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The Role of Extension and Advisory Services in Strengthening Farmers' Innovation Networks to Adapt to Climate Extremes

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Abstract: There is anecdotal evidence of the effectiveness of Extension and Advisory Service (EAS) agencies for strengthening innovation networks to adapt to extreme events that impact agricultural production and productivity. In Bangladesh, the Department of Agricultural Extension (DAE) is responsible for ensuring sustainable rice farming, which is damaged by flash flooding every year. This study investigates how EAS can strengthen farmers' innovation networks by examining DAE's efforts to adapt rice cultivation to flash flooding. Using surveys and interviews from farmers affiliated with DAE (DAE-farmers) and farmers independent of DAE (non-DAE farmers), the effectiveness of innovation networks was examined. One of the key findings of this paper is that DAE's efforts to strengthen the innovation networks of farmers to adapt rice cultivation to flash flooding focused on the facilitation of the agronomic network development. The organization missed the opportunity to enable the harvesting networks' efficacy. As the harvesting activities are highly exposed to flash flooding, the absence of adequate support from the DAE and timely updates of local weather and flash flooding information indicates that farmers are still at significant risk. This study also shows the value of including both formal (e.g., EAS agencies, research organizations) and informal actors (e.g., relatives, local input dealers) in the innovation network as a way of ensuring diversity of information access.

Keywords: extension and advisory services; climate extremes; flash flooding; innovation networks; rice cultivation

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1. Introduction

Enhancing agricultural innovation is considered a key process for adapting the agricultural sector to climate change [1,2]. This process involves an interactive, dynamic, collaborative, and flexible way of dealing with the complex nature of agriculture under the continual effects of climate change [3]. To support agricultural innovation, strengthening innovation networks is critical [4]. An innovation network is defined as "a diverse group of actors that voluntarily contribute knowledge and other resources (such as money, equipment, and land) to jointly develop or improve a social or economic process or product" [3] (p. 16). Extension and Advisory Service (EAS) agencies are considered the key player for helping to strengthen innovation networks [5] and are recognized as an engine for supporting agricultural innovation [6]. EAS agencies are conceptualized as "all the institutions from different sectors that facilitate farmers' access to knowledge, information, and technologies; their interaction with markets, research, and education; and the development of technical, organizational, and management skills and practices" [7] (p. 1).

The current body of literature broadly outlines the roles and strategies that EAS agencies need to perform in order to strengthen innovation networks in the context of climate change. The Food and Agriculture Organization (FAO) suggested that EAS agencies need to play a broader range of intermediary roles to enhance innovation network formation and support interaction among multiple actors for climate change adaptation [2]. According to the Global Forum for Rural Advisory Services, EAS agencies need to connect farmers with diverse actors, such as various agencies, communities, and institutions, to utilize the benefits of information and resources [8]. However, empirical studies on the role of EAS agencies in strengthening the innovation networks for climate change adaptation remain rare. A case study in Sweden reported that EAS agencies confined the discourse of climate change adaptation to farmers and EAS organizations and lacked the involvement of a wider range of stakeholders [9]. A study in a mountainous region of Pakistan identified that EAS agencies made minimal efforts to connect farmers with diverse actors, and consequently, farmers had very limited information sources [10]. In this vein, Tensay [11] showed that key actors were missing from farmers' innovation networks in Ethiopia and emphasized the need for the improvement of partnerships and linkages among various Ethiopian actors. Smallholder farmers in Malawi argued that they wanted to be linked with research institutions to conduct on-farm adaptive research for adapting to climate change [12]. In addition, a study in China proposed an evaluation framework of EAS to enhance innovation in the agriculture sector [13], and Charatsari et al. [14] reported the use of information and communication technology in the farming sector and suggested various pathways to enhance innovation.

According to the FAO, the role of EAS agencies in strengthening innovation networks should not be considered as a one-size-fits-all approach and should be responsive to the particular context [2]. In the current literature of innovation networks studies, there is little understanding of EAS agencies' roles related to particular climate extremes, such as floods, cyclones, and droughts. Although wetland agriculture (e.g., marshes, Haors) is highly affected by climate change [15,16], to date, there has been little study of how innovation networks could be enhanced in this case. Again, public EAS agencies are considered to perform the leading role in supporting innovation [5,6], but little is known on how they could strengthen the innovation networks and support adaptation to the particular stressors of climate change. This article is positioned within this empirical knowledge gap. In the context of Bangladesh's rice production, we investigated the effectiveness of EAS for strengthening innovation networks, specifically for the case of adaptation to flash flooding.

Rice is the staple food in Bangladesh and is predominantly produced in the Haor areas [17]. Haors are large bowl-shaped floodplain depressions located in the northeastern part of the country [18]. In the Haor areas, rice is cultivated over 1.74 million hectares, representing 15.3% of the total rice cultivation area of Bangladesh and 16.5% (about 5.25 million metric tons) of the total rice production of the country [19]. Monocropping of Boro rice (cultivated from December to May) is the dominant cropping pattern [20] and is practiced in more than 80% of Haor areas [21].

Flash flooding damages Boro rice every year in Haor areas [22,23] and severely affects Bangladesh's food security and economic growth [24]. Flash flooding is sudden, localized flooding produced by heavy rainfall over a short period (a few hours to a day) within a catchment and produces rapidly rising and fast-moving river flows [25]. The flash flooding in 2017 was the most devastating in Bangladeshi history and damaged 371,381 hectares of land, with a loss of 0.88 million metric tons of Boro rice [25,26]. Flash flooding coincides with the harvesting period (March–April) of Boro rice [27,28]. It has recently been occurring 2 to 3 weeks before the harvesting of Boro rice [24–26,29]. The increased intensity and variability of flash flooding is linked to climate change [30,31]. Several models and predictions conclude that climate change will increase pre-monsoon rainfall, which will lead to earlier and more frequent flash flooding in Haor areas [28,32–34]. In response to this increased risk, EAS activities have been promoted to mitigate the loss of rice production. This enhancement of EAS has been undertaken by the country's lead agricultural EAS agency, the Department of Agricultural Extension (DAE).

The Department of Agricultural Extension (DAE) is the leading agency for implementing agricultural policy and provides EAS [35,36]. In 2012, the Ministry of Agriculture in Bangladesh formulated the National Agricultural Extension Policy, which is comparable with the principles and strategies of enhancing agricultural innovation [37]. The policy highlighted multi-stakeholder partnerships and collaboration as the cornerstone of service delivery [37]. In this vein, DAE has emphasized networking and collaboration among the agricultural stakeholders to enhance information, knowledge sharing, and broad-based understanding to better utilize resources and expertise [36,38].

DAE has declared Haor areas as special zones and formulated guidelines to help farmers to adapt Boro rice production to flash flooding [38]. Communication in Haor areas is restrictive due to their remoteness and geographical context (e.g., flooded for 7 to 8 months a year) [39,40]. Consequently, the organization has focused on supporting effective communication, connecting different actors with farmers' innovation networks, and strengthening farmers' innovation networks for better knowledge and resource sharing [38].

The objective of this research is to examine the effectiveness of EAS for strengthening innovation networks using measures of diversity, balance in the connection between formal and informal actors and strong and weak ties, trust among the connected actors, and intercluster connections. This was done in the context of DAE's efforts to help farmers to adapt Boro rice production to flash flooding in Bangladesh.

2. Theoretical Framework

The study adopted agricultural innovation and innovation network theory as a way of defining the limits of the Extension frameworks. A social network can be conceptualized as a set of people or organizations and their relationships [41]. People perpetually communicate and interact with members of different groups, such as professional, social, religious, and communal groups [42]. These groups work like a network, and members of one group have connections with a variety of groups with diverse interests. Thus, they develop a "networked society." This network has a highly flexible boundary that allows the transfer of information, develops ideas, and affects people's actions [43]. Therefore, social networks facilitate the generation, acquisition, and diffusion of knowledge and information [44].

Agricultural innovation is conceptualized as the process whereby "individuals or organizations bring existing or new products, processes, and forms of organization into social and economic use to increase effectiveness, competitiveness, resilience to shocks or environmental sustainability, thereby contributing to food and nutritional security, economic development, and sustainable natural resource management" [45] (p. x). Traditional linear innovation processes only focus on knowledge transfer from scientists to EAS agencies to farmers. However, enhancing agricultural innovation is a complex nonlinear process that occurs through interaction among heterogeneous actors [46].

The innovation process needs extensive connections among multiple knowledge and information sources [47]. An effective innovation process is evaluated by the extent to which the innovation networks can accumulate diversity in resources and capabilities from varied actor types [48]. Diversity enhances the flow of different and new information and ideas to the networks [49,50] and increases the innovativeness of the actors [51]. Innovation in the agriculture sector may originate from the actors and institutions, including those who usually do not regard themselves as a component of that sector, such as stakeholders related to meteorological and other public and private sectors organizations [5]. Therefore, in many cases, important actors may remain absent or do not interact and contribute in ways that could enhance innovation processes [52]. Thus, information flow from the likely important actors is restricted and becomes "sticky." Networking, collaboration, and sharing of information among the diversified actors allow the "sticky" information to be disentangled and utilized to enhance the innovation processes [47]. Thus, developing, diversifying, and strengthening innovation networks is a crucial part of innovation processes [4,45,46,53].

Enhancing innovation is primarily associated with the exchange and use of information and resources [45]. Therefore, the types and ways interactions occur among the actors are important considerations [46]. The degrees of relationships among the actors are called 'ties' (contacts), which vary in their interpersonal strength [54,55]. Granovetter [56] (p. 1361) described the idea of the tie strength as "a combination of the amount of time, the emotional intensity, and intimacy and the reciprocal services which characterize the tie." Ties regulate the ways, means, and expression of communication, and affect the motivation, needs, and desires for communication [57]. Granovetter [56] suggested that a network of relationships usually encompass strong, weak, and absent ties. Ties are weak if there are no frequent or significant interactions, and ties are strong if there are numerous interactions [58].

