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REVIEW ARTICLE

How do farmers perceive climate change? A systematic review

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Abstract

In this paper, a systematic literature review was conducted to synthesize understanding on farmers' perception on climate change. Farmers' perception of climate change is conceptualized as comprising of three dimensions—first, as farmers' "awareness"; second, "conceptual understanding"; and third, the "experience" of climate change. The review included 162 papers published during the period January 2000 to July 2019. The highest number of studies was conducted in Africa, followed by Asia. A large majority of farmers report being aware of climate change. However, only a few studies elicit the difference between climate variability and climate change from farmers. A negligible number of studies attempt to identify the role of agricultural activities in greenhouse gas emissions and climate change. Furthermore, authors compare farmers' perception with meteorological evidence, which is more aligned in terms of change in "temperature" rather than "precipitation." The insights from the review provide guidance on conceptualization and operationalization of the variable "farmers' perception of climate change" for future studies.

Keywords Awareness · Perception · Meteorology · Climate change and variability · Farmers · Agriculture

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1 Introduction

Agriculture, in the developing countries, is more sensitive and vulnerable to risks like climate change due to its dependence on climatic conditions and low coping ability of less developed areas (Intergovernmental Panel on Climate Change [IPCC] 2007). Societal and individual adaptation to climate is not new; individuals and societies have always made adjustments to their way of living in response to the stimuli provided by diverse environments and changes in these environments over longer and shorter time frames. In the agricultural sector, this is particularly true as there are numerous examples of different kinds of adjustments and adaptations that farmers make to observe, perceive, and anticipate changes in weather, climate, and ecology. But adjustments and revisions in action for coping with change may not be enough to tolerate the rapid change in the climate conditions, and actions different from those of simply coping with climate variability are likely to be required. For example, in the case of a region afflicted with droughts, a farmer may cope by changing the sowing date, but what may actually be required in light of more severe or more frequent droughts under a climate change regime is shifting to a drought-tolerant variety of that crop—or changing the crop being grown altogether.

One of the first prerequisites for farmers to engage in the adaptation to climate change is the perception of risk that climate change poses. Without the perception of risk, the farmer may not feel the need to take action. There is a large body of literature, which assesses farmers' perception of climate change. Despite a large number of studies, what we know about farmers' perception of climate change is limited. This is because perception is conceptualized differently in different studies.

The dictionary meaning of perception according to Collins English dictionary is "… the way that you *think* about it or the *impression* you have of it." English Language Learners Definition of *perception*: the way you think about or understand someone or something. Therefore, farmers' perception of climate change would mean how farmers think about and understand climate change. We conceptualize farmers' perception of climate change through three dimensions: first is the dimension of awareness of the term "climate change," second is the dimension of conceptual understanding of what climate change constitutes, and third is the dimension of experience, i.e., how have farmers experienced climate change. The experience dimension would create their impression of it.

Awareness is the first step in any perception being created. Hence, it is important to assess the level of awareness of the term "climate change" among farmers. The second dimension pertaining to farmers' perception of climate change is their "conceptual understanding" of climate change. Conceptual understanding would refer to whether the farmers understand climate change as anthropogenic in nature and that it is distinct from natural, year-to-year variability. It is important to know whether farmers understand this distinction or not because climate change would eventually demand actions which are more in the nature of being transformational (e.g., changes in practices, technologies, etc.) rather than simply incremental action typically required to cope with the natural climate variability (Kates et al. 2012). If the farmers do not understand the distinction between climate change and variability, then the chance of their taking action beyond the incremental activities to simply cope with climate variability will be much smaller. While the actual actions taken by farmers would be determined by a number of socio-economic factors—including affordability—the need for taking an action different from the usual would require the understanding of the conditions (e.g., climate change as distinct from climate variability) that require the non-incremental/transformational action to be taken.

Another aspect of conceptual understanding of climate change on part of farmers would lie in their understanding of whether the cause of climate change is anthropogenic or natural and whether farmers understand that some agricultural activities and practices may themselves lead to greenhouse gas (GHG) emissions. While understanding the distinction between anthropogenic climate change and climate variability is important from the point of view of adaptation activities to be undertaken by farmers, farmers' understanding of the link between human activities, including agricultural activities and GHG emissions, may be important if farmers are to be induced to undertake mitigation actions or change their practices for mitigation in the future. While it cannot be assumed that simply knowledge of the link between agricultural practices and greenhouse gases would lead to mitigation action on part of farmers—particularly in the least developed or developing country context where agriculture sector is dominated by smallholder farmers who face multiple constraints in their decision-making, which makes survival a priority rather than meeting environmental goals—nonetheless, even the uptake of state-supported mitigation actions by farmers would require conceptual understanding on part of the farmers about the nature of anthropogenic climate change. Studies in contexts other than agriculture (e.g., Ortega-Egea et al. 2014) do provide evidence that knowledge about the causes of climate change and solutions to climate change can lead to greater mitigation action among individuals.

The third dimension of perception, i.e., the experience of climate variability, change, and extreme events, is perhaps the most observable dimension of perception, and studies on farmers' perception of climate change report in maximum numbers on this dimension. There is empirical evidence (e.g., Waibel et al. 2017; Kahsay et al. 2019) that experience of farmers with climate variability and extreme events does affect the coping and adaptation activities they undertake to come to terms with the current risk—and mitigate future risk. Hence, clearly farmers' perception can be a critical element likely to affect adaptation activities. However, farmers' perception of climate change itself has been conceptualized and measured in various ways, and we propose that most conceptualizations presented in the literature are incomplete in the sense that they often measure only one or two dimensions of perception for the purposes of their study. In this review paper, we focus on the characterization of farmers' perception of climate change and assess literature with respect to such a characterization. The insights we derive from the review of literature may be treated as guidelines for conceptualization and measurement of farmers' perception of climate change in future studies on this matter. A multi-dimensional conceptualization avoiding the pitfalls in conceptualization and measurements made in previous studies would likely provide a more consistent as well as nuanced understanding of the relationship between farmers' perception and various other important and actionable variables—such as adaptation or mitigation activities undertaken by the farmer, use of climate change information products by farmers, and the determinants of farmers' perception of climate change itself in future studies on such topics.

An assessment of the farmers' perceptions of climate change naturally leads to the question: do they match reality? The extent to which perceptions match observed data on changes in climate would indicate how accurately or not farmers perceive the change in climate, and we also review the literature on this issue on this paper. We did not come across any synthesis of various literature on farmers' perception and awareness of climate change either through systematic review or otherwise.

