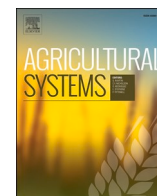




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Multi-faceted impact and outcome of COVID-19 on smallholder agricultural systems: Integrating qualitative research and fuzzy cognitive mapping to explore resilient strategies

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ABSTRACT

The shock of Coronavirus Disease 2019 (COVID-19) has disrupted food systems worldwide. Such disruption, affecting multiple systems interfaces in smallholder agriculture, is unprecedented and needs to be understood from multi-stakeholder perspectives. The multiple loops of causality in the pathways of impact renders the system outcomes unpredictable. Understanding the nature of such unpredictable pathways is critical to identify present and future systems intervention strategies. Our study aims to explore the multiple pathways of present and future impact created by the pandemic and “Amphan” cyclonic storm on smallholder agricultural systems. Also, we anticipate the behaviour of the systems elements under different realistic scenarios of intervention. We explored the severity and multi-faceted impacts of the pandemic on vulnerable smallholder agricultural production systems through in-depth interactions with key players at the micro-level. It provided contextual information, and revealed critical insights to understand the cascading effect of the pandemic and the cyclone on farm households. We employed thematic analysis of in-depth interviews with multiple stakeholders in Sundarbans areas in eastern India, to identify the present and future systems outcomes caused by the pandemic, and later compounded by “Amphan”. The immediate adaptation strategies of the farmers were engaging family labors, exchanging labors with neighbouring farmers, borrowing money from relatives, accessing free food rations, replacing dead livestock, early harvesting, and reclamation of waterbodies. The thematic analysis identified several systems elements, such as harvesting, marketing, labor accessibility, among others, through which the impacts of the pandemic were expressed. Drawing on these outputs, we employed *Mental Modeler*, a Fuzzy-Logic Cognitive Mapping tool, to develop multi-stakeholder mental models for the smallholder agricultural systems of the region. Analysis of the mental models indicated the centrality of “Kharif” (monsoon) rice production, current farm income, and investment for the next crop cycle to determine the pathways and degree of the dual impact on farm households. Current household expenditure, livestock, and soil fertility were other central elements in the shared mental model. Scenario analysis with multiple stakeholders suggested enhanced market access and current household income, sustained investment in farming, rapid improvement in affected soil, irrigation water and livestock as the most effective strategies to enhance the resilience of farm families during and after the pandemic. This study may help in formulating short and long-term intervention strategies in the post-pandemic communities, and the methodological approach can be used elsewhere to understand perturbed socioecological systems to formulate anticipatory intervention strategies based on collective wisdom of stakeholders.

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1. Introduction

The Pandemic COVID-19 has risked both the lives and livelihoods of people at a global scale, and its fullest impacts are yet to be observed (Morton, 2020). Although the spread of the disease decreased in some countries, the pace is still high in some other countries and the fear of a second wave is palpable. The frequently cited global problem in this context is food emergency which is affecting hundreds of millions of people across the world, including women and children. Already 135 million people suffer from acute hunger due to adverse socio-economic and environmental conditions, and another 183 million are feared to get affected by extreme hunger if other stresses in the global food systems continue to occur (FAO, 2020a). COVID 19 outbreak has drastically aggravated such feared pre-condition across the global food systems (IPES-FOOD, 2020).

In India, like many other countries in Asia, Africa, and South America, the pandemic has threatened the farming community due to the periodic and prolonged lockdowns, transport restrictions, and lack of buyers in the market (Morton, 2020; Mishra et al., 2020). The farm operations have been impeded due to restricted movement of farm labor, their illness and death during the quarantine. Besides, the movement of agri-food labor has also been contained in many cases which have hampered the marketing value chain systems (Stephens et al., 2020). The fear of contracting the disease has often restricted farmers to engage the family labor in the field operations, further complicating the choice of suitable crops, varieties, cropping systems, and farm operations. The farmers needed to re-think many factors, such as – the management decisions enhancing the resilience of their farming systems, labor required for the farm practices, and market facilities for the harvested products among the others (Lin, 2011; Meuwissen et al., 2019). Following Meuwissen et al. (2019), we conceptualize ‘resilience’ as the ability of farming systems to demonstrate robustness, adaptability, and transformability, instead of maintaining the equilibrium of the farming system that existed before the lockdown and Amphan. Putting simply, farmers’ adaptations and proposed external interventions in the affected farming systems need to support their existing farm production, and/or to enhance adaptive capability of farmers to sustain their livelihoods, and/or to enable the transformation of the farming systems to move into a different survival regime. Although the smallholder farming systems demand less hired labor and agri-inputs movement have sometimes received preference in this pandemic situation (Stephens et al., 2020), it may not remain sustainable in the long-run unless the socio-economic constraints of crop production are adequately addressed (FAO, 2020b). Apart from sustainable productivity enhancement, the nutrition aspect in the smallholder farm households is also required to be re-thought and re-designed for existing food systems (Bhavani and Gopinath, 2020).

One of the intriguing aspects of the incidence of COVID-19 in agriculture and food systems is its overarching and ubiquitous presence and influence over systems outcomes (Singh et al., 2020). This ubiquity renders the system outcomes unpredictable without a thorough understanding of systems elements and their nature of interactions. Studies of complex systems suggest that informed systems intervention is possible only if the elements of the systems are precisely mapped, and their interactions are measured (van Mil et al., 2014; Douthwaite et al., 2017). Developing this understanding is extremely challenging for smallholder agriculture that embodies huge systems diversity in terms of their elements, interactions and contexts within which such interactions take place (Tittone et al., 2007).

The COVID-19 and consequential lockdown is bound to affect the smallholder systems globally, triggering multi-faceted impacts and unpredictable pathways. This impact on smallholders is critically important because of the essentiality of smallholder agriculture in maintaining food and nutritional security, especially in the global south (Boughton et al., 2020). Unfortunately, the pandemic has severely constrained the scope of empirical studies based on primary information, while reports

based on secondary information have just started to emerge (Pu and Zhong, 2020; Rawal et al., 2020) and they are more speculative than empirically grounded (Dev, 2020; Siche, 2020). Moreover, analyses of secondary information might miss the contextual nuances of agricultural systems dynamics, which are often understood best through the study of human (farmer) experience.

There has been a long tradition of systems study in agriculture vis-à-vis disaster management (Monasterelo et al., 2016; Broska et al., 2020) because of their causal link to multiple systems (agriculture) or their simultaneous impact on systems interfaces (disaster). However, knowledge on the impact of health disaster on agriculture remains limited to specific contexts, such as - HIV-AIDS vis-a-vis farm labor availability (Barnett et al., 1995). Moreover, when a system perturbation affects all sectors together, reductionist knowledge or theories are bound to fall short (Bawden et al., 1984). Many of these stresses on agroecological systems are best understood when the experiences of the subjects are studied, which asks for employing alternative research paradigms, often used by qualitative researchers (Phillips, 2014). The insights generated about the impact of COVID-19 through such alternative research paradigms are minimal and less synthesized at this point. A qualitative exploration of the impact of COVID-19 might also benefit future quantitative or mixed-method researches immensely.

In this study, apart from qualitative exploration, we employed fuzzy cognitive mapping (FCM) approach to understand the reasoning and prediction of different stakeholders regarding the outcomes of COVID-19 and ‘cyclone Amphan’ (a cyclonic storm that hit the Sundarbans delta in eastern India and Bangladesh in May 2020; Prema et al., 2020) on the agricultural systems of the study region in India. FCM is a ‘mental modelling’ approach to create a map of cognition for individuals concerning a given problem space (Gray et al., 2014). A mental model is an internally held representation of external reality by an individual (Jones et al., 2011) and may embody their reasoning about the structure and functioning of complex systems. Gray et al. (2014) established the usefulness of FCM as an analytical tool for aggregating the mental models of diverse stakeholders thus facilitating the amalgamation of different knowledge systems for collective decision-making (Halbrendt et al., 2014). In the same vein, we applied FCM to improve our understanding of the perturbed agricultural systems by generating unique mental models of diverse stakeholders, combining them to develop a shared mental model (Kosko, 1993), and by understanding the differences in individual mental models. In practice, FCM parameterized the cognitive maps, thus translating static qualitative models of the perturbed agricultural systems into semi-quantitative dynamic models using *Mental Modeler* software (Gray et al., 2013). This flexibility of the approach in conceptualizing systems elements, and valuing their relationship seemed suitable in the context of COVID-19 pandemic to develop the shared mental models of the perturbed agricultural systems. It is noteworthy to mention that, in this study, we define systems element as a symbolic entity in which the impact of COVID-19 and Amphan was perceived to be expressed and they advanced the causal links in the impact pathways.

In the present study, we aimed to understand how COVID-19 pandemic – along with cyclone Amphan – impacted smallholder farmers’ agricultural and food systems and how the farmers developed initial adaptation measures. Then, based on the identified system elements, we generated mental models for different stakeholder groups and aggregated them to develop a shared mental model for the perturbed agricultural system. We characterized the network properties of the mental models and identified the areas of consensus and differences among the stakeholders in weighing the relationships among system elements. Finally, we aimed to understand the expected system outcomes under different sets of system intervention strategies using scenario analysis.