Examination of information, ideas, and resource exchange needs to consider the existence of strong and weak ties in a particular network [59]. Strong ties are more competent providers of information flows within organization and groups, while weak ties facilitate the flow of information outside the groups [60]. Actors who share only strong ties could have narrow prospects for further acquisition of new information and resources because they belong to similar interests in terms of outlook and knowledge. On the contrary, weak-tied pairs have a greater chance of heterogeneous information and resource exchange because they function in dissimilar social networks and access different knowledge, ideas, and resources [61]. Thus, new and complementary information and ideas are achieved through only the weak ties [62]. Strengthening innovation networks, therefore, should focus on achieving a balance between utilizing weak ties and promoting strong ties [60,63].

The innovation networks can be strengthened by allowing the combination of both formal and informal actors and encouraging their interactions [51,64]. Formal relationships and interactions are contractual, rules-based, and largely established by prior membership in a particular group or organization [65]. On the other hand, informal interactions originate through trust- and emotion-based relationships among specific actors who are known to one another and mostly connected by friendship, kinship, and proximity [66]. The scope for and occurrence of informal contacts can develop and strengthen a trust-based relationship [5]. The nonappearance of formal organizational structures and working strategies allows actors considerable flexibility to adapt to new challenges and broaden scopes to enhance innovation processes [67,68]. However, both under- and over-formalization of relationships in innovation networks can serve to restrict innovation [69]. EAS agencies should support farmers in a way that allows them greater openness and enhances their access to and collaboration with diverse formal and informal actors [5,70,71].

In order to leverage the potential for enhancing innovation, actors involved in the innovation networks should develop trust between one another [72]. Specifically, opportunities of the innovating actors to connect and interact through different ties and relationships might not ensure the effective exchange of information and resources if trust is lacking [73]. In the innovation network, trust is the "relational glue" that supports interactions between both formal and informal actors, enabling knowledge access and sharing and enhancing innovation process [74]. Since innovation networks comprise multiple actors with diverse interests, conflict and distrust may arise that EAS agencies need to minimize, and EAS agencies must focus on rebuilding trust and relationships among actors to forge a viable basis for cooperation [72].

"Clusters" can also be developed to enhance knowledge creation, sharing, and resource exchange among the innovating actors [75,76]. Clusters may be defined as the geographically adjacent farmers and other actors who are involved in a particular crop sector and who establish linkages and share resources for the benefits of farming [77,78]. Membership of a farmer cluster creates an opportunity to foster connections and interactions with diversified actors [79,80]. Membership of such a cluster also influences trust in other innovating actors in the networks [79]. Scholars have argued that encouraging inter-farmer clusters connections [81] and linking them with various innovating actors might help explore and utilize heterogeneous information and resources required to enhance innovation [80,82].

In order to strengthen farmers' innovation networks, EAS thus needs to connect farmers with various actors in a way that supports diversity, ensures balance in the connection between formal and informal actors and strong and weak ties, develops trust among the connected actors, and encourages intercluster connections.

3. Methods

The study followed a mixed-method social research approach to examine how DAE has strengthened the Haor farmers' innovation networks to adapt Boro rice cultivation to flash flooding [83]. The research was conducted at Shanir Haor, which is locally known as the grain-bowl of Sunamganj, a northeastern district in Bangladesh [25]. Mapping a particular actor's or group's innovation network could provide valuable insight about a particular commodity or location-based innovation process [84]. Therefore, an egocentric network approach was followed to achieve the research objective [85]. The egocentric network develops a picture of a particular actor or group by identifying the types of connected actors, the nature and quantity of ties, and the kind of information and resources exchanged with connected actors [86]. The particular actor or group of interest is defined as the ego, and all the actors/groups connected with ego are defined as the alter [41]. The relationship between the ego and the alter is defined as a tie [41], which can be strong, weak, or absent [56].

DAE provides EAS through group approaches [38]. Although individual farmers can obtain services from DAE, farmers' groups are prioritized as the locus for implementing EAS strategies or programs [36]. The lowest administrative unit of DAE is the block. DAE forms 12 groups in each block, and each group consists of 30 farmers [38]. In this research, farmers of the DAE formed groups are called DAE-farmers, and all other farmers are identified as non-DAE farmers. The research compared DAE- and non-DAE farmers' innovation networks because comparison among different farmer groups provides insights on the dynamics that underlie access to information and resources from various sources [79,81].

DAE has a total of 5 blocks in Shanir Haor. Through discussions with DAE agents, 20 functional farmer groups were identified. We randomly selected 5 groups that accounted for 150 DAE-farmers. With the help of local representatives, the same number of non-DAE farmers (i.e., 150) were randomly selected from the blocks where DAE-formed groups were initially identified. At the beginning, informal discussions were conducted with both groups of farmers following a name generator approach [87]. Farmers were asked to name 5 actors important to them for securing information and farm inputs to adapt Boro rice production to flash flooding. Consequently, 2 lists of actors were prepared, 1 for performing agronomic activities (e.g., seed sowing, fertilizer application) and another for conducting harvesting activities.

An interview schedule was developed that contained 2 identical sets of questions for agronomic and harvesting activities. The interview schedule included questions to examine the sociodemographic characteristics, such as age, level of education, family size, and farm size, of the respondents (see Supplementary Materials). Informed by Makini et al. [88], the survey was conducted with 150 DAE-farmers and 150 non-DAE farmers. The respondents were requested to identify the actors with whom they are connected from a list. The respondents were asked the number of times they had contacted identified actors during the Boro rice production season. They were also requested to identify the type of support they received from these actors in the form of information and farm inputs [89]. The respondents were asked to mention their levels of trust in identified actors according to the Likert-type scales with the response options high, moderate, and low [90,91]. After this phase, key informant interviews were conducted with 5 DAE-farmers and 5 non-DAE farmers to understand the roles of DAE in their networks, the types of information and farm inputs they secured, and the reasons for more/less contact and high/low trust in particular actors. In addition, a focus group discussion with 12 DAE-farmers was conducted. Data from key informant interviews and focus group discussions were audio-recorded. Data were collected from January to April 2019.

In the survey data, the identified and nonidentified actors were coded as 1 and 0, respectively. Centrality measures for the ego networks, such as size and degree, were calculated. "Size" shows the number of alter directly connected with an ego [92], and "Degree" denotes the importance of an ego in the network [84]. Scores of 1 and 2 were assigned for information and farm inputs, respectively, to understand the types of supports obtained. The responses on trust were coded as 3, 2, and 1 for high, moderate, and low, respectively. The data were entered in the Microsoft Excel Worksheet 2016, and descriptive statistics were performed [93]. To calculate the mean difference in various parameter of DAE- and non-DAE farmers, the Statistical Package for the Social Sciences software (IBM SPSS Statistics Version 26) was used. In order to quantify strong ties, the first integer value to reach the mark of the mean value of contact number was considered [60,94]. The integer values to reach the mark of the mean value of contact number were 7 and above for agronomic activities and 4 and above for harvesting activities. Any value below these was designated as a weak tie and used to compare with strong ties [94]. Innovation networks maps were drawn using UCINET (version 6.689) software. The key informant interview and focus group discussion data were transcribed and coded using NVivo (version 12 Pro) software with codes such as information sources, farm input sources, agronomic practices, harvesting activities, connections, links, support, contact, and trust. The coded texts were organized under themes such as important actors, types of supports secured, support from DAE, and trust in the connected actors to explore the findings [95].

4. Results

The results highlight the effectiveness of DAE in strengthening innovation networks using a range of measures. These include sociodemographic characteristics, centrality measures, types of connected actors, type of connections with actors, support secured from the connected actors, and trust in connected actors. The results include a comparison of DAE- and non-DAE farmers' innovation networks for agronomic and harvesting activities, which are two distinct stages of rice production.

4.1. Sociodemographic Characteristics of DAE- and Non-DAE Farmers

There was no significant difference in sociodemographic characteristics between DAE- and non-DAE farmers. The mean value of age and level of education of DAE- and non-DAE farmers was 43.25 years and 45.67 years and 4.14 years and 3.96 years of schooling, respectively. DAE- and non-DAE farmers had a mean family size 6.30 and 6.65 and mean farm size 2.41 hectare and 2.24 hectare, respectively (see Table 1). These results highlight that differences in innovation effectiveness in the DAE- and non-DAE farmers' networks are driven by the specific characteristics of the innovation networks rather than differences in demographics.

4.2. Innovation Networks

4.2.1. Agronomic Networks

Centrality Measures

There was a significant difference in centrality measures such as size and degree between DAE- and non-DAE farmers. The network size of DAE- and non-DAE farmers was 4.69 and 4.92, respectively. DAE- and non-DAE farmers had the network degree score of 0.52 and 0.55, respectively (see Table 2). This indicates that the innovation networks of non-DAE farmers are more cohesive than that of DAE-farmers.

Types of Connected Actors

DAE- and non-DAE farmers had a connection with formal public sector actors, such as DAE and research institutions; and private sector actors, such as private companies and local input dealers. They were also connected with informal actors, such as DAE and non-DAE farmers, relatives, friends, harvesting laborers; civil society actors, such as NGOs; electronic media (TV/Radio); and the internet (see Figures 1 and 2). A large proportion of the DAE-farmers developed clusters with DAE, research institutions, DAE-farmers, and local input dealers that are located at the center of the map. On the contrary, most of the non-DAE farmers created clusters with local input dealers, non-DAE farmers, relatives, and harvesting laborers that are positioned at the middle of the map (see Figures 1 and 2).

Table 1. Sociodemographic characteristics of Department of Agricultural Extension (DAE)- and non-DAE farmers.

Characteristics	Unit of Measurement	DAE-Farmers	Non-DAE Farmers	*t*-Value of Mean Difference
Age	years	43.25	45.67	−1.838 ^{NS}
Level of education	years of schooling	4.14	3.96	0.542 ^{NS}
Family size	number of people	6.31	6.65	−1.308 ^{NS}
Farm size	hectares	2.41	2.24	0.962 ^{NS}

Significance level: NS = not significant.

Table 2. Centrality measures for the agronomic networks.