2 Methodology

For making an assessment of the literature on farmers' perception of climate change, we followed the systematic review method. A systematic review of the literature makes an assessment of the state of knowledge on a given topic, based on a set of clearly formulated questions or criteria identified by the researcher. The set of questions and criteria are applied to each of the relevant literature. The findings from this exercise are then synthesized and summarized as the state of knowledge on the topic of interest. Also, search terms and criteria for inclusion and exclusion of articles, and documents excluded from the review, are fully reported. Systematic reviews are beginning to be recognized as an essential method within the domain of climate change adaptation and mitigation research (Ford et al. 2011). The methodology in the study draws on the systematic review undertaken by Ford et al. (2011).

The first search we made was for the articles with keyword "systematic review" for the period between January 2000 and July 2019 in EBSCO discovery service (choosing the fields "TITLE" and "ABSTRACT") and Clarivate web of science (choosing the field "TITLE" and "TOPIC") (see Table 1 in supplementary material). Both these databases are available at the central library of IIT Delhi. Some 2,23,510 articles using the word "systematic review" showed up in EBSCO discovery service and 1,64, 399 articles in Clarivate Web of Science. Then, we searched for the articles with the keywords "systematic review" and "climate change," again, with choosing the fields "TITLE" and "ABSTRACT" in EBSCO discovery service and fields "TITLE" and "TOPIC" in Clarivate Web of Science. After removing overlaps, 562 articles were retrieved from EBSCO discovery service and 835 articles (which includes some duplicate articles) from Clarivate Web of Science. This reflects that less than 1% of documents indexed in EBSCO discovery service (562 of 2,23,510) and Clarivate Web of Science (835 of 1,64,399) with the term "systematic review" in the title, abstract, or topic related to research areas of the climate change (supplemental materials, search 1). Out of these articles retrieved, only 23 were systematic reviews related to topics of climate change and agriculture. Dominant topics of other systematic reviews related to climate change include adaptation, vulnerability, health, mitigation, and governance, but not a single systematic review was on farmers' awareness and perception of climate change.

Second, we searched (see supplementary materials, Table 3) the EBSCO discovery service and Clarivate Web of Science databases using the following search string in the search engine of EBSCO discovery service, TITLE ("farmer* *and* climat* change *and* perception"; "farmer* *and* climat* change *and* awareness"), ABSTRACT ("farmer* *and* climat* change *and* perception"; "farmer* *and* climat* change *and* awareness"), and in search engine of Clarivate Web of Science, TOPIC ("farmer* *and* climat* change *and* perception"; "farmer* *and* climat* change *and* awareness"). This search retrieved 1350 number of articles. We focused on literature published between January 2000 and July 2019. The year 2000 was selected as the starting point because in 1998, the Kyoto Protocol was adopted—which is the world's first GHG emissions reduction treaty. Around that time, the literature on climate change started emerging. In the late 1990s, the World Meteorological Organization (WMO[1]), National Meteorological and Hydrological Services (NMHSs), regional institutions, and other international organizations initiated an innovative process known as the regional climate outlook forums, which produce regional climate outlooks based on climate predictions. This led to the emergence of literature in agriculture and social sciences on farmers' awareness and perception of climate change approximately from the year 2000 onward. Only peer-reviewed and electronically available journal articles published in the

English language were selected—articles in other languages or books, book chapters, conference papers, dissertations/theses, and magazines were not included.

All 1350 retrieved documents were evaluated for suitability for inclusion in the final review based on the following criteria: first, studies based on empirical findings; second, studies published in environmental and social sciences journals; third, the terms "perception," "awareness," and "climate change" must be present or clearly implied in the title, topic, or abstract; and fourth, documents whose main objective explicitly was to assess farmers' perception and awareness of climate change and climate variability (see Table 2 in supplementary material for more details on inclusion and exclusion criteria). After the screening of the papers based on the above criteria, 338 articles were eligible for review. After examining the 338 articles, 176 articles were excluded as some did not primarily focus on the farmers perception or awareness of climate change. In addition, the overlaps between the articles were excluded through manual scanning of titles, abstracts, and keywords. The articles meeting the above inclusion criteria resulted in 162 articles eligible for review. The inventory of papers included and excluded is provided in the sections U and V of the supplementary material. The research questions/criteria (questionnaire) that we applied in reviewing all 162 papers are included in the section D of supplementary material.

3 Analysis and results

The following sections present the results of the systematic review based on the questions mentioned above. However, first, the evolution of literature related to farmers' awareness and perception of climate change over time and space has been presented.

3.1 Temporal and spatial evolution (regional focus) of literature related to farmers' perception and awareness of climate change

Figure 1 presents the number of papers published per year, and it shows that it is after the year 2008 that publications on farmers' perception of awareness of climate change start picking up. The highest number of papers published are in the year 2016 and 2017.

Figure 2 presents the number of studies carried out in different regions across the globe. The highest number of studies are in Africa (103) (Nigeria (25), Ethiopia (16), Ghana (15), South Africa (8), followed by Tanzania (7), Kenya (6), Niger (4), Uganda (3), Malawi (3), Mali (2), Zimbabwe (2), Benin (2), Sudan (1), Burkina Faso (1), Sahel (1), Zambia (1), Gambia (1), West Africa (1), Southern Africa (1),Sub-Sharan Africa (1), Egypt (1), and Swaziland (1)), whereas the number is comparatively less in Asia (50) (India (15), Nepal (9), Pakistan (6), China (6), Bangladesh (5), Vietnam (3), Thailand (2), Sri Lanka (1), Malaysia (1), Indonesia (1), and Philippines (1), and least number of studies are conducted in Central and South America (3) (Bolivia (1), Chile (1), Mexico (1), and developed nations (6) (USA (3), Ireland (1), Italy (1), and New Zealand (1)). Many African and Asian countries in the above list are counted among the least developed countries by the United Nations, exhibit the lowest indicators of socio-economic development, and are ranked low in the Human Development Index.

