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Towards understanding vulnerability: Investigating disruptions in cropping schedules in irrigated rice fields in West Java

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ABSTRACT

Unsafe conditions may increase the vulnerability of farmers natural hazards and reduce the capacity of farmers to prevent or recover from disaster impacts. This study aimed to investigate disruptions in cropping schedules to understand unsafe conditions that contribute to vulnerability in irrigated fields served by Ir. Djuanda (Jatiluhur) reservoir in West Java. Firstly, the deviation of ongoing cropping schedules from the official cropping calendar was evaluated using the time-series Enhanced Vegetation Index (EVI) derived from MODerate-resolution Imaging Spectroradiometer (MODIS) imageries. Secondly, reasons for disruptions in cropping schedules were explored using an in-depth interview with farmers, extension officers, and water managers and analyzed using a qualitative content analysis. Thirdly, the progression from potential causes to consequences of the disruption was identified using a Bow-Tie analysis. Unsafe conditions were identified using the result of the Bow-Tie analysis. Finally, several ways to reduce vulnerability were suggested. This study has successfully showed that cropping schedules deviate from the official cropping calendar in the study area. Reasons for disruptions in cropping schedules include economic motives, weather variabilities, geographic locations, coping strategies, farmers' interactions, and agricultural infrastructures. The Bow-Tie analysis has visualized the progression from potential causes, disruptions in cropping schedules, to potential disaster impacts. Unsafe conditions have been identified, categorized into the dangerous locations, unsustainable farming activities, unsuitable coping strategies, fragile infrastructures, and inaccurate perceptions, have been pinpointed. Addressing unsafe conditions is likely to able to reduce vulnerability in irrigated rice fields.

1. Introduction

The vulnerability of farmers to natural hazards (hereafter referred to as vulnerability) may partly be explained by unsafe conditions [72], such as unsustainable farming practices [11] or low cooperation among agricultural stakeholders [7]. Vulnerability refers to the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard [64]. According to the Pressure and Release (PAR) model (Fig. 1), the origin of unsafe conditions may be traced back to the dynamic pressures and root causes of vulnerability [72]. Unsafe conditions are the specific forms in which the vulnerability of people is expressed in space and time in conjunction with natural hazards [72]. Unsafe conditions may reduce the capacity of farmers to prevent, mitigate, or recover from natural hazard impacts [1]. However, identifying unsafe conditions is not without challenges. Firstly, unsafe conditions may be determined by many reasons, including farming practices [15,21], community coordination [40], and irrigation water availability [30,65], among others. Secondly, rice agricultural stakeholders may have perceptions about dynamics in rice fields different from researchers [47]. Researchers need to translate terms such as 'unsafe conditions' or 'vulnerability' into the daily language of stakeholders [18,54]. There exists a need to locate a common ground so that researchers can provide suggestions to address unsafe conditions and reduce vulnerability in irrigated rice fields.

In the context of scheduled irrigated rice fields, disruptions in cropping schedules may be used as a 'common language' to understand mechanisms of how unsafe conditions may increase vulnerability. On the one hand, extension officers and water managers regulate the implementation of an official cropping calendar and irrigation distribution to achieve the rice production target. On the other hand, farmers may adjust planting dates according to their perceptions of physical and socioeconomic conditions to maximize productivity from their rice fields. Previous studies have identified causes that potentially influence rice cropping schedules in irrigated rice fields, broadly categorized into physical, technical, and socioeconomic factors [32]. The former is related to the geographic location where rice fields are cultivated, such as

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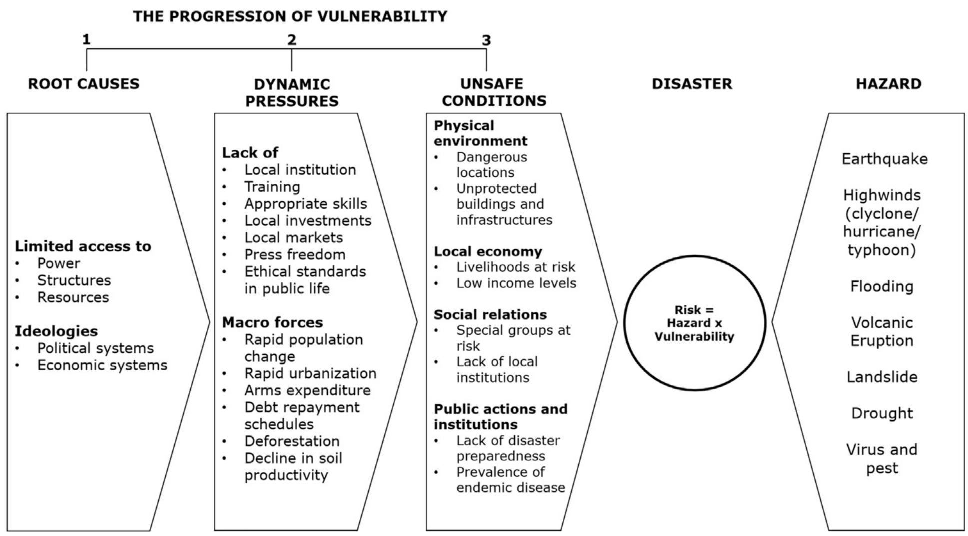

