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Climate change impacts and the rice farmers' responses at irrigated upstream and downstream in Indonesia

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ABSTRACT

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1. Introduction

Climate change impact is one of the major challenges facing farmers in tropical and sub-tropical countries due to its negative impact on agricultural activities. A decrease in agricultural production has been caused by an increase in air temperature, changes in rain patterns, and extreme climates ([illegible]). According to Khan et al. (2020) the severity of droughts, storms, and floods is expected to rise as climate patterns change. Drought reduces crop yields ([illegible]), increases plant pests and diseases ([illegible], 2020), and pose a significant threat to future global food security ([illegible]).

Agriculture is the major contributor to the Indonesian economy, producing food and employing approximately 30% of the workforce by 2020 ([illegible]). However, the country usually faces the problem of reduced production of agricultural products due to climate disasters. The production of rice, which is one of the main food crops, has decreased by almost 1% in the last 3 years, leading to a decline in the National GDP by 1.26% ([illegible]; [illegible]). This was caused by rising temperatures and reduced rainfall, which affected the livelihood system, making small farmers more vulnerable to extreme climatic events ([illegible]). As a result, adaptation to the effects of climate change is required in order

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to reduce the vulnerability of their livelihood systems. Farmers implemented a wide range of adaptation measures in response to climate change conditions, such as non-farm activities ([illegible], 2021), improved seed variety ([illegible], 2021), and crop diversification ([illegible], 2022). Previous researches have found that farmers who have a good understanding and perception of climate change are more likely to choose the appropriate adaptation strategy ([illegible] et al., 20[illegible]; [illegible] and [illegible], 2021).

The concept of perception is essential to understanding and responding to climate change risks ([illegible] et al., 20[illegible]). This is formed by knowledge of the environment and involvement in the interpretation of an event or information ([illegible] et al., 2018; [illegible] et al., 2020). According to [illegible] et al. (2020) and [illegible] et al. (2021), perception is a subjective measure of a concept that is affected by demographics, social, political, and cultural factors, as well as the environment. The demographic variables and socio-economic characteristics that influence farmers adaptation decisions including education level, age, gender and household size ([illegible] and [illegible], 2021).

The factors of age and farming experience are indicators of attachment to a place for a long period, therefore, it recognizes climate change and the accumulation of local knowledge about environmental management ([illegible] et al., 2020; Habtemariam et al., 2016). The differences in the perceptions between individuals about climate change are caused by their long-term observations of some variables such as temperature and rainfall ([illegible] and [illegible], 2021; [illegible] et al., 2019).

Research on climate change perceptions has shown that farmers' perceptions and knowledge are the fundamentals for their adaptation actions to facilitate sustainable agricultural practices ([illegible] et al., 2019; [illegible] et al., 2019; Mahmood et al., 2021). Previous studies have examined the knowledge and perceptions of farmers on irrigated and rainfed land ([illegible] and [illegible], 2021; [illegible] et al., 2016; Niles and Mueller, 2016; [illegible] et al., 2020). However, there is no research on farmers' knowledge and perceptions of lowland rice comparing downstream and upstream irrigation area, causing a limited exploration of the principles in the adaptation decision-making process. Several rice fields in the downstream area of Bulukumba Regency, South Sulawesi Province, Indonesia are experiencing problems with water availability, especially when there is a change in rainfall. Irrigated rice fields in the downstream are more susceptible to drought than irrigated rice fields in the upstream area because of the limited sources of water, leading to a decrease in rice production. Therefore, this research analyzed the farmers' knowledge, perceptions, and adaptation efforts at downstream irrigated rice with a higher risk of climate change and compared to the upstream. The results of this study provide a substantive theory that conditions, actions and consequences in the context of adaptation to the impacts of climate change on the downstream and upstream.

The rest of the paper is organized as follows. Section 2 provides a review of the existing literature. Section 3 then includes a description of the study context and methodological approach. Section 4 discusses the empirical findings of farmers' knowledge, perception, and adaptation, as well as the results. Finally, in Section 5, we provide our conclusions, including policy implications, limitations, and future research recommendations.

2. Literature review

This section provides a brief overview of the existing literature on farmers' perceptions of the impacts of climate change on their farms. The importance of perceptions of climate variability and the factors that shape perceptions in the adaptation process has gained much attention since the early 1980s (Whitmarsh and Capstick, 2018). Islam et al. (2021) reported that farmers perceive high salinity as the impact of climate change, which decreases rice production in Bangladesh. Meanwhile, the majority of farmers in Pakistan experience specific and unusual climate changes in temperature as well as rainfall intensity in several regencies of Khyber Pakhtunkhwa Province ([illegible] et al., 2021). According to Guo et al. (2021), most farmers in China perceive that climate change is occurring and has an impact on agricultural products.

The literature review conducted by [illegible] et al. (2022) reported that research on perceptions of climate change impacts was generally dominated by southern and eastern African countries (Ethiopia, Kenya, and Tanzania) and South Asia (Bangladesh, Nepal) with few cases from the northern, central, and western regions. This demonstrated that there was still a lack of knowledge on how Indonesia, particularly the vulnerable smallholder farmers, perceived the effects of climate change. Farmers' perceptions of climate variability can significantly impact their ability to cope, mitigate, and adapt. Therefore, this research aims to provide an overview of the perceptions of upstream and downstream irrigated rice farmers on the impact of climate change.

According to Taylor et al. (1988), the four coherent elements, that can influence farmers' perceptions of climate change include experiences, memories, expectations, and definitions. Meanwhile, experience serves as a benchmark for assessing future environmental expectations. Perceptions may be impacted by prior negative climate change experiences (Escarcha et al., 2020; Taylor et al., 1988). Perception is a subjective phenomenon because different people in the same area may construct different perceptions about climate change. The perceptions they construct depend on individual characteristics and geographic variations (Habtemariam et al., 2016).

Farmers' perceptions of climate variability are very complex and include various psychological constructs such as knowledge, beliefs, and attitudes. These factors are influenced by the characteristics of the farmer's household, past experiences with the local climate, particularly the impact of climate change on agricultural productivity, socio-cultural context, and geographical conditions (Whitmarsh and Capstick, 2018). Based on a previous report, it was discovered that education, farm income, and agroecological influence farmers' ability to understand climate change (Gunamantha et al., 2016). Climate change is communicated through mass media, interpersonal communication, formal learning, and other non-formal channels (Whitmarsh and Capstick, 2018). Therefore, farmers can discuss their knowledge and experiences with family members, neighbors, and local extension staff, or participate in different membership groups.