3.2 Are farmers aware of climate change?

A total of 60,758 farmers were interviewed across the 162 studies if we sum up the sample sizes across all studies. Out of these, 35,455 farmers were interviewed across Africa, 21,987

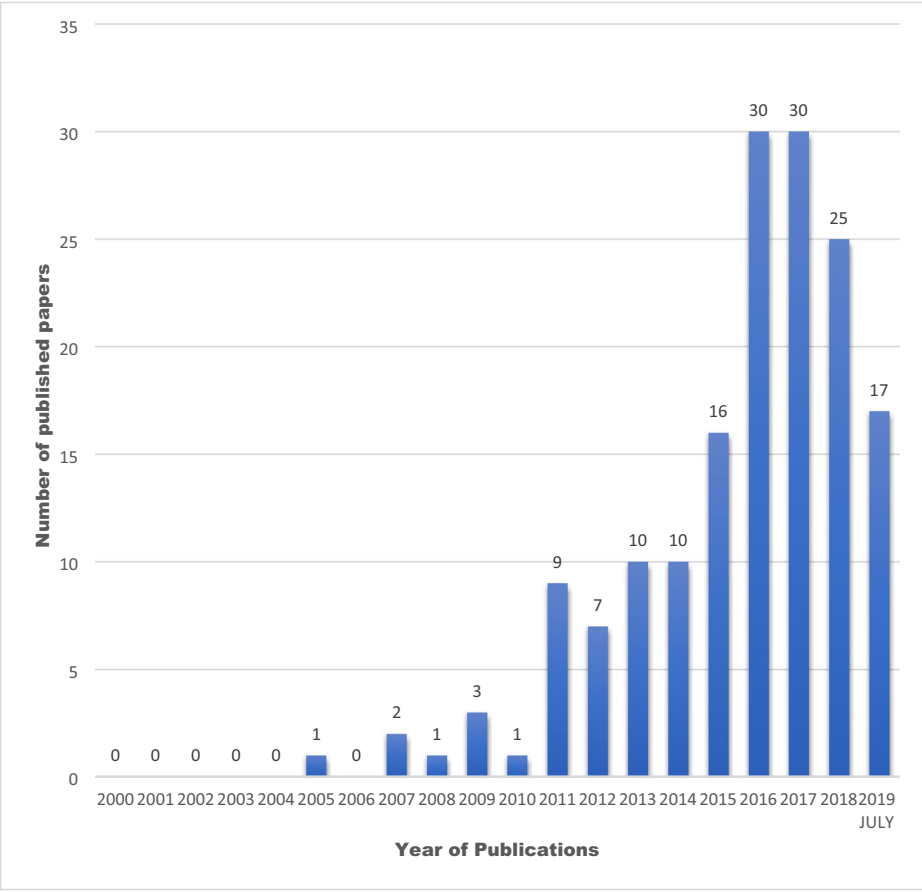

Fig. 1 Number of publications by years

farmers in Asia, 758 farmers were interviewed in Central and South America and 2558 farmers were interviewed in developed nations.

The first thing we assessed was whether the farmers had even ever heard of the term "climate change," i.e., whether they were aware of the term "climate change" or not.

Out of 162 studies, 41 studies provide a numeric figure on the percentage of farmers aware of climate change (see Table 4 in supplementary material). Out of the 41 studies, in 20 studies, the researchers explicitly report the question, which they use to probe the farmers' awareness of climate change (see Tables 5 and 6 in supplementary material). Some 12 studies out of 20 studies use binary choice response (yes/no) to the question on awareness of climate change, and 9 studies provide multiple response options (e.g., 4-point format (Yes, No, I do not know, I am not sure). About 20 studies did not report the question asked to elicit farmers' awareness of the term "climate change."

The total number of farmers interviewed across the 41 studies is 17,117 (range of sample sizes: minimum of 78 farmers in Ahmed and Haq (2019) study in Bangladesh and 5060 farmers in Shrestha et al. 2019 study in Nepal). Some 10,526 (62%) farmers reported that they are aware of the term "climate change." In 19 out of 41 studies, 5525