Fig. 1. Pressure and Release (PAR) model Source: Wisner et al [72]. At Risk: Natural Hazards, People's Vulnerability, and Disasters, 2nd edition, Routledge, New York.

soil texture and moisture-holding capacity, topography, and non-extreme and extreme weather variabilities [23,42]. The latter may manifest in natural hazards, such as flooding [37,51] and drought [12]. The technical factor is related to water availability or irrigation management [57,68], and technologies that can be used to support farming practices, such as rice varieties or labor farmers [10]. Finally, socio-economic factors encompass a broad range of social and economic conditions from the local to global level, including agricultural policies or regulations [49].

The present study mainly focuses on irrigated rice fields served by a multi-purpose Ir. Djuanda (Jatiluhur) reservoir (e.g., hydroelectric power generation, water supply, irrigation) under the management of Perusahaan umum Jasa Tirta II (PJT II) in West Java, Indonesia (Fig. 2). The construction of the reservoir and development of irrigation systems since 1967 have improved agricultural productivity, marked by the change from a single- to the double-rice cropping cycle (http://jasatirta2.co.id/). Since then, the irrigation committee, currently consisting of the ministry of agriculture, provincial government, Balai Besar Wilayah Sungai Citarum (Citarum river basin office), and Dinas Pendayagunaan Sumber Daya Air (water resource management office) of West Java, and Perusahaan umum Jasa Tirta II (state company PJT II), have suggested a cropping calendar to satisfy irrigation water demand for the vast rice fields (approximately 240,000 ha) during wet and dry planting seasons. The cropping calendar is a recommendation of cropping schedules for farmers and a guide for PJT II in distributing irrigation water to rice fields (Table 1). The calendar was designed based on the operational pattern of the reservoir and seasonal periods of wet (October-March) and dry (April-September) seasons. The calendar also serves as a method to stop rice pest and disease reproduction, maintain soil fertility, and determine labor requirements, among others. Annually, the government of West Java and PJT II pass an official cropping schedule after discussing the draft of the cropping calendar with the irrigation committee. The calendar is disseminated among stakeholders (e.g., farmers, extension officers, local government) through various means, such as village meetings or mosque announcers. The irrigation committee conducts two weekly meetings at the sub-district level *(minggon)* to discuss the implementation of the cropping calendar.

The cropping calendar suggests that irrigation water is distributed to each rice field class according to stipulated schedules to ensure equal access and to avoid massive irrigation water demand due to concurrent planting dates (Table 1). Rice field classes categorize rice fields according to periods of receiving irrigation water. Rice field classes are determined by PJT II partly based on locations and access of rice fields relatively to primary irrigation channels. The rice field class I is located closer to primary irrigation channels and receives water first, while the rice field class V mostly is located at the tail end of irrigation channels and receives water last (Table 1). The amount and timing of water

