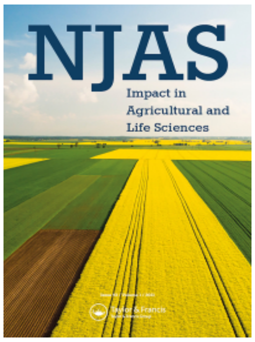

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Common sources and needs of weather information for rice disease forecasting and management in coastal Bangladesh

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ABSTRACT

Rice farmers in coastal Bangladesh are severely affected by climate change. Climate variability and change impact crop production in numerous ways, including by changing occurrences of different rice diseases. Weather and climate information services (WCIS) can assist farmers in improving agricultural decision-making, in relation to rice disease management. Currently, however, farmers in coastal Bangladesh have limited access to accurate, timely, and location-specific information on weather and climate. To design actionable information services, it is important to know the types of information that farmers need. With this in mind, the current research addressed three questions: (i) What types of weather information do coastal farmers need to forecast rice diseases? (ii) What types of weather information are currently available to coastal farmers? (iii) How does weather information play a role in rice disease management-related decision-making? Results indicate that coastal rice farmers have access to weather and climate information services mainly through personal experiences, neighbouring farmers, agricultural extension agents, local knowledge and input dealers. During interviews, farmers indicated that they mainly needed information on temperatures, rainfall, relative humidity, cloud cover, fog and wind information to predict rice disease outbreaks sufficiently in advance. Raising awareness about application of climate information services in rice disease management and building the capacity of farmers through training and education is vital to address major challenges faced by the coastal farmers in accessing weather information. We conclude that the farmers need more accurate, timely, location-specific, trustworthy and actionable weather information services to forecast and manage rice diseases.

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1. Introduction

Climate change has a negative impact on the sustainability of agricultural production systems due to increasing variability of temperatures and rainfall, sea level rise, and greater frequency and severity of extreme weather events (Duan et al., 2019; Holden et al., 2018; Hoque et al., 2019). Since agriculture is weather-dependent and crop yields are diminished by excessively high temperatures, there is concern that climate change will affect food security in many regions of the world, including Bangladesh. Bangladesh is an agrarian country where agriculture contributes almost 14% of the national gross domestic product (GDP); moreover, agriculture generates income and employment for around 43% of the population (BBS, 2019; Clarke et al., 2015; Kashem et al., 2013; Paparrizos et al., 2020). Rice is the most important crop in Bangladesh. It accounts for 92% of the food grains produced in the country and covers about 77% of the agricultural land (Uddin et al., 2019). Rice is also the main food source for about 150 million people in Bangladesh, and almost 13 million families in the country are involved in rice cultivation (BBS, Ministry of Planning, 2018). Given this reliance on rice as a food staple, any negative impact of climate change on rice production will affect the country's food security. Climate change can reduce rice yields by influencing rice pest and disease occurrences, affecting the reproduction, spread, and severity of pathogens (Das, 2017; Uddin et al., 2019). Indeed, due to climate change, coastal rice farmers in Bangladesh have experienced higher disease incidence and rice yield losses (Jakariya et al., 2020).

32% of Bangladesh's landmass consists of coastal area, and almost one-third of the country's inhabitants live in this region (Ahmad, 2019; BBS, Ministry of Planning, 2018). Although local rice varieties are adapted to the coastal topography and geo-hydrological system, rice yields have decreased due to climate variability and change (Afroz et al., 2018; Szabo et al., 2016). In the future, primary impacts of climate change, such as sea level rise, salinity intrusion, and extreme weather events, are expected to diminish the area suitable for rice cultivation by 60% (Pender, 2007), with secondary impacts being increased pest and disease occurrence in rice crops in the coastal zone. Additionally, sustainable rice production in Bangladesh, especially in the coastal areas, is threatened by other climate change-induced meteorological changes, which are expected to affect patterns of rice disease outbreaks (Jakariya et al., 2020; K. -H. Kim & Cho, 2015).

High temperatures reduce yields of high-yielding varieties (HYV), specifically, *aus, aman*, and *boro* rice.[1] Flash floods and drought mainly affect *aus* cultivation, while high temperatures and hot, humid weather stimulate the occurrence of diseases and insect infestations during *aus* season (Al Mamun et al., 2021). Regarding *aman* rice, planting can be delayed by salinity, due to changing rainfall patterns, cloudy weather, early floods, drought, and other climatic hazards, leading to lower production (Biswas et al., 2020; Mir Kabir et al., 2014). Regarding *boro* rice cultivation, heat waves at the flowering stage, rice blast disease, brown plant hopper, and flash floods pose significant challenges (M. S. Rahman et al., 2020). Furthermore, in Bangladesh, bacterial leaf blight and neck blast are becoming increasingly severe diseases occurring in both the transplanted *aman* and *boro* rice. Sheath blight is also worsening in severity in the transplanted *aman* rice (Kabir et al., 2020). Among insect pests, the yellow rice stem borer, rice hispa, brown plant hopper, white-backed planthopper, leaf folder, and gall-midge are the major threats to rice production (Kabir et al., 2020).

Several studies have found that a temperature increase of 1–2°C, combined with reduced sun exposure, produces sterility in rice spikelets (Habiba et al., 2015). According to Lal et al. (2014), climatic factors such as temperature and relative humidity are the major drivers of rice disease development. Moreover, rising temperatures, increased CO2 levels, reduced rainfall, increased rainfall variability and greater frequency of extreme weather influence different aspects of rice pathogens and diseases (Barbetti et al., 2012; Garrett et al., 2013; Launay et al., 2014). This includes rice pathogens' life cycle, dissemination, development rates, inoculum production, host resistance, disease epidemiology, and severity of disease epidemics (Barbetti et al., 2012; Ghini & Bevitori, 2014). Increasing temperature and humidity due to climate change are the most crucial factors in incidence and severity of pathogens in rice. Temperatures of 35°C during the day and 27°C at night are favourable for infection of bacterial leaf blight in rice (Horino & Yamada, 1982).

Rain and high air humidity enable maximum pathogen development in rice; as for example, at least five hours of leaf wetness period and a relative humidity above 90% are needed for blast to develop in rice (Magarey et al., 2005). Rice crops are affected by many diseases. Rice diseases such as rice blast, sheath blight, brown spot, sheath rot, bacterial leaf blight, false smut, and tungro are becoming more widespread due to climate change impact (Das, 2017; Gupta et al., 2017; Kobayashi et al., 2006). Disease scenarios have changed due to global climate change. A growing literature recognizes the importance of environmentally friendly disease control practices and technologies. Effective application of these requires weather-based disease monitoring and forecasting systems (Gupta et al., 2017). Currently, however,

[1]*Aus, aman*, and *boro* are three types of rice according to growing seasons.

coastal rice farmers in Bangladesh have little knowledge at their disposal regarding climate phenomena and how they relate to rice diseases. Greater access and use of weather and climate information services (WCIS) could assist them in taking precautionary measures. Currently, the national weather forecasts available are too general, and no specific weather information is broadcast for particular farming communities. The general forecasts provide little actionable information for farmers; moreover, farmers do not consider them trustworthy sources, due to their lack of precision. Thus, farmers are in need of location-specific and accurate WCIS for rice disease forecasting and even they are willing to pay for such timely, accurate, and needs-based services (Paparrizos et al., 2021).