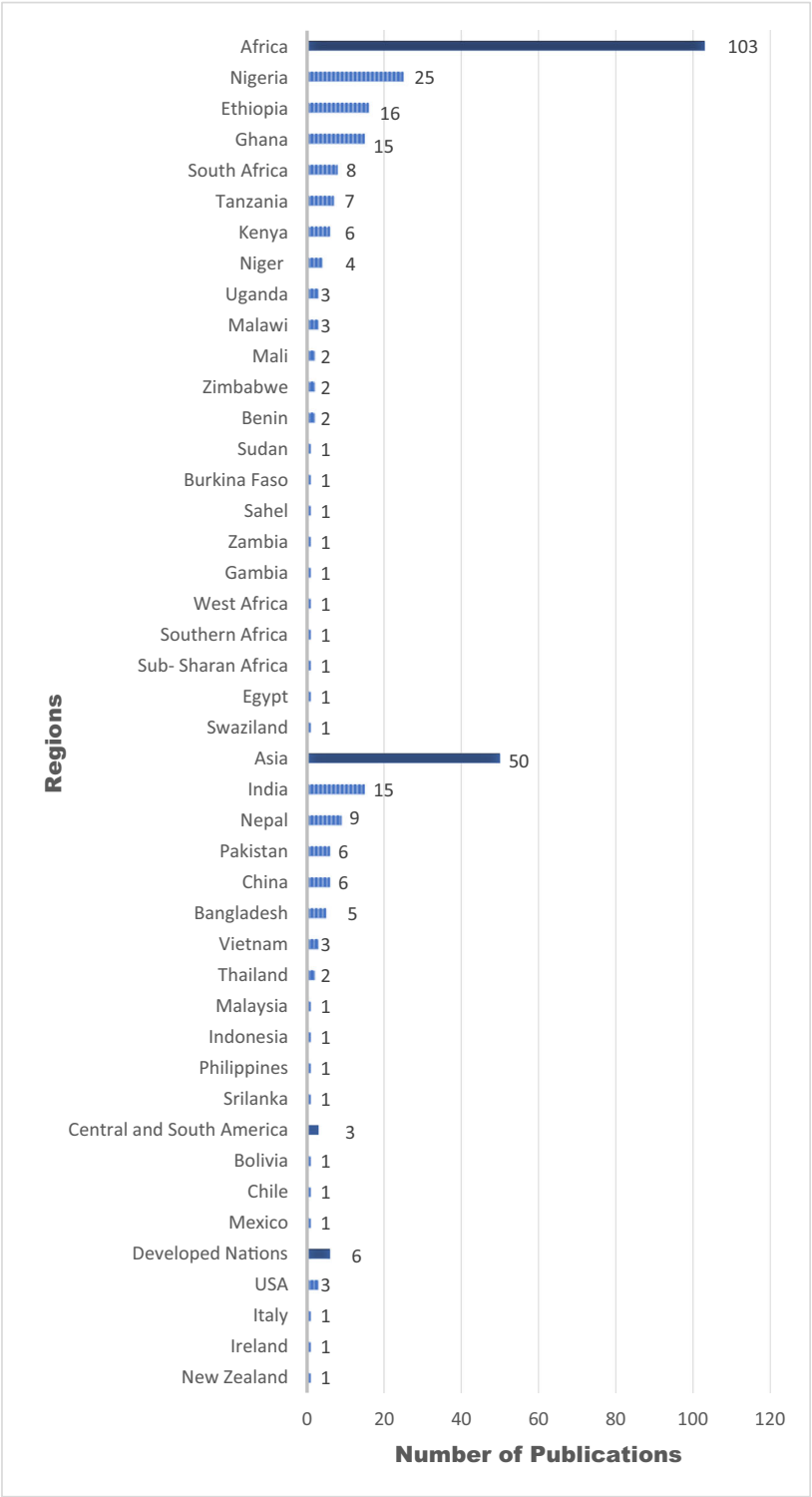

Fig. 2 Number of publications by region

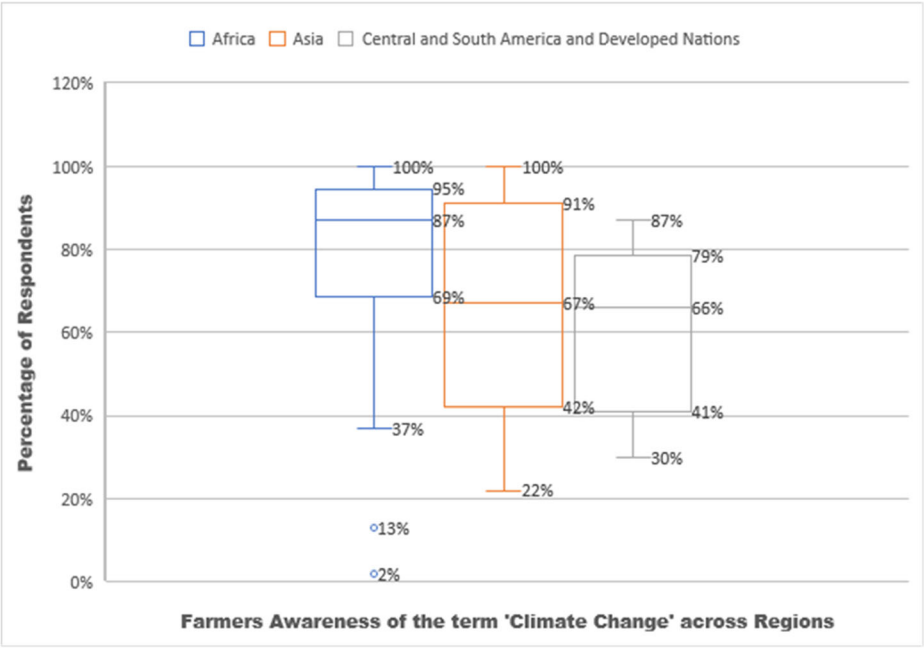

Fig. 3 Box plot of percentage of respondents who are aware of the term "climate change" across different regions

farmers specifically reported that they are not aware of the term "climate change." For the remaining 1066 farmers out of a total of 17,117, the authors did not clearly report whether farmers are not aware of the term "climate change." One assumes that 1066 farmers are also not aware of the term "climate change." While a majority of farmers (62%) seem to be aware of the term "climate change" across all studies, however, there is considerable variation in the percentage of farmers aware of the term "climate change" across the studies. The mean percentage of farmers aware of the term climate change across all 41 studies is 73% (standard deviation, 23.4%). The range of percentage of farmers aware of climate change is between a minimum of 2% (Nyadzi (2016) in Ghana) and a maximum of 100% (for example in Raghuvanshi et al. (2017) in India).

There is a considerable variation in the range of climate awareness of farmers across different regions and within a region. Figure 3 shows farmers' climate change awareness across different regions of the world. The variation is highest for Africa, followed by Asia and the developed nations. An example for within region and even within-country variation in farmers' awareness of climate change is that there are 4 studies (Raghuvanshi et al. 2017; Sarkar and Padaria 2015; Shukla et al. 2018; Tripathi and Singh 2013) from India represented in the pool of 41 studies. The range of percentage of farmers aware of the term "climate change" is from 22% (Sarkar and Padaria 2015) to 100% (Raghuvanshi et al. 2017). Both Raghuvanshi et al. (2017) and Sarkar and Padaria (2015) conducted their studies in the hill states of Himachal Pradesh and Uttarakhand, respectively. The authors who reported 100% farmers' awareness of climate change may simply have been referring to climatevariability as climate change rather than referring to the phenomenon of climate change as conceptualized by IPCC and other scientific literature. We assess this in the next section.

3.3 Conceptual understanding of climate change

We probe the question of farmers' conceptual understanding of climate change by assessing the literature for: one, whether the farmers understand the difference between climate variability and long-term climate change; two, whether farmers understand the anthropogenic nature of climate change; and three, whether the farmers understand the role of agriculture in contributing to climate change.

3.3.1. Whether farmers understand the distinction between climate change and climate variability To assess whether the farmer understands the difference between climate change and variability,[1] we ask two questions: (1) whether the author(s) make the distinction between climate change and variability while posing the question to farmers for eliciting their perception on climate change and (2) whether farmers respond meaningfully to the question posed on the distinction between climate change and variability. This is because the farmer is likely to report a distinction between climate change and climate variability only if the author asks them about that difference and does so in a manner in which farmers can understand the distinction and respond meaningfully.

We studied three aspects of the question posed by researchers to elicit farmers' perception of climate change—one, whether the researcher(s) made a distinction between climate variability and climate change while posing their questions to the farmers; two, the time duration over which the authors have considered the perception of the farmers; and three, the different parameters of climate about which farmers' perceptions were elicited.

Some 10 studies included questions on only awareness of climate change and, hence, do not form part of the pool of 152 studies on farmers' perception of climate change. While some authors reported the exact question posed to the farmers to elicit their perception of climate change, not all authors did so. However, it was possible to infer the kind of question that may have been posed based on the information provided in the text of the paper. In Table 7 of supplementary material is compiled and listed all the questions posed by the author to the farmers across 152 studies.