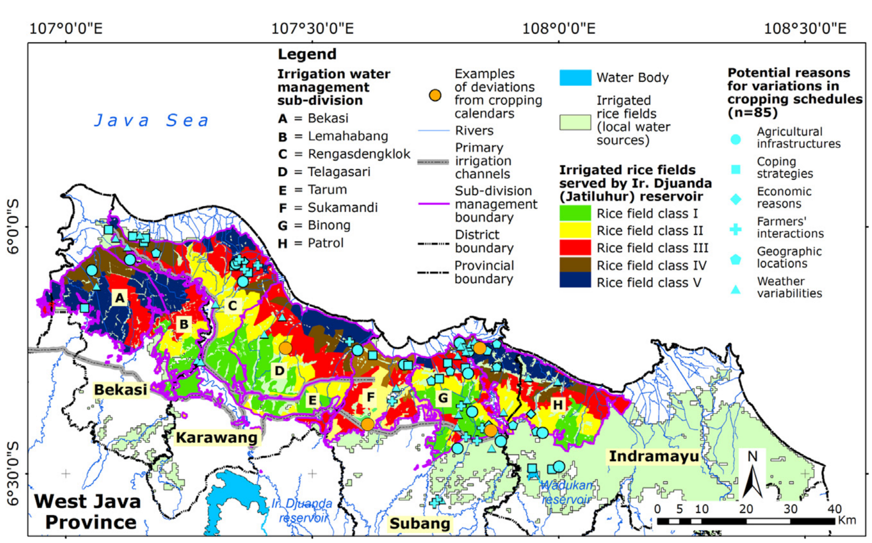

Fig. 2. Study area is irrigated rice fields served by Perusahaan umum Jasa Tirta (PJT) II. Water managers supervise irrigation water distribution at sub-division offices (Letters A-H). Cropping schedules for each rice field class (I-V) correspond to Table 1. Blue points (n = 85) are respondents and correspond to Table 2. Orange points correspond to Table 4 and Fig. 7.
(Source: Perusahaan Umum Jasa Tirta II and Sianturi et al [55]).

Table 1
Official cropping calendar for irrigated rice fields served by Ir. Djuanda (Jatiluhur) reservoir. Farmers may adjust planting dates according to perceived environmental and socioeconomic factors. Letter P (Planting) is the reference Day of Year (DOY) for the Start of Season (SOS). Rice field classes in Table 1 corresponds to Fig. 2. Source: Perusahaan Umum Jasa Tirta II.

Rice field class	Wet planting season												Dry planting season											
	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		June		July		Aug		Sept	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
I	T	T	**P**	G	G	F	F	F	M	M	T	T	**P**	G	G	F	F	M	M					D
II		T	T	**P**	G	G	F	F	F	M	M	T	T	**P**	G	G	F	F	M	M				D
III			T	T	**P**	G	G	F	F	F	M	M	T	T	**P**	G	G	F	F	M	M			D
IV				T	T	**P**	G	G	F	F	F	M	M	T	T	**P**	G	G	F	F	M	M		D
V					T	T	**P**	G	G	F	F	F	M	M	T	T	**P**	G	G	F	F	M	M	D

T: tillage (30 days); P: planting (15 days); G: growth (30 days); F: flowering (45 and 30 days in wet and dry planting seasons, respectively); M: maturation (30 days); "blank space": fallow period; D: irrigation channel drying.

channeled to rice field classes I to V during wet and dry planting seasons is regulated according to the data of PJT II on rice field areas. However, irregularities in the amount and timing of water distributed to rice fields are present, especially during dry planting seasons, due to many factors, including water needs in other rice fields and sectors (e.g., electricity generation, drinking water). Thus, irrigated rice fields may not be given water priority during limited water resources, for example during an El-Niño period. Three regional water divisions (Divisi Pengelolaan Air - DPA) manage the distribution of irrigation water from primary to secondary irrigation channels (off-farm). Eight subdivision offices aid these division offices, comprising Bekasi and Lemahabang for DPA I; Sukamandi, Rengasdengklok, Telagasari, and Tarum for DPA II; and Binong, and Patrol for DPA III. From tertiary channels to rice fields (on-farm), the irrigation distribution is managed by farmer groups (P3A/Mitra Cai). Additionally, primary irrigation channels were scheduled for a complete drying in September for maintenance and halting rice pest reproduction (Table 1); however, nowadays, the drying is performed mainly in secondary irrigation channels due to increasing water users (e.g., drinking water, factories).

The implementation of the cropping calendar frequently faces constraints in the study area. As previously mentioned, extension officers and water managers perform their duties according to the official cropping calendar while farmers who have more access to irrigation water may modify planting dates to maximize their rice production. There are no sanctions in terms of financial or water right cuts if farmers do not conform to the regulation. The efficiency of irrigation management decreases if farmers do not perform the cropping calendar. Also, incentives are non-existent if farmers follow the cropping calendar. Furthermore, the cropping calendar has existed for more than three decades as a guide for regulating planting and irrigation schedules in vast rice field areas. The calendar was strictly regulated during the old order era (before 1998), contributing partly to rice availability and price stability. Nowadays, some farmers still consider the calendar in their farming practices. In contrast, cropping schedules in other rice fields deviate from the stipulated calendar. This irregularity in planting dates is likely to influence irrigation water availability. For example, a delay in planting dates in the rice field class I may lead to a delay in planting dates in rice fields classes II to V. Although the delay in the rice field class I may mean more water is available, farmers in other areas may not necessarily perform rice cultivation based on irrigation water availability. Some farmers may only start planting seasons if farmers in previous rice classes have cultivated rice fields to avoid problems in irrigation water schedules during growing seasons. The unsafe conditions that arise are therefore in part caused by the irregularity in irrigation water distribution.