2. Materials and methods

2.1. The context of the study – Stressed agricultural systems, COVID-19 lockdown, and cyclone Amphan

The farmer respondents were from a cluster of villages in Gosaba Block of South 24 Parganas district in West Bengal in eastern India that typically represent the coastal-saline agroclimatic zone including Sundarbans delta with forests and small islands. The area is geographically less integrated, frequently experiences extreme climatic events such as cyclonic storm and surged river water, several other biophysical stresses and represents fragile agroecosystems. During extreme weather events, tidal surge recurrently breaches river embankment causing the intrusion of saline water into the cropland, and small ponds (source of irrigation), especially in the riparian villages (Misra et al., 2017). This increases soil salinity in drier months and reduces the availability of fresh water for irrigation which makes farming difficult in the dry season. Low-lying lands become suitable for *kharif* (monsoon) season paddy cultivation only in the wet season, and inadequate drainage facilities delay the sowing of the subsequent *rabi* (winter) season crop (Ghosh and Mistri, 2020; Mainuddin et al., 2019). The groundwater is saline, and surface water dries up or becomes unsuitable for irrigating crops in the dry season due to higher salinity (Mainuddin et al., 2020). Besides, the scope of crop intensification in the dry season is challenged by lack of storage facility for perishable crops, being further from big cities, and inadequate market infrastructure and market intelligence (Ray et al., 2019, 2020; Mandal et al., 2020). Professional extension support and institutional credit services are limited, especially in the less integrated islands. Political favouritism exacerbates the targeting of social security schemes against resource-poor farm households. This nexus of biophysical and infrastructural stresses, along with limited local employment opportunities, have historically plagued agriculture and rural livelihoods in these areas and triggered recursive male outmigration (Saha and Goswami, 2020). Natural disasters often cause inflexion in the trajectory of agricultural and livelihood systems (Misra et al., 2017), causing a sudden exodus of male family members towards big cities. Many of these migrants came back in these areas during the nation-wide lockdown due to the COVID-19 pandemic (Bhowmick and Kamal, 2020). While these have caused a labor influx in the areas, it also stopped the flow of remittance in the local economy that would otherwise be invested back in agriculture or household asset creation and family welfare (Saha et al., 2018). In addition, a super cyclonic storm Amphan hit the region in May 2020 causing massive damage to natural resources and properties (Prema et al., 2020; Rajaram et al., 2020). However, the returned labor force could not go back to their working places, causing temporary idle labour forces in the region. This compounded stress of lockdown and Amphan crippled local agriculture and rural livelihoods (Majumdar and DasGupta, 2020).

Bidhan Chandra Krishi Viswavidyalaya (BCKV) have been promoting improved technologies in the region for many years and have worked with Australian Centre for International Agricultural Research (ACIAR) to promote sustainable intensification in the study areas through a project titled “Cropping system intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India (CSI4CZ)” (<http://aciarc.gov.au/project/lwr-2014-073>) during 2016–2020. Hence, farmers are somewhat trained in the use of improved technologies and aware of the concept of agricultural systems and sustainable intensification (Ray et al., 2019).

2.2. The approach to the study

To understand the impact of COVID-19 and cyclone Amphan, we used the FCM approach and developed mental models of different stakeholders, primarily because of the unpredictable and complicated outcomes expected in the agricultural and associated systems. Mental models are internally held cognitive structure of external reality (Jones

et al., 2011). They can reasonably represent the knowledge structure held by individuals related to complex socio-ecological systems (Targetti et al., 2018) and thus help in managing uncertain conditions (Halbrendt et al., 2014). Mental models exist in the human mind, and therefore, cannot be inspected or measured directly (Jones et al., 2011). Fuzzy-logic cognitive mapping has recently been used to develop mental models of individuals for better understanding of socio-ecological systems (Henly-Shepard et al., 2015) and collective decision-making in the premise of natural resource management (Gray et al., 2014). We followed a multi-stage method to formulate mental models of stakeholders concerning the impact of COVID-19 and Amphan, and developed scenarios to understand probable system performance under different scenarios (Fig. 1).

2.2.1. Selection of respondents, data collection, and qualitative data analysis

At the first stage, we purposefully identified the initial respondents (and procured their phone numbers) in consultation with the key informants with whom the authors had been working for several years. Collection of data in FCM is generally done through multi-stakeholder workshops (Gray et al., 2015), which was not possible during the lockdown. The first author formally trained in applied social sciences with several years of experience in conducting mixed-method research. He trained the second author in mixed-method research, including the application of qualitative data analysis software. An interview guide was prepared and pre-tested with three farmers and refined for further interviews which were conducted over mobile phones during mid-May to mid-June 2020. Hence, we conducted individual interviews with farmers by respecting the pandemic’s rule of social distancing, especially during the lockdown. The objectives of the study were clearly explained to the respondents before the interviews. The individual interview lasted for 45 min on an average. During the interview, we also identified other relevant respondents whom we interviewed them later (Flick, 2018; Creswell, 2002). Such snowballing continued till the tenth interview, after which no more system elements could be traced, and we assumed a saturation of concepts (i.e. system elements). This sample size was reasonable in identifying requisite number of elements in our study (Özesmi and Özesmi, 2004). Participants enjoyed this sort of interview style, and no respondents refused to participate in the interview. Critical notes were taken during and after all the interviews. All the interviews were conducted and audio-recorded with the prior consent of the respondents.

The interviews were translated, transcribed, and coded. Codes were iteratively grouped to identify significant themes (Creswell, 2002) concerning the impact of the pandemic and cyclone Amphan. Reflexive memos were recorded throughout the coding procedure. Coding of text-based data (such as interview transcript) has been widely used in qualitative research, and different approaches to coding are proposed to suit different contexts (Saldaña, 2013). The coding exercise is often guided by the research paradigm and the objectives for which coding is done (Madill and Gough, 2008). The primary objective of coding in our study was to understand how and where the lockdown and Amphan had created impacts. Since the primary objective was to identify the (system) elements for mapping the perturbed system, priority of coding was given to the identification of elements in agricultural and food systems. The impact of COVID-19 and Amphan was expressed in the system elements, and it was causally linked to one or more entities in the proposed model. Two independent coders performed coding and resolved the code discrepancy through repeated discussions. The analysis of qualitative data was performed in ATLAS.ti 8 software (Scientific Software Development GmbH. Qualitative Data Analysis. Version 8.0. Berlin, 2018). Since we did not want to start from any predisposed knowledge about the impact, we employed the ‘open coding’ principles of Grounded Theory (Corbin and Strauss, 1990) to develop a code hierarchy. The reporting of qualitative analyses mostly followed the guidelines of Consolidated Criteria for Reporting Qualitative Research (Tong et al.,

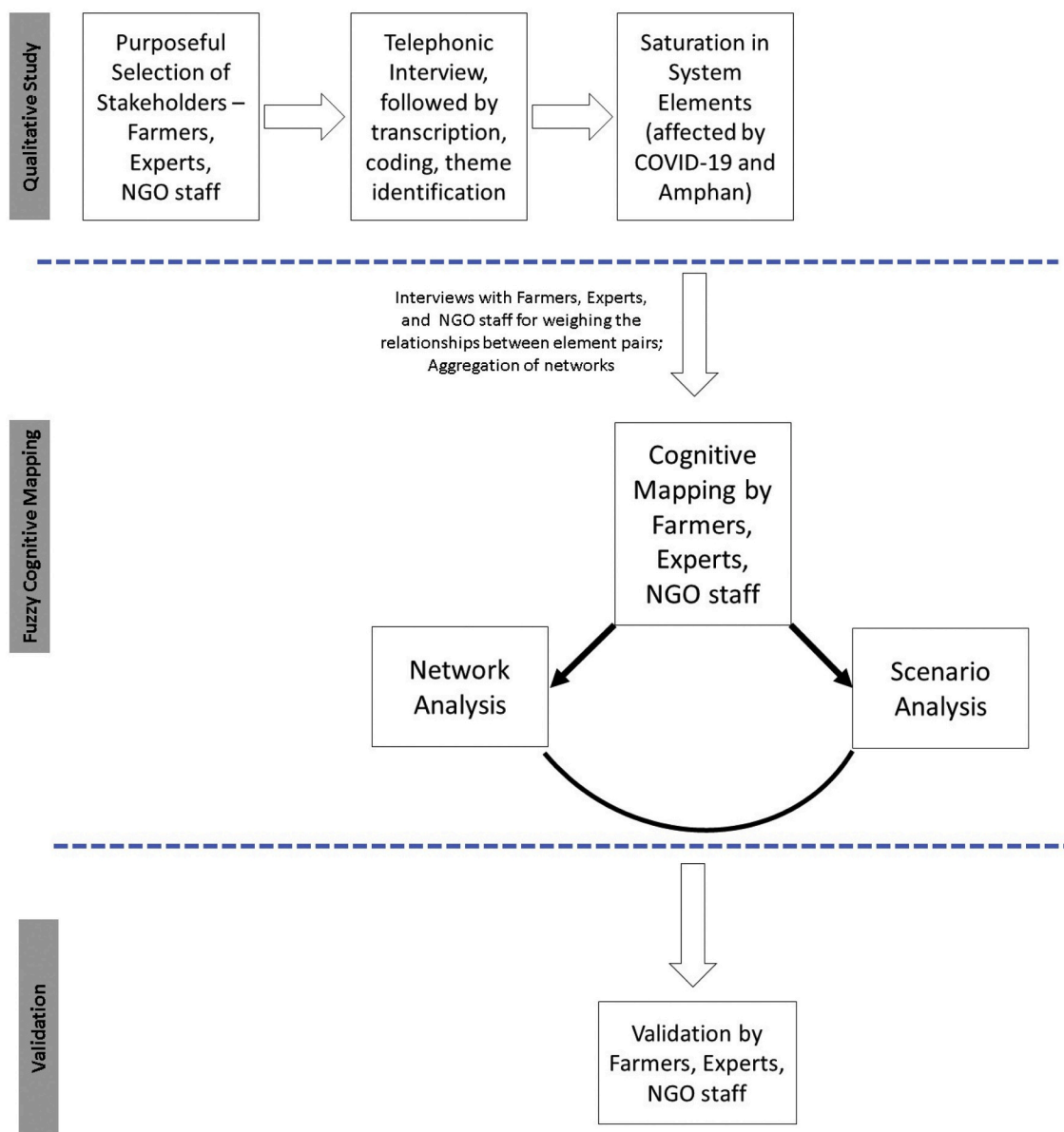


Fig. 1. The methodological outline of the research. In the first stage, qualitative research was used to identify system elements. In the second stage, identified system elements were used in the fuzzy cognitive mapping exercise by all the stakeholders. All the stakeholders weighed relationships between element pairs. Network analysis was performed for all the mental models, and scenario analysis was done to study the system outcomes as a result of changes in one or more system elements. At the third stage, the study outcomes (shared model and scenario analysis) were validated by the stakeholders. The hollow arrows suggest sequential stages and the narrow solid arrows are associated with independent operations with the cognitive maps.

2007).

2.2.2. Fuzzy cognitive mapping, network analysis, and scenario analysis

The identified system elements in the qualitative analysis were recorded as a matrix, which was used for weighing the relationship between pairs of system elements. The stakeholders slightly modified the outcomes of the qualitative analysis during the FCM to maintain the logical relationship among elements without any contradiction. For example, although it was not mentioned that lower cost of labor would lead to higher ability to spend on farming, stakeholders suggested that this element be added to the model to make the ‘story flowing’.

Two farmers, who demonstrated a clear understanding and logical explanation of the agricultural system during the first stage (the interview), were selected for the FCM exercise in the second stage. Two experts (research fellow and subject matter specialist) and one NGO staff

having a deep understanding of the local agroecosystem were also selected at the second stage. Thus, five selected stakeholders developed the cognitive maps. Please note, the system boundary was thus effectively defined by the qualitative study followed by the FCM exercises and they were not physical boundaries. The shared FCM (i.e., aggregated FCM of all stakeholders) defined the system boundary – the boundary that a group of stakeholders could collectively delineate, on which the impact of Lockdown and Amphan cyclone was felt or expected to be manifested. The five stakeholders weighed all possible pairs of system elements by specifying the direction of the relationship and its magnitude against a -1 to $+1$ scale. The description of system elements and their implications for the study are given as Supplementary Information (Table S1).

The relevant elements and the recorded weights were then imported to *Mental Modeler*, a software used for system modelling to capture the

knowledge of individuals and communities, and computes network properties following Özesmi and Özesmi (2004) (see www.mentalmodeler.org; Gray et al., 2013). *Mental Modeler* generated the mental models of stakeholders and their network properties (centrality, out-degree, in-degree). We also used the matrix in UCINET 6 (Borgatti et al., 2002) and NeTDraw (Borgatti, 2002) software to generate versatile visualizations with scaled nodes (by centrality scores) and computations of specific network properties of the mental models such as betweenness centrality, density, and connectedness. Explanations of the network properties are given as the Supplementary Information (Table S2). The variability of weights assigned to individual pairs of elements by the five stakeholders was also studied by box-plot visualization.

Then, we developed the shared mental model by augmenting and summing individual cognitive maps of all the stakeholders (Özesmi and Özesmi, 2004; Gray et al., 2012). First, we created adjacency matrices for individual FCM. New elements, if any, of another FCM were added to the matrix (augmentation), and at the end of adding all FCMs we summed the matrices (See Fig. S1, supplementary information). Shared mental models represent the degree of shared understanding among a group of individuals (Jones et al., 2011), and it is now widely used in natural resource management to enhance shared understanding of complex systems and collective decision-making (Abel et al., 1998). The central elements in the shared mental model were used for the identification of the essential elements in the model. Also, the favorably weighed pair of elements (i.e. causal relationships) were considered as possible intervention strategies (i.e. the scenarios) during the scenario analysis.

Scenario analysis is a simulated representation of system elements as a response to the manipulation of one or more system elements (i.e. the scenarios). It suggests how a complex system might react to planned intervention strategies and what might be the expression of outcomes (Ozesmi and Ozesmi, 1987). We developed scenarios by assuming the irreversibility of certain elements (e.g. crop damage caused by Amphan), and they were neither manipulated nor studied for outcomes. Based on our understanding developed through qualitative analysis and shared mental model, we developed four different scenarios (detailed in Section 3.6) presenting different combinations of system intervention strategies (i.e. changes in several system elements together). Specifically, we considered the frequently reported codes in qualitative analysis, central nodes in the shared FCM, and highly weighed edges connecting a pair of elements, and discussed their possible combinations with the stakeholders. Care was taken to propose distinct scenarios – and the extent of changes to be made on the system elements under individual scenarios – which could realistically be implemented at the local level (Scenario 2), as the short-term policy support (Scenario 3), and long-term policy support (Scenario 4). A control scenario was also kept for comparative purpose (Scenario 1). The scenario analysis was performed using *Mental Modeler* software, which produced the positive and negative relative changes in system elements when a scenario, i.e., a combination of projected interventions on one or more system elements, was imposed.

2.2.3. Validations of approaches and mental model

Validation of both qualitative research and FCM are essential to developing reasonable knowledge that can be acted upon. We cannot formally validate mental models since they might represent different understanding of the same system; rather a qualitative validation and ‘reality check’ by stakeholders are suggested (Özesmi and Özesmi, 2004). We validated the findings of our qualitative study, group mental model, and scenario analyses separately with the stakeholders which were not the respondents of interviews conducted previously. The changes suggested by the stakeholders might be due to the time difference between the data collection and the validation of the study. However, we have reported the reflections of the stakeholders in the Supplementary Information (Page 7).

3. Results

3.1. Description of the farmer respondents

Farmers in the study locations grow paddy in the monsoon (*khari*) season, and vegetables and zero-tilled potato in winter (*rabi*) season. Growing vegetables in homestead land is a common practice. Farmers have started small-scale diversification with vegetables and became ‘local experts’ while working closely with the experts of BCKV. They were exposed to diverse options of sustainable intensification and shared the acquired technological knowhow quickly in the region (Ray et al., 2019; Mandal et al., 2020). The respondents depend on local input retailers for procuring input timely and receiving advisory services. Mechanization is extremely limited in the region because of the marginal landholding of the farmers; thus, manual labor is required for farm operations but engaging them is essential in farm management. Availing veterinary extension services is still limited despite the growing importance of livestock in the region. Farm households do not extensively use institutional credit due to the issue of procedural complexities. Assured wage employment work of federal government is well-implemented by village panchayats and forms a safety net for the vulnerable population.

3.2. The impact of COVID-19

The impact of COVID-19-driven lockdown was complex, multi-faceted and experienced differently by the farmers. We primarily reported the undesired impacts on the agricultural systems to facilitate corrective actions for enhancing the resilience of farm families (Fig. 2).

3.2.1. Labor

The lockdown was enforced in late March 2020, and the migrant labors started to come back to their native areas from late April to early May 2020. Since public gathering was not allowed, farm owners could engage only a few labors at a time, thus extending the working hour of hired labors. Some labors worked secretly in the early morning to evade routine police patrol. Although the wage for labor was still unchanged (USD 4/day), it was predicted to increase if the migrant labors went back to their working places. A marginal farmer (R-3) observed –

“The labor wage has now gone up; it is now USD 4.5/ day”.

3.2.2. Livestock

The supply chain of livestock, livestock feed and medicines were disrupted. Local vendors and retailers exploited the situation by levying higher prices for animals and their feed and medicines. Price of ducklings went up by 70% and the price of cattle mesh increased by 20%. Doorstep veterinary services and medicines were also missing. The procurement chain of milk collection was also disrupted. A marginal farmer (R-2) with two cows shared –

“I have two milking cows, and I sell milk in large quantities. I sell milk at a decent rate to the milkman who comes to my house... I sell milk to local confectioners also. But, this year, I could not sell milk at all.”

On the contrary, the price of indigenous poultry chick did not change much. A backyard poultry practitioner (R-5) said –

“I have procured 10-15 indigenous poultry chicks during the lockdown at the cost of INR100 per chick (approx. USD1.4) ... the price did not change much.”

3.2.3. Farm input

We recorded contrasting views regarding the availability of farm inputs during the lockdown. Some farmers could procure inputs easily; others found it difficult and anticipated a significant price rise. Price of