We assess the above-mentioned questions and found that only in 8 studies did the researcher attempt to elicit whether the farmers understand the difference between climate change and climate variability (see Table 8 in supplementary material). About 6 out of these 8 studies also elicited farmers' perception of changes in mean temperature and rainfall over a period of time. The assumption on part of most researchers that farmers may not understand the changes in mean and variance of temperature and rainfall distributions could be the possible reason for such a small number of researchers eliciting the above from farmers. Majority of the studies (112) assessed farmers' perception of change in climatic variables such as temperature and precipitation, typically over the long term (usually 10 to 40 years). In the framing of the questions, these 112 studies have included the term "climate change" or changes in "long-term climatic pattern" or changes in "temperature" and "precipitation" over

[1] According to World Meteorological Organization (WMO), "climate variability" is defined as variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events. Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). In essence, climate variability looks at changes that occur within smaller time frames, such as a month, a season or a year, whereas climate change considers changes that occur over a longer period of time, typically over decades or longer. A key difference between climate variability and change is in persistence of "anomalous" conditions—when events that used to be rare occur more frequently, or vice versa.

the long term—usually 10 to 40 years. Out of these 112 studies, only in 26 studies did the researchers elicit information on changes observed in extreme events by the farmers (see Table 9 in supplementary material). Some 21 studies included both "climate change and variability" in framing their questions for the farmers, and another 19 studies included only the term "climate variability" or "changes to local weather" in the question posed to the farmers. Only in 14 studies (see Table 10, supplementary material) did farmers raise concern about future climate risk and the need for an increase in adaptation measures. The authors reported, in these studies, that farmers are aware of the future risk of climate and concerned about its negative impact (Debela et al. 2015).

With respect to the time duration over which the authors considered the perception of farmers about climate change (see Table 7 in the supplemental material), different studies have understood and communicated to the farmers the "long term" associated with climate change in different ways. Out of 152 studies, in 57 studies, the question on the duration is posed in qualitative terms such as "few years" (6 studies), "past years" (14 studies), "recent years" (3 studies), "long term" (2 studies), "over the years" (30 studies), "change for many years" (1 study), and "several years" (1 study) (see Fig. 4 in supplementary material). There is no quantitative estimate attached to the duration in years that would be considered as "long-term" change. Some 95 studies out of 152 are more specific about the time duration they consider while eliciting the farmers' observations and perceptions of climate change. For example, in 2 studies, the time span of 3 years and 5 years is mentioned respectively; and in 22 studies, the time duration of 10 years is stated; and 20 years is mentioned in 36 studies. The time period of 21 years and 24 years is reported in 1 study respectively, interval of 25 years is mentioned in 2 studies, and a duration of 30 years is mentioned in 21 studies, while 2 studies mentioned 40 years' time duration, and in 1 study, duration of 50 years is reported.

Next, we report on the climate parameters about which farmers' perceptions have been elicited by different authors. Two climate parameters that have been reported most frequently are temperature and precipitation. But there is variation in what aspects of change in temperature and precipitation have been reported in different studies (see Fig. 5 in supplementary material). Some 58 out of 152 studies focused on farmers' perception of only "increase in temperature," and 48 studies tried to capture farmers' perception on three parameters of "increase, decrease, and no change in temperature," and while 19 studies focus on farmers perception of both "decrease and increase in temperature," 12 studies inquire about the farmers' perception of "increase and no change in temperature." In 15 studies, the authors have not specified the direction of change in temperature while posing the question to the farmers. Rather, they have simply asked about "change" in the intensity of heat, "change" in summer-winter and day-night temperatures, and change in the duration of hot and cold periods.

Similarly, for precipitation in 57 out of 152 studies, the researcher tried to elicit the farmers' perception of only "decrease in precipitation," and 30 out of 152 studies capture the farmers' perception of both "increase and decrease in precipitation." About 25 studies interrogate about the farmers' perception of "increase, decrease and no change in precipitation." In 15 studies, the author questioned farmers' perception of both "decrease and no change in precipitation," whereas only 6 studies mentioned farmers' perception of "increase in precipitation." About 19 out of 152 studies use other parameters of climate variability without mentioning the direction of change such as "precipitation became unpredictable," "rainfalls were more regular and predictable," and "decrease in summer and winter rainfall."

Many studies had elicited parameters in addition to increases/decreases/no change in temperature and precipitation. For example, while 64 out of 152 studies capture the farmers' perception of irregular rain or delay in onset/cessation of rain, 26 studies interrogate the change in length of the growing season. And while 45 studies questioned the farmers' perception of the occurrence of dry spells and droughts, 22 studies elicit farmers' experience of unusual and heavy flooding. Other parameters of weather events elicited from farmers are reductions in snowfall (6 studies), short winter and/or long summer (4 studies), sunshine intensity decreases (3 studies), changes in intensity and frequency of storms and cyclones (2 studies), and shortening of the monsoon period (2 studies).

The inference we arrive at after reviewing the 152 studies is that very few studies have communicated or elicited from farmers the distinction between climate variability and climate change. There is a huge amount of variation across studies in the time period over which farmers' perception has been elicited. In little over 50% of the studies, the time period is either vague (e.g., recent years, past years) or too short (5 to 10 years) to say anything meaningful about climate change. About 50% of studies inquired about the "increase in temperature" and "decrease in precipitation" which seem to be the partial notion of the researcher that due to global warming, there will be increase in the temperature and decrease in precipitation without considering the possibility that there can be "decrease" in temperature and "increase" in precipitation due to climate change as well. It is the changes in extremes that could be more important from a farmer's perspective, though much fewer studies have elicited farmers' perception of these.

Next, we review whether farmers understand the difference between climate change and variability. In at least 4 (See Table 8, supplementary material) out of 152 studies, the farmers are able to respond meaningfully on the difference between climate change and variability. For example, Komba and Muchapondwa (2012), in their study in Tanzania, show that farmers perceive mean precipitation has decreased, while the variance of precipitation has increased. In some studies, the farmers reported in qualitative terms the belief that the climate is changing and it is no longer as it was some years back with respect to the amount of rainfall and its distribution and temperature. While the farmers are well acquainted and experienced about climate variability—and also notice long-term changes in weather patterns, like change in rainfall pattern, changes in rainfall onset, and cessation of rain and seasonal variability over the decades—with a few exceptions, the elicitation of farmers' perception about climate change does not always reflect this understanding across most studies.

3.3.1 Whether the farmers understood that climate change is anthropogenic/ human-induced?

To assess whether farmers understood that climate change is an anthropogenic phenomenon, we examined the different causes of climate change reported by the farmers. Few (only 30 out of 162) studies have asked the question on the cause of climate change. The review of 30 studies showed different causes enumerated by farmers for climate change, but these can broadly be divided into three categories, i.e., supernatural cause, natural causes, human-induced causes, and a fourth category where no explanation was provided by the farmer. Figure 6 in supplementary material provides greater detail on the causes of climate change in different studies.

The total number of farmers interviewed across the 30 studies if we sum up the sample sizes is 5093, which ranged from a minimum of 18 farmers interviewed in a study in South Africa (Clarke et al. 2012) to a maximum of 530 farmers in a study in Nepal (Paudel et al. 2019). The mean sample size across the 30 studies is 233, and the standard deviation is 29.2.