This study aims to investigate disruptions in cropping schedules to understand unsafe conditions that contribute to the vulnerability of farmers to natural hazards in irrigated rice fields served Ir. Djuanda (Jatiluhur) reservoir in West Java. The primary goal is to provide insights on reducing vulnerability. Firstly, we evaluate the deviation of ongoing cropping schedules from the official cropping calendar using time-series remote sensing data. As an indicator of the cropping schedule, we use the Start of Season (transplanting date) because it can be detected from variations in rice cover. The maps of deviations of long-term average (LTA) planting dates from the official cropping calendar are provided. Secondly, we explore reasons for disruptions in cropping schedules using an in-depth interview and qualitative content analysis. Using the first two results, we provide examples of locations and periods of the reasons. Thirdly, we demonstrate the progression from potential causes of disruptions to adverse disaster impacts using a Bow-Tie analysis. Using the result of the Bow-Tie analysis, we identify unsafe conditions that potentially increase vulnerability. Finally, we suggest ways to reduce vulnerability based on the results. The findings can be used as inputs by extension officers, water managers, and disaster risk reduction officers for designing pathways for reducing the vulnerability of farmers to natural hazards.

2. Materials and methods

2.1. Remote sensing analysis

A remote sensing analysis was performed to obtain information about the deviation of ongoing cropping schedules from the official cropping calendar in space and time. MODerate-resolution Imaging Spectroradiometer (MODIS) 8 day 500 m spatial resolution imageries (MOD09A1) from 2000-Date Of Year (DOY) 49 to 2015-DOY 225 were downloaded from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/) over the study area. The MOD09A1 data were stacked to produce a time-series dataset, and the study area was a subset of the dataset. A time-series Enhanced Vegetation Index (EVI) dataset was generated from the time-series MOD09A1 dataset. The formula for deriving the EVI is as follows:

$$EVI = 2.5x\frac{NIR - RED}{NIR + 6x\,RED - 7.5x\,BLUE + 1} \quad (1)$$

where NIR is the near-infrared band (841–875 nm, Band 2); RED is the red band (621–670 nm, Band 1); and BLUE is the blue band (459–479 nm, Band 3). The Adaptive Savitzky-Golay filter focusing on the upper envelope was performed to reduce the remaining noises and to smooth the time-series EVI dataset [3–5,17,36,70]. The 8 day time-series EVI (1 year = 46 imageries) is interpolated into daily time-series EVI (1 year = 365 imageries).

The Start of Season (SOS) is used to obtain the DOY when farmers start rice cultivation. In practice, the SOS indicates the period when farmers start rice transplanting. The use of SOS to investigate the deviation in cropping schedules is preferred than other phenology metrics, such as the heading stage or end of season, because adverse events may damage rice cultivation during growing periods, reducing yield quantity and quality or causing harvest failures. Sianturi et al [55] estimated the SOS using MOD09A1 in irrigated rice fields in northern districts of

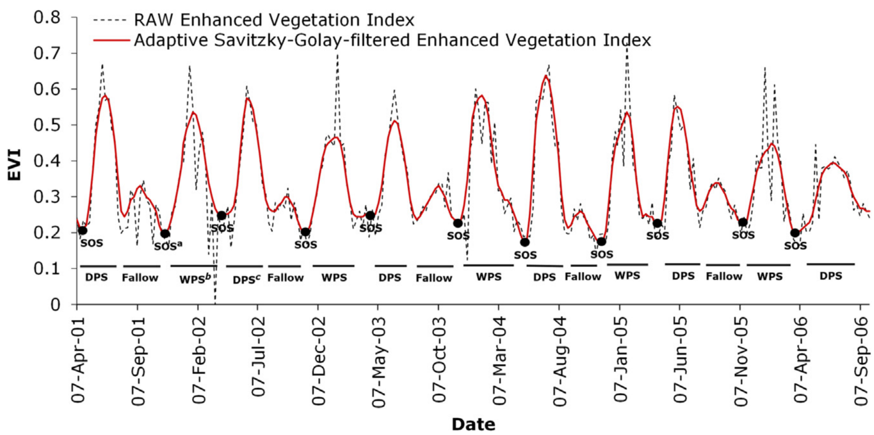

Fig. 3. Example of a smoothed time-series Enhanced Vegetation Index (EVI). [a]SOS = Start of Season; [b]WPS = Wet Planting Season; [c]DPS = Dry Planting Season.