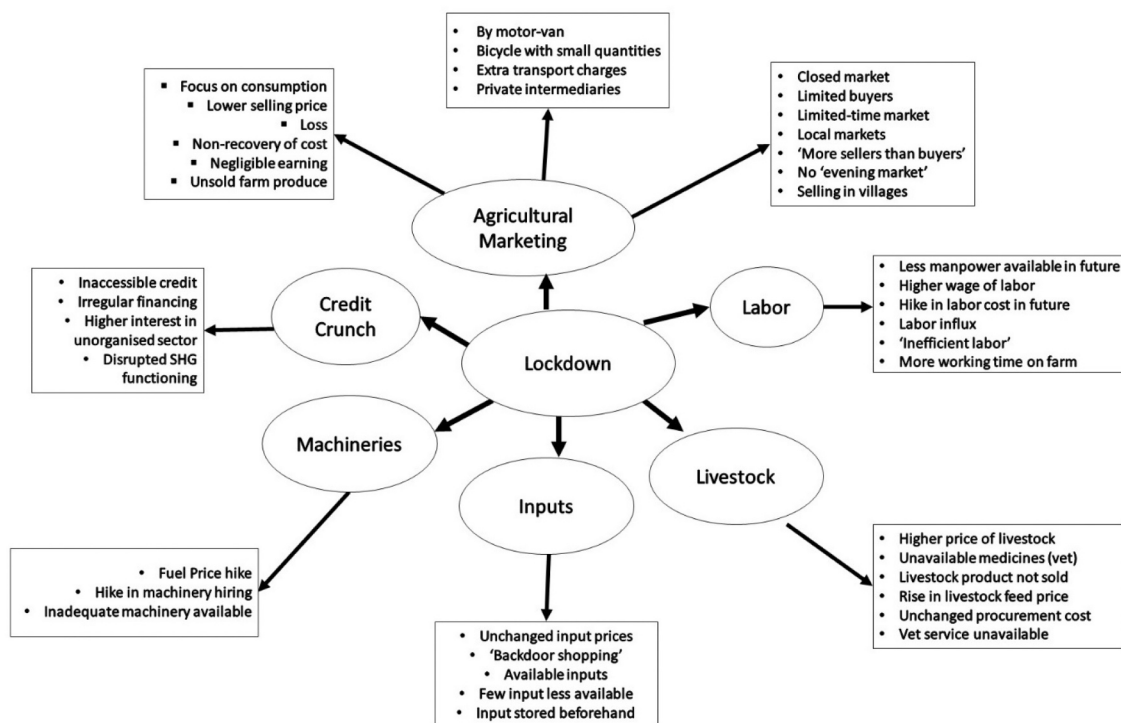


Fig. 2. Hierarchy of themes and sub-themes concerning the impact of COVID-19 lockdown on agricultural systems. The themes were identified from open coding exercises performed on the interview transcripts generated from in-depth telephonic interviews with farmers, farm women, NGO staffs, and university experts.

mustard oil cake and Di-Ammonium Phosphate (DAP) fertilizer rose by nearly 70% and 20%, respectively. A farmer (R-1) explained –

“Shop owners used to sell secretly through the backdoor of the shop, especially when it was quiet and the police were not around”.

On the contrary, many farmers stored inputs on the anticipation of a lockdown and never experienced the problem of accessing inputs or procuring them at a higher price. Triangulation of facts confirmed that access to inputs was not significantly affected.

3.2.4. Farm machinery

No significant impact on the availability of machinery was reported. This was because of the predominance of marginal farmers in the Sundarbans delta where tractors or combined harvesters are not used frequently. ‘Power tillers’ for land preparation were available locally, but the increased fuel prices during the later phases of lockdown (late May 2020) made its use or hiring costly. However, some operators did not levy higher charges. A farmer (R-5) said –

“I hired a small hand tractor (power tiller), but the hiring rate remained unchanged (USD 4 per hour).” (parenthesis added).

3.2.5. Credit sources

Farmers and Self-Help Groups (SHGs) usually availed loans from a formal banking and financial service provider, whose agents stopped visiting the area during the lockdown. Both farmers and SHGs suffered due to the credit crunch. Village moneylenders, or even the wealthy neighbours, exploited the opportunity to offer loans at higher interests. A farmer (R-5) said ruefully –

“The rich neighbours use this as an opportunity and charge 2% interest per month to earn extra money.”

3.2.6. Marketing of farm produces

The marketing of rabi crops (2019–20) was the most affected. The markets were closed, and farmers were compelled to sell farm produce in local markets, neighbouring villages, or to local grocery shops. Farmers took smaller quantities of harvested crops on bicycles and sold

them in nearby villages or to local grocery shops. Small manually operated van rickshaw or motor vans were used to reach the local market, which incurred transport costs. Some farmers made distress sale, some others consumed their produce, and a few of them could not sell their produce at all. Local markets opened for a limited time (6:00 am to 9:00 am) and the local police did not allow the evening market to open. Since no outsiders were allowed in the market, the number of sellers was more than the number of buyers, thus lowering the selling price. Often unsold produces had to be brought back to home. Some farmers sold the produce to private intermediaries at a lower price. In any case, the earning was negligible for all. Some could barely recover the cost; others incurred a loss. Few pulse growers, however, managed to get a more than usual price for their crops.

3.3. Impacts of cyclone ‘Amphan’

The impact of ‘Amphan’ is captured in Fig. 3. It was difficult to isolate the impact of COVID-19 and Amphan distinctly; some elements associated with crop production were directly affected by ‘Amphan’, and the structural barriers such as access to markets and labours were more associated with COVID-19 driven lockdown.

3.3.1. Crop damage

The farmers affirmed that the damage caused by Amphan was “unprecedented” in comparison to Aila in 2009 (IMD, 2009) and cyclone Bulbul in 2019 (Erdman, 2019). All the standing crops in the field and/or on the homestead were either partially or entirely lost. The crop loss happened due to prolonged submergence of crops in the field, strong wind, storm with continuous rain, delayed harvest due to submerged field and rotting of harvested crops due to lack of local storage infrastructure. Also, pest infestations immediately after the cyclone destroyed paddy panicles. A farmer (R-4) recalled –

“For eight continuous days, tidal waves were here, and saline water was all over the fields.”

All these factors led to plummeted production and lesser marketable

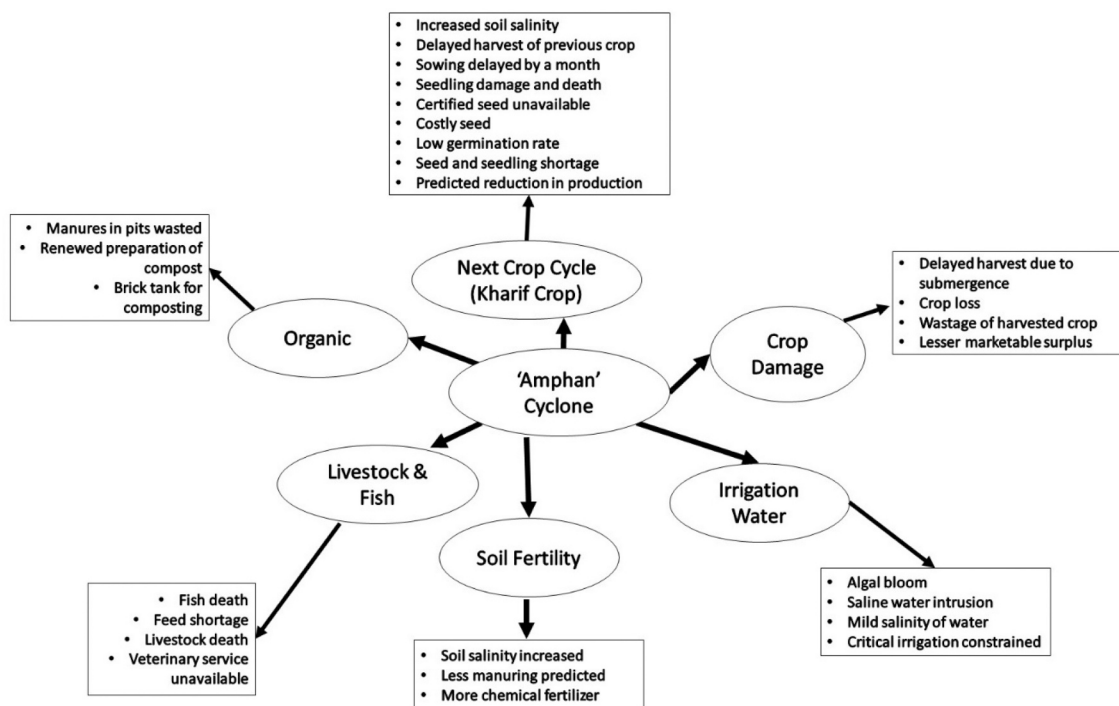


Fig. 3. Hierarchy of themes and sub-themes concerning the impact of cyclone Amphan on agricultural systems. The themes were identified from open coding exercises performed on the interview transcripts generated from in-depth telephonic interviews with farmers, farm women, NGO staffs, and university experts.

surplus, in a time when they critically needed cash earning during the lockdown. Their survival was at stake as reflected by a vegetable grower (R-4) –

“Since the standing vegetables are gone, we have to buy vegetables from the market (instead of selling them).” (parenthesis added).

3.3.2. Irrigation sources

The intrusion of saline water into the irrigation sources (mainly ponds) enhanced the salinity of the water. These inland water sources were necessary for irrigating crops in drier months. It harboured diverse fish species, which were essential sources of animal protein and an integral part of local food culture. Even after rainfall, the water remained slightly saline since soils on the pond banks were still saline and leached into the water. Eutrophication was also observed as a farmer (R-2) reported –

“Water quality in the pond has deteriorated; they are now filled with algae.”

3.3.3. Soil fertility

It was observed through the experience and impression that soil salinity increased significantly due to the intrusion of saline water during the cyclone. This higher salinity might not subside quickly without a season of continuous rain which washes the salt away. Farmers anticipated that accumulation of salts in manure pits, and death of cattle and other livestock would reduce the application of organic manure in the field, causing reduced soil fertility. This is critical since the inability to apply enough chemical fertilizer could also lead to yield penalty as well as nutrient mining from the field.

3.3.4. Livestock

Feed shortage was widely experienced as the straw was rotten due to the rain. Mass death of livestock happened, especially of poultry birds whose shelters were destroyed. Ducks and goats also died in large numbers. Cattles suffered after drinking saline water from the ditches and absence of veterinary services made the condition worse. Fishes in water bodies were either killed or washed away, affecting livelihood of

fishermen. A pond owner (R-6) reported–

“Pond water was spoiled by fallen leaves and twigs during the storm, killing all the fishes.”

3.3.5. Use of organic manure

The manure pits were destroyed during the storm due to the intrusion of saline water. Some farmers could protect the pit with straws, or by taking out the manure before the storm landed. Many farmers started preparing compost in the same pit after the storm for the next crop cycle, while others prepared brick-made protected structure.