Context-relevant and reliable weather information services have emerged as an effective approach to help farmers better adapt to climate change and variability (WMO, 2015). The introduction of weather forecasting services for risk management in agriculture appears to have significant potential, since timely weather information could enable farmers to make appropriate decisions regarding crop disease management (Chandni Singh et al., 2017). The aim of WCIS is to transform weather and climate-related data, combined with context information, into customised products, such as projections, forecasts, trends, economic analyses, best practices, development and evaluation of solutions, user interactions, capacity development, and tailored climate-related knowledge; providing these products to farmers in a timely manner, so that they can utilize it to minimize losses and increase income (Findlay, 2021; Ouedraogo et al., 2018; Vaughan & Dessai, 2014; Vogel et al., 2019). Farmers can thus use the information products to make important decisions about crop planning, such as when to plough, sow, fertilise, apply insecticides and pesticides, irrigate, and harvest; thus reducing exposure to risks (Tall et al., 2014). Early warning services for rice diseases are useful, as timely forecasts can give farmers an opportunity to make appropriate rice disease management decisions (K. H. Kim & Jung, 2020).

Nevertheless, WCIS for rice disease management are largely unavailable to smallholder rice farmers in coastal Bangladesh, due to the high illiteracy rate, low technical knowledge, lack of financial resources, and weak infrastructure (Singh, 2016 Chandni Singh et al., 2017). To achieve the goal of designing a climate information service to forecast rice diseases, understanding of farmers' information needs is a vital first step for tailoring weather and climate service for coastal rice farmer in rice diseases management decision-making (Swart et al., 2017; Tall et al., 2014; Vaughan & Dessai, 2014). Without such an understanding, the targeted farming community is less likely to find the information provided usable and helpful (Nieto et al., 2014; Tall et al., 2018).

At this moment, climate services to forecast and manage rice diseases in coastal Bangladesh are still limited, and coastal farmers are not benefiting from recent scientific and technological advances. Keeping that in mind, the current research sought to understand what weather and climate information coastal farmers need for rice disease forecasting and management. It examined farmers' existing sources of weather information and, subsequently, the role of weather information services in rice disease management decision-making. To address these points, this study deploys an exploratory research framework by combining various participatory research approaches to set the basis for the design of these future services to provide weather and climate information to smallholder farmers to forecast and manage rice diseases.

2. Materials and methods

2.1. Description of the study area

The study area is part of Dashmina Upazila, Patuakhali District, in Bangladesh. *Upazila* in Bangladesh is analogous to "sub-district". Patuakhali District is located on the fringes of the Bay of Bengal, on the south-central coast of Bangladesh, in the Division of Barisal. Geographically, this area falls within the tropical climatic zone, and is dominated by substantial rainfall from April to September (kharif season), with little rainfall the rest of the year (Hoque et al., 2019). The Rabi season (October to March) is marked by relatively low temperatures, with an abundance of sunshine from November to February. The average annual temperature is 25.9°C, and average annual rainfall is 2,654 mm (Hoque et al., 2019). Approximately 80–90% of rainfall occurs during the monsoon months of May to October. This period offers an excellent opportunity for rainfed cultivation (Kumar, Werners, Paparrizos, et al., 2020). The main source of income in the region is agriculture (Hoque et al., 2019). The major crops are rice, mung bean, sunflower, groundnut, potato, sweet potato, pulse, chilli, watermelon, betel leaf, and vegetables. The major diseases affecting cultivation in this coastal area are blast, sheath blight and bacterial leaf blight of rice; late blight and early blight of potato; yellow mosaic virus and leaf spot of mung bean; yellow mosaic virus, foot and root rot of grass pea; tikka and anthracnose of groundnut; leaf spot and head rot of sunflower; red rot of sugarcane; stem rot of sweet potato; downy mildew of watermelon; anthracnose and damping off of chilli; and alternaria leaf spot of cabbage and cauliflower. Farming communities in the region adhere to three cropping seasons, namely, rabi (mid-November to mid-March), kharif-I (mid-March to mid-July), and kharif-II (mid-July to mid-November). Farmers cultivate *aus, aman*, and *boro* rice, respectively, in kharif-I, kharif-II, and rabi seasons respectively. The distinct cropping patterns found in the region are mung bean/grass pea – fallow – transplant *aman* rice, followed by groundnut/sunflower–*aus*–transplant *aman* rice and *boro*–fallow–transplant *aman* rice.

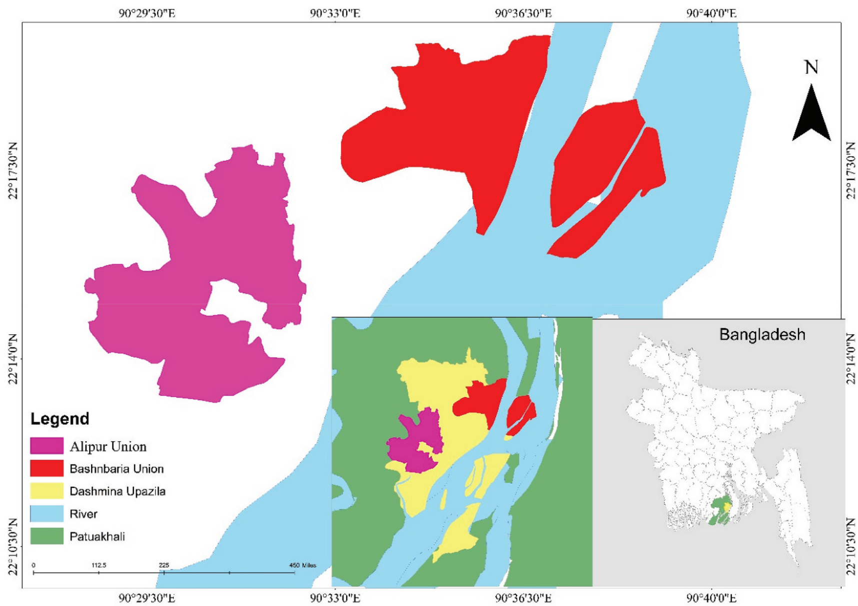


Figure 1. Location of study area in Patuakhali District, Bangladesh. Patuakhali is shaded in green on the inset map. Dashmina Upazila is shaded yellow. The study unions, Banshbaria and Alipur, are shaded red and pink, respectively, on the lower centre inset and main map. Source: Authors.

The study area falls under Ganges tidal floodplain (AEZ-13) which is vulnerable to cyclones and storm surges, salinity intrusion, flooding, land erosion, waterlogging, drought, and hydro-climatic variabilities due to climate change impacts (Ferdous et al., 2017). This area was selected for the research because of its importance in regional food supply, especially of rice, and due to the susceptibility of farming communities here to climate change consequences. The sub-district of Dashmina has seven "unions", of which two, Banshbaria and Alipur, were selected for the current study. A "union" is the lowest administrative unit of the government and is composed of several villages. Figure 1 depicts the general location of the study area.