Assessing farmers' perceptions of climate variability can help identify entry points for developing pro-farmer climate policies, mitigation, adaptation, and sustainable agriculture strategies ([illegible] and [illegible], 2021). In Bali, farmers perceive the impact of climate change in form of high temperatures, as well as decreased and erratic rainfall. Therefore, they prefer adaptation strategies by cultivating other types of crops, changing planting times, adjusting crop management, and working off-farm (Gunamantha et al., 2016). Several factors such as socio-economic dimensions, information channels, institutions, and cultural contexts influence farmers' perceptions, mitigation, and climate adaptation strategies (Bohensky et al., 2016; Khan et al., 2020; Mahmood et al., 2021). Abid et al. (2015) discovered that information about weather forecasts is a significant predictor of perceptions and adaptation to climate change. In India, the factors that are significantly correlated with the preference of farming households in adapting to the impacts of climate change include the age of the family head, education, gender, assets, group membership, and use of extension services (Funk et al., 2020). Rice farmers in the Philippines build their local knowledge system about weather and climate by reading the weather based on the interaction of clouds, sky, wind, sun, or rain, and also insect behavior (Ruzol et al., 2021).

Investigation of perceptions of climate change impacts is faced with various options regarding methodological approaches and research traditions. According to the literature study by Karki et al. (2020), perception research does not employ a standard methodology. This is due to the fact that some publications used mixed methods, while others took a qualitative approach or applied a quantitative strategy. Case research of the perception of rice farmers in Bali is presented with descriptive

statistics, while the factors that influence farmers' perceptions and their adaptation strategies are analyzed using a econometric approach with binary logistic regression (Gunamantha et al., 2016). However, less attention has been paid to qualitative approaches, specifically grounded theory which aims for broader theoretical development. As a research approach, grounded theory is based on the assumption that social science theory can be systematically constructed in social settings (Glaser and Strauss, 1967). Since the qualitative approach and the desire to build theoretical propositions based on farmers' perceptions of the impacts of climate change, the grounded theory seems appropriate for this research.

3. Methodology

This research was carried out in Bulukumba, which is among the regencies with a high Disaster Risk Index, especially drought. Therefore, it requires special attention to overcome the impacts of climate change (National Disaster Management Agency, 2018). The focus area was in Gantarang (Figure 1), the largest rice-producing sub-district with the biggest irrigated rice fields in Bulukumba Regency. In 2020, the total population in Gantarang Sub-district was 81,170 people, and approximately 50% are farmers (Statistics Indonesia Bulukumba Regency, 2021), with an area of 8,011 ha, categorized as irrigated rice fields (BPS Statistics of Bulukumba Regency, 2020). The average temperature ranges from 23.82 °C to 27.68 °C with a humid or slightly wet climate. Bulukumba Regency is in the eastern sector, where the *gadu* (dry) season is between October and March, while the *rendengan* (rain) season is from April to September.

The location was purposively selected in the Bettu Irrigation Area that irrigates 1917 ha of rice fields with different village characteristics. This was carried out based on the location and vulnerability level due to the impact of climate change. Dampang, Barombong, and Paenre Lompoe villages are upstream areas, while Bonto Sunggu and Bukit Tinggi villages are downstream areas. However, the rice fields in the irrigation areas usually experience drought due to a lack of water.

The data used were collected through interviews with farmers selected by snowball sampling of those with over a decade of farming experience who identify changes over the last few decades. A total of 55 farmers were interviewed to obtain a saturated level of data because no new information was obtained from the results of subsequent interviews (Corbin and Strauss, 1990). The interviews were conducted in-depth and semi-structured to invite farmers to openly speak about their livelihood, agricultural activities, perceptions, knowledge, and adaptation efforts to climate change. It was carried out using two languages, namely Indonesian and Bugis (local language), which were later translated into Indonesian. All questions were asked in an open-ended format, which allows discussions with farmers to run smoothly and avoid the dominance of researchers. Interviews with additional parties that were specifically chosen based on data from farmers were also done. This included three representatives from the irrigation officer, the extension agent, and the village administrator.

In this research, the grounded theory method was used to guide qualitative analysis, where the process of data collection, analysis, and theory building was carried out iteratively to facilitate the formation of new concepts (theories) (Corbin and Strauss, 1990). There are three stages of codification, namely open, axial, and selective coding. The initial codification was used to examine the statements of the sample during the interview. Subsequently, the information was segmented related to the research question and labeled with certain concepts. This was followed by axial coding to organize the initial concepts that have been made based on the relationships between these categories. In the last stage, the formulation was carried out on a statement that is more

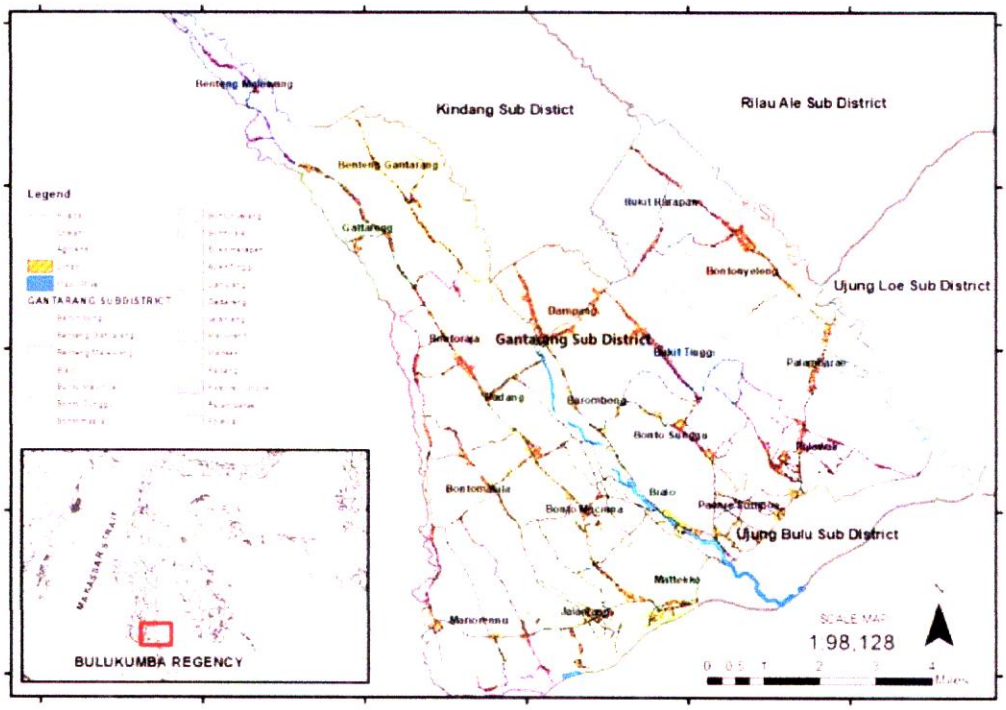

Figure 1. Research location in Gantarang sub-district, Bulukumba Regency.

abstract and general, which can accommodate all the core concepts collected in the axial coding stage (Strauss et al., 2008).

According to Corbin and Strauss (2008), theory development in grounded theory research is structured around the linkages between conditions, actions/interactions, and consequences. The hypothesis statement developed as a dynamic reference in data collection for this study is that there is a relationship between climate change conditions, farmers' adaptation actions to climate change, and reduced vulnerability of farmers to climate change impacts in the context of upstream and downstream.

Regarding ethical considerations, this research has been approved by The Institutional Review Board of the Graduate School of Hasanuddin University (Approval No. 2070/UN4.20.1/PT.01.04/2021, 28th April 2021). Before interviewing participants, the researchers obtained permission from the relevant government office at the research site (Approval No. 0322/DPMTSP/VI/2021, 15 June 2021).

All participants were given information about the study's objectives, benefits and potential risks. Prior to conducting interviews, participants provided written informed consent. The participants participations were entirely voluntary and anonymous. All data and information obtained from participants were kept strictly confidential and no one would be able to access to their identities and opinions.

4. Results and discussion

The results are divided into three categories, namely (i) characterization of farmers' knowledge about the phenomenon of climate change, (ii) perceptions of farmers on the impacts, and (iii) actions taken by farmers to overcome the impacts of climate change.

4.1. Characteristics of farmers' knowledge about climate change phenomenon

Farmers gain knowledge about the impacts of climate change from two sources, namely personal experiences, and external information. The characteristics of this knowledge are stated in Table 1.

4.1.1. Farmer knowledge from personal experience

The majority of farmers in the downstream and upstream areas had not heard of climate change in a scientific context, but they were aware based on their observations and experiences. From the interviews, several indicators of events on their understanding of climate change were discovered. It was also shown that the farmers estimated variations in weather patterns based on interpretations of changes in animal and plant behavior, as well as solar system phenomena.

Farmers who were 45 years and above with more than 20 years of experience understood climate change through natural signs based on the difference in the weather condition within 20 years. This information was implicitly presented from the statements of the farmers as stated below.

> I have not heard of the term climate change, but there are several changes in the weather conditions. It is no longer the same as in the past because there are always problems with the weather, especially the long dry season, whose duration can not be predicted (T, 53 years old, Farmer in downstream).

Moreover, one of the indicators of their understanding of climate change impacts was the phenomenon of major disasters or extreme climates. The statement below was conveyed by one of the farmers through an interview.

> I feel the weather has changed in the last 10 years. There was a flash flood in 2018 that damaged the irrigation wall. Droughts, on the other hand, are more common. (T, 49 years old, a farmer in upstream).

The farmers who were interviewed, especially in the downstream, felt that long drought was the most frequent climate disaster they experience. The elderly farmers stated that extreme climate events were experienced in the past 50 years, but only occurred once in a decade. Therefore, they were considered that the incident as a normal occurrence in a certain period. This was conveyed by the following farmer.

> The long dry season occurred in 1971 when I was still in elementary school. Subsequently, the next incident was in 1982, and the 1990s. It did not happen continuously, therefore, it is not a problem. (M, 60 years old, Farmer in downstream)

Farmers experienced extremely high temperatures throughout the prolonged summer months, which was distinct from the previous decade. This was stated by the following farmer.

> During the dry season, the temperature also increases and the weather becomes very hot. (R, 44 years old, Farmer in downstream).

One of the irrigation officers stated that the water flow was reduced due to the long dry season. He perceived an increase in water management operations as a sign of climate change.

> The most extreme phenomenon was the drought in 2019 because we were unable to regulate the use of water for farmers' fileds. As irrigation officers, we must communicate the problem to farmers and extension workers in order to find a solution. (T, 46 years old, Irrigation Officer).

Table 1. Characteristics of farmers' knowledge on the impact of climate change

Knowledge Source	Climate Change Impacts	Indicators	Number of Respondents (%) (n = 55)
Personal Experiences	Natural phenomenon and the movement of the solar system	• Hard to predict the weather • Big disaster • Extreme climate • High temperature • Seasons shift • Reduced water flow	45
	Animal Behavior Pattern	• Dog droppings on the rice fields signify the coming of the rainy season • Rat attack on young rice plants is a sign that the rainy season will be long	24
	Plant Behavior	• Poor growth of bamboo shoots is a sign of a long dry season • Banana shoots growing close to the mother are a sign of a long dry season	31
External Information	Communication media (Television, Internet)	• Information from the Meteorology, Climatology and Geophysics Agency (BMKG)	47
	Other parties (extension officer, other farmers)	• Discussion about the weather with farmer groups • Discussion with other more experienced farmers	53

Interviews with farmers showed that farmers' knowledge about the impacts of climate change also comes from animal behavior patterns, including rats and dogs. The statements of the farmers are presented below.

> Mice attacks at the start of the planting season are a sign that the rainy season will last longer. (T, 62 years, Farmer in downstream).

> Several dog droppings on the rice fields also shows that heavy rain will come (M, 57 years old, Farmer in upstream).

The indicator of extreme climate changes was also observed from plant behavior such as bananas and bamboo. This is shown in the following statement.

> A long dry season is expected when the bamboo shoots are not growing properly. For banana plants, the growth of the saplings closer to the mother shows that there will be a long dry season. When these signs are observed, the farmers must immediately start planting (K, 53 years old, Farmer in downstream).

The results showed that the farmers built knowledge about climate change based on their experienced, observed, and practiced through personal experiences, others, or the environment. This is in line with the previous research, where climate change knowledge is embedded in the context of one's beliefs and practices (Bohensky et al., 2016). Farmers' knowledge of climate change from personal experience is informal or local. It has been recognized as the main source of insight scientific disciplines such as traditional medicine ( ), agroforestry ( ) ( ), resource management (Jones et al., 2018) natural disaster management ( ). Furthermore, their knowledge and skills on the phenomenon of climate change are sourced from observations and experiences over a long period, which is passed to the next generation through oral tradition (et al., 2020; et al., ; et al., ; et al., ; Sullivan, and Ingram, 2020; et al.,).

Additionally, it was shown that farmers in the older age groups still rely on local knowledge to assess climate change. This is in line with et al., 2020) researcher in Vietnam, who stated that current local knowledge is better known and used by elders, while younger people are attracted to modern scientific and technological knowledge.

Moreover, one source of knowledge about climate change that is still used by farmers in the Bulukumba Regency is the traditional calendar. Currently, farmers in the research location and other areas such as Yogyakarta, are aware of the differences between the instructions in the traditional calendar system and the perceived climate change. Subsequently, they begin to question the effectiveness in changing situations (et al., 2014).

4.1.2. Farmer knowledge from external sources (external information)

Generally, young farmers and group leaders learn about effects of climate change from external sources, such as the media and other parties. Climate information based on scientific knowledge is obtained from the mass media through television and the internet. This was in line with a statement by the following farmers.

> I know the term climate change from television, which relates to unpredictable weather, floods, or droughts. (R, 37 years old, Farmer in downstream)

> I have read about climate change on the internet. (S, 35 years old, a farmer in the upstream).

The group leader who often communicated with agricultural extension workers or attended meetings at the regional level with related agencies obtained more information about climate change than other farmers. This is stated below by the following farmers.

> We have heard the term climate change through PPL (Field Agricultural Extension Officer) during training last year. It is currently happening, which makes it difficult to obtain water (A, 47 years old, a farmer in the downstream).

An informal meeting of farmers and stakeholders was the most popular venue for the exchange of knowledge on climate change. This included the *Tudang Sipulung*, which was routinely carried out at the beginning of the planting season. Through gatherings of the farmers, the government, and stakeholders, the Bugis Makassar community used this practice to schedule planting, harvesting, and other agricultural activities. The following was a farmer's reaction to the event.

> *Tudang Sipulung* event discussed climate change in the last 2 years. According to the Department of Agriculture, we must be aware of these changes because there could be a long drought, flooding, or pest attack. (B, 45 years old, a farmer from downstream)

The results of the meeting between the farmer group leaders at the regional or sub-district level, such as the impact of climate change, are socialized to members. This was stated by the following farmer.

> I have heard the term climate change from fellow farmers and the leader. During this period, we met some farmers, sat down, and talked about last year's drought. The climate changes bring differences in farming methods and the natural signs that are usually observed when dry rain is about to fall (S, 48 years old, a farmer in upstream).

Generally, some information flows occurred when farmers gathered, through incidental or formal meetings with extension workers and group leaders. The results showed the important role of informal social networks in the process of exchanging information on climate change. They meet spontaneously and communicate with one another for an unlimited flow of information. When farmer group leaders shared scientific knowledge about climate change with their members, old farmers with extensive farming experience shared their local knowledge. This included knowledge passed down through generations to predict the occurrence of extreme weather events.

The interviews also showed that farmers with access to external sources of information had more knowledge about climate change. Moreover, social networks play a very important role in shaping farmers' knowledge and perceptions on ecology and climate (Bohensky et al., 2016). This is in line with (et al., 2020) who reported a significant relationship between access to external information and farmers' knowledge on climate change. Previous research by et al., showed that the role of mass media, namely television and internet, as well as access to extension services affected the knowledge and perceptions of farmers on climate variability, thereby, increasing their awareness of its impact on agricultural production.

4.2. Farmers' perceptions on the impact of climate change

The interviews with farmers in Gantarang Sub-district showed that there were differences in perceptions between farmers whose rice fields were in the upstream and downstream, especially climate change impact on farming and predictions of future consequences. A summary of these differences in perception is shown in .

4.2.1. Farmers' perceptions on the causes of the climate change

Based on observations over a long period, farmers in upstream and downstream were aware of climate change. However, they generally stated that the cause of climate change is God's will. And as a consequence of human actions that are not in line with religious guidance and cultural traditions of the Bugis Makassar community. The statement from one farmer was given below.

> Perhaps it is God's will. Based on the knowledge of old people, when rice fails, it means that there are people in our village who violate

Table 2. Farmers' perceptions on the impact of climate change.

Perceptions		Location of Rice Fields from Primary Irrigation Channels		
	Upstream	Number Of Respondents (N) (n = 25)	Downstream	Number of Respondents (N) (n = 30)
Causes of Climate Change	God's will	70	Natural factor	43
	Deforestation	30	Barren forest	20
			Land conversion	37
Impact of Climate Change for Farming	Increased pest attack	55	Drought	47
	Reduced production	30	Reduced water flow	30
	Declined rice quality	15	Reduced production	9
			Increased pest attack	7
			Declined rice quality	5
			Crop failure	2
Impact of Climate Change for Socio-economic aspects of Farmer household	Malnutrition	57	Family food Consumption Decreased	25
	Health Problems	43	Working outside the village	25
			Working in the off-farm sector	20
			Selling asset	13
			The kinship bond strengthened	17
Prediction of Future Impact	The weather will be more erratic.	83	The weather changes will get worse.	80
	Stay as it is, sometimes it's good, sometimes it's not.	13	The weather will be more erratic.	20
		4		

religious rules. We need to change our behavior and beg God's pardon (A, 60 years old, a farmer in the upstream).

The perception of farmers in the downstream on the causes of climate change was more diverse than those in the upstream. Although many older farmers attributed the phenomenon to moral and religious issues, young ones generally perceived that it was a consequence of the nature exploitation by the community.

It was also discovered that farmers whose rice fields often experience drought had higher concerns about the impact of climate change, as shown through discussions with other parties. They understood the function of forests and the negative impacts of land conversion such as the conversion from forests to residential areas. The statement by one farmer was shown below.

> Building houses, ponds, rice fields, or gardens require the felling of big trees (AR, 49 years old, a farmer in downstream).

A farmer stated that climate change was due to the reduction in a forest area that serves as a water buffer.

> In my opinion, climate change is the reduced water buffer forest, therefore there will be flooding when it rains. During the dry season, the water runs out quickly, unlike decades ago, even though it has not rained for a long time, there was still water in the river (H, 69 years old, a farmer in the downstream).

Based on the interview, the negative impacts forced farmers to better understand the phenomenon. The research by Ayanlade et al. (2021) in Iran also showed that people were more conserned when they felt the impact of climate change.

Farmers' belief, according to Bohensky et al. (2016), is closely related to their perception of the impact of climate change. Farmers who have personal experience with climate change believe it is a natural process. Meanwhile, the understanding that climate change is caused by humans is based on information from the media and other parties.

4.2.2. Farmers' perceptions on the impact of climate change for farming business

Farmers in the upstream and downstream areas have different perceptions of the impact of climate change. Meanwhile, those in Dampang Village, where the irrigation center is located, stated that the climate changes did not significantly affect their farming business.

> We do not feel the climate changes here, because water is always available (H, 55 years old, a farmer in the upstream).

Farmers in the upstream considered that climate changes did not significantly affect their farming, because they used the drought as an indicator. This shows that the most important impact of climate change for upstream farmers was drought. Similarly, farmers' perceptions of the drought are based on the research in several regencies in South Sulawesi Province. Research by Nurlatifah et al. (2021) discovered that the increase in temperature and drought is mostly caused by climate change.

Meeting the water needs for rice fields in the downstream has been challenging due to the drought. The following was a statement from a farmer.

> We have not received water during the dry season twice. There is irrigation station but no water (A, 59 years old, a farmer in the downstream).

When a long drought occurred, they could not prepare their land for the next planting season. The long dry season causes a decrease in water flow, which reduces agricultural production and causes crop failure. This was conveyed by the following farmer.

> There was no water in my rice field for two or three days; there is irrigation, but my ricefield is far from the station. Last year, the water was good, however, the condition was different from the past two years. Sometimes we can harvest or have no proceeds. Usually, the land is large but there is no yield, or it can reduce by 50%. This is comparable to the situation in 2019, when many people did not harvest the crop. (MS, 58 years, a farmer in downstream).

Farmers in upstream and downstream believed that an increase in pest attacks was another factor contributing to the decline in rice production. This was conveyed through interviews.

> The pest which is widely known as mate mappong ase, causes the rice leaves to turn yellow, shoots wither, and empty the fruit. It often occurs in the dry season (S, 65 years old, a farmer in the downstream)

Farmers in upstream were more concerned to the pest attacks than by reduced water supply during the long drought. The following was a statement by a farmer.

Pests are increasing, especially if crops are planted three times per year. The number of harvests is reduced when blast disease attacks (J, 50 years old, a farmer in the upstream).

The findings of this study, which showed that the upstream farmers with good irrigation facilities were less affected by rising temperatures and drought, were consistent with previous research ( ) who stated that irrigation infrastructure can cause cooling of the soil surface and air temperature. However, this did not apply to rice farmers in the downstream area.

4.2.3. Farmers' perceptions on the impact of climate change for socio-economic aspects of farmers' household

Apart from farming, farmers also perceived the impact of climate change through the occurrence of food insecurity, malnutrition, health problems, unemployment, migration and decreased income and ability to save. Food insecurity was a major impact of climate change-induced drought. Due to reduced yields during the long dry season, smallholder farmers were experiencing a serious cycle of food insecurity. When faced with this situation, the most common strategy used by households was to reduce the amount of food consumed by family members or to switch their diet from rice to instant noodles. A housewife stated that:

"Crop yields have decreased over the last ten years, making it difficult to manage money for kitchen expenses: if we can't afford to buy fish, we only eat rice and vegetables" (M, 49-year-old housewife, in the downstream).

Female respondents reported that climate change increased the risk of the nutritional status in the family as stated below.

During a long dry season, rice yields decrease, which reduces the budget for buying daily needs. Therefore, children are compelled to eat instant noodles only when there are no more fish buyers (N, 40 years old, a female farmer in the downstream).

Since the female respondents were tasked with meeting daily food needs of the families, they were mostly concerned about the impact of climate change.

Farmers reported that they made various efforts to earn additional income when facing food shortages. Farmers who were experiencing drought and low yields in their rice fields decided to leave their villages and migrated to the cities to find of alternative livelihoods. According to the following farmer:

"We have to leave the village to find work elsewhere, usually in the city as a mason or carpenter." (A, 39 years old, farmer from the downstream area).

Furthermore, farm households were sometimes forced to sell their assets in order to meet their daily needs. This strategy caused a decrease in the number of farmers' assets when facing the climate crisis. The following farmer's statement demonstrated this.

"I once sell a cow after experiencing a decrease in yields from the fields; my wife is required to sell the gold" (A, 58 years old, farmer in the downstream area).

Farmers reported that because of the temperature change and the unpredictable schedule of the rainy and dry seasons, family members frequently suffered from illnesses such as itching and flu fever. The farmer expressed this in the following manner.

"As the weather warms and the air becomes dryer and dustier, many children experience itching" (S, 40 years old, a housewife in the upstream).

Farmers in the study area perceived the impact of climate change as an opportunity to work together and work collaboratively. During a long dry season, they volunteer to assist farmers whose fields were suffering from drought, either through material or labor assistance. This was stated by one farmer.

"I am grateful because my neighbours and farmer friends help when the harvest fails, either with seeds or with loan money." (R, 56 yaers old, farmer from the downstream area)

Farmers' solidarity in dealing with the effects of climate change strengthened their bonds. The highly valued social relationship with their neighbours and relatives in terms of sharing information, knowledge and experiences. Sharing activities among farmers without any time or place limitations strengthened the adaptive capacity of households. Farmers' social networks not only provided access to information, but also allowed for the exchange of solutions that assist farmers in reducing vulnerability.

4.2.4. Farmers' perceptions of predicting the impact of climate change for farming businesses in the future

Farmers were disturbed by the impact of climate change, however, those in two different locations were unable to predict the future condition. They only relied on God to have a favorable climate in the future for their farming.

I do not know whether the future condition is the same or gets worse. However, with proper management and effort, we should rely on God. The important thing is that we have worked, there is God who manages it (K, 58 years old, a farmer in the upstream).

The statement above showed the powerlessness to face the impacts of climate change. However, farmers with external sources were motivated to think about predicting future impacts.

In my opinion, this situation will get worse in the future due to climate changes. Because since the last 10 years, the climate is becoming more unclear, with a decrease in rice production. Farmers should have other businesses. Then we should be aware of the state of the government, where the lack of fertilizer is caused by the government who is taking care of the COVID-19 pandemic (S, 55 years old, a farmer in the downstream).

The bad experience with climate change caused farmers to think more criti and act anticipatively for the future. stated that the availability of extension services and access to other information services increased farmers' awareness to act adaptively. With a fairly high intensity of meetings with extension workers, the farmer group leaders, young and old, had sufficient scientific knowledge to perceive the impact of c ate change and prepare for anticipatory steps.

An increase in the awareness of climate change led to a greater level of concern, which positively affects farmers' preparation. Research showed that farmers in Africa perceive greater impacts climate change in the future, particularly the problems of floods and hurricanes. However, farmers in Bulukumba Regency have started thinking about anticipatory measures, while those in Africa had no plans to deal with the growing impact of climate change in the future.

4.3. Farmers' actions in facing the impact of climate change

Farmers in all areas have experienced climate change and extreme events, especially an increase in temperatures, shifting seasons, and decreasing rainfall intensity that significantly affect their farming businesses. They resp to these impacts through various efforts to adjust farming activities based on their perceptions and knowledge. A summary of the differences between upstream and downstream farmers is shown in Table 1.

4.3.1. Farmers' actions in facing drought

The long drought is most often felt by farmers in the downstream, especially in Bukit Tinggi Village. Farmers made several efforts when

Table 3. Farmers' actions in facing the impact of climate change.

Farmers Perception/knowledge	Actions			
	Downstream	Number of Respondents (%) (n = 25)	Upstream	Number of Respondents (%) (n = 35)
Reduced water discharge/Drough	Utilizing other water sources	47	Regulating Water Usage	100
	Regulating water usage	28		
	Adjusting the planting schedule	20		
	Changing rice varieties	5		
Decreased production/crop failure	Growing horticultural crops	40	Growing horticultural crops	36
	Looking for other sources of income	30	Looking for other sources of income	28
	Looking for a loan	30	Looking for a loan	27
	Farm Insurance		Farm Insurance	9
Increased pest attack	Spraying	35	Spraying	48
	Adjusting the planting schedule	33	Adjusting the planting schedule	32
	Application of local knowledge	14	Planting with the Salibu system	20
	Using pest-resistant varieties	8		

irrigation experienced a decrease in water discharge due to the long dry season, including using alternative water sources. The existence of rivers or tributaries around the rice fields also helps the farmers to irrigate their fields. A farmer stated as follows.

> When water is difficult to obtain, we use a water pump from the river. Each farmer buys one and there is also a group of 4–5 people. We bought the machine in 2006 and use it every year because it is always hard to get water. Consequently, costs increase due to the use of machines (I, 38 years old, a farmer in the downstream).

The use of river water to irrigate rice fields was a solution to stabilize rice production. Farmers with large financial capital could afford to buy their pumps and pipes. However, for smallholders, the use of alternative water sources to meet the water needs of their paddy fields carried costs that should be borne. This sometimes made them obtained loans from relatives or other farmers. This was reported by the farmer in the following statement.

> Based on the credit facilities for farming, I usually take loans from my family because it can be returned any time, by only relying on the trust principle. During the harvest time, we also give the yield to the family as an appreciation (T, 47 years old, a farmer in the downstream).

Additionally, during the protracted dry season, farmers used water reservoirs to retain extra rainwater for use in irrigating rice crops. This facility was a government aid for farmers whose rice fields were vulnerable to drought. This quantity, meanwhile, was relatively small in comparison to the area of rice fields, which frequently experienced drought. The following is a statement from the farmer. One of the extension officers stated that the number of available reservoirs was still insufficient due to the limited government budget for the procurement.

> Government programs or assistance related to climate change adaptation efforts are adjusted to the budget. This includes the budget allocated to the pond, which is above IDR 100 million in one year at most five or six per district (HH, 40 years, Field Extension Officer).

Regulating the use of water through a rotating system was another effort made by farmers, both irrigation and pumped river water. Farmers in the upstream area utilised irrigation water first when the water discharge decreases. This was stated by the head of the Water User Farmer Association (P3A) as follows.

> The solution is to rotate the water once in four days, where the fifth day will be given to another. The upstream farmers use water before the downstream because they consider as the owners. But under certain conditions, it is also normal for us to give the worst one first when we can not stand it for one week (M, 55 years old, Head of P3A).

The party with a very influential role in regulating water usage was the water user officer. Apart from understanding the process of maintaining sluice gates, the officer should be respected and hade the ability to control farmers. However, one of the officers stated that sometimes they face a dilemma, especially for farthest rice fields from secondary or tertiary irrigation canals. Therefore, there should be sacrifices, where rice fields that are far from water sources are abandoned.

The results showed that the social network context was crucial in measuring the adaptability of farmers through trust, communication, and support in the adaptation process. This was reflected in the behavior of farmers who entrusted adaptation strategy decisions to respected people and prefer loans from relatives or other farmers because of building social capital based on mutual trust and adherence to norms (Neef et al., 2018; Sumane et al., 2021). This is in line with the research in Fiji showed, where people can rebuild residential facilities damaged by floods (Neef et al., 2018). Through a network of trust, farmers can improve their adaptability and overcome the impacts of climate change by accessing loans, information, and mutual assistance efforts (Bott and Braun, 2019).

4.3.2. Farmers' actions in facing reduced production

The cultivation of secondary crops and horticulture was an alternative to get other income, especially when there was a decrease in rice production due to the long dry season. The crops most often planted are watermelon, cucumber, and corn. This was conveyed by the farmer through the following statement.

> The planting is carried out twice, interspersed with short-term horticulture, namely watermelon, cucumber, and corn. This type of plant does not need water, and the price is pretty cheap. The yield can be used to meet the children's needs, especially when the rice production also decreases (M, 52 years old, a farmer in the downstream).

Farmers can dealt with the problem of water shortages by selecting the types of horticulture that did not need a lot of water in the cultivation process. They felt financially secure because there was an alternative income from the sale of secondary crops and horticulture. This effort increased their resilience when facing the impacts of climate change.

Meanwhile, farmers who had assets other than rice fields were also searching for alternative incomes through the cultivation of plantation crops, livestock, and non-agricultural activities (non-farm activities). This was further described by a farmer as stated below:

> Farmers are always looking for alternatives because rice yields can no longer be expected. Therefore, some rear cows, masons, or gardening. For me, cloves are the same as cocoa, but they are good (M, 61 years old, a farmer in the downstream).

Farmers have implemented various strategies simultaneously to deal with the impacts of climate change. Moreover, the decline in rice

production raises the awareness to carry out financial diversification strategies based on their assets and skills. Those with large agricultural land have a greater ability to deal with the impacts of climate change because they produce several commodities. As a result, even if a commodity's production declines, farmers can still survive on the yields of other commodities that are unaffected by climate change.

The adaptation level is also determined by the skills possessed by farmers. This is shown by some farmers, especially smallholders or sharecroppers, who use their spare time to become masons or carpenters in villages that are still close to their homes. In India, it was reported that migration to cities in search of alternative livelihoods has a significant relationship with marginal farmers with small land ( ).

Several farmers stated that the agricultural extension program had introduced an insurance program, which has been used by some groups of farmers. However, they have a wrong perception of the insurance program because the premium payment process does not match the expectations of farmers who experience crop failure.

4.3.3. Farmers' actions during the increased pest attacks

Farmers in Gantarang Subdistrict perceive that increasing temperature and decreasing water discharge cause an increase in pest attacks. Meanwhile, the pests that often attack rice crops during climate change are rats, brown planthoppers, and blast.

Therefore, various efforts are made to overcome pest attacks on their farming business such as the development of a planting schedule made by farmers who are 50 years old and above. This was further explained by a farmer in the statement below.

> Scattering should be carried out on the fifth, no later than December 15th. After this date, the plant only becomes caterpillar food because it is the time for them to eat. Similarly, the rats' mouths are wide open to eat our rice (S, 53 years old, a farmer in the upstream).

It is believed that a planting schedule can overcome pest attacks. However, the effort is very dependent on the availability of water, which requires cooperation and cohesiveness from farmers with close rice fields to make planting schedules simultaneously. A farmer explained this in the following statement.

> The planting schedule depends on the water availability. The same planting schedule is necessary to prevent pest attack. The availability of tractors in the fields shows that the water is already available and the farmers simultaneously start planting. Information about the water availability is spread only by word of mouth (T, 65 years old, a farmer in the downstream).

Farmers also apply the habits of the old farmers who avoid planting schedules during the full moon. This was stated by the farmer in the following statement.

> The past teaching that is still being used is the planting schedule, for example, do not start planting on a full moon to avoid damage. According to old people, at this time, pests from the ground come out. Then it is estimated that the rice is booting during the half-moon, not the full time, hence, the rice will not be affected by stem borer pests (T, 66 years old, a farmer in the downstream)

The system for determining the planting schedule to avoid pest attacks is becoming difficult to implement. This is because of the problem of water availability that should be another consideration. Therefore, farmers make other efforts to overcome pest attacks on their rice plants. This was also explained in the following statement from a farmer.

> When we use poison, the money is not enough because the price is expensive. We commonly purchase grass poison, but others are natural. I use red ants and brown sugar as their food to catch the rats into the hole. The rats will automatically run away, the babies will die and leave the hole. For caterpillar pests, old people used tobacco soaked in water and sprayed. Meanwhile, for rice bugs, shrimp paste or coconut fiber are put on the ends of the sticks to gather the pests. I learn this method from old people. (A, 49 years old, Farmer in upstream).

Based on the interview, it was discovered that the efforts taken by farmers are also dependent on their financial capabilities.

Generally, young farmers do not know traditional pest management methods, they use the easy way, namely poison. However, some young farmers have a bachelor's education background and learn a lot from the internet. They apply a cropping pattern with the Salibu system (Salin Ibu) because it was considered the best solution for the current situation.

> There are only two farmers that applied Salibu or Salin Ibu system. I learned from the internet and try the system. This is because it is easy to maintain and can save water up to 50%. This system is also pest resistant because I have never used pesticides and have practiced this for 4 years. I usually teach other farmers, but they are afraid of rat attacks, although with the crucifixion system we can avoid rat attacks. The harvest schedule is in the middle of the 10th month, while the rat pest attack usually occurs in the 11th month (H, 47 years old, Farmer in the upstream).

Young farmers and group leaders used pest-resistant types of seeds to prevent a decrease in production due to pest attacks The following was a statement by farmers regarding this matter.

> In the past, I used Ciliwung but now turning to Cikilis. Cikilis is resistant to disease, but the harvest is relatively long, namely 100 days. When the water supply is good, the yields are good and the scales are also heavy. The rice plants in the mature phase should be kept inundated, or the results can be bad. (M, 53 years old, Farmer in the downstream).

The results showed that farmers in Gantarang Subdistrict apply pest management practices in lowland rice, based on their experience, information, and financial capabilities. An increase in attacks of rat pests, brown planthoppers, and blasts reported by rice farmers in the Bulukumba Regency also occurred in the Bone and Kendari Regencies due to changes in temperature and rainfall (;). This is consistent with the findings of ( ), who discovered that plants under drought stress are more vulnerable to pest attacks due to decreased production of secondary metabolites with a defense function.

The planting schedule system to avoid pest attacks was practiced by farmers in the research area and Guatemalan farmers. The farmers start planting corn in late March or early April to avoid insect damage. This is because they assumed that planting earlier or later than the schedule allows pests to attack their crops ( ).

4.4. Context of climate change, farmers' adaptation actions and their outcomes

The results of this study provided the basis for a grounded theory regarding the differences in the responses of rice farmers in the downstream ( ) and upstream ( ), in terms of context, causal conditions, action/reaction and consequences of climate change impacts (see).

Conditions that caused the occurrence of incidents or events that cause the emergence of phenomena are referred to as causal conditions. Farmers in downstream irrigated areas perceived water shortages and rising temperatures as causal conditions for the impact of climate change, where extreme climate events were increasingly being felt in the last decade. Meanwhile, farmers in upstream irrigated areas perceived pest explosions as significant evidence of climate change. Farmers' perceptions of the causes of climate change differed in upstream and downstream, indicating that, while rainfall patterns and temperatures tend to be similar, downstream areas felt a greater impact of climate change due

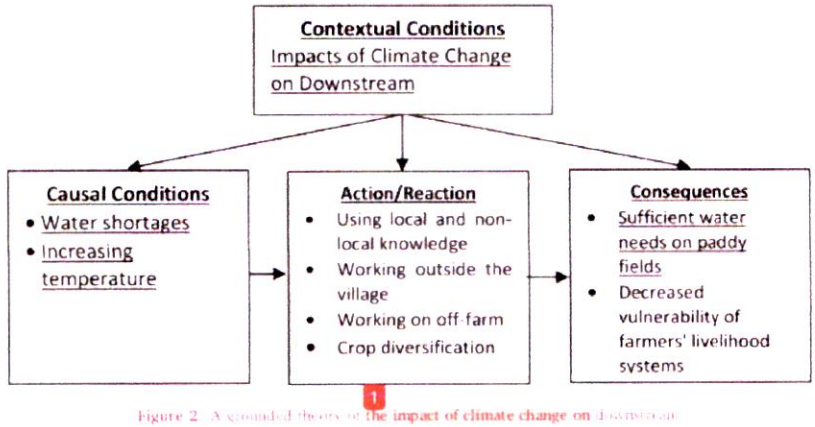

Figure 2. A grounded theory of the impact of climate change on downstream.

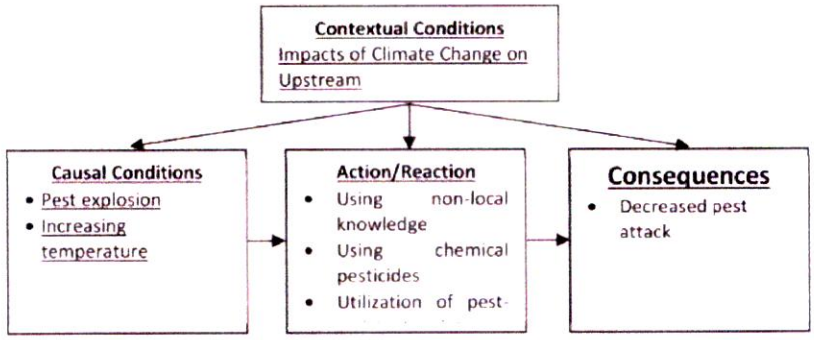

Figure 3. A Grounded theory of the impact of climate change on upstream.

to their reliance on water requirements for lowland rice growth. The results of this study are almost the same as the findings of ( ) who observed that although the rainfall patterns may be similar, some areas are severely affected, due to different levels of vulnerability.

Farmers' knowledge of climate change was based on personal experience, which was considered informal knowledge. This finding was in line with the results of a study conducted on the Xo Dang community in Vietnam which make physical observations of the environment the basis for knowledge about climate change ( ).

Action and interaction strategies are reactions to dealing with causal conditions which ultimately lead to consequences. Farmers' responses to the effects of climate change differed as well between downstream and upstream. The majority of farmers in downstream used the local knowledge to deal with the effects of drought, which was in line with the findings of several other studies (; ;), where they also reported that the majority of farmers use knowledge which are obtained from generation to generation to deal with the impacts of climate change, including migrating to cities to look for other jobs outside the agricultural sector, such as being a construction worker.

Another study found that, in addition to using local knowledge, farmers use non-local knowledge in adaptation actions either separately or in combination (; ;) which corresponds to our findings. In addition to using chemical pesticides for pest management, some farmers in upstream apply scientific methods to deal with water shortages by planting cultivation methods with low water requirements.

Consequences are the outcomes of actions taken in response to the phenomenon of climate change impacts. The action strategy that could reduce the impact of climate change on downstream rice fields had two consequences: an adequate supply of water in the paddy fields and reduced vulnerability to farmers' livelihood systems. The consequence of the action in the upstream rice fields was a reduction in pest attacks on rice plants. Through knowledge and perceptions about the causes of climate change impacts and good adaptation efforts, farmers could increase resilience in facing the impacts of climate change.

In this study, the theoretical structure developed through the grounded theory procedure was validated by showing key informants the structure of the theory that was produced, as described by ( ). The key informants confirmed and agreed that the theory's elements effectively reflect the results of the interviews and can explain the reality of the phenomenon under study.

5. Conclusions

This research shows several important discoveries related to climate change perceptions, knowledge, and adaptation at the local level. Significant differences are examined between farmers in downstream and upstream in observing climate change as the source of their knowledge. The majority of downstream farmers are aware of climate change based on increasing temperature and drought, while those in upstream areas perceive increased pest attacks as a major sign of climate change.

The presence of external parties through television, the internet, or agricultural extension workers as a medium for conveying information on climate change also enriched the knowledge of farmers. The downstream farmers are more active in seeking scientific information, especially young farmers and group leaders. Although the leaders are generally old, they

easily accept science-based climate change information. The experiences and losses due to the impacts of climate change felt by farmers in the downstream further improved their adaptation efforts. This demonstrated that having a higher level of knowledge can change people's perceptions of the cause of climate change to be scientific.

The findings of this study demonstrate the theoretical construction of climate change's impact on communities in the downstream, which was built in the context of local characteristics in response to water shortages and rising temperatures. Farmers combine local and non-local knowledge through crop diversification, work in the off-farm sector, and work outside their villages to reduce the vulnerability of farmers' livelihood systems in downstream areas. Farmers in upstream, in contrast to farmers in downstream, perceive pest explosions and temperature increases as causal conditions of climate change. Upstream farmers use chemical pesticides and pest-resistant seeds to reduce pest attacks.

Therefore, a local or regional adaptive management policy is needed for local communities. It is also necessary to formulate the right policies by accommodating their local knowledge using a bottom-up approach. Furthermore, it was discovered that farmers apply local adaptation strategies to deal with extreme climate situations that have been practiced for generations. These collaborative efforts between scientists and local communities in handling the phenomenon are used as recommendations in the formulation of adaptation policies based on participatory approaches.

This research has shown the concept of knowledge, perceptions, and adaptation efforts to climate change in rice fields. It also described the role of informal communication social networks in conveying climate change information effectively. However, several limitations should be addressed in subsequent research. This study applies a qualitative approach using the grounded theory method with a small sample size. Further research in the form of quantitative approach using economic analysis with a larger sample size is expected to complete this research. Since the study of the impact of climate change is complex, collaboration in various fields of science, such as economics, geography, and socio-culture, is required to reveal the relationship between farmer perceptions and adaptation efforts. Furthermore, socio-cultural and economic differences in the community influence perceptions and adaptation strategies, necessitating a study to examine differences in perceptions of the impact of climate change among lowland, coastal, and mountain farmers, particularly vulnerable groups of farmers.

Declarations

Author contribution statement

Arifah: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

D.Salman: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A.Yassi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

EB Demmallino: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Data included in article/supp. material/referenced in article.

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The authors declare no conflict of interest.

Additional information

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