Measures	DAE-Farmers	Non-DAE Farmers	*t*-Value of Mean Difference
Size	4.69	4.92	−1.568 **
Degree	0.52	0.55	−1.720 *

Significance level: ** = $p < 0.01$, * = $p < 0.05$.

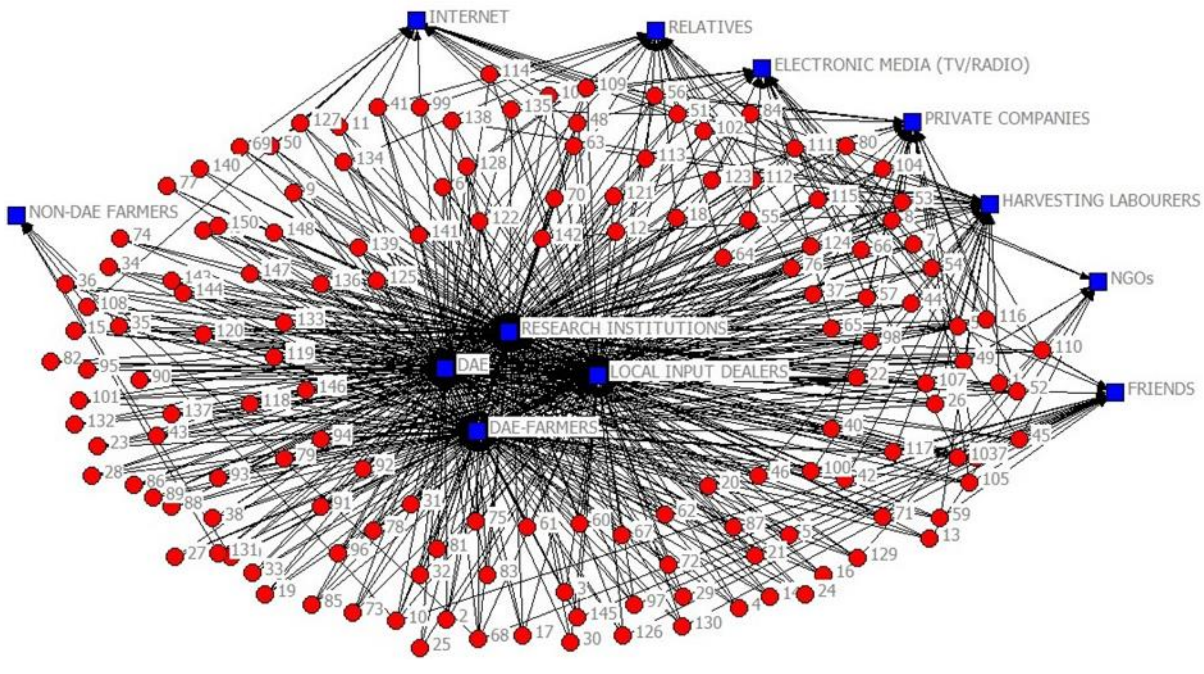

Figure 1. Innovation networks of DAE-farmers for agronomic activities (red circle = DAE-farmer, blue square = connected actor).

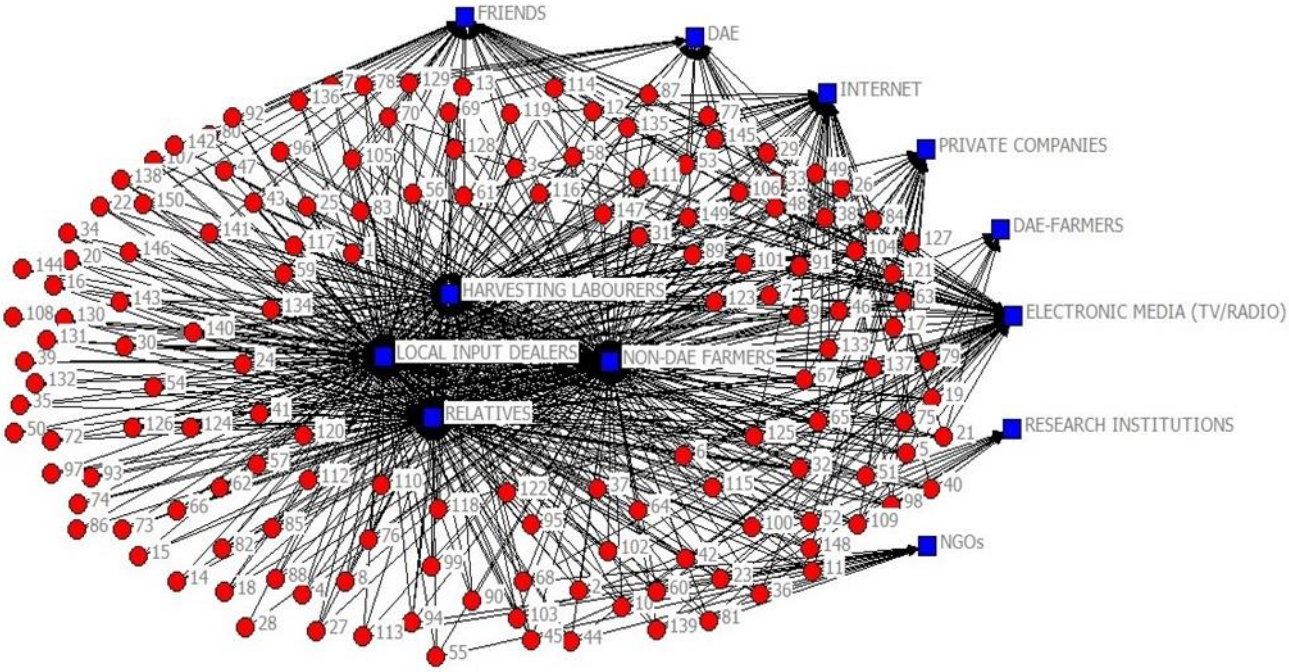

Figure 2. Innovation networks of non-DAE farmers for agronomic activities (red circle = non-DAE farmer, blue square = connected actor).

Types of Connections with Actors

DAE-farmers had strong ties with DAE and other DAE-farmers (see Table 3). They regularly contacted DAE to attend training, field visits, and demonstrations. DAE-farmers frequently communicated with other DAE-farmers who were either members of the same or different DAE-farmer groups. On the contrary, non-DAE farmers maintained strong ties with three actor types: Non-DAE farmers, local input dealers, and relatives. They regularly communicated with other non-DAE farmers. Non-DAE farmers visited local input dealer shops almost every week. They frequently contacted relatives who lived in areas with comparatively higher land and cultivated rice. DAE-farmers had weak ties with local input dealers and relatives. They occasionally visited input dealer shops and contacted relatives to perform agronomic activities. The DAE- and non-DAE farmers had weak ties with one another. Both DAE- and non-DAE farmers had weak ties with other connected actors.

Table 3. Types of connections with actors in the innovation networks for agronomic activities.

Connected Actors	**Ties**	
	DAE-Farmers	**Non-DAE Farmers**
DAE	Strong	Weak
Research institutions	Weak	Weak
Local input dealers	Weak	Strong
Private companies	Weak	Weak
DAE-farmers	Strong	Weak
Non-DAE farmers	Weak	Strong
Relatives	Weak	Strong
Friends	Weak	Weak
Harvesting labourers	Weak	Weak
Electronic media (TV/Radio)	Weak	Weak
Internet	Weak	Weak
NGOs	Weak	Weak

Support Secured from the Connected Actors

A significant proportion of DAE farmers secured support from the formal actors. All the DAE-farmers obtained information about modern Boro rice cultivation from DAE (see Table 4). The major portion of DAE-farmers (96.28%) secured information on short-duration early rice varieties and pest control measures from research institutions. Whereas 73% of DAE-farmers obtained information from other DAE-farmers, 3.33% secured from non-DAE farmers. Only 10.67%, 8.67% and 6.12% of DAE-farmers obtained agronomic information from local input dealers, relatives, and harvesting laborers, respectively. DAE-farmers believed that they obtained enough scientific and reliable information and knowledge of Boro rice cultivation since they were connected with DAE and research institutions. For this reason, they were not interested in seeking information from other sources. One DAE-farmer mentioned that *"We get information from DAE. What do the input dealers know? We go to input dealers only to buy inputs . . . . .Private companies tell input dealers to sell their products, so input dealers will suggest me to buy bad quality products."* According to DAE-farmers, the information provided by the relatives might not be scientifically proven and as reliable as formal actors.

Table 4. Types of supports secured from the connected actors in the innovation networks for agronomic activities.

Connected Actors	Information		Farm Inputs	
	DAE-Farmers (%)	Non-DAE Farmers (%)	DAE-Farmers (%)	Non-DAE Farmers (%)
DAE	100	14.67	10.67	0
Research institutions	96.28	6.00	0	0
Local input dealers	10.67	100	100	100
Private companies	15.33	12.67	0	0
DAE-farmers	72.67	5.33	0	0
Non-DAE farmers	3.33	100	0	0
Relatives	8.67	94.00	2.72	24.00
Friends	6.24	29.33	0	2.00
Harvesting labourers	6.12	67.33	0	0
Electronic media (TV/Radio)	10.07	37.33	0	0
Internet	7.33	22.67	0	0
NGOs	6.90	8.00	0	1.33

A large portion of non-DAE farmers utilized support from the informal actors. All the non-DAE farmers collected agronomic information and knowledge from non-DAE farmers and local input dealers. They thought that local input dealers had connections with diverse actors, such as DAE, private companies, and other input dealers. So, local input dealers have rich and diverse information, which will help them for Boro rice cultivation. A considerable percentage of non-DAE farmers secured information from relatives (94.00%) and harvesting laborers (67.33%). One non-DAE farmer reported that *"Last year one of my sons in law lives in Jamalganj Upazila (administrative unit) cultivated Janak Raj (hybrid rice variety) and harvested bumper yield. This year I have collected four (4) kg seeds from him and cultivated. My field is in very good condition now."* In order to harvest Boro rice, harvesting laborers were called mostly from localities with higher land, which are practiced for rice cultivation in three seasons per year. Non-DAE farmers discussed with harvesting laborers how they cultivate rice in their locality and obtained new information, ideas, and opportunities for Boro rice cultivation.

Both DAE- and non-DAE farmers bought farm inputs (e.g., seeds, fertilizers) from local input dealers. Only 10.67% of DAE-farmers collected farm inputs from DAE. DAE provided inputs, such as seeds and fertilizers, to conduct demonstrations and motivate farmers to practice modern Boro rice cultivation. About one-fourth of non-DAE farmers obtained farm inputs, mostly seeds of new and short-duration rice varieties, from their relatives. There was no farm input sharing between DAE and non-DAE farmers.

Trust in Connected Actors

DAE-farmers had the highest trust in DAE (2.05), with a possible score of 1 to 3 (see Table 5). Their other trusted actors were DAE-farmers (1.98) and research institutions (1.94). They believed that information provided by the formal actors was authentic and scientific. Their trust level for local input dealers and relatives was low, with scores of 1.13 and 1.22, respectively. They thought that local input dealers delivered information and advised only for business. On the contrary, non-DAE farmers had the highest trust in relatives and local input dealers, with the mean value of 2.85 and 2.11, respectively. They thought that relatives would remain trustworthy for rice cultivation. Non-DAE farmers believed that local input dealers would not cheat as a resident of the same village or area. They could interrogate local input dealers about any issue that requires clarity. DAE- and non-DAE farmers had less trust in one another, with a score of 1.14 and 1.13, respectively.

Table 5. Level of trust (rank) in connected actors in the innovation networks for agronomic activities.

Connected Actors	DAE-Farmers [1]	Non-DAE Farmers [1]	*t*-Value of Mean Difference
DAE	1 (2.05)	11 (1.04)	27.280 ***
DAE-farmers	2 (1.98)	10 (1.13)	16.005 *
Research institutions	3 (1.94)	9 (1.17)	17.991 ***
Private companies	4 (1.22)	8 (1.21)	0.132
Relatives	4 (1.22)	1 (2.85)	−34.357 **
Non-DAE farmers	5 (1.14)	3 (1.97)	−19.817 *
Local input dealers	6 (1.13)	2 (2.11)	−16.761 ***
Electronic media (TV/Radio)	7 (1.08)	6 (1.40)	−6.569 ***
NGOs	8 (1.06)	10 (1.13)	−2.159 ***
Friends	9 (1.04)	5 (1.50)	−9.798 ***
Harvesting labourers	9 (1.04)	4 (1.91)	−24.290 ***
Internet	10 (1.00)	7 (1.29)	−7.738 ***

[1] Value in the parenthesis indicates the mean score; Significance level: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$.

4.2.2. Harvesting Networks

Centrality Measures

There was a significant difference in centrality measures such as size and degree between DAE- and non-DAE farmers. The network size of DAE- and non-DAE farmers was 7.09 and 7.03, respectively. DAE- and non-DAE farmers had the network degree score of 0.68 and 0.66, respectively (see Table 6). This indicates that the innovation networks of DAE-farmers are more cohesive than that of non-DAE farmers.

Table 6. Centrality measures for the harvesting networks.

Measures	DAE-Farmers	Non-DAE Farmers	*t*-Value of Mean Difference
Size	7.09	7.03	0.373 ***
Degree	0.68	0.66	1.528 ***

Significance level: *** = $p < 0.001$.

Types of Connected Actors

DAE- and non-DAE farmers had connections with formal public sector actors, such as DAE, the meteorological department, and the local public administration; and private sector actors, such as private companies. They were also connected with informal actors, such as DAE- and non-DAE farmers, relatives, friends, harvesting laborers, embankment guards, and transport vehicle lessors; and local elites, such as Haor committee members, local representatives, and religious leaders (see Figures 3 and 4). A large percentage of both DAE- and non-DAE farmers developed clusters with informal, local, and elite actors, such as embankment guards, transport vehicle lessors, harvesting laborers, local representatives, and Haor committee members. DAE was excluded in the DAE-farmers' clusters and is located at the periphery of the map.

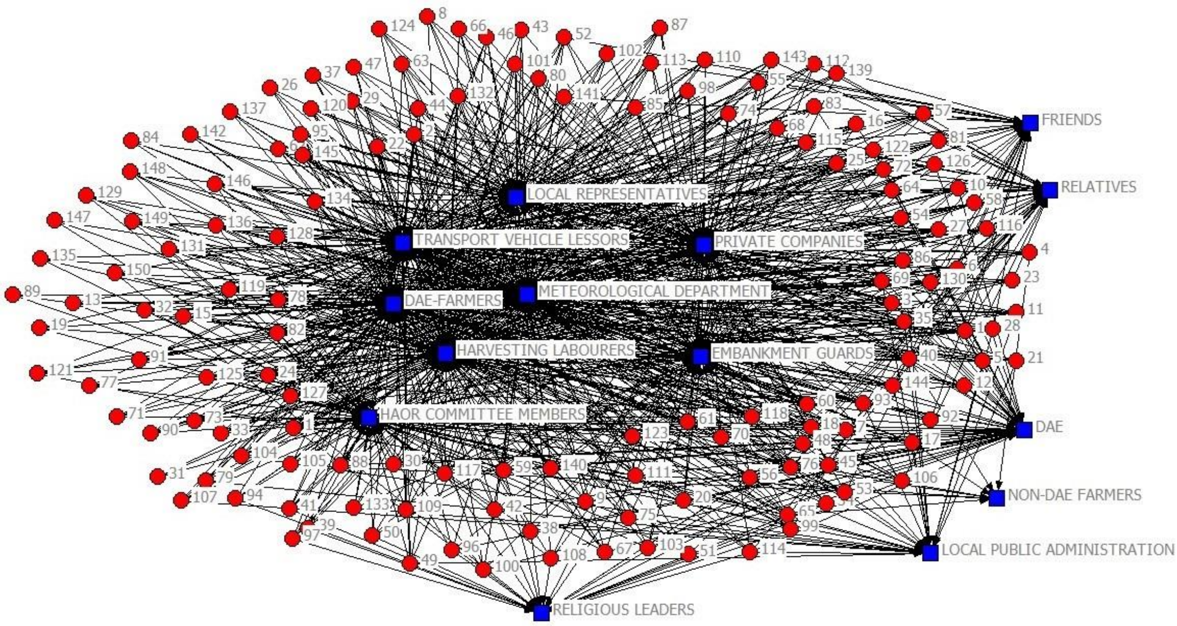

Figure 3. Innovation networks of DAE-farmers for harvesting activities (red circle = DAE-farmer, blue square = connected actor).

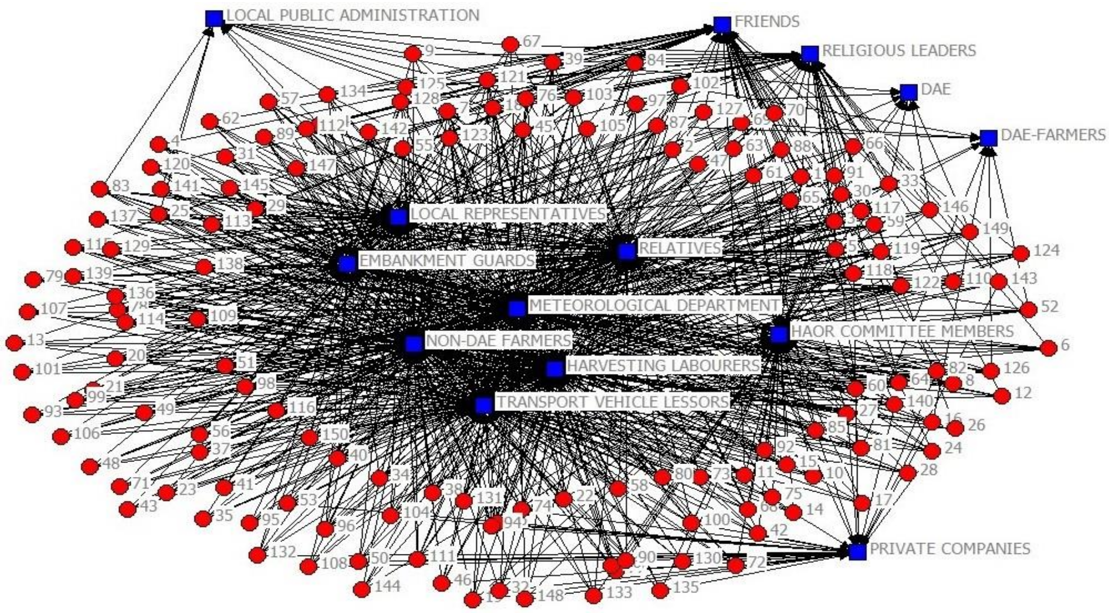

Figure 4. Innovation networks of non-DAE farmers for harvesting activities (red circle = non-DAE farmer, blue square= connected actor).

Types of Connections with Actors

DAE-farmers had strong ties with the meteorological department and DAE-farmers (see Table 7). They observed weather news on television released by the meteorological department almost every evening at local tea stalls. DAE-farmers regularly contacted other DAE-farmers. They had weak ties with DAE. On the contrary, non-DAE farmers had strong ties with the meteorological department, non-DAE farmers, and relatives. They contacted other non-DAE farmers frequently during the harvesting period. Non-DAE farmers had regular communication with their relatives as well. However, DAE-farmers had weak ties with relatives. DAE- and non-DAE farmers had weak ties with one another. Both groups of farmers maintained weak ties with other connected actors in their networks.

Table 7. Types of connections with actors in the innovation networks for harvesting activities.

Connected Actors	Ties	
	DAE-Farmers	Non-DAE Farmers
DAE	Weak	Weak
Meteorological department	Strong	Strong
Local public administration	Weak	Weak
Private companies	Weak	Weak
Transport vehicle lessors	Weak	Weak
DAE-farmers	Strong	Week
Non-DAE farmers	Weak	Strong
Relatives	Weak	Strong
Friends	Weak	Weak
Harvesting labourers	Weak	Weak
Embankment guards	Weak	Weak
Haor committee members	Weak	Weak
Local representatives	Weak	Weak
Religious leaders	Weak	Weak

Support Secured from the Connected Actors

DAE farmers mostly secured support from the local, informal actors for performing harvesting activities (see Table 8). They obtained the rain and flash floods forecasting from the meteorological department that released weather updates for the entire Sylhet region (consists of four districts, including Sunamganj). DAE-farmers discussed the rain, probability of flash flooding and harvesting information with other DAE-farmers (78.67%). They visited private companies, as motivational tours organized by DAE, to obtain information about Boro rice harvesting-related machinery, such as hand reapers and combined harvesters. DAE-farmers secured information about flash flood occurrences, as well as the water levels in the nearby river and condition of crop-saving embankments from local representatives (56.67%), embankment guards (56.67%), and Haor committee members (50.00%). There was less information sharing between DAE- and non-DAE farmers. About 30% of DAE-farmers obtained information from DAE. The results from both interviews and focus group discussions suggest that during the harvesting period, DAE had minimal support in delivering rice maturity indicators and the timing of harvesting information. DAE was found to be lacking in its ability to connect DAE-farmers with related actors and provide timely and up-to-date local information on weather and flash flooding to enable DAE-farmers to make an informed decision. One DAE-farmer mentioned that "*During the harvesting period, DAE does not tell us about crop-saving embankment conditions and water levels in the river, they just tell us about crop harvesting*."

Similar to DAE-farmers, all non-DAE farmers obtained information about rain and flash flooding from the meteorological department. They contacted other non-DAE farmers (98.00%) to find out about the likelihood of rain and flash flooding. Non-DAE farmers discussed flash flood occurrences, as well as harvesting support, such as machinery, transport vehicles, and laborers with their relatives (75.33%). They sought information about crop-saving embankments (e.g., water leakage, weak points) and water levels in the nearby river from embankment guards (70.17%).

In order to harvest timely and quickly, most of the DAE- and non-DAE farmers secured support from harvesting laborers and transport vehicle lessors. These actors provided necessary instrumental support, such as labor, boats, trolleys, and carts. A small percentage of DAE-farmers (3.33%) obtained input support from DAE, who provided only government-subsidized harvesting machinery, such as mini-combined harvesters and hand reapers. On the other hand, 18.67% of non-DAE farmers secured farm inputs from relatives who offered self-labor, as well as harvesting machinery and transport vehicles. There was no farm input exchange between DAE- and non-DAE farmers noted in our sample.

Table 8. Types of supports secured from the connected actors in the innovation networks for harvesting activities.

Connected Actors	Information		Farm Inputs	
	DAE-Farmers (%)	Non-DAE Farmers (%)	DAE-Farmers (%)	Non-DAE Farmers (%)
DAE	29.33	5.33	3.33	0
Meteorological department	100	100	0	0
Local public administration	17.33	8.67	0	0
Private companies	63.33	20.67	0	0
Transport vehicle lessors	6.67	14.00	84.67	80.67
DAE-farmers	78.67	6.00	6.67	0
Non-DAE farmers	5.33	98.00	0	10.34
Relatives	24.14	75.33	3.33	18.67
Friends	17.33	27.33	0	0
Harvesting labourers	4.00	11.33	87.33	91.33
Embankment guards	56.67	70.17	0	0
Haor committee members	50.00	41.33	0	0
Local representatives	56.67	55.33	0	0
Religious leaders	20.67	24.14	0	0

Trust in Connected Actors

DAE-farmers had the highest trust in other DAE-farmers, with a mean value of 2.02 (see Table 9). As DAE-farmers had good understanding and collective working experience with other DAE-farmers while participating in different programs executed by DAE, other DAE-farmers were considered credible sources of information. They had less trust in DAE (1.25). The results from both interviews and focus group discussions suggest DAE-provided harvesting machinery was not effective in operating in the Haor areas. In addition, DAE lacked the capacity to communicate necessary and timely information about flash floods, and ultimately could not become a trustworthy actor for the DAE-farmers. Conversely, non-DAE farmers highly trusted in other non-DAE farmers (mean value: 2.03). Local elites (e.g., local representatives) and embankment guards often visited the crop-saving embankments and nearby rivers. So, they had timely updates on the flash flood occurrences. In addition, they were highly valued actors in farming communities. So, their endorsement on any update related to flash flooding and suggestions on crop harvesting achieved greater trust and acceptability among the DAE- and non-DAE farmers. However, DAE- and non-DAE farmers had less trust in one another.

Table 9. Level of trust (rank) in connected actors in the innovation networks for harvesting activities.

Connected Actors	DAE-Farmers [1]	Non-DAE Farmers [1]	*t*-Value of Mean Difference
DAE-farmers	1 (2.02)	11 (1.11)	24.326 ***
Meteorological department	2 (1.90)	5 (1.82)	0.524
Religious leaders	3 (1.89)	2 (1.97)	−1.660
Local representatives	4 (1.85)	6 (1.75)	1.871 ***
Haor committee members	5 (1.78)	7 (1.72)	0.888 *
Embankment guards	6 (1.75)	3 (1.95)	−3.177 ***
Harvesting labourers	7 (1.61)	5 (1.82)	−2.798
Transport vehicle lessors	8 (1.60)	8 (1.61)	−0.215
Relatives	9 (1.39)	4 (1.85)	−8.836 ***
Local public administration	10 (1.30)	12 (1.07)	4.893 ***
DAE	11 (1.25)	13 (1.00)	6.985 ***
Private companies	12 (1.20)	10 (1.13)	1.721 ***
Friends	13 (1.08)	9 (1.49)	−8.870 ***
Non-DAE farmers	14 (1.00)	1 (2.03)	−32.803 ***

[1] Value in the parenthesis indicates the mean score; Significance level: *** = $p < 0.001$, * = $p < 0.05$.

5. Discussion

The research examined how DAE, as a public EAS agency, has strengthened the innovation networks of Haor farmers to adapt rice cultivation to flash flooding. The findings indicated that DAE had supported the innovation networks of Haor farmers, which was most prevalent for agronomic practices of rice cultivation as compared to harvesting activities.

5.1. Innovation Networks for Agronomic Activities

For innovation networks associated with agronomic practices, a large percentage of DAE-farmers were connected with, and secured support from, formal actors (e.g., DAE, research institutions). Formal actors are often considered as reliable sources by the farmers [66]. However, evidence shows that donor and government-supported innovation networks often prevailed with a number of formal actors that mostly had less internal cohesion among the innovating actors. Therefore, those connections do not ensure the networks' sustainability and tend to disappear once the external support has ended [3].

Development of farmers' clusters has been argued to enhance connections with diversified actors and strengthen innovation [76,79,80]. This study found that clustering leads to DAE-farmers connect with limited actors [81]. Due to developing clusters with formal actors, DAE-farmers did not extensively look for other actors beyond the clusters to secure information and support in the agronomic networks. As a result, they missed important information and new ideas from the potential informal actors, such as local input dealers, relatives, and harvesting laborers. However, like non-DAE farmers, a significant portion of farmers in Bangladesh obtain agricultural information from local input dealers [96]. In addition, informal actors such as neighbors, relatives, and friends play an important role in providing farming information and resources to the rice farmers in Bangladesh [96].

Innovation networks should not be allowed to embrace rigid structures [97]. A network's openness to develop new relationships has been proven to be supportive for enhancing innovation [5]. Empirical case studies on successful commercial innovations showed that 23% of the cases utilized informal networks for innovation. More than half of the cases (54%) incorporated ideas and resources from external actors, and nearly half of the cases (46%) employed relevant inputs and knowledge from informal actors [51]. Therefore, scholars [65,87,98] have suggested that public EAS agencies need to enhance synchronization and secure balance between formal (contractual, rule-based) and informal (emotion- and trust-based) actors in the innovation networks. The formal and informal relationships should be combined in cyclical patterns so innovating actors could obtain the benefits from the networks through interactions [49,64].

In the innovation networks, strong ties may lead to a 'lock-in' situation [49] and cause network failure [68]. A 'lock-in' situation is a state in which actors are locked into a similar way of thinking through strong-tie relationships that restrict new information access from outside networks and limits new collaboration [68,99]. The results from both surveys and interviews suggest that DAE-farmers' strong-tie relationships with DAE and other DAE-farmers might lead to a 'lock-in' situation in the agronomic networks. So, the strong-tie relationships need to be utilized in a way that can eschew from the said situation [100]. In the context of information abundance, ideas and opportunities travel through strong ties and cohesive networks [46]. However, knowledge and opportunities are searched for through weak ties and loosely connected networks when the context suffers from information scarcity [46,101]. There is insufficient information on adapting rice cultivation to flash flooding in Haor areas due to rice cultivation in only one season per year and poor communication infrastructure, such as roads and transport solutions [102]. DAE-farmers therefore need to utilize the benefits of weak ties through their innovation networks. However, there is a concern for weak network failure. This is a state in which actors are loosely connected, and no effective exchange of knowledge and resources occurs [63,68,99]. The weak tie relationships among DAE-farmers and other innovating actors (e.g., local input dealers) to perform the agronomic activities might lead to weak network failure. These two forms of network failure often lead to a paradox in supporting innovation networks [64]. So, there should be a balance between openness (i.e., creating new relationships) and closure (i.e., maintaining exiting relationships) in the innovation networks by exploiting weak ties and fostering strong ties [49,98]. Diversity and heterogeneity in the innovation networks need to be balanced with commonality to obtain dynamic stability [49].

5.2. Innovation Networks for Harvesting Activities

EAS agencies respond to the issue of climate change mostly by emphasizing the need for increasing production efficiency, rarely reconsidering services and operational strategies to enhance innovation [9]. Likewise, this study found that DAE provided very negligible support to strengthening innovation networks for rice harvesting activities. Therefore, both DAE-farmers and non-DAE farmers developed clusters with local elites and informal actors in the harvesting networks. This finding is supported by a previous study that reported the significant role of local representatives and schoolteachers in helping farmers to adapt to flooding in Bangladesh [103]. Farmers connect themselves with informal actors in their networks for information and knowledge acquisition when they have less access to and support from formal actors [104]. The current study indicated that DAE-farmers lacked the required and timely updates on local weather and flash floods occurred during the harvesting period. This is a common limitation of many EAS activities. Therefore, EAS needs to extend its support and connect farmers with relevant actors in order to get timely and updated local weather, rain and flash floods information. EAS should help farmers by providing effective and adequate instrumental support, such as harvesting machinery, laborers, and transport vehicles, for quick harvesting.

5.3. Clusters Connections

There is little evidence of the flow of information and farm inputs from DAE-farmers to non-DAE farmers and vice versa. A study of single-crop growing farmers in China explored limited exchange of information and ideas between farmers who attended plant clinics to obtain support for plant disease management and farmers who were non-attendees [66]. The limited sharing was also evident among several farmer clusters in Mexico which had different degrees of improved palm cultivation technologies adoption [81]. In the context of information scarcity, such as in the Haor areas and other wetland agriculture, developing connections with various clusters and obtaining information beyond own clusters are highly relevant for farmers to enhance adaptation to climate extremes [81]. Broader inclusion and connections among the affected clusters are among other significant ways for successfully strengthening innovation networks [67]. Farmers should reap the benefits of connections with other informal and trust-based actors by developing linkages, as well as by exchanging information and resources with a range of farmers groups to establish interfarmer cluster connections and the sharing of knowledge and resources [81]. Thus, EAS should actively seek to enhance a balance between formal and informal actors in the innovation networks of farmers [66].

5.4. Limitations and Future Research

This study has some limitations that emphasize the requirement for future research on this topic. The study examined and compared the innovation networks of two groups of farmers. Future research exploring other innovating actors' networks would be relevant to developing a fuller picture of information flows and the associated knowledge landscape that exists among the actors of a particular crop farming [105]. It would be interesting to investigate the innovation networks of EAS to better understand how agencies have connected and linked farmers with diversified actors. The reasons behind the limited sharing of information and resources between farmer groups need to be more extensively explored to better formulate the ways of establishing interfarmer cluster connections [81]. EAS agencies, particularly in developing countries, showed resistance to reconsider organizational principles and reform service strategies that could enhance innovation [106,107].

Therefore, the shortcomings of current organizational policy, mandates, and operational strategies of EAS need to be identified to better comprehend how public EAS agencies can support the innovation networks for harvesting activities of the wetland farmers in Bangladesh and beyond.

6. Conclusions

Strengthening innovation networks is considered a critical process to ensure agricultural sustainability in the context of climate extremes. This research's objective was to examine the effectiveness of EAS for strengthening innovation networks using measures of diversity, balance in the connection between formal and informal actors and strong and weak ties, trust among the connected actors, and intercluster connections. This was done in the context of DAE's efforts to help farmers adapt Boro rice production to flash flooding in Bangladesh. The findings indicate that while DAE intent was to strengthen farmers' innovation networks to adapt rice cultivation to flash flooding, it only supported the facilitation of the agronomic network development and missed the opportunity to enable the harvesting networks' efficacy. As the harvesting activities are highly exposed to flash flooding, the absence of adequate support from the DAE indicates that farmers are still at significant risk of production losses due to flood related damages. DAE-farmers developed clusters with formal, rule-based actors, such as DAE and research institutions, and obtained information and resources to perform agronomic activities. On the other hand, non-DAE farmers created clusters with informal, trust-based actors, such as relatives, local input dealers, and harvesting laborers to draw supports. Dependency on formal actors and clusters effectively restricted DAE-farmers from contacting and utilizing other informal actors (e.g., local input dealers, relatives) to conduct agronomic activities. In the harvesting networks, DAE provided minimal support in delivering rice maturity indicators and the timing of harvesting information. DAE-farmers lacked the required and timely updates on local weather, rain and flash flood occurrences during the harvesting period. There was a limited exchange of knowledge and resources between DAE- and non-DAE farmers in both agronomic and harvesting networks. The results also indicate that adaptation to flash flooding is most effectively achieved by including both formal and informal actors in the innovation networks. This allows information to be accessed from a much broader set of actors and provides greater opportunity for adaptation to flash flooding.

This paper examined the theory of enhancing innovation and investigated approaches to quantifying the effectiveness of EASs for strengthening innovation networks. Using innovation theory, this study contributes to understanding the role of actors within an innovation network and allows formal measurement of the effectiveness of networks in supporting adaptation. This analysis shows the value of including both formal and informal actors in the innovation network as a way to prevent a lock-in situation and network failure. From the EAS practices and policy perspective, the study indicates that the current strategies to support the adaptation of wetland agriculture to climate extreme need to be revisited and that it is imperative to consider the role of both formal and informal actors in the process of adaptation. EAS agencies should help wetland farmers connect with both formal and informal actors to maximize information access. In addition, EAS agencies need to encourage the sharing of information and resources among the farmers who are included in the institutional support programs and the farmers who are excluded. The policymakers and EAS agencies need to rethink the support services that are provided during the harvesting period of wetland crops and extend support and connect farmers with relevant actors in order to obtain timely and updated local weather, rain, and flash flood information. The implication of this study suggests that effective EAS strategies must include both formal and informal actors, as well as ensuring effective communication with broader farmer groups.

There are several avenues for further study related to strengthening the innovation networks for adaptation to climate extremes. These include understanding the reasons behind the limited sharing of information and resources among various farmer groups and approaches to developing better strategies that enhance cluster connections. The shortfalls and inadequacies of the current EAS policy and operational strategies need to be examined to formulate better ways of supporting farmers during the crop harvesting period.

Supplementary Materials: The following is available online at https://www.mdpi.com/2071-1050/13/4/1941/s1, Survey questionnaire: The Role of Extension and Advisory Services in Strengthening Farmers' Innovation Networks to Adapt to Climate Extremes.

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References

1. Food and Agriculture Organization (FAO). *FAO′s Work on Agricultural Innovation: Sowing the Seeds of Transformation to Achieve the SDGs*; Food and Agriculture Organization: Rome, Italy, 2018.
2. Leeuwis, C.; Hall, A.; van Weperen, W.; Preissing, J. *Facing the Challenges of Climate Change and Food Security: The Role of Research, Extension and Communication for Development*; Food and Agriculture Organization: Rome, Italy, 2013.
3. World Bank (WB). *Agricultural Innovation Systems: An investment Sourcebook*; World Bank: Washington, DC, USA, 2012.
4. Leeuwis, C.; Aarts, N. Rethinking communication in innovation processes: Creating space for change in complex systems. *J. Agric. Educ. Ext.* **2011**, *17*, 21–36. [CrossRef]
5. Rajalahti, R.; Janssen, W.; Pehu, E. *Agricultural Innovation Systems: From Diagnostics toward Operational Practices*; World Bank: Washington, DC, USA, 2008.
6. Rivera, W.M.; Sulaiman, V.R. Extension: Object of reform, engine for innovation. *Outlook Agric.* **2009**, *38*, 267–273. [CrossRef]
7. Davis, K.; Sulaiman, V.R. *Note 0: Overview of Extension Philosophies and Methods*; Global Forum for Rural Advisory Services (GFRAS): Lindau, Switzerland, 2016.
8. Hachigonta, S. *Risk Mitigation and Adaptation in Extension and Advisory Services, Module 13*; Global Forum for Rural Advisory Services (GFRAS): Lindau, Switzerland, 2016.
9. Stål, H.I.; Bonnedahl, K.J. Provision of climate advice as a mechanism for environmental governance in Swedish agriculture. *Environ. Policy Gov.* **2015**, *25*, 356–371. [CrossRef]
10. Safdar, U.; Shahbaz, B.; Ali, T.; Khan, I.A.; Luqman, M.; Ali, S. Role of agricultural extension services in adaptation to climate change in highlands of Kaghan valley, Pakistan. *Pak. J. Agric. Sci.* **2014**, *51*, 1095–1100.
11. Tensay, T.M. Climate Change Adaptation, Social Networks, and Agricultural Extension Reforms in Ethiopia. Ph.D. Thesis, University of Hohenheim, Stuttgart, Germany, 2016.
12. Mkisi, R.B. The Role of Agricultural Extension in Smallholder Farmer Adaptation to Climate Change in Blantyre District, Malawi. Master′s Thesis, Purdue University, Indiana, IN, USA, 2014.

13. Wang, Z.; Wang, J.; Zhang, G.; Wang, Z. Evaluation of agricultural extension service for sustainable agricultural development using a hybrid entropy and TOPSIS method. *Sustainability* **2021**, *13*, 347. [CrossRef]
14. Charatsari, C.; Lioutas, E.D.; De Rosa, M.; Papadaki-Klavdianou, A. Extension and advisory organizations on the road to the digitalization of animal farming: An organizational learning perspective. *Animals* **2020**, *10*, 2056. [CrossRef] [PubMed]
15. Chen, H.; Zhang, W.; Gao, H.; Nie, N. Climate change and anthropogenic impacts on wetland and agriculture in the Songnen and Sanjiang plain, northeast China. *Remote Sens.* **2018**, *10*, 356. [CrossRef]
16. Junk, W.J.; An, S.; Finlayson, C.; Gopal, B.; Květ, J.; Mitchell, S.A.; Mitsch, W.J.; Robarts, R.D. Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis. *Aquat. Sci.* **2013**, *75*, 151–167. [CrossRef]
17. Habiba, U.; Shaw, R.; Takeuchi, Y. Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh. *Int. J. Disaster Risk Reduct.* **2012**, *1*, 72–84. [CrossRef]
18. Miah, M.R. Enhancing food security through acclimatized species domestication in the Haor region. *ABC J. Adv. Res.* **2013**, *2*, 49–65. [CrossRef]
19. Centre for Environmental and Geographic Information Services (CEGIS). *Master Plan of Haor Area*; Centre for Environmental and Geographic Information Services: Dhaka, Bangladesh, 2012; Volume 1.
20. Karim, M.M.; Bhuiya, M.S.U. Poverty alleviation of farming community in Haor area through farming systems. *Asian J. Poverty Stud.* **2017**, *3*, 131–137.
21. Alam, M.S.; Quayum, M.; Islam, M. Crop production in the Haor areas of Bangladesh: Insights from farm level survey. *Agriculturists* **2010**, *8*, 88–97. [CrossRef]
22. Sutradhar, L.; Bala, S.; Islam, A.; Hasan, M.; Paul, S.; Rhaman, M.; Pavell, M.; Billah, M. A review of good adaptation practices on climate change in Bangladesh. In Proceedings of the 5th International Conference on Water & Flood Management, Dhaka, Bangladesh, 6–8 March 2015.
23. Coirolo, C.; Commins, S.; Haque, I.; Pierce, G. Climate change and social protection in Bangladesh: Are existing programmes able to address the impacts of climate change? *Dev. Policy Rev.* **2013**, *31*, o74–o90. [CrossRef]
24. Hossain, M.S.; Nayeem, A.; Majumder, A.K. Impact of flash flood on agriculture land in Tanguar Haor basin. *Int. J. Res. Environ. Sci.* **2017**, *3*, 42–45. [CrossRef]
25. Kamal, A.M.; Shamsudduha, M.; Ahmed, B.; Hassan, S.K.; Islam, M.S.; Kelman, I.; Fordham, M. Resilience to flash floods in wetland communities of northeastern Bangladesh. *Int. J. Disaster Risk Reduct.* **2018**, *31*, 478–488. [CrossRef]
26. Network for Information, Response And Preparedness Activities on Disaster (NIRAPAD). *Flash Flood Situation Update, May 03, 2017*; Network for Information, Response And Preparedness Activities on Disaster: Dhaka, Bangladesh, 2017.
27. Ministry of Disaster Management and Relief. *District Level Disaster Management Plan Development, District- Sunamganj*; Ministry of Disaster Management and Relief: Dhaka, Bangladesh, 2014.
28. Ahmed, A.U. *Bangladesh: Environmental and Climate Change Assessment*; International Fund for Agricultural Development: Rome, Italy, 2013.
29. Rashid, M.; Yasmeen, R. Cold injury and flash flood damage in Boro rice cultivation in Bangladesh: A review. *Bangladesh Rice J.* **2018**, *21*, 13–25. [CrossRef]
30. Guhathakurta, P.; Sreejith, O.; Menon, P. Impact of climate change on extreme rainfall events and flood risk in India. *J. Earth Syst. Sci.* **2011**, *120*, 359–373. [CrossRef]
31. Choudhury, M.; Haque, C.E. We are more scared of the power elites than the floods: Adaptive capacity and resilience of wetland community to flash flood disasters in Bangladesh. *Int. J. Disaster Risk Reduct.* **2016**, *19*, 145–158. [CrossRef]
32. Suman, A.; Akther, F.; Bhattacharya, B. Climate change impact on Haor flooding in Bangladesh using three global circulation models. *Int. J. Sci. Eng. Technol.* **2014**, *3*, 1170–1174.
33. Nowreen, S.; Murshed, S.B.; Islam, A.S.; Bhaskaran, B. Change of future climate extremes for the Haor basin area of Bangladesh. In Proceedings of the 4th International Conference on Water & Flood Management, Dhaka, Bangladesh, 9–11 March 2013.
34. Nowreen, S.; Murshed, S.B.; Islam, A.S.; Bhaskaran, B.; Hasan, M.A. Changes of rainfall extremes around the Haor basin areas of Bangladesh using multi-member ensemble RCM. Theor. *Appl. Climatol.* **2015**, *119*, 363–377. [CrossRef]
35. Uddin, M.N. Agricultural extension services in Bangladesh: A review study. *Bull. Inst. Vocat. Tech. Educ.* **2008**, *5*, 119–130.
36. Department of Agricultural Extension (DAE). *Annual Report, 2013–2014*; Department of Agricultural Extension: Dhaka, Bangladesh, 2015.
37. Ministry of Agriculture (MOA). *National Agricultural Extension Policy (NAEP)*; Ministry of Agriculture: Dhaka, Bangladesh, 2012.
38. Department of Agricultural Extension (DAE). *Agricultural Extension Manual*, 4th ed.; Department of Agricultural Extension: Dhaka, Bangladesh, 2016.
39. Islam, M.; Hossain, M.; Hoque, M.; Tusher, T.; Kabir, M. Study on natural resource management in relation with socio-economic status at Tanguar haor in Sunamgonj district of Bangladesh. *Bangladesh J. Environ. Sci.* **2014**, *26*, 59–66.
40. Rabby, T.G.; Alam, G.M.; Mishra, P.K.; Hoque, K.E.; Nair, S. Different economic and policy perspectives in micro population for sustainable development: A study of the Haor livelihood in Bangladesh. *Afr. J. Bus. Manag.* **2011**, *5*, 2475–2492. [CrossRef]
41. Hanneman, R.A.; Riddle, M. *Introduction to Social Network Methods*; University of California: California, CA, USA, 2005.
42. Wellman, B.; Hampton, K. Living networked on and offline. *Contemp. Sociol.* **1999**, *28*, 648–654. [CrossRef]
43. Acevedo, M. Network cooperation: Development cooperation in the network society. *Int. J. Inf. Commun. Technol. Hum. Dev.* **2009**, *1*, 1–21. [CrossRef]

44. Cvitanovic, C.; Clunn, R.; Jacobs, B.; Williams, C.; Measham, T. *An Introduction to Social Networks for Engaging the Community in Climate Policy*; The Institute for Sustainable Futures (ISF): Sydney, Australia, 2014.
45. Tropical Agriculture Platform (TAP). *Common Framework on Capacity Development for Agricultural Innovation Systems: Guidance Note on Operationalization*; Food and Agriculture Organization: Rome, Italy, 2016.
46. Spielman, D.J.; Davis, K.; Negash, M.; Ayele, G. Rural innovation systems and networks: Findings from a study of Ethiopian smallholders. *Agric. Hum. Values* **2011**, *28*, 195–212. [CrossRef]
47. World Bank (WB). *Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems*; World Bank: Washington, DC, USA, 2006.
48. Spielman, D.J.; Ekboir, J.; Davis, K. The art and science of innovation systems inquiry: Applications to Sub-Saharan African agriculture. *Technol. Soc.* **2009**, *31*, 399–405. [CrossRef]
49. SOLINSA. Learning and Innovation Networks for Sustainable Agriculture: A Conceptual Framework. Available online: http://www.solinsa.org/fileadmin/Files/deliverables/D8.1_Revised_Conceptual_Framework_web.pdf (accessed on 10 December 2020).
50. Jacobsen, E.; Beers, P.J.; Fischer, A.R.H. Inventions for future sustainable development in agriculture. In *The TransForum Model: Transforming Agro Innovation Toward Sustainable Development*; Van Latesteijn, H., Andeweg, K., Eds.; Springer: Dordrecht, The Netherlands, 2010; pp. 21–39.
51. Pittaway, L.; Robertson, M.; Munir, K.; Denyer, D.; Neely, A. Networking and innovation: A systematic review of the evidence. *Int. J. Manag. Rev.* **2004**, *5*, 137–168. [CrossRef]
52. Sharma, R.; Peshin, R.; Khar, S.; Ishar, A.K. Agriculture innovation system approach for sustainable agriculture development: A review. *Agro-Economist* **2014**, *1*, 1–7.
53. Leeuwis, C. *Communication for Rural Innovation: Rethinking Agricultural Extension*, 3rd ed.; Blackwell Science: Oxford, UK, 2004; p. 127.
54. Christensen, L.O.; O′Sullivan, R. Using social networking analysis to measure changes in regional food systems collaboration: A methodological framework. *J. Agric. Food Syst. Community Dev.* **2015**, *5*, 113–129. [CrossRef]
55. O′Murchu, I.; Breslin, J.G.; Decker, S. Online social and business networking communities. In Proceedings of the ECAI Workshop on Applications of Semantic Web Technologies to Web Communities, Valencia, Spain, 23–27 August 2004.
56. Granovetter, M. The strength of weak ties. *Am. J. Sociol.* **1973**, *78*, 1360–1380. [CrossRef]
57. Constant, D.; Sproull, L.; Kiesler, S. The kindness of strangers: The usefulness of electronic weak ties for technical advice. *Organ. Sci.* **1996**, *7*, 119–135. [CrossRef]
58. Haythornthwaite, C. Social networks and internet connectivity effects. *Inf. Commun. Soc.* **2005**, *8*, 125–147. [CrossRef]
59. Friedkin, N.E. Information flow through strong and weak ties in intraorganizational social networks. *Soc. Netw.* **1982**, *3*, 273–285. [CrossRef]
60. Kaushik, P.; Chowdhuy, A.; Hambly Odame, H.; van Passen, A. Social media for enhancing stakeholders' innovation networks in Ontario, Canada. *J. Agric. Food Inf.* **2018**, *19*, 331–353. [CrossRef]
61. Granovetter, M. The strength of weak ties: A network theory revisited. *Sociol Theory* **1983**, *1*, 201–233. [CrossRef]
62. Burt, R.S. The network structure of social capital. *Res. Organ. Behav.* **2000**, *22*, 345–423. [CrossRef]
63. Gilsing, V.A.; Duysters, G. Understanding novelty creation in exploration networks- structural and relational embeddedness jointly considered. *Technovation* **2008**, *28*, 693–708. [CrossRef]
64. Håkansson, H.; Ford, D. How should companies interact in business networks? *J. Bus. Res.* **2002**, *55*, 133–139. [CrossRef]
65. Klerkx, L.; Aarts, N. The interaction of multiple champions in orchestrating innovation networks: Conflicts and complementarities. *Technovation* **2013**, *33*, 193–210. [CrossRef]
66. Danielsen, S.; Mur, R.; Kleijn, W.; Wan, M.; Zhang, Y.; Phiri, N.; Chulu, B.; Zhang, T.; Posthumus, H. Assessing information sharing from plant clinics in China and Zambia through social network analysis. *J. Agric. Educ. Ext.* **2020**, *26*, 269–289. [CrossRef]
67. Rijswijk, K.; Brazendale, R. Innovation networks to stimulate public and private sector collaboration for advisory services innovation and coordination: The case of pasture performance issues in the New Zealand dairy industry. *J. Agric. Educ. Ext.* **2017**, *23*, 245–263. [CrossRef]
68. Klerkx, L.; Van Mierlo, B.; Leeuwis, C. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming Systems Research into the 21st Century: The New Dynamic*; Darnhofer, I., Gibbon, D., Dedieu, B., Eds.; Springer: Dordrecht, The Netherlands, 2012; pp. 457–483. [CrossRef]
69. Nooteboom, B. Institutions and forms of co-ordination in innovation systems. *Organ. Stud.* **2000**, *21*, 915–939. [CrossRef]
70. Hall, A.; Dijkman, J. *Capacity Development for Agricultural Biotechnology in Developing Countries: Concepts, Contexts, Case Studies, and Operational Challenges of a Systems Perspective*; Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT): Maastricht, The Netherlands, 2006.
71. Zossou, E.; Arouna, A.; Diagne, A.; Agboh-Noameshie, R.A. Learning agriculture in rural areas: The drivers of knowledge acquisition and farming practices by rice farmers in West Africa. *J. Agric. Educ. Ext.* **2020**, *26*, 291–306. [CrossRef]
72. King, B.; Fielke, S.; Bayne, K.; Klerkx, L.; Nettle, R. Navigating shades of social capital and trust to leverage opportunities for rural innovation. *J. Rural Stud.* **2019**, *68*, 123–134. [CrossRef]
73. Newell, S.; Swan, J. Trust and inter-organizational networking. *Hum. Relat.* **2000**, *53*, 1287–1328. [CrossRef]