2.2. Site selection

Exploratory field visits were made to five coastal villages in Banshbaria and Alipur. These villages are partitioned into agricultural "blocks", each with its own sub-assistant agriculture officer (SAAO). The SAAO is an employee of the Department of Agricultural Extension (DAE) and provides agricultural extension services to the farmers at the block level. Two villages, Gosani and East Alipur, respectively, in Banshbaria and Alipur, were selected as study sites because they were easily accessible and adjacent to Dashmina Upazila. During the visits, five focus group discussions were conducted with farmers to obtain a better understanding of local agricultural practices and to gain an overview of the sources used to access weather and climate information and their role in decision-making related to rice disease management. Farmers' information needs were also explored. In all of the study villages, similar cultivation patterns were observed, with two major crops (*T-aman* and mung bean) combined with other pulses and different types of vegetables throughout the year.

2.3. Data collection and analysis

This study applied an exploratory research methodology encompassing desk research, secondary data collection, and primary data collection through the abovementioned focus group discussions, as well as semi-structured interviews of farmers and experts (Figure 2).

Specifically, five focus group discussions, 74 farmer interviews, and 10 expert interviews were carried out, with data collection extending from June to September 2021. Secondary data on crops, population, and livelihood characteristics of farm families in the research area were gathered from documentary sources, such as the literature, reports from the Bangladesh Bureau of Statistics (BBS), and unpublished documents from the DAE's district and sub-district offices. The primary data on weather and climate information sources and needs for forecasting rice diseases were collected through focus group discussions and farmer and expert interviews, both of which were guided by checklists and questionnaires.

- Focus group discussions

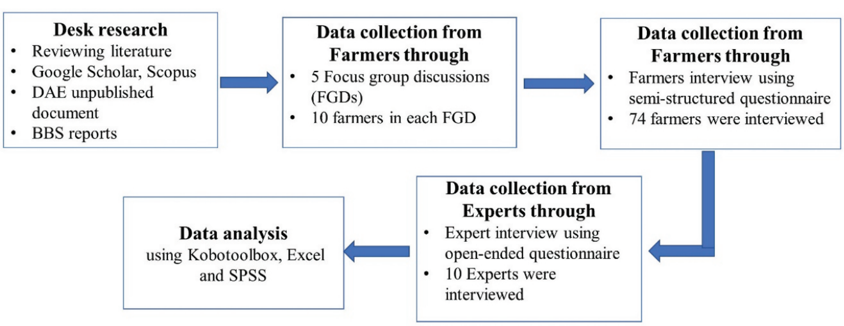


Figure 2. Methodological flow of the study. Note: BBS=Bangladesh Bureau of Statistics, DAE=Department of Agricultural Extension. Source: Authors.

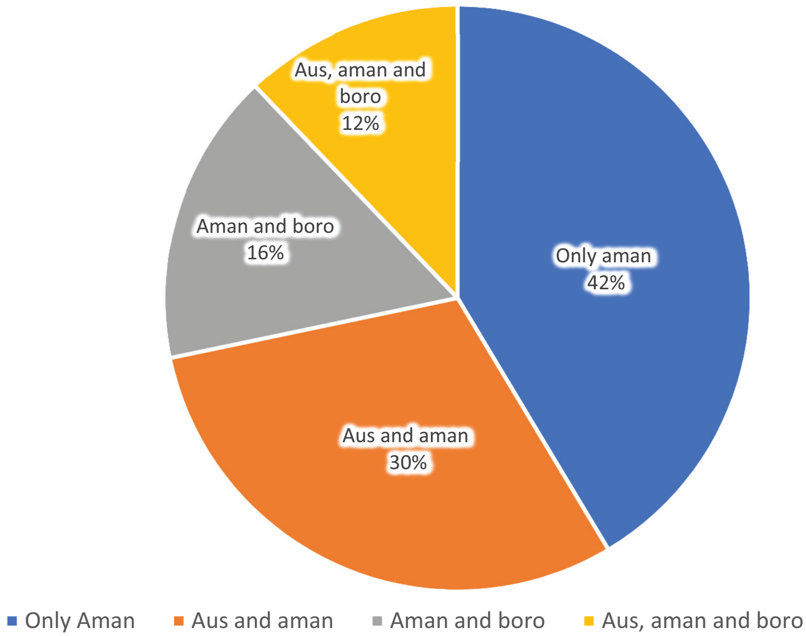


Figure 3. *Aus, Aman* and *Boro* rice cultivation by coastal farmer of Bangladesh based on farmers' interviews (*n*=74).

The first step in the fieldwork was to conduct five focus group discussions in the villages of Gosani and East Alipur. Two meetings were held in each village. The conduct of all meetings was guided by a checklist (see supplementary material A), covering five key topics: (i) current agricultural practices, (ii) rice disease trends in the study area, (iii) perceptions of climate change and access to WCIS for rice disease forecasting and management decision-making, (iv) indigenous knowledge of weather forecasting and rice disease management, and (v) farmers' interest in WCIS for forecasting and managing rice diseases. In each focus group discussion, 10 farmers were present. The discussions were held in the farmers' villages in June 2021. During the events, two research assistants took notes. Qualitative data gathered during the meetings were compiled and imported into Excel for further analysis and interpretation.

- Farmer interviews

Following the focus group discussions, 74 farmers were interviewed in July 2021. Among these, 41 were from Bashnbaria and 33 were from Alipur. The interviews sought a quantitative overview of aspects of the coastal farming communities and their farming practices, including rice disease outbreaks on farmers' fields in the past five years, and farmers' perceived management options, alongside their WCIS needs regarding decision-making to adequately forecast and manage rice diseases. To guide the farmer interviews, we prepared a semi-structured questionnaire (see supplementary material B). The questionnaire was pre-tested with 10 farmers, who were randomly selected from both villages. Based on the pre-test results, the initial questionnaire was modified to better align with the purpose of the study. During the farmer interviews, the open access online interview tool KoBoToolbox (www.kobotoolbox.org) was used to collect primary data. In Bangladesh, women farmers are often unwilling to communicate directly with unfamiliar men. For this reason, a female interviewer conducted the interviews with the women farmers. Interviewees were chosen using simple random sampling, and they took one month to complete. Finally, the quantitative data was analysed and interpreted using KoBoToolbox (www.kobotoolbox.org), Excel, and SPSS Statistics 20 software.

- Expert interviews

Ten experts were interviewed, guided by an open-ended questionnaire (see supplementary material C). Expert interviews focused on the extension services currently provided, including WCIS available to farmers; limitations of existing WCIS; status of rice diseases in Patuakhali District; climatic factors affecting outbreaks; and the need for weather and climate information to forecast rice diseases and manage these in advance. A number of other topics were raised with experts as well, such as challenges farmers faced in accessing WCIS, the role of WCIS in rice disease management decision-making, and the need for capacity building among both farmers and extension agents to promote WCIS usage. Finally, the results of the interviews were compiled and put into Excel for analysis and interpretation. The study area map was created using QGIS Standalone Installer Version 3.22.