Supernatural cause Out of a total of 5093 farmers, 1372 farmers in 18 studies reported that climate change is due to a supernatural cause. The supernatural cause of climate change mentioned by the farmers typically related to the notion of Gods or nature being angry with human behavior, for example, "lack of respect for divinities and social norms" (Zoundji et al. 2017), "sinful behavior" (Falaki et al. 2013), and punishment for destroying the environment and ecosystems. The mean percentage of farmers who thought that there is a supernatural cause behind climate change is 42%; the range is between a minimum of 3.6% (Esan et al. 2017 in Nigeria) to a maximum of 94% (Zoundji et al. 2017 in Benin), with the standard deviation at 28%.

Natural cause Some708 farmers in 10 studies, out of a total of 5093 farmers in 30 studies, stated that climate change is due to natural factors. Farmers observed that climate change is a natural process (Okunlola 2014; Moyo et al. 2012). The mean percentage of farmers who supported the natural causes behind climate change is 32%, which ranged from a minimum of 5.2% farmers in a study in Benin (Teka et al. 2013) to a maximum of 61.3% farmers in a study in Nigeria ((Esan et al. 2017), with the standard deviation at 19%.

No explanation Out of 5093 farmers in 30 studies, 465 farmers in 9 studies reported that farmers do not know about the cause of climate change. The mean of the farmers who did not have any response or were unaware of the cause of climate change is 23%, which ranged from a minimum of 2.40% farmers (Teka et al. 2013 in Benin) to a maximum of 86% farmers (Nyadzi 2016 in Northern Ghana), with the standard deviation at 29%.

Human cause Out of 5093 farmers in 30 studies, 2548 farmers reported in 30 studies agreed on the human-induced causes of climate change. The different human-induced causes reported are deforestation (Sarkar and Padaria 2015), bush burning (Terdoo and Adekola 2014), industrial activities (Lelethu 2014), pollution (Sarkar and Padaria 2015), domestic activities (Okunlola 2014), forest fires (Raghuvanshi et al. 2017), overgrazing by livestock (Tesfahunegn et al. 2016), use of chemical fertilizer (Sarkar and Padaria 2015), emission of GHG (Idrisa et al. 2012), urbanization (Tesfahunegn et al. 2016), population (Raghuvanshi et al. 2017), global warming (Liu et al. 2014), soil degradation by erosion (Tesfahunegn et al. 2016), and pesticides (Raghuvanshi et al. 2017). The mean of the farmers who supported human activities as the major factor behind climate change is 43%, which ranged from a minimum of 2.8% farmers in a study in Nigeria (Esan et al. 2017) to a maximum of 93.96% farmers in a study in Nepal (Paudel et al. 2019), with the standard deviation at 26%.

3.3.2 Whether farmers reported on the role of agricultural activities in contributing to climate change

Most studies did not elicit if the farmers know that agriculture contributes a significant share in enhancing climate change. According to the IPCC's Fifth Assessment Report, the agriculture sector is the main contributor (10–2%) to the GHG emissions and climate change. Only in 7 (see Table 11 in supplementary material) out of 162 studies did farmers report on the role of agricultural activities in contributing to climate change. For example, Sarkar and Padaria (2015) study in India asked the farmers, "Are you informed that practices like the burning of crop residues in field is also contributing toward climate change?" While farmers

acknowledge and agree that human activities such as burning of the vegetation, cutting of trees and the increase in agricultural land, indiscriminate setting fire to bushes before farming, farming alongside river bodies, overgrazing of animals, and poor farming practices have led to climate change, only a very limited number of studies attempt to elicit from farmers whether they understand and know how the increase in the agriculture sector to meet the demand of global food supply is impacting GHG emissions. There is the paucity of research on farmers' understanding of how the agricultural inputs (pesticides and fertilizer), farm machinery (irrigation, harvesting, threshing, and use of manure), and the management of agricultural land (crop residue burning), crop types (such as paddy), and livestock rearing influence atmospheric GHG concentrations.

3.4 How do farmers perceive climate change?

This section presents farmers' perceptions that have been formed through their experience of the climate and variability. A total of 57,013 farmers were interviewed across 152 studies with a mean sample size being 365 farmers, which ranged from a minimum of 12 farmers (Traore et al. 2015) to a maximum of 5060 farmers (Shrestha et al. 2019 in Nepal), with the standard deviation at 56%.

3.4.1 Change in temperature observed by farmers

Out of the total 57,013 farmers in 152 studies, 33,229 farmers in 136 studies, i.e., majority of farmers, perceive an "increase in temperature" (see Table 12 in supplementary material). The mean percentage of farmers across 136 studies who perceive an increase in temperature is 70%. Only 4975 farmers (mean 22% farmers) in 58 studies perceive a "decrease in temperature." And 5186 farmers (mean 22 % farmers) in 64 studies perceive "no change in temperature over the long-term."

Other indicators of temperature which are mentioned in a few studies are heat waves (6 studies), increase in winter temperature (3 studies), increase in summer temperature (3 studies), no change in summer and winter temperature, and rainfall (1 study), the intensity of heat increased (1 study).

3.4.2 Change in precipitation observed by farmers

The question on change in precipitation has been asked in only 118 studies out of 152. A total 28,752 farmers across 118 studies (see Table 12 in supplementary material) perceive "decrease in precipitation" with mean being 61% of farmers across 118 studies; 6259 farmers in 62 studies perceive "increase in precipitation," with the mean being 35% of farmers; 2406 farmers in 42 out of 152 studies perceive "no change in precipitation," with mean being 26% of farmers. The range and standard deviation of the mean percentage of farmers who observed "decrease," "increase," or "no change" in temperature and precipitation are presented in the box plot in Fig. 7 in the supplementary material.

3.4.3 Weather events experienced by farmers

The number of farmers who reported experiencing irregular rain or delay in onset/cessation of rain was 12,419 (mean = 54%, SD = 30) across 61 studies. The number of farmers who

reported dry spells and drought was 15,231 (mean = 66 % farmers, SD = 52 %) across 42 studies, and the number who reported shortening of the growing season was 2,247 (mean = 62%, SD = 27%) across 11 studies.

3.5 The trends in meteorological data observed in those studies which had made a comparison of the farmers' awareness and/or perception of climate change to the evidence in the meteorological data

In 70 out of 152 studies, the authors have not only tried to capture farmers' observation and perception about changes in temperature and precipitation over a period of time but have also tried to assess how closely these observations and perceptions align with the realized meteorological data. This section summarizes findings from studies which compare the trend in meteorological data with farmers' perceptions of climate change and variability.

Majority of studies use meteorological data for 20 to 30 years to gauge the change in the temperature and rainfall pattern. Only 1 out of 70 studies did not explicitly mention the method used to analyze the climate data. About 69 studies have reported different methods used for analyzing the data, such as Mann-Kendall test, time series analysis, and trend analysis. Few studies have used the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), Pettitt and Hubert Segmentation, Cumulative Departure Index, Rainfall Anomaly Index (see Table 13 in supplementary material).

3.5.1 Change in temperature

Majority of studies that analyze meteorological data reported an "increase in temperature" (see Table 13 in supplementary material). Out of 70 studies, 23 mention an "increase in temperature." Some 21 studies observe an "increase in annual maximum temperature," and 13 studies show "increase in minimum temperature," but only 2 studies show "decrease in minimum temperature." About 7 out of 70 studies analyze the "increase in mean monthly temperature." And only 1 out of 70 studies analyze "anomalies in average temperature." And 3 studies were only on farmers' perception on changes in rainfall and not change in temperature.

3.5.2 Change in rainfall

About 41 out of 70 studies witness a "decrease in rainfall," and only 8 studies report "increase in rainfall." 1 study observes "rainfall remain constant," and there is "no average change in rainfall." Out of 70 studies, 10 studies (see Table 13 in supplementary material) show a "change in annual rainfall pattern." Some 8 studies analyze "variation in rainfall amount," and only 1 study examines "variation in rainfall density," and 1 study shows "rainfall anomaly in different years" and finds "no average change in rainfall." Figure 8 (in supplementary material) presents the meteorological evidence of change in temperature and precipitation elicited in different studies.

3.6 Whether there is (mis)alignment between the meteorological evidence and farmer's perception

Farmers' perceptions and observations about temperature studies are aligned with meteorological trends in 65 studies out of 70. Out of 65 studies, 63 show farmers' perception of an

"increase in temperature"—which matches with the meteorological data—while in 2 studies, farmers' perception of "decrease in temperature" agree with meteorological data (see Table 14 in supplementary material). In 2 out of 70 studies, farmers' perception is not aligned with the meteorological data. In the study of Kabote et al. (2017) in Tanzania, "farmers' perception of warming and increasing trend of temperature is not validated by meteorological data due to missing meteorological data in some months, and lack of meteorological data stations at the village or ward levels," and in the study of Chepkoech et al. (2018), farmers perceive "increase in temperature," which is not supported by the meteorological data. In 3 studies the author did not mention about any change in temperature.

Farmers' perceptions about change in precipitation are in alignment with the meteorological evidence in 43 out of 70 studies. Out of these 43 studies, in 37 studies, farmers' perception matches with meteorological data with respect to "decrease in precipitation," and in 5 studies, farmers' perception is in confirmation with the climate data with respect to "increase in precipitation," with 1 study matching in terms of "variation in rainfall." In 27 out of 70 studies, farmers' observation and meteorological evidence regarding the "change in precipitation" are inconsistent (see Table 14 in supplementary material). Out of 27 studies that did not match, in 20 studies, farmers perceive a "decrease in precipitation," and the meteorological data show an "increase in precipitation." While in 3 studies, farmers perceive an "increase in precipitation, while the" meteorological data shows a "decrease in precipitation". In 1 study, farmers did not notice any changes in precipitation, while meteorological data show decreasing trend. And in 2 studies, farmers' perception of the rainy season having started later and stopped earlier is not supported by meteorological data. In 1 study the author did not mention about the change in precipitation.

The point that emerges from the above paragraphs is that perceptions about temperature are more consistent with meteorological evidence than perceptions about rainfall. In almost all studies, the farmers' observation of the increase in temperatures aligns with the meteorological evidence. And although in the majority of studies farmers' perception of change in precipitation is in confirmation with meteorological evidence, there are a substantial number of studies in which farmers' perception about precipitation did not match meteorological evidence.

4 Some observations

This review identifies three dimensions of farmers' perception of climate change, i.e., farmers' "awareness" of climate change, farmers' conceptual understanding of climate change (characterized as whether farmers understand the distinction between climate change and variability; whether farmers understand climate change to be anthropogenic; and whether farmers understand the role of some agricultural practices in contributing to build-up GHG), and farmers' experience of climate change. In this section, we summarize the insights from this review.

From the review, it is clear that there is a proliferation of studies on farmers' perceptions on climate change and their impacts in African and Asian countries but particularly in the African countries. This is because more than 60% of Africa's and Asia's population lives in rural areas, and their economy is largely dependent on agriculture. Both the African and Asian regions are frequently affected by hydro-meteorological hazards such as tropical cyclones, flooding, landslides, drought, erratic temperatures, and other rainfall-related phenomena. Clearly, how

farmers perceive climate change is an important question, particularly in these regions—though it is likely important for farmers in all parts of the globe.

Are the farmers aware of climate change? If one simply considers the numbers reported across different studies, it may seem that a large majority of farmers are aware of the term climate change, but there is a lot of variation in the percentage of farmers who reported being aware of climate change both across and within regions. This is because when the farmers are reporting awareness of climate and weather variability rather than climate change (e.g., Lelethu 2017, Raghuvanshi et al. 2017) or the local population has received communication about climate change through local media (e.g. Komba and Muchapondwa 2012), then the percentage of farmers reporting "awareness of climate change" is high. It is low when the author of the study makes it a point to capture awareness of anthropogenic climate change (e.g., Sarkar and Padaria 2015).

Another reason for the variations in climate awareness across regions and within countries may be because the term climate change, when communicated to farmers in their local language, may be variously interpreted by local people. For example, the term climate change when translated in Hindi (a language used in the major northern and central belts India) is termed as "jalvayu parivartan" (reference: https://www.indifferentlanguages.com/words/climate_change). While technically this sounds correct as it is a literal translation of the term climate change, from authors' own experience in the field while interviewing farmers on climate change, it is understood that this is a very pure form of the Hindi language and may be differently interpreted by the farmers in the large Hindi-speaking belt of India, and not necessarily as climate change that the researcher may be wanting to communicate. One does not know what term the researchers used for climate change while communicating with the farmers as none of the studies reported the exact term used in regions where English is not the native language.

Do farmers understand the difference between climate change and variability? They typically have deep experiences of climate variability. From the qualitative comments of farmers reported in some studies, it is clear that farmers intuitively understand that there are changes happening to climate which may be beyond variability. This is also corroborated by the review of studies (Section 3.6) which compare farmers' perceptions of changes in temperature and precipitation to meteorological evidence, where in a large majority of studies for a large majority of farmers, their perception and meteorological evidence are in alignment. However, in most studies (except in a few studies like Komba and Muchapondwa 2012; Cullen and Anderson 2017), it is not absolutely clear whether farmers understand the difference between climate variability and climate change. This has happened because, in most studies, the question that the researcher posed to the farmer did not elicit this distinction clearly. This review provides insights regarding certain pitfalls to be avoided or certain practices to be followed by the researcher in posing the question to the farmers on their perception of climate change, which are detailed in the next section on conclusions.