74. Mayer, R.C.; Davis, J.H.; Schoorman, F.D. An integrative model of organizational trust. *Acad. Manag. Rev.* **1995**, *20*, 709–734. [CrossRef]
75. Brasier, K.J.; Goetz, S.; Smith, L.A.; Ames, M.; Green, J.; Kelsey, T.; Rangarajan, A.; Whitmer, W. Small farm clusters and pathways to rural community sustainability. *Community Dev.* **2007**, *38*, 8–22. [CrossRef]
76. Van der Lee, J.; Klerkx, L.; Bebe, B.O.; Mengistu, A.; Oosting, S. Intensification and upgrading dynamics in emerging dairy clusters in the east African highlands. *Sustainability* **2018**, *10*, 4324. [CrossRef]
77. Kilelu, C.W.; Klerkx, L.; Leeuwis, C. Supporting smallholder commercialisation by enhancing integrated coordination in agrifood value chains: Experiences with dairy hubs in Kenya. *Exp. Agric.* **2017**, *53*, 269–287. [CrossRef]
78. Porter, M.E. Location, competition, and economic development: Local clusters in a global economy. *Econ. Dev. Q.* **2000**, *14*, 15–34. [CrossRef]
79. Joffre, O.M.; De Vries, J.R.; Klerkx, L.; Poortvliet, P.M. Why are cluster farmers adopting more aquaculture technologies and practices? The role of trust and interaction within shrimp farmers' networks in the Mekong delta, Vietnam. *Aquaculture* **2020**, *523*, 735181. [CrossRef]
80. Joffre, O.M.; Poortvliet, P.M.; Klerkx, L. To cluster or not to cluster farmers? Influences on network interactions, risk perceptions, and adoption of aquaculture practices. *Agric. Syst.* **2019**, *173*, 151–160. [CrossRef]
81. Aguilar-Gallegos, N.; Muñoz-Rodríguez, M.; Santoyo-Cortés, H.; Aguilar-Ávila, J.; Klerkx, L. Information networks that generate economic value: A study on clusters of adopters of new or improved technologies and practices among oil palm growers in Mexico. *Agric. Syst.* **2015**, *135*, 122–132. [CrossRef]
82. Huyer, S.; Nyasimi, M. *Climate-Smart Agriculture Manual for Agriculture Education in Zimbabwe*; Climate Technology Centre and Network: Copenhagen, Denmark, 2017.
83. Creswell, J.W.; Creswell, J.D. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed.; Sage Publications: California, CA, USA, 2017; p. 233.
84. Mittal, S.; Surendran Padmaja, S.; Ajay, A. Agricultural information and knowledge network in rural India: A case of Bihar. *J. Agric. Educ. Ext.* **2018**, *24*, 393–418. [CrossRef]
85. Haythornthwaite, C.; de Laat, M. Social networks and learning networks: Using social network perspectives to understand social learning. In Proceedings of the 7th International Conference on Networked Learning, Aalborg, Denmark, 3–4 May 2010.
86. Haythornthwaite, C. Social network analysis: An approach and technique for the study of information exchange. *Libr. Inf. Sci. Res.* **1996**, *18*, 323–342. [CrossRef]
87. Hermans, F.; Sartas, M.; van Schagen, B.; van Asten, P.; Schut, M. Social network analysis of multi-stakeholder platforms in agricultural research for development: Opportunities and constraints for innovation and scaling. *PLoS ONE* **2017**, *12*, e0169634. [CrossRef] [PubMed]
88. Makini, F.W.; Kamau, G.M.; Makelo, M.N.; Adekunle, W.; Mburathi, G.K.; Misiko, M.; Pali, P.; Dixon, J. *Operational Field Guide for Developing and Managing Local Agricultural Innovation Platforms*; Kenya Agricultural Research Institute: Nairobi, Kenya, 2013.
89. Mapila, M.A.; Yauney, J.; Thangata, P.; Droppelmann, K.; Mazunda, J. Who Talks to whom in Malawi's agricultural research information network? *J. Agric. Educ. Ext.* **2016**, *22*, 7–23. [CrossRef]
90. Beierle, T.C.; Konisky, D.M. Values, conflict, and trust in participatory environmental planning. *J. Policy Anal. Manag.* **2000**, *19*, 587–602. [CrossRef]
91. Walther, J.B.; Bunz, U. The rules of virtual groups: Trust, liking, and performance in computer-mediated communication. *J. Commun.* **2005**, *55*, 828–846. [CrossRef]
92. Carolan, B.V. Measures for egocentric network analysis. In *Social Network Analysis and Education: Theory, Methods & Applications*; Carolan, B.V., Ed.; Sage Publications: California, CA, USA, 2013; pp. 139–168. [CrossRef]
93. Carr, N.T. Using Microsoft Excel®to calculate descriptive statistics and create graphs. *Lang. Assess. Q.* **2008**, *5*, 43–62. [CrossRef]
94. Gilbert, E.; Karahalios, K.; Sandvig, C. The network in the garden: Designing social media for rural life. *Am. Behav. Sci.* **2010**, *53*, 1367–1388. [CrossRef]
95. Yami, M.; Vogl, C.; Hausera, M. Comparing the effectiveness of informal and formal institutions in sustainable common pool resources management in Sub-Saharan Africa. *Conserv. Soc.* **2009**, *7*, 153–164. [CrossRef]
96. Afrad, S.I.; Wadud, F.; Babu, S.C. Reforms in agricultural extension service system in Bangladesh. In *Agricultural Extension Reforms in South Asia: Status, Challenges, and Policy Options*; Babu, S.C., Joshi, P.K., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 13–40. [CrossRef]
97. Rycroft, R.W.; Kash, D.E. *The Complexity Challenge: Technological Innovation for the 21st Century*; Thomson Learning: Belmont, CA, USA, 1999; p. 98.
98. SOLINSA. Final Report of the Solinsa Project. Available online: http://orgprints.org/25520/1/D%208.2%20SOLINSA%20Final%20Report.pdf (accessed on 12 December 2020).
99. Hermans, F.; Klerkx, L.; Roep, D. Structural conditions for collaboration and learning in innovation networks: Using an innovation system performance lens to analyse agricultural knowledge systems. *J. Agric. Educ. Ext.* **2015**, *21*, 35–54. [CrossRef]
100. Klerkx, L.; Leeuwis, C. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technol. Forecast. Soc. Chang.* **2009**, *76*, 849–860. [CrossRef]

101. Darr, D.; Pretzsch, J. Mechanisms of innovation diffusion under information abundance and information scarcity—On the contribution of social networks in group vs. individual extension approaches in semi-arid Kenya. *J. Agric. Educ. Ext.* **2008**, *14*, 231–248. [CrossRef]
102. Kamruzzaman, M.; Shaw, R. Flood and sustainable agriculture in the Haor basin of Bangladesh: A review paper. *Univers. J. Agric. Res.* **2018**, *6*, 40–49. [CrossRef]
103. Rotberg, F.J. Social networks and adaptation in rural Bangladesh. *Clim. Dev.* **2010**, *2*, 65–72. [CrossRef]
104. Thuo, M.; Bell, A.A.; Bravo-Ureta, B.E.; Okello, D.K.; Okoko, E.N.; Kidula, N.L.; Deom, C.M.; Puppala, N. Social network structures among groundnut farmers. *J. Agric. Educ. Ext.* **2013**, *19*, 339–359. [CrossRef]
105. Filippini, R.; Marescotti, M.E.; Demartini, E.; Gaviglio, A. Social Networks as drivers for technology adoption: A study from a rural mountain area in Italy. *Sustainability* **2020**, *12*, 9392. [CrossRef]
106. Hounkonnou, D.; Kossou, D.; Kuyper, T.W.; Leeuwis, C.; Nederlof, E.S.; Röling, N.; Sakyi-Dawson, O.; Traoré, M.; van Huis, A. An innovation systems approach to institutional change: Smallholder development in West Africa. *Agric. Syst.* **2012**, *108*, 74–83. [CrossRef]
107. Chowdhury, A.H.; Hambly Odame, H.; Leeuwis, C. Transforming the roles of a public extension agency to strengthen innovation: Lessons from the National Agricultural Extension Project in Bangladesh. *J. Agric. Educ. Ext.* **2014**, *20*, 7–25. [CrossRef]