3. Results

3.1. Socio-demographic characteristics of farmers and cropping patterns

Among the farmers interviewed for this study, 69% were men. They were involved mainly in agricultural crop production, day-to-day farm management, and operational decision-making. The remaining 31% were women. They were engaged mainly in homestead agricultural operations, such as vegetable production, compost preparation, crop processing, storage, livestock rearing, and field crop-related activities.

Table 1. Descriptive statistics of the sample coastal farmers, Patuakhali, Bangladesh, based on data collected from 74 farmers through farmers' interviews.

Socio-demographic Variables	n = 74	%	Socio-demographic Variables	n = 74	%
Location			Gender		
Banshbaria	41	55	Male	51	69
Alipur	33	45	Female	23	31
Age (Years)			Family type		
36–50	33	45	Nuclear	51	69
18–35	28	38	Extended	21	28
Above 50	13	17	Singledom	2	3
Education			Farm type		
Illiterate	11	15	Crop dependent	8	11
Primary	21	28	Crop and livestock	6	8
Secondary	17	23	Crop and fisheries	5	7
S.S.C[3]	6	8	Fisheries	1	1
H.S.C[4] and Above	11	15	All (Crop, livestock, fisheries)	54	73
Graduate	8	11			
Income-expenditure/year			Mobile phone access		
Income = expenditure	29	39	Normal mobile phone	24	34
Expenditure > income	29	39	Smartphone	46	62
Expenditure < income	16	22	Mobile used in agriculture	27	37

Table 1 presents descriptive statistics on the interviewed farmers. Most were between 36–50 (45%) and 41–60 (38%) years of age. Regarding educational status, about half were educated at the primary (28%) or secondary (23%) level. Less than one in five (15%) was illiterate. The farmers had, on average, 29 years of rice farming experience. Regarding livelihoods, 73% of farmers were dependent on a variety of farm activities, such as crop cultivation, livestock rearing, and fisheries. The average monthly income per household was 14,521 Bangladeshi taka (BDT), equivalent to about US $166.[2] Many farmers had access to normal mobile phones (34%) and smartphones (62%), and more than a third (37%) used these to access agricultural information.

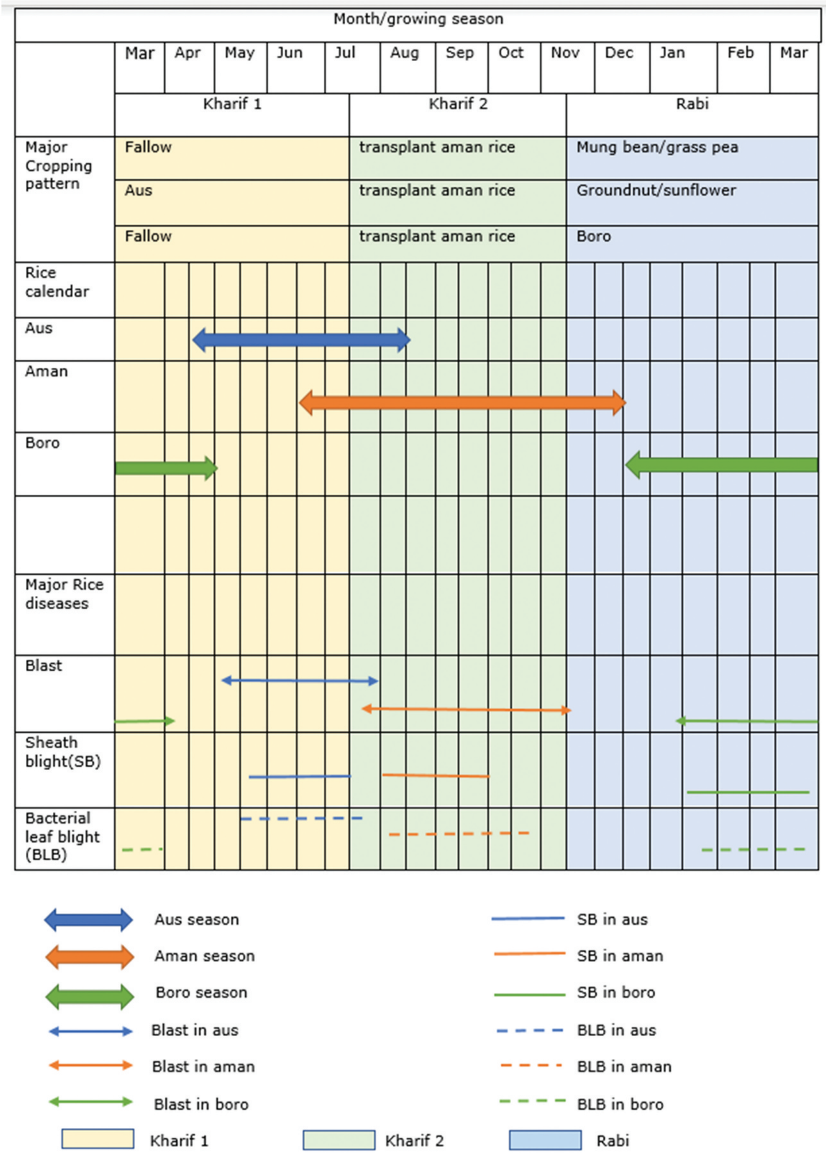
Table 2 shows an overview of major cropping patterns, rice calendar, and major rice diseases of coastal Bangladesh in relation to growing seasons based on data collected from 10 experts and 74 farmers through expert interviews and farmer interviews respectively.

3.2. Rice cultivation in coastal Patuakhali region

Thirty-one rice varieties, both local and high yielding, were cultivated in the study area. Farmers cultivated four rice varieties on average. *Aus* varieties (BRRI dhan 27, BRRI dhan 48, BRRI dhan 82, and BRRI dhan 85) were cultivated in the kharif-I season, from mid-March to mid-June. During this period, however, most lands in the region were left fallow, while *aus* was cultivated

[2]Exchange rate as of 13 May 2022.
[3]Secondary School Certificate (SSC).
[4]Higher Secondary School Certificate (HSC).