3.3.6. Production of the existing crop (kharif)

The intrusion of saline water in the crop fields increased soil salinity significantly. Paddy seedlings became reddened and dried up when the day temperatures were high. This was because the intruded water evaporated, leaving the salt on the soil surface. A high salt concentration in soil solution reduces the ability of plant to acquire water, referred to as the osmotic effect of salinity. This caused a shortage of seedlings and an anticipated delay in transplantation (by a month), thus a delayed harvest affecting the next crop cycle. Seed shortage in the area enhanced seed price by 20% in local seed shops. Some farmers were compelled to sow low-cost ‘local’ seeds resulting in poor germination. All these predicted to plummet the production of kharif crop.

3.4. Surviving the lockdown and Amphan

We present the coping strategies against lockdown and Amphan together since they were not taken up separately after the cyclone hit these areas. During the early days of labor influx, people were hesitant to employ hired labor. Also, engaging several labors together was not allowed. Farmers primarily employed family labor, which is the default labor management strategy for family farms. Sometimes, farmers exchanged labors with fellow farmers to save the cost of hiring labor. Some farmers worked secretly to perform critical farm operations. A farmer shared (R-2) –

“During the lockdown, no work was done properly. Few people secretly

went to essential works like the excavation of pond, or garden works, up to 10–11 am (since sunrise).’

Because of the dual crises of lockdown and Amphan, farmers borrowed from family members and relatives, and local moneylenders at high-interest rates, or from the wealthy neighbours. Some others reduced the area of their cash-earning crops. A vegetable grower (R-6) submitted –

“What I did, I reduced the farm expenditure by reducing the area of vegetables; they would surely have required investment in pesticides and fertilizers.”

Others stopped buying foods and depended on free rationing services. A farm woman (R-10), whose husband worked in a ration shop said – *“Rationing helps a lot.”*

Farmers expressed their helplessness in feeding their livestock and reduced or stopped buying animal feed. Others used saved straw of harvested paddy to avoid the death of animals. Some others (R-3) experimented with new practices to avoid the crisis –

“I started cultivating azolla to feed them (livestock).”

Farm women started hatching chicks at home instead of procuring them from the market. Paid veterinary services were availed in emergency conditions, especially when the farmers were staying near the veterinary extension office. Some cattle owners (R-2) lessened milking to avoid wastage –

“I use to process milk to prepare ghee and cheese cards at home. Still, some milk was wasted. So, we lessened the milking of our cattle, like once in two to three days.”

The cyclone killed animals and caused feed shortage. Farmers took their livestock to the storm-shelters and stayed with their livestock in the same room. The farmers who lost their livestock had to procure small livestock again. Some fish farmers respawned fishes in their ponds. Some others had to sell their animals at low prices. A farm woman (R-10) ruefully expressed.

“We cannot feed her (cow) anymore, but cannot bear her hunger too; we had to sell her.”

To avoid crop loss due to Amphan, some farmers harvested their crop early and/or bought them home for household consumption. However, the saved crop had to be sold later at a lower price. Few farm households started growing vegetables in the less-saline homestead land for home consumption and local sale. Some others decided not to grow any crops in saline soil in order to avoid crop loss, and thus save money. A farm woman (R-10) could save her farm produce in the safe places of her house –

“I had put some crops in gunny bags and stored them on the covered roof to get rid of saline water. The potatoes were well-packed and stored under the bed.”

Farmers who owned pond decided not to re-excavate ponds this year (2020), because of the cost involved, while others decided to fix it immediately to save the next crop. Many pond-owners started draining the saline water out from their pond and waited for the rain to refill them with fresh water. A farmer dug canal around the home to capture more rainwater to fill the pond quickly.

Some farmers tried to apply as much organic manure as possible, while others applied phosphatic fertilizers to reduce soil salinity. Few others waited for the monsoon to drain out the salt completely. Some farmers had to sow paddy twice, others opted for more salinity-resistant varieties, or continued with their ‘pet’ varieties. Few others (R-2) changed planting density –

“I decided to plant 1-2 seedlings per hill instead of my usual 3-4 seedlings that I plant in a normal year.”

Farm assets are the accumulation of value created by a farm family over the years, and farmers assign significant cultural value to them. Despite the compounded perturbation of lockdown and Amphan, the farmers rarely sold any physical assets. A resilient farmer (R-1) reflected –

“No, sir. I did not (sell any asset). These are my only assets. Even though I should have sold these, I did not. I borrowed money at high interest, but I did

not sell any asset.”

3.5. The mental models of the stakeholders – Farmers, experts, NGO staffs

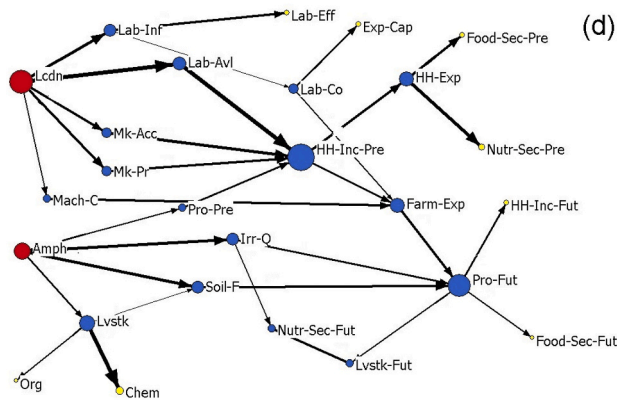
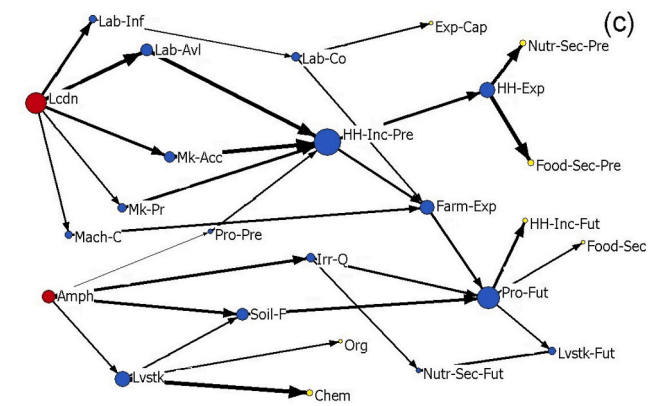
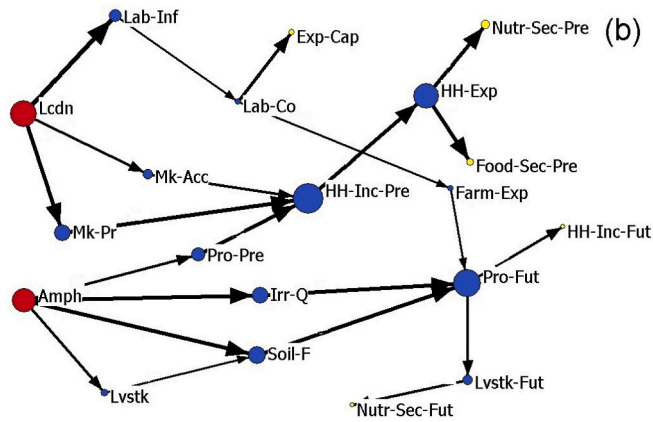
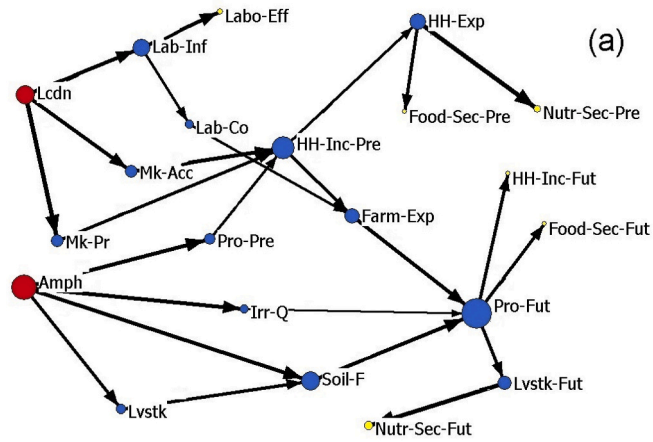
The networks generated by the stakeholders demonstrated extensive causal links among system elements through which the impact of lockdown and Amphan transitioned (Figs. 4a, 4b, and 4c). The elements from which the edges flowed out only were the ‘drivers’ of the system (lockdown and cyclone Amphan) that created two distinct paths of impact for all three networks. The “lockdown” involved market access, the market price of harvested crop and labor availability; and the cyclone Amphan affected livestock, soil fertility, and quality of irrigation water. Later, these elements interacted to create impacts on farm households in the form of present and future food and nutritional security.

[COVID-19 Lockdown (Lcdn), Amphan Cyclone (Amph), Livestock (Lvstk), Soil fertility (Soil-F), Labor influx (Lab-Inf), Market price (Mk-Pr), Quality of irrigation (Irr-Q), Future farm production (Pro-Fut), Current household income (HH-Inc-Pre), Current nutritional security (Nutr-Sec-Pre), Future nutrition security (Nutr-Sec-Fut), Market access (Mk-Acc), Future livestock holding (Lvstk-Fut), Labor Efficiency (Lab-Eff), Cost for hired labor (Lab-Co), Future Household Income (HH-Inc-Fut), Household expenditure (HH-Exp), Current food security (Food-Sec-Pre), Future Food Security (Food-Sec-Fut), Expenditure in farming (Farm-Exp), Current production (Pro-Pre), Labor Availability (Lab-Avl), Cost for hiring machinery (Mach-C), Application of chemical fertilizer (Chem), Application of organic manure (Org), Capacity to invest in farming (Exp-Cap)].

Lockdown primarily impacted the market access, market price of produces, and labour influx in the study area; where cyclone Amphan directly damaged crops, rendered the irrigation water source (pond) saline and affected soil fertility by enhancing soil salinity and (predicted) reduced application of manure. Together, these impacts were expressed through current farm production and household income, future farm expenditure and future farm production. All the stakeholders suggested that current family income lowered due to affected market access and price, and crop damage occurred due to cyclone Amphan.

Farmers and NGO staffs articulated that the future crises might emerge via lower production in the next crop cycle; this might happen due to the lower ability to invest in farming along with depleted natural resources, i.e. quality of irrigation water and soil fertility. Specifically, farmers mentioned the issue of reduced labor efficiency due to the influx of unskilled agricultural labors and identified future expenditure in farming as an outcome of both current income and labor cost. NGO staffs added cost of farm machinery to the model. They added another important causal loop to future nutritional security caused by the death of livestock and fishes in the ponds affected by saline water.

In the mental models of all the stakeholders, current household income and future farm production showed the highest indegree indicating a higher impact created through these elements (by several other system elements) (Table 1). Also, soil fertility was important for farmers and NGO staffs, and expenditure in farming was important for NGO staffs. Except Lockdown and Amphan, future farm production, household expenditure, and labor influx showed the highest outdegree in farmers’ mental model since they created the impetus through several other system elements. For experts, highest outdegree was found for household expenditure and future farm production, and for NGO staffs these were livestock and household expenditure, followed by future farm production and present household income. Future farm production and present household income was central to all three networks, other important elements were household expenditure and soil fertility. See Figs. S2a-S2d in the Supplementary Information for the original outputs of *Mental Modeler* software showing positive (+) or negative (–) relationships between pairs of system elements.



(caption on next page)

Fig. 4. 4a, 4b, 4c, 4d: Structure of the mental models of Farmers (a), Experts (b), NGO staff (c), and shared mental model (d). Nodes are system elements, edges are direct causal relationships between the nodes. Nodes are scaled by their centrality score. The thicker edges represent a higher degree of predicted impact. Red nodes are drivers, yellow nodes are receivers, and the blue nodes are ordinary nodes. The graph-theoretic layout of the output in NETDRAW software (Borgatti, 2002) was manually changed to render the network roughly chronological from left to right.

The shared mental model presented a holistic and articulated pathway of impacts in the agricultural system (Fig. 4d). Present household income, farm expenditure, livestock, labour availability, and soil fertility were the most central elements in the shared mental model. We found that present household income, farm expenditure, and future farm production had highest betweenness centrality in the network (Fig. S3, supplementary information) implying their critical roles in linking the impact of lockdown and Amphan from one section of the network (present) to the other section (future). Betweenness centrality is a measure of the extent to which a node (i.e. an element) is lying in between other connected nodes (Newman, 2005), and it represents the influence of a node over the flow of anything (i.e. impact) in a network. It suggested that all system intervention strategies must be rendered operational temporally before these elements, i.e. present household income, farm expenditure, and future farm production happen in real-time. The tie strength (thickness of edges of the group mental model) suggested that intervention strategies at the interface of labor availability \leftrightarrow present household income, market access \leftrightarrow present household income, cost of hiring machinery \leftrightarrow farm expenditure, present household income \leftrightarrow farm expenditure, soil fertility \leftrightarrow future farm production, and quality of irrigation water \leftrightarrow future farm production were the possible points of interventions through which the system outcomes can be improved. Summarily, central nodes and elements linked with them by thick lines (higher weight) were critical for the system intervention. As said earlier, we would use these intervention strategies as different possible scenarios in the scenario analyses.

The network of NGO staffs was had higher number of network elements, total connections, and connections per element, degree centralization and complexity score (Table 2). The higher number of elements and total connections indicated a more articulated system model and showed more branches in the impact pathways, thus suggesting more points of possible system interventions. A higher degree centralization suggested concentration of connections around a few of system elements and higher complexity score denoted relatively higher number of receivers such as (present and future) food and nutritional security.

We also examined the differences in assigned weights by different stakeholders to understand the extent of their disagreement at the interfaces of system elements (Fig. 5). We see that stakeholders agreed most regarding the link of Amphan with livestock, irrigation quality, and soil fertility; lockdown with labor influx; market price of farm produce with current income; soil fertility with future crop production, and future crop production with future food and nutrition security of farm families. The disagreement was recorded for the linkages between lockdown and market price, current production and present income, market access and present income, irrigation quality and future production, and farm expenditure and future crop production. Noticeably, the differences were only in the magnitude of impacts, and not in their directionality.

3.6. Scenario analysis

We conducted a scenario analysis based on the shared mental model of all the stakeholders (Fig. 6). Application of scenario analysis on shared mental model was done to elicit comprehensive and more predictable scenario outcomes. Moreover, we were more interested to know the ex-ante outcomes of system intervention strategies instead of finding the differences between the perception of stakeholders in generating scenario outcomes. Based on the qualitative analysis, we assumed that the drivers of the system (i.e. lockdown and Amphan) were given and kept outside the purview of alteration during the scenario analysis.

Stakeholders suggested that at least half of the labor, who came back during the pandemic, would go back to their working places, resulting in enhanced wages, which cannot be regulated in the short run. Also, the production loss due to Amphan was given and could not be reversed. Further, although access to the market can be handled in the short run, stakeholders expressed their doubt regarding the price stabilization of farm produce in the short run. Considering these grassroots realities and stakeholders' views, we ran the 'Scenario' module of the *Mental Modeler* for four distinct scenarios. Following the stakeholder consultation, the extent of realistic changes were made in the system elements during the scenario analyses. These are given as Supplementary Information (Table S4). These scenarios were:

Scenario 1: We do not intervene in the system and wait to see the impact of COVID-19 on the system at the end of the next crop season.

Scenario 2: We cannot manage both labor availability and market price, but enhance access to market, access to farm machinery (e.g. through custom hiring) and assist farmers in enhancing farm expenditure (e.g. through access to credit and/or input).

Scenario 3: In addition to scenario two, we enhance the current income of the farm family (e.g. direct fund transfer and/or assured support through social security and food security programs).

Scenario 4: In addition to Scenario 3, we manage labor availability and market price.

For Scenarios 2, 3, and 4, we replace the dead livestock and improve sources of fresh irrigation water.

Under scenario 1, we found that almost all the system elements – both present and future – showed a decline. Under scenario 2, although farm production showed an impressive increase in the future production (Pro-Fut), followed by the recovery of soil fertility (Soil-F), the food security (Food-Sec-Pre) and nutritional security (Nutr-Sec-Pre) in the short run might be slightly compromised. Under scenario 3, this issue was addressed by the enhanced present income of the households that resulted in an improvement in both Pro-Fut and Food-Sec-Pre and Nutr-Sec-Pre. Scenario 4 improved all aspects of system elements and outcomes by controlling labor, market, and degraded natural resources together. These four scenarios gave us varied choices to make decisions based on the ability of an agency working at different systems hierarchies.

4. Discussion

The thematic analysis indicated that the COVID-19 initiated lockdown primarily impacted the access to critical inputs and services for farming, and the cyclone caused direct damage to crops and natural resources, thus crippling the rural livelihoods. Application of fuzzy cognitive modelling FCM with three different groups of stakeholders generated different mental models with varying degrees of system complexity and articulation. The mental models captured by the FCM indicated the present and future impact pathways created by the lockdown and Amphan on agricultural systems. The mental models of different stakeholders helped us develop a comprehensive shared mental model, and understand the nature of consensus (or lack of it) among stakeholders in valuing the relationships among system elements.

4.1. Localized adaptation by the farming communities

The Sundarbans deltaic areas in eastern India are marked with physical isolation, fragile ecosystems, disaster-proneness, and inadequate human development causing extensive male outmigration (Hajra and Ghosh, 2018; Andharia, 2020). Such geographical isolation, along

Table 1

Network properties of the fuzzy cognitive maps of three different stakeholders. Mean values of Indegree, Outdegree, and Centrality are given. Outdegree is the sum of weights moving out from the element, indegree is the sum of weights moving into an element, and centrality is the sum of Indegree and Outdegree.