How do farmers perceive climate change? The review (Section 3.4) shows that a large majority of farmers reported perceiving an increase in temperature and decrease in precipitation over a period of time, though this perception is not universal as there is a small proportion of farmers who have perceived a decrease/increase or no change in temperature and precipitation as well. But most studies have attempted to capture farmers' perceptions through changes in temperature and precipitation, whereas other temperature and precipitation-related events such as heat waves and cold spells, changes in the pattern of rainfall, and shortening of the rainy season could be more

important from a farmer's perspective, though much fewer studies seem to have elicited farmers' perception on these.

Are farmers aware of anthropogenic origin of climate change? The review also covered farmers' responses on the cause(s) of climate change. The various causes mentioned by farmers can be grouped into four broad categories: supernatural, natural, human-induced, and no explanation. The proportion of farmers who considered that climate change has natural causes and farmers who admitted to not knowing any reason that could cause climate change is very small. However, traditional ways of understanding the relationship between acts of man and the wrath of nature are prevalent among a substantial proportion of farmers. They are aware of the role of human activity in climate change. Majority of farmers believe that deforestation (burning of the vegetation, cutting of trees) and increase in industrial activity are the major factor behind climate change. But few farmers or studies mentioned GHG emissions in the atmosphere and global warming as the cause of climate change. Most farmers do not understand the causal link between human activity (such as deforestation, bush burning or industrial activity, and transportation) and a build-up of carbon dioxide and other GHG in the atmosphere, which would contribute to climate change.

Are farmers aware of the role of some of agricultural activities and practices contributing to GHG emissions and, therefore, climate change? With a few exceptions, there are limited studies regarding farmers' perceptions on the contribution of agricultural activities on climate change. By and large, farmers are not aware of the role of agricultural activities and practices in contributing to the build-up of GHG and, therefore, climate change.

5 Conclusions

In this section, we highlight the implications of the insights from this review for operationalizing the variable, "farmers' perception of climate change" in future studies. We acknowledge that there will always be differences across studies in the way a researcher poses the question to farmers based on the local and regional variations in climate, geography, custom, and researcher preference. Our objective is not to advocate one standard way of eliciting farmers' perception of climate change. However, the review provides insights on certain pitfalls to be avoided or certain practices to be followed by the researcher in posing the question to the farmers on their perception of climate change.

First, in regions where English is not the native language, it will be useful if future researchers do report in their papers the exact terminology used by them to communicate the idea of climate change in the local language and how they ensured that farmers understood the meaning of the term used as intended by the author.

Second, the researcher should avoid asking farmers their perception of climate change with a blank slate. Natural climate variability across regions and places can be very different—with some places with low variability and other places with a naturally high variability. Since most of the researchers operationalized the perception of climate change by asking farmers their observations/perceptions about changes in precipitation and temperature, and also sometimes included changes in extreme events (floods and droughts), the perception of the farmers about changes in these climate variables could vary based on whether a farmer is located in a place with naturally high variability or a naturally low variability. The farmer is likely to attribute

anomalies due to natural variability to climate change in response to questions posed on their observation of changes in temperature, precipitation, and extremes depending on whether he/she is located in a place with high or low natural variability. To avoid such a situation, it would be a useful practice to provide farmers an idea about the natural variability in their locality (maybe through maps or games depending on the literacy rates of farmers) before eliciting their experience of anomalous climate events and anomalous trends in temperature and precipitation in their locality or region.

Third, the researcher should avoid asking about "climate change" and "climate variability" simultaneously in the same question to the farmer. In 23 studies included in this review, the authors include both the terms "climate change" and "climate variability" together in the question posed to the farmer. Including both terms can cause confusion as in response one may not be sure whether the farmer is responding about climate change or climate variability.

Fourth, the researcher should explicitly ask the difference between climate change and climate variability to the farmer. This may also help communicate to the farmer that the researcher is treating both concepts as distinct and may nudge the farmer to think more carefully before responding to the question.

Fifth, the researcher should avoid ambiguous specification of time period over which farmers' perception of climate change is elicited. Eliciting farmers' perception on climate change over "past years" and "recent years" makes the question ambiguous, and it becomes difficult to say whether the farmer is responding about climate variability or climate change.

Sixth, the response options for eliciting changes in climate parameters should include an exhaustive set of options—for example, when asking about changes in temperature over a period of time, the response option must include all three options, i.e., "increase," "decrease," and "no change" rather than one or two of these options.

Seventh, the researcher should ask farmers about *persistence* of "anomalous" conditions, i.e., when events that used to be rare occur more frequently to capture perception on climate change as distinct from climate variability. For farmers, more than the changes in average temperatures and precipitation, what matters are indicators such as the start and end of rainy season, the pattern and distribution of rainfall, the maximum and minimum temperatures, and extreme events (e.g., change in heat waves, change in winter temperature, change in summer temperature, extreme day and night temperature, duration and intensity of hot periods and cold periods, reduction in snowfall, changes in intensity and frequency of storm and cyclone, and shortening of the monsoon period) as it is these aspects of weather and climate that affect agricultural operations more dramatically rather than average changes in temperature and precipitation. Depending on the region, the questions to farmers should elicit their perception about these indicators as well.

Eighth, for future researchers, it would be useful to include questions on whether farmers understand the causal link between human activities, the build-up of GHG and climate change as well as on the role of agricultural activities and practices in contributing to the build-up of GHG, and, therefore, climate change.

Most studies included in this review have focused on one or, at most, two dimensions of farmers' perception of climate change. In future studies, the researchers may find it useful to operationalize farmers' perception of climate change using all three dimensions discussed above. This is because, typically, farmers' perception of climate change is elicited in different studies to study its association with farmers' coping or adaptation activities and their use of climate information services to understand

determinants of farmers' perception of climate change. A more comprehensive operationalization of the variable (farmers' perception of climate change) with all three dimensions included should lead to an enhanced understanding of the above-mentioned associations.

[1] National Meteorological Services as part of the World Meteorological Organization's World Weather Watch (which networks the observing stations to national, regional and global weather climate prediction centers) produce daily weather forecasts, seasonal forecast, long-term forecast, and early warnings for natural hazards such as hurricanes and cyclones.

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