Table 2. Main cropping patterns, rice calendar, and rice diseases in coastal Bangladesh in relation to growing seasons. Source: Data collected from farmer interviews (n=74), expert interviews (n=10) and focus group discussions.



in a limited area. During Kharif-II, from mid-June to mid-November, *aman* rice varieties were cultivated (BR 11, BR 22, BR 23, BRRI dhan 34, BRRI dhan 52, BRRI dhan 62, BRRI dhan 72, BRRI dhan 76, and BRRI dhan 77), alongside the local varieties *shada chikon, lal chikon, motha mota, shada mota, matirchak,*

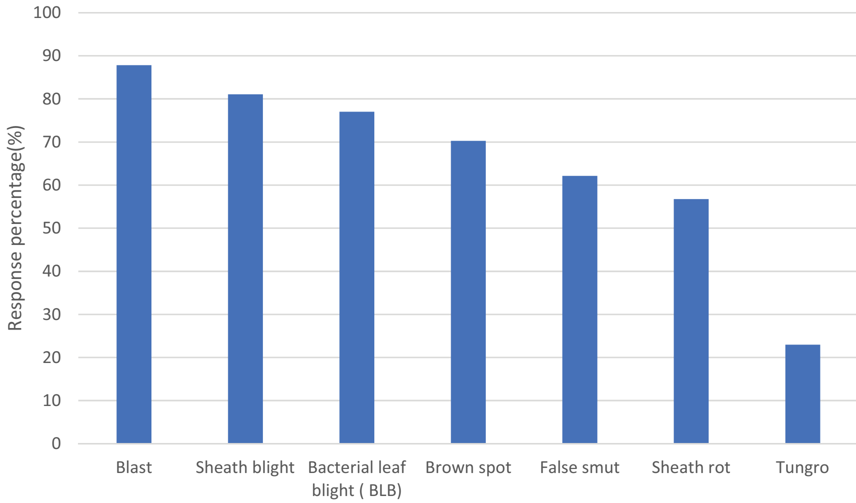


Figure 4. Occurrence of major rice diseases in coastal Bangladesh based on data collected during farmers' interviews (n=74).

shornomushuri, dingamoni, lothormota, shakkhorkhora, and *kalijira*, using all cultivable lands. During *rabi*, from mid-November to mid-March, *boro* varieties were cultivated (BRRI dhan 28, BRRI dhan 29, BRRI dhan 47, BRRI dhan 67, BRRI dhan 74, and BRRI dhan 49), alongside the local varieties *kalo boro*, and *lal boro*. The largest share of coastal farmers planted only *aman* rice (42%), followed by those cultivating a mix of *aus* and *aman* (30%), *aman* and *boro* (16%), and *aus, aman*, and *boro* (12%) (Figure 3).

3.3. Rice diseases and their causes

With climate change, rice plants could be affected by more diseases. Indeed, a greater expanse of rice area in Bangladesh's coastal area has been infected by rice diseases in recent decades, undermining sustainable crop production. The interviewed farmers and experts noted that agriculture here had experienced greater occurrence of major rice diseases, such as rice blast, sheath blight, bacterial leaf blight, brown spot, sheath rot, false smut, and tungro in their fields. Figure 4 shows that most of the farmers reported that in the last 5 years their fields were infected by blast (88%) diseases of rice followed by sheath blight (81%), bacterial leaf blight (77%), and brown spot of rice (70%). Tungro disease (23%) of rice was the least severe disease which affected rice fields. Farmers were provided printed illustrations of rice diseases during the interviews to help them identify the diseases that had affected their fields.

The respondent farmers in the study area mentioned six general causes of rice diseases: drought, lodging, flooding, physical injury of

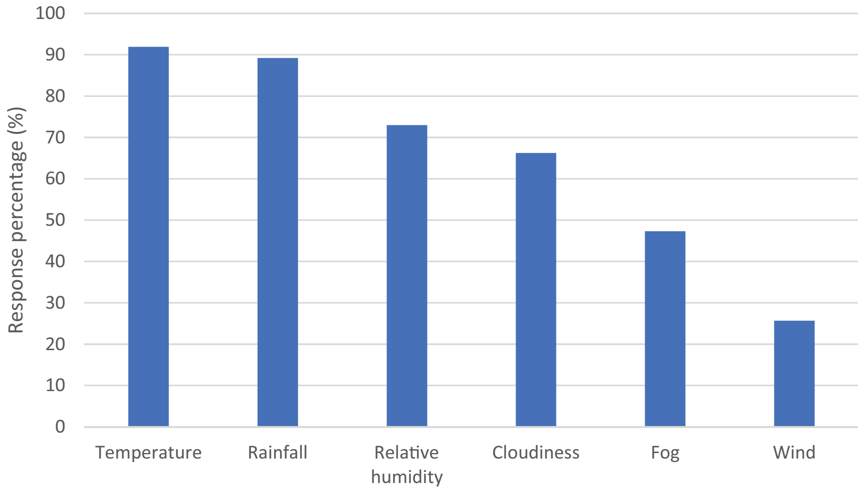


Figure 5. Weather and climatic factors causing major rice diseases in coastal Bangladesh based on data collected during farmers' interviews (*n*=74).

seedlings, soil fertility, and infected seed. According to DAE experts, excessive use of nitrogenous fertiliser (urea), sowing infected seeds, lack of balanced fertilisation, and climate change were the main general causes of increased rice disease in coastal Bangladesh. In the focus group discussions, farmers expressed their perceptions of climate change. Some observed that 30 years ago there were six agricultural seasons throughout the year (summer, rainy season, autumn, late autumn, winter, and spring), while at present only three seasons (summer, rainy season and winter) were distinguishable. Moreover, the interviewed farmers indicated that they had observed changes in climatic phenomena. Over three quarters (78%) of the farmers mentioned that they felt extreme hot during summer which means temperature was increasing whilst 64% of the farmers observed that the summer season was lengthening. In regard to rainfall, 69% of the farmers noted that rainfall was irregular, and 57% stated that rainfall was not ample during the rainy season (appendix Figure A1).

The farmers, furthermore, considered temperature, relative humidity, rainfall, cloudiness, fog, and wind direction as the primary climatic factors triggering rice diseases in their fields. Most of the farmers (92%) identified temperature as the most important climatic factor (Figure 5) causing diseases in their fields, followed by rainfall, relative humidity, cloudiness, and fog. Wind was considered a less important factor in causing rice diseases.

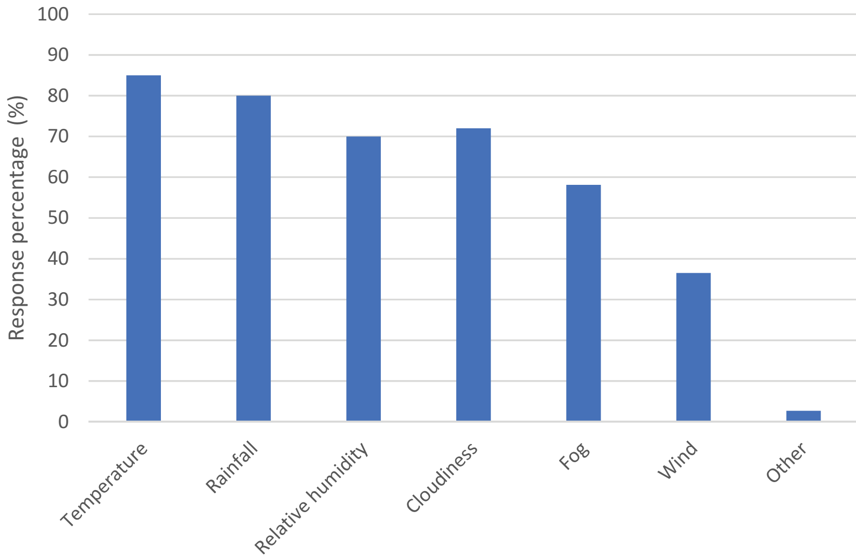


Figure 6. Weather information needs of coastal rice farmers in Patuakhali, Bangladesh based on data collected during farmers' interviews (*n*=74).