West Java (Bekasi, Karawang, Subang, Indramayu). The authors showed a reasonable result with Root Mean Square Error (RMSE) of 9.21 days. Furthermore, the unit analysis for deriving the SOS is rice field classes (I-V). EVI values in all pixels within a rice field class were averaged. The SOS was derived from the time-series EVI data for each rice field class within each water sub-division for both wet and dry planting seasons manually. The periods of wet and dry planting seasons were identified and used as a time boundary to discriminate between wet and dry planting seasons. Normally, the periods of wet and dry planting seasons are from October to March and from April to September, respectively. The DOY when the EVI value reaches 0.1 at the beginning of each planting season was derived from the time-series EVI. If the minimum EVI value throughout a cropping season is higher than 0.1 because of the influence of mixed pixels, the DOY of the lowest value (through) is selected as the SOS, as shown in Fig. 3. Furthermore, the areas of rice fields served by Ir. Djuanda reservoir were also obtained from Sianturi et al [55] in the form of a raster dataset. The authors mapped irrigated rice fields in four northern districts of West Java using MOD09A1 with R^2 = 0.81–0.93.

The procedure for obtaining samples (N) for the DOY of the SOS is as follows. This study uses EVI data from 2000 to 2015, so there are at least 15 SOSs for each wet and dry planting season. Eight water sub-divisions are present in the study area (see Fig. 2). Each water sub-division comprises rice field classes. The samples were obtained from all pixels in each rice field class (I-V). Some water sub-divisions have five rice field classes while others may have only 3 or 4 rice field classes. The total number of samples is the multiplication of the number of years (e.g., 15 years) and the number of similar rice field classes in all water sub-divisions at each planting season (wet and dry planting seasons). For example, the rice field class III exists in all water sub-divisions. So, the number of SOS samples for each wet and dry planting season is 120. The inclusion of all pixels in a rice field class is to avoid the sample bias associated with the difference in the areas of water sub-divisions. The estimated SOS derived from MOD09A1 were compared with the reference SOS using a *t*-test to investigate whether the ongoing planting dates deviate from the official cropping calendar. The null hypothesis (H_0): there is no difference between the estimated and the reference SOSs in each rice field class. The reference SOS is the official cropping calendar stipulated by the provincial government of West Java and PJT II for each rice field class. The DOYs of the reference SOSs for the wet and dry planting seasons in each rice field class are as follows: Class I, DOY 305 and DOY 91; Class II, DOY 320 and DOY 106; Class III, DOY 335 and DOY 121; Class IV, DOY 350 and DOY 136; and Class V, DOY 1 and DOY 152, respectively (see Table 1). It is worth mentioning that this study used the earliest DOYs during planting periods as the references SOS, leading to maximum deviation duration.

2.2. Interviews

Field interviews (85 respondents in total) were conducted from October to November 2014, and from January to February 2015 to obtain information on reasons for irregularities in cropping schedules. Practically, it is not possible to collect actual data on a wide range of conditions (e.g., the length of damaged irrigation channels) and activities (e.g., the amount of pesticide uses per cropping season) from different stakeholders in the study area. In this regard, in-depth interviews offer the advantages to capture perceptions of rice agricultural stakeholders about disruptions in cropping schedules [18,54]. The respondents include farmers, extension officers, and water managers. The primary question used as the guideline to probe reasons for disruptions in cropping schedules was 'why is the cropping schedule irregular?' The most dominant answers per respondent were presented per category in Fig. 2. However, the demonstration should not be compared between districts provided a respondent may deliver more than one answer, and a specific weight was not given to responses during the data collection. It is expected that responses to the particular question may reveal unsafe conditions and their contribution to the vulnerability of farmers to natural hazards. The follow-up questions were varied based on the interviewees' responses and tailored according to the roles of respondents, whether as farmers, extension officers, or water managers. The primary investigator was the lead author and was present during whole data collection processes. The interviews were conducted in Bahasa Indonesia and further translated into English for publication purposes. The interviews were recorded to reduce information loss. Before the end of each interview, the responses were reviewed. The contents were also cross-checked with other stakeholders in other interview sessions to address ambiguous and unclear answers and to produce robust data. Table 2 shows the number of respondