extension workers, and local government officials have the highest out-closeness values, meaning that these actors tend to reach out to other actors in social networks.

5. Conclusions and recommendations

The knowledge flow among lowland rice farmers involves various stakeholders, either direct or indirect, including farmers, agricultural extension workers, local government officials, traders of agricultural products and inputs, neighbors, and family members. These stakeholders come from both the private and public sectors, and each of them is involved in process of disseminating climate change adaptation knowledge in agricultural knowledge systems. They are involved in the creation and dissemination of knowledge through experience, observation, research, application, and policy. The findings of this study indicate that CFS is an effective medium in

Table 1
Results of Social Network Analysis (SNA) of knowledge flow on climate change adaptation in Bulukumba Regency.

Actor	In-degree (%)	Out-degree (%)	Betweenness (%)	In-closeness (%)	Out-closeness (%)
Male farmer in CFS (25)	6.00	11.00	1.85	55.00	100.00
Male farmer not in CFS (13)	10.00	3.00	0.00	91.70	40.70
Female farmer in CFS (15)	6.00	11.00	1.85	55.00	100.00
Female farmer not in CFS (10)	10.00	3.00	0.00	91.70	40.70
Head of farmer group in CFS (5)	6.00	11.00	1.85	55.00	100.00
Head of farmer group not in CFS (5)	6.00	4.00	0.00	57.90	44.00
Local government official (5)	6.00	11.00	1.85	55.00	100.00
Agricultural extension worker (6)	6.00	11.00	1.85	55.00	100.00
Trader (5)	6.00	10.00	34.00	68.80	91.70
Staff of the Meteorology, Climatology, and Geophysics Agency (MCGA) (5)	5.00	7.00	0.29	42.30	73.30
Family member of CFS actor (12)	11.00	4.00	31.45	100.00	57.90
Neighbor of CFS actor (14)	11.00	3.00	0.00	100.00	40.70

Note: The number shown in the parenthesis is the number of participants of corresponding actor type in the survey of this study.

the knowledge flow of knowledge co-production-based climate change adaptation strategy. Among all the actors, family member and neighbor of CFS actor are the most common actors in disseminating climate knowledge information and closest to other actors in the network; agricultural trader and family member of CFS actor collaborate most with other actors in the community network; and farmers participated in CFS, including those heads of farmer groups, agricultural extension workers, and local government officials are more willing to contact with other actors in the network.

An effective knowledge co-production-based climate change adaptation strategy is needed to reduce vulnerability through increased accessibility and utilization. The success of knowledge co-production is determined by the level of participation and the joint efforts between farmers and other stakeholders such as policymakers and development agencies. All stakeholders must recognize that they need each other's knowledge and benefit from participating in collaborative process.

Aside from the involvement of actors, appropriate communication channels and techniques are critical factors in facilitating the flow of knowledge from source to recipient. Communication necessitates a level of trust between the recipient and the provider of knowledge. Government and the private sector should collaborate to expand information and technology infrastructure, allowing people to access more information about climate change. More research is needed to investigate the challenges and successes of knowledge co-production in various contexts by involving larger groups of people. When there is a healthy reflective learning process and shared perspectives, knowledge co-production is successful.

Ethic statement

The interviews conducted in this study have been approved by the Institutional Review Board of the Graduate School of Hasanuddin University (2070/UN4.20.1/PT.April 01, 2021). Also, before interview, we obtained the permission from Investment and Integrated One-Stop Services Agency (No. 0322/DPMTSP/VI/2021). All participants agreed to share information and all interviews were conducted in accordance with research ethics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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