3.4. Weather information needs and lead times

To forecast potential onset of rice diseases and minimise outbreaks, these coastal rice farmers reported needing accurate information on temperatures, rainfall, relative humidity, cloudiness, and fog (Figure 6). Most farmers (85%) expressed a need for information on temperature, rainfall (80%), and relative humidity (70%). More than half (58%) wanted information on fog, while almost three quarters (72%) wanted information on cloudiness. Chi-square test results indicate that farmers' information-seeking behaviour regarding weather parameters was related to their literacy level (see appendix Figure A2 and appendix Table A1). Specifically, the more educated farmers (those with a secondary school certificate or higher) sought information on a greater number of weather variables.

In terms of lead time, most farmers (85%) were interested in receiving weekly (7 days) forecasts, and less than half (47%) were interested in three-day forecasts (see appendix Figure 3). Very few (6%) expressed a need for real-time weather forecasting, seasonal or three-month forecasts, or one-day in advance forecasts. Besides, coastal farmers observed that they would be unlikely to make decisions for rice disease management more than one to two weeks in advance.

3.4.1. Choice of the communication platform

Regarding choice of communication platform, farmers expressed a preference for obtaining weather and climate information by mobile phone using SMS (47%) or voice calls (32%), though a few were interested in receiving the information via smartphone apps and social media (see appendix Figure 4). Most farmers (64%) did not as yet use mobile phones to obtain agricultural information. More than half (57%) stated that economic issues and lack of ICT knowledge would limit their ability to access information via smartphone. A chi-square test was performed to explore the relationship between farmers' preferred communication platform and literacy level. Results show that the choice of communication platform significantly varies with the literacy level of farmers (appendix Table 2). Farmers with a lower educational level (primary) or no education (illiterate) preferred receiving information through a voice call. Farmers with a secondary or higher education preferred receiving information via SMS. The farmer who had completed tertiary education indicated a preference for receiving information through smartphone apps and social media.

3.5. Weather and climate information sources to forecast and manage rice diseases

The farmers identified eight available sources of weather information with which to forecast and manage rice diseases. The majority of farmers (85%) drew on their own personal experience to forecast rice diseases and manage them in advance. Among the farmers, 65% received weather information from peers. Farmers said they discussed and consulted with their peers on various agricultural issues, with these interactions occurring in their fields, at the shopping mall, and during free time, for example, at the tea stall. Among the interviewed farmers, 54% reported obtaining weather information from the SAAO. The SAAOs engaged with farmers through individual contacts, meetings, and training. Furthermore, 35% of the farmers use their local knowledge to forecast rice disease outbreaks. Local knowledge refers to knowledge that is specific to a culture or society, created by analysing local conditions, and passed down by communities from generation to generation, mainly by word of mouth and traditional agricultural practices (Chaudhury et al., 2012; Lebel, 2012; M. H. Rahman & Alam, 2016; Morshed, 2007; Senanayake, 2006).

About one-fifth (19%) of the respondents obtained weather information from input dealers. These exchanges happened when farmers went to the market to buy agricultural inputs such as seed, fertilisers, and pesticides. The input dealer then informed them of, for example, weather forecasts, fertiliser application guidelines, and disease management strategies. Very few farmers (5%) obtained weather information specifically for forecasting rice diseases

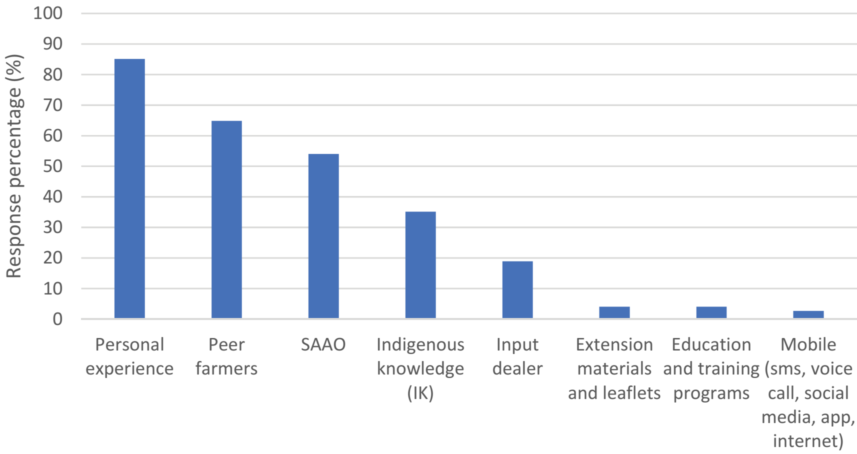


Figure 7. Available sources of weather information to forecast and manage rice diseases in advance in coastal Patuakhali region based on data collected from 74 farmers through farmers' interviews.

from education and training programmes, mobile phone services, or extension materials and leaflets. The education and training programmes mentioned were provided mainly by DAE officers and non-governmental projects and include Farmers' Field Schools (FFS), group discussions, yard meetings, and field demonstrations. Only a small percentage (3%) of the farmers received weather information from mobile phones. None of the interviewed farmers obtained weather information to forecast and manage rice disease from the Agriculture Information Service (AIS), non-governmental organisations (NGOs), radio, or television programmes. About a fifth (19%) of the respondents mentioned that they received no information of any kind on weather for forecasting and managing potential rice disease outbreaks. Figure 7 presents the distribution of available sources of information to forecast and manage rice diseases, as reported by farmers in the study area.

3.6. Indigenous weather forecasts using local indicators

Indigenous weather forecasting is based on observation of local indicators, such as natural phenomena, celestial objects, animals, plants, and insects. The majority of the interviewed farmers (88%) used such indicators to predict weather and climatic conditions in the study area. Table 3 presents the significance of indicators such as sun, temperature, wind, and the appearance the moon to predict weather and climate conditions. The majority of the farmers (82%) used the sun to predict local weather. Temperature, wind, and the appearance of the moon were also considered important to predict

Table 3. Indigenous indicators that are used by farmers ($N = 74$) in coastal Bangladesh for weather forecasting based on farmer interviews.

Local indicators	Significance to predict weather and climatic condition	(N =74)
Sun	–Sun hitting without wind indicates that it will rain that day	82.4
Temperature	–High temperature indicates that rain is on the way on that day –High temperature during the night imply that it will rain the next day	67.5
Wind	–East wind indicates increasing water level in rivers, channels, ponds and fields –West wind indicates onset of rain –Wind from north-west direction increases chance of storm rain	63.5
Moon	–The moon's appearance in a circle form (normal) indicates the start of rain –New moon and full moon indicate rain	60.8
Animals	–Ants appearing everywhere in large numbers including inside homes, and appear to be celebrating, it indicates the start of rains and increasing water level –When frogs start to make a noise is an indication of rainfall onset	29.7
Star	–Clear sky with numerous stars indicates good weather for the next day	18.9
Cloud	–Moon surrounded with heavy clouds indicates onset of rain	13.5

weather and climate-related phenomena. Stars and cloud cover were identified as important indicators by 19% and 14% of the interviewed farmers, respectively.

3.7. Role of weather information in rice disease management related key decision making

Weather information is required to forecast rice disease outbreaks and manage diseases in advance. Farmers in Patuakhali considered weather and climate information as a key input on which to base decisions concerning agricultural activities. Most farmers "strongly agreed" (68%) that weather and climate information was vital in agricultural decision-making, while 31% "moderately agreed" with this statement. Nonetheless, most of the farmers (90%) believed that weather conditions and rice disease occurrence and development were strongly related.

At the time of the fieldwork, coastal farmers in the study area made rice disease management decisions based on personal experience, peer farmers, and advice from the SAAO. However, the role of this information in guiding agricultural activities remained limited, mainly due to the lack of accurate, timely, and location-specific weather information with which to forecast rice disease outbreaks in this coastal region. Nevertheless, the interviewed farmers stated that due to climate change, seasonal weather patterns were shifting, and that knowledge drawn from personal experiences was no longer sufficient. The majority of farmers consulted peers regarding weather conditions and information, different rice diseases and insects, how to manage these, fertiliser and pesticide applications, and other agricultural problems and practices, and made decisions based on their recommendations. The SAAOs interacted with a limited number of farmers in the study area. Furthermore, they did not have in-depth knowledge about weather and forecasts, and played a very minor role in disseminating such information to farmers. The SAAOs eagerly stated, however, that they were interested in gaining a better understanding of weather and climate information and disseminating relevant information to farmers, for example, after training to improve their capabilities in this domain.

All of the farmers interviewed stated that tailored services would help them make more strategic and sophisticated rice disease management decisions. Farmers and experts expressed that if weather information, such as temperatures, rainfall, humidity, fog, and cloud cover, could be better forecast, communicated, and disseminated among farmers with sufficient lead time (1 week), better management decisions could be made to safeguard rice crops from larger disease outbreaks. For example, with timely weather forecasts, they could spray pesticides to achieve maximum effect with lower application amounts, reducing crop losses and saving on input costs. Better forecasts could thus lead to increased production, income, and more successful adaptation to the changing climate. The forecast information services could assist not only in reducing the amounts of agrochemicals used but also improve the effectiveness of applications. With timely forecasts, farmers could initiate management measures at an early stage, reducing the chance of a severe disease outbreak. With better WCIS, farmers stated that they could reduce the number of times they sprayed agrochemicals, as for instance, good information would help them avoid them spraying before or during the rains. This would result in reduced pesticide wastage and overall lower phototoxic effects of pesticides on crops and the environment. In one example, farmers said they had planned to apply pesticide and fertilizer in the coming days; however, when they received the weather forecast and became aware that rain was expected, they decided to postpone the application to a later date when a sunny period was expected. Indeed, rains can wash away pesticides and fertiliser. Without access to the weather information, they might have had to apply pesticides and fertiliser again to safeguard production.

Following the results of the current study, some patterns became obvious in the user-driven and data-driven approaches that are needed to co-produce tailored services that will help farmers in more informed decision-making. A conceptual framework is sketched in an effort to foster future services. Figure 8 represents the conceptual framework of future WCIS to forecast and manage rice diseases.

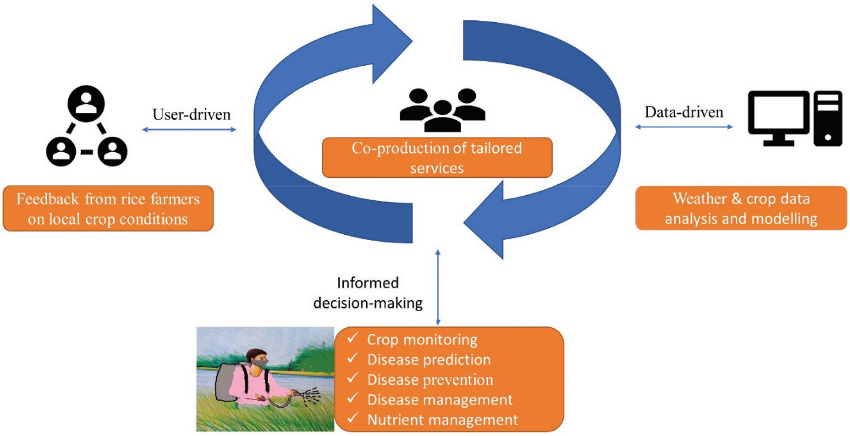


Figure 8. Conceptual framework of future weather and climate information services to forecast and manage rice diseases. Source: Authors.

4. Discussion

This study was conducted to assess the weather information needs of coastal rice farmers in Bangladesh. It sought to identify available sources of weather information for forecasting and managing rice diseases, and to determine what role weather and climate information services (WCIS) could play in rice disease management decision-making. The results indicate that farmers could substantially benefit from appropriate weather information services to better forecast and manage crop diseases, as the sources of weather information currently available do not meet their needs.

4.1. Coastal farmers' weather information needs to manage rice diseases

Climatic conditions influence all phases of the rice disease cycle, from the germination of spores to the initiation of lesions (Ghini & Bevitori, 2014). Most pathogens, for instance, germinate, penetrate, and infect plants under conditions of high relative atmospheric humidity. With high temperatures and high humidity levels, most pathogens have a shorter life cycle, which accelerates the potential spread of disease (Agrios, 2005). As disease spread is affected by climatic conditions, farmers could potentially take disease control measures in advance if they are informed about climate and weather conditions such as temperature, rainfall, relative humidity, cloudiness, and fog.

The results of the current study show a large gap between the information needs of farmers and the weather information available to them, to forecast rice disease outbreaks. The majority of the farmers consulted stated that they had no source of accurate, timely, and location- and crop-specific weather information. This finding is consistent with Benard et al. (2014), who found that most rice farmers expressed dissatisfaction with the weather information at their disposal. Similar to the current research, in that study, 95% of rice farmers expressed a need for timely weather information to make more precise decisions for managing diseases and applying manure and fertiliser (Benard et al., 2014). Stigter (2002) also observed that having access to appropriate weather information and communicating it appropriately could considerably reduce risk and uncertainty in agricultural operations.

Farmers particularly need information on temperatures and rainfall. Those participating in the focus group discussions for the current research said that they had, in the past, based agricultural decisions on local knowledge. However, due to climate change, the timing, frequency, and intensity of rainfall were shifting while temperatures were increasing (Alam et al., 2017; Ayanlade et al., 2018). This makes predictions based on local knowledge more precarious. Several previous studies, such as Hasan and Kumar (2020) and Shameem et al. (2015), too, indicate that coastal farmers perceived temperatures as increasing, while the timing of rains had changed and rainfall had become more erratic. In the current study, farmers added that, due to increasing temperatures and variability of rainfall and humidity, they were experiencing more extensive outbreaks of diseases and pests in their rice fields.

The farmers also observed that pattern of rainfall had become more irregular and that rainfall was diminishing, with more frequent droughts. Drought can predispose rice to *Bipolaris oryzae*, which causes brown spots of rice disease (Haq et al., 2011). Furthermore, with increased temperatures, pathogens become more active, and they are more likely to infect plants, ultimately causing disease (Agrios, 2005). For example, favourable weather conditions for rice blast disease include drizzling rain, fog, cloudy skies, hot days, and cold nights. This implies that if farmers can be informed about weather variables that present favourable weather conditions for rice disease occurrence in the fields; they could manage these diseases in advance and avoid unnecessary usage of pesticides. In Macedonia, tailored pest and disease advisories from WCIS have enabled farmers to increase their production while reducing environmental pollution due to overuse of herbicides and pesticides (FAO, 2021). In Bangladesh, a seasonal forecast-based early warning system has been developed to predict the onset of wheat blast (K. -H. Kim & Choi, 2020). Additionally, in many countries smart technologies, such as the Internet of Things (IoT), machine learning, and artificial intelligence (AI), are being used in early rice disease detection (Aggarwal et al., 2022; Debnath & Saha, 2022; Habib & Nura, 2021).

4.2. Available weather information source to forecast and manage rice diseases

Like previous research (Benard et al., 2014; Chaudhury et al., 2012; Md et al., 2016), the current study found that the majority of farmers relied on interpersonal sources to obtain weather information. Furthermore, over the years, they gained personal experience through cultivating rice in their fields. These experiences provide useful insights in the production technology of rice including climate requirements, disease prediction, and disease management practices of rice crops. The reliance among farmers on their own personal experience pertaining to crop production was similarly found by Kumar et al. (2020) and Ahmad (2019).

However, none of the farmers interviewed used either television or radio, nor did they use the formal Agriculture Information Service (AIS) to obtain weather information to predict rice disease outbreaks. Farmers claimed that weather forecasts on television and radio were not sufficiently specific to manage rice diseases. In a similar vein, Kumar, Werners, Roy, et al. (2020) reported that interviewed farmers expressed distrust of the weather forecasts on television and radio. This was attributed to the lack of location-specific information, as radio and television provided general forecasts focused on the district level or an even larger geographical area. However, farmers needed more precise location- and crop-specific weather information to adequately manage rice diseases.

The experts interviewed in the current study did mention that farmers could receive agriculturally relevant weather information through the Bangladesh Meteorological Department (BMD) and the Bamis portal provided by the DAE. Yet, in the focus group discussions and the interviews, farmers said they had no access to information from these sources. The BMD has a smartphone weather app which is available in the study area; however, farmers were completely unaware of its existence.

The most important sources of information for most farmers in making rice disease management decisions were their own experiences and interpersonal contacts. At present, they emphasised particularly the need for timely, location-specific weather information to forecast and manage rice diseases. Although the majority of the farmers relied on informal contacts as their primary information source, they also mentioned obtaining specific and effective information from extension departments, particularly the SAAO, as well as from education and training programmes, and from extension materials and leaflets. However, in the study area, each SAAO was responsible for disseminating information to approximately 2,000 farmers, indicating the challenge of providing timely information to all farmers. Kumar, Werners, Roy, et al. (2020) found that state extension departments were farmers' primary source of specific and effective information in peri-urban Khulna, in south-west Bangladesh. However, weather information relevant for forecasting and managing rice diseases was hardly available to farmers via agricultural extension personnel in the study area. As there were some sources that farmers could access, this underscores the need to build farmers' understanding of how to use the information for rice disease management and their ability to access these sources. If farmers can harness these resources, receiving information from one or multiple channels, they could be better able to manage rice diseases.

4.3. Challenges faced by farmers in accessing weather information

Rice farmers in the study area faced a number of challenges in accessing weather and climate information. For instance, there was a limited number of SSAOs, insufficient to effectively reach all farmers. With the current number of extension officers, it is unfeasible to reach out individually to all rice farmers. Aina (2006) and Benard et al. (2014) similarly found a low ratio of population to agricultural extension agents in the developing agricultural economies of Africa. If the number of extension agents could be expanded, and training provided on WCIS to produce actionable knowledge on weather and climate conditions in relation to rice diseases, it could assist coastal farmers in managing their agricultural activities.

The current study found that most farmers were unaware of the existence of weather information sources. For example, one farmer reported having no idea where to seek out such information, except from friends, family members, and personal experience. Therefore, where they exist, agricultural information sources and services should be more widely publicised and promoted, to reach the farming community. Moreover, farmers need education and training on the use of WCIS. Most of the interviewed farmers did not know how to utilise a smartphone to access weather information via weather apps, SMS, call centres, social media platforms, or websites. In a focus group discussion, when asked why they did not use a smartphone for weather information and other agricultural information, one farmer stated that nobody had informed them that a smartphone could be used for agricultural information purposes. This suggests that a needs-based information service could benefit farmers and that farmers need to be made aware of the potential of using a mobile phone to access weather information services.

4.4. Recommendations for Tailoring WCIS for coastal farmers to forecast and manage rice diseases

The findings of this research suggest seven recommendations for tailoring weather information services according to coastal farmers' needs, to assist them in forecasting and managing rice diseases in advance.

- Weather information services should be accurate, timely, and location- and crop-specific in order to forecast and manage specific diseases and outbreaks (Islam et al., 2013; Lackstrom et al., 2014; Rengalakshmi, 2018).
- Weather information services should consider local rice farmers' needs (Carr et al., 2016; Chavas et al., 2019; Vincent et al., 2015).
- Rice farmers need regular training in the use of weather forecasts for agricultural decision-making, as well as in identifying different rice diseases and insects, managing diseases in fields, applying pesticides, choosing which pesticides to use for which diseases, favourable weather conditions for different rice diseases, and general causes of rice disease occurrences.
- Weather information should be provided in the local language with local interpretation of weather forecasts for farmers (Guido et al., 2016).
- Awareness needs to be raised among farmers regarding weather information services and their role in agricultural decision-making. Indeed, 95% of the respondent farmers had a mobile phone, and 62% had smartphone. But they did not know how to use these devices to access weather information services.
- ICT specialists should work jointly with the meteorology department (BMD), agricultural extension specialists (DAE), and plant pathologists – especially rice disease specialists – to develop tailored WCIS for climate-smart rice disease management in coastal Bangladesh.
- Due to constraints in funding and numbers of extension agents, private organisations could be involved in supporting rice farmers, particularly in disseminating weather information to ensure widespread access to timely, location- and crop-specific weather information services.

5. Conclusions

The current study identified a pressing need among coastal farmers in Bangladesh for information on multiple weather variables with which to forecast rice disease outbreaks. The farming communities in the study area accessed their weather and climate information mainly via interpersonal contacts, drawing on their own experiences, peer farmers, and own local knowledge. However, these sources cannot keep up with the weather and climate shifts associated with climate change, nor do they meet farmers' current needs. From this study, we can conclude that coastal rice farmers understand the value of tailored, accurate, timely, and location- and crop-specific weather and climate information services (WCIS) to enable them to forecast rice disease outbreaks and manage these in advance to adapt to the changing climate. There is substantial potential for the use of ICT platforms, such as smartphones and social media, as most farmers had access to mobile phones or smartphones. Farmers could be made aware of the climate information services already available. With targeted training and capacity building and more frequent interactions with extension agents, they would be better able to apply weather forecast information in making climate-sensitive decisions, and environment-friendly management of rice diseases.

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