Elements	Element Code	Farmers			Experts			NGO Staffs			Shared			Element Type
		Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality	
COVID-19 Lockdown	Lcdn	0.0	1.6	1.6	0.0	2.1	2.1	0.0	2.8	2.8	0.0	2.9	2.9	Driver
Amphan Cyclone	Amph	0.0	2.1	2.1	0.0	1.9	1.9	0.0	1.8	1.8	0.0	2.0	2.0	Driver
Livestock	Lvstk	0.5	0.4	0.9	0.4	0.2	0.6	0.4	1.6	2.0	0.4	1.5	1.9	Ordinary
Soil fertility	Soil-F	1.0	0.6	1.6	0.8	0.6	1.4	1.0	0.6	1.6	0.9	0.6	1.5	Ordinary
Labor influx	Lab-Inf	0.5	0.9	1.4	0.8	0.2	1.0	0.6	0.3	0.9	0.6	0.8	1.4	Ordinary
Market price	Mk-Pr	0.6	0.4	1.0	0.7	0.6	1.3	0.4	0.6	1.0	0.6	0.5	1.1	Ordinary
Quality of irrigation	Irr-Q	0.5	0.2	0.7	0.7	0.6	1.3	0.6	0.5	1.1	0.6	0.8	1.4	Ordinary
Future farm production	Pro-Fut	1.3	1.2	2.5	1.4	0.8	2.2	1.6	1.4	3.0	1.5	1.3	2.8	Ordinary
Current household income	HH-Inc-Pre	1.2	0.7	1.9	1.7	0.7	2.4	2.6	1.1	3.7	2.4	1.0	3.4	Ordinary
Current nutritional security	Nutr-Sec-Pre	0.6	0.0	0.6	0.7	0.0	0.7	0.7	0.0	0.7	0.7	0.0	0.7	Receiver
Future nutrition security	Nutr-Sec-Fut	0.7	0.0	0.7	0.4	0.0	0.4	0.5	0.0	0.5	0.9	0.0	0.9	Receiver
Market access	Mk-Acc	0.5	0.5	1.0	0.4	0.4	0.8	0.6	0.8	1.4	0.5	0.6	1.1	Ordinary
Future livestock holding	Lvstk-Fut	0.4	0.7	1.1	0.4	0.4	0.8	0.4	0.5	0.9	0.4	0.5	0.9	Ordinary
Labor Efficiency	Lab-Eff	0.5	0.0	0.5	–	–	–	–	–	–	0.5	0.0	0.5	Receiver
Cost for hired labor	Lab-Co	0.4	0.3	0.7	0.2	0.3	0.5	0.3	0.8	1.1	0.3	0.8	1.1	Ordinary
Future Household Income	HH-Inc-Fut	0.4	0	0.4	0.4	0	0.4	0.6	0.0	0.6	0.5	0.0	0.5	Receiver
Household expenditure	HH-Exp	0.3	1.0	1.3	0.7	1.3	2.0	0.6	1.5	2.1	0.5	1.2	1.8	Ordinary
Current food security	Food-Sec-Pre	0.4	0.0	0.4	0.6	0.0	0.6	0.8	0.0	0.8	0.6	0.0	0.6	Receiver
Future Food Security	Food-Sec-Fut	0.4	0.0	0.4	–	–	–	0.4	0.0	0.4	0.4	0.0	0.4	Receiver
Expenditure in farming	Farm-Exp	0.7	0.5	1.2	0.3	0.2	0.5	1.4	0.5	1.9	1.3	0.5	1.8	Ordinary
Current production	Pro-Pre	0.6	0.3	0.9	0.4	0.7	1.1	0.2	0.4	0.6	0.4	0.5	0.9	Ordinary
Labor Availability	Lab-Avl	–	–	–	–	–	–	0.8	0.8	1.6	0.8	0.8	1.6	Ordinary
Cost for hiring machinery	Mach-C	–	–	–	–	–	–	0.4	0.5	0.9	0.4	0.5	0.9	Ordinary
Application of chemical fertilizer	Chem	–	–	–	–	–	–	0.8	0.0	0.8	0.8	0.0	0.8	Receiver
Application of organic manure	Org	–	–	–	–	–	–	0.4	0.0	0.4	0.4	0.0	0.4	Receiver
Capacity to invest in farming	Exp-Cap	–	–	–	0.5	0.0	0.5	0.4	0.0	0.4	0.5	0.0	0.5	Receiver

Table 2
Network properties of the cognitive maps of different stakeholders regarding the projected impact of COVID-19 lockdown and cyclone Amphan.

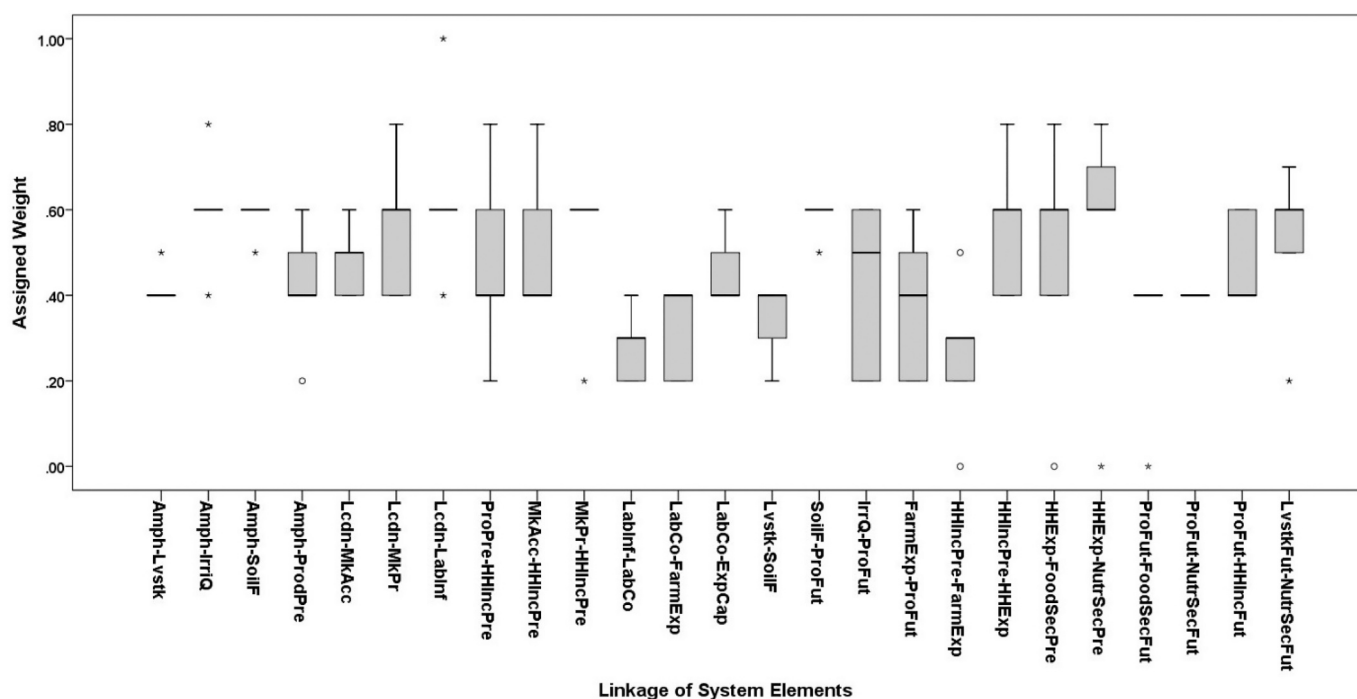
	Farmers	Experts	NGO staff	Shared
Number of elements*	21	20	25	26
Total connections	25	23	32	33
Connections per element	1.19	1.15	1.28	1.27
Density	0.06	0.06	0.05	0.05
Degree centralization	0.13	0.14	0.16	0.16
Complexity score	3.0	2.5	4.0	4.5

with the inadequate extension, marketing and financial services, caused crises in both production and marketing products. However, analysis of narratives suggested that the nature and extent of such impact could be too localized with considerable spatial variation, which aligned well with the existing theory and empirical evidence in the similar area (Cumming, 2011; Sarker et al., 2020). Villages located near the regulated markets and functional financial institutions were relatively better placed than other villages. The experience of villages with lesser migrant population could be fundamentally different from villages with a large migrant population because of the different demand-supply dynamics of agricultural labours. Further, farm households depending on family labours were more resilient than farms employing hired labor (Cortignani et al., 2020), at least in terms of engaging labours. Also, substantial social capital facilitating labor exchange among farmers enhanced their resilience (Meuwissen et al., 2019; Sutherland and Burton, 2011). On the other hand, Amphan harmed standing crops, caused the death of

livestock and damaged forests and the natural resources (soil and water) used in farming. Such impact was severe in riparian settlements where the intrusion of saline water was pronounced, and restoration of normalcy after the disaster took a long time. Farmers' adaptation to the changes in socio-ecological systems are reported to be diverse (Shukla et al., 2019). We also recorded various endogenous adaptive measures taken up by the farmers to handle the COVID-19 and cyclone-driven crises. The impact of these two perturbations on agricultural systems was thus a complex interaction of local conditions and the adaptive capacity of the farmers. Although these adaptive measures have not been included in the mental model directly, we presume that the conceptualization of pathways accounted for the adaptive strategies indirectly. For example, stakeholders suggested that food security could be handled with the help of free ration of food grain; storage of inputs helped them avoid the crisis of procuring farm inputs in time. These were reflected in the inclusion of system elements and the weighing of their relationship.

4.2. The shared mental model of the perturbed agricultural systems

The mental model of NGO staffs was more articulated (more elements and connections) than that of the farmers and experts. On the other hand, farmers and experts demonstrated similar network structure, which is not commonly reported in the literature (Schoell and Binder, 2009; Halbrendt et al., 2014). The NGO staffs worked closely with the farmers and experts and drew on both the worlds, while experts worked closely with the farmers during the implementation of their



Amphan Cyclone (Amph), Livestock (Lvstk), Quality of irrigation (IrrQ), Soil fertility (SoilF), Current production (ProdPre), Market access (MkAcc), Market price (MkPr), Labor influx (LabInf), Current household income (HHIncPre), Cost for hired labor (LabCo), Expenditure in farming (FarmExp), Capacity to invest in farming (ExpCap), Future farm production (ProFut), Household expenditure (HHExp), Current food security (FoodSecPre), Current nutritional security (NutrSecPre), Future nutrition security (NutrSecFut), Future Food Security (FoodSecFut), Future household income (HHIncFut)

Fig. 5. Weights assigned by the stakeholders to pairs of system elements in the fuzzy-logic cognitive mapping exercise. The Box-Plots bear conventional meaning. The analysis is based on the weights assigned by five individuals from three stakeholder groups. The original weights assigned are given as supplementary information (Table S3).

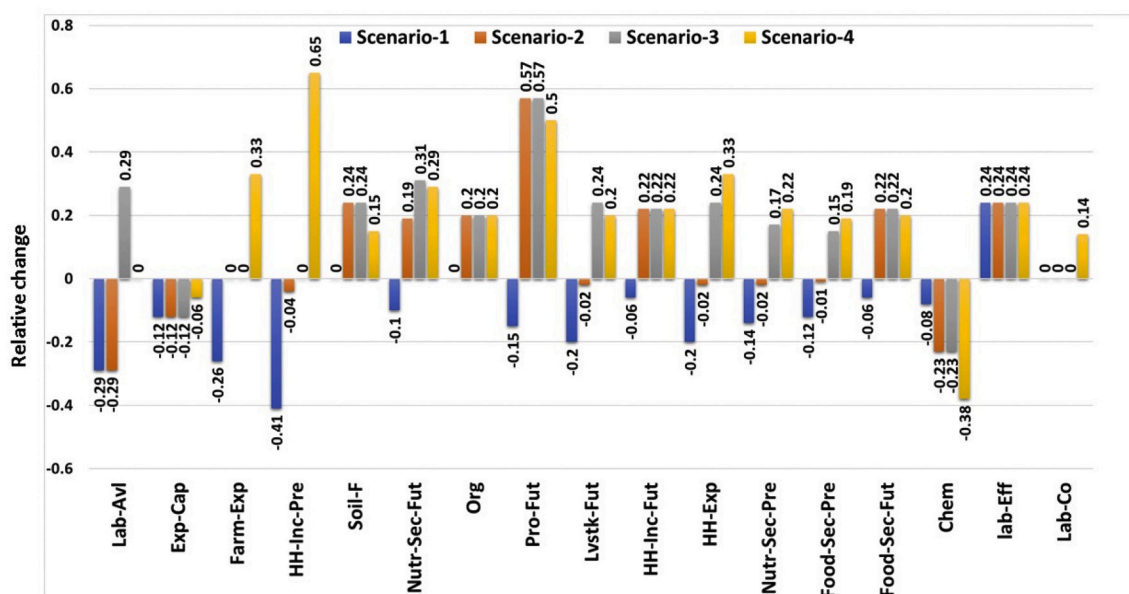


Fig. 6. Scenario analysis showing the predicted impact on the system elements under four different scenarios. The X-axis represents the system elements, and Y-axis represents the relative change expected in given system elements in response to system interventions (scenarios). Values above and below zero suggest positive and negative changes, respectively. Missing bar/s in a cluster suggests that the system element/s was/were manipulated during analysis. Original values of the elements' responses were generated in *Mental Modeler* (Gray et al., 2013) using 'scenario analysis'. Visualizations for different scenarios are given as supplementary information (Figs. S4a-S4d).

projects and developed an understanding of their knowledge system, a prerequisite for adaptive system management (Tran and Rodela, 2019). Literature suggests that the aggregation of semi-quantitative cognitive maps is possible (Kosko, 1993) from which multiple stakeholders can develop a holistic understanding of complex systems (Olazabal et al., 2018). Our shared mental model suggested the centrality of current household income, expenditure in farming (in the next crop cycle), and future crop production. It also suggested the labor availability, market access, expenditure in farming, and management of soil fertility and quality of irrigation water as possible means to manage the crises in the perturbed agricultural systems. We used these intervention strategies later in the scenario analysis, thus creating a scope of ex-ante understanding of possible outcomes of systems intervention strategies. Incorporating stakeholders' views in systems understanding and collective decision-making are essential in participatory natural resource management (Nyaki et al., 2014; Halbrendt et al., 2014). This was evident from the development of a shared mental model that not only helped us understand the scope of the pandemic but also suggested possible areas of intervention to handle the crises. Cyclone Amphan affected the current crop production and thus logically narrowed the scope of intervention to other central elements of the shared mental model. Amphan also affected the soil and water quality, thus endangering the future crop production. This unique crisis suggested that the management in post-COVID-19 situations will be extremely context-bound, especially in disaster-affected areas.

4.3. Strategies to handle the post-Covid crises

The scenario analyses using FCM is recently reported for ex-ante assessment of systems intervention strategies and collective decision-making (Papageorgiou and Kontogianni, 2012; Gray et al., 2015; Francine et al., 2016). We developed scenarios based on the shared mental model of stakeholders that suggested a varied technological and policy options to handle the COVID-19 and Amphan crisis. The analyses suggested a combination of both short-term (improvement of the livestock sector, improvement in the quality of irrigation water, enhanced household income, and investment in farming) and long-term (labor

availability, market price stabilization) strategies to handle the post-COVID-19 and Amphan crisis in agriculture. This assessment seems to be a pragmatic, evidence-based strategy at our disposal for systems intervention during the constrained mobility of researchers. However, such combinations of intervention strategies will need institutional convergence at different spatial hierarchy in the post-COVID-19 situation. For example, replacing livestock in India could best be done by the livestock extension offices. Monitoring of soil fertility is handled by agricultural extension officers or relevant agencies such as Agricultural Technology Management Agency (ATMA) or its block-level entities. Labor availability and their management could involve village panchayats and civil society organizations, and providing access to credit to farmers could be addressed by agricultural cooperatives, SHGs, or the existing credit programmes of the federal and state governments.

Analysis of narratives hinted diverse, often contradictory, adaptive strategies pursued by the farmers. These covered the management of farm labor and cash (using social capital), withdrawal from expenditures, lessening entrepreneurial activities linked to market uncertainty, innovations in resource utilization, alterations in farm operations, and protection of household assets. The diversity in adaptation measures stemmed from the heterogeneity of farm resource endowments and thus their ability to rebuild the assets (e.g. digging or draining a pond) or invest in farm enterprises (e.g. buying new livestock) or holding the sale of crops for a better price. These adaptations and ability to sustain them was critically important for the successful implementation of measures suggested by the scenario analysis (Davies et al., 2009; Lin, 2011). We have not directly addressed adaptation as a part of the FCM and scenario analysis, but report them separately to hint at the endogenous responses in the systems already taking place to appreciate the real context of the study outcomes.

4.4. The methodological novelty

FCM is recently used in the management of agricultural systems through the development of mental models (Halbrendt et al., 2018; Gray et al., 2015). However, the issue of collecting and analyzing data, especially the aggregation of individual mental models, has been

debated (Gray et al., 2012; Olazabal et al., 2018). Majority of the studies have employed workshops (Gray et al., 2015) or interviews (Targetti et al., 2019) for developing mental models. We innovated in the data collection by using qualitative methods that did not only help us in identifying system elements to be used in FCM exercise, but also let us develop a deeper understanding of the impact in different sectors and their interactions. In the next phase of analysis, we logically used the critical paths (thick lines) in the shared mental model as the possible intervention strategies in the scenario analysis. Thus, our methodology adds to the existing repertoire of mental modelling through FCM by using qualitative research as the basis of FCM.

Qualitative and mixed-methods research is essentially interpretative (Creswell et al., 2006), and researchers continuously remain self-critically aware and reflexive in writing the research report (Palaganas et al., 2017). Although the data were primarily collected from the stakeholders through telephonic interviews, the researchers proactively triangulated information and recorded reflexive memos during coding operations. We observed that lower-income in future (due to back-to-back low income from farming) might also affect the household welfare including child education, health expenditure and the care of old members of the family (Saha et al., 2018). We guess that the casualty of small livestock might also lead to adverse nutritional outcomes of farm families and undesired gender outcomes in terms of cash earning, and access and control over farm resources (Waters-Bayer and Letty, 2010). Return of male family members might also adversely affect the decision-making power of women (Saha et al., 2018). At the regional level, the thwarted flow of remittance would affect local non-farm economy due to the lower purchasing capacity of the villagers and ability of farmers to build assets in agriculture (Kharel et al., 2020; Saha and Goswami, 2020). Also, the death of a large number of trees during the Amphan will affect the farm families indirectly, especially in villages where dependence on non-timber forest product was high (Singh et al., 2010), or trees on their farms and homesteads played critical roles in the farming system.

5. Conclusions

Lessons learnt from the past nine months since the pandemic started lead us to conclude that the response of agricultural research and extension in the post-COVID-19 scenario should be fundamentally different from the business-as-usual. This is because of the overarching impact of the pandemic on agriculture and food systems affecting human lives. Our research demonstrated that informed interventions in these complex systems are possible when we build on the diverse cognitive structure of stakeholders and anticipate the system outcomes based on their inputs.

The shared mental model suggested the importance of current household income and expenditure in farming, and future crop production in transitioning the impact of COVID-19 and Amphan cyclone into the future. It also suggested that intervention in labour-management, market access, investment in farming, and soil fertility and irrigation quality management could be the most effective means to manage the crises in the perturbed agricultural systems. Scenario analysis suggested a combination of these strategies to impact the maximum number of systems elements culminating in the present and future food and nutritional security of the farm families. However, such intervention strategies will require mechanisms for institutional convergence at different hierarchies of rural administration.

The three groups of stakeholders shared a substantial number of systems elements, the NGO staffs being more articulated in their elaboration. The differences were mostly in the impact pathways and magnitude of weighing the relationships among elements. The differences and similarities in mental models among stakeholders provided a means to examine the potential consensus and discrepancies in developing shared mental models based on which locally-relevant management strategies could be crafted in the post-COVID-19 situation. We

applied the methodology to the representative geographic, farming and the socio-ecological systems spanning the Sunderbans delta in eastern India and Bangladesh, which provided substantial insights to act upon the agricultural systems in post-COVID-19 situations.

The farmers had started implementing adaptive strategies for surviving the dual crises of COVID-19 and Amphan cyclone, which have not directly been accounted for in our mental models. The accurate assessment of the impact of dual crises on agricultural systems – after accounting for the adaptive strategies in place – is still beyond our knowledge and opens up the scope for future research.

Declaration of Competing Interest

The author declares that the research as well as the article is original in nature and does not have any conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.agsy.2021.103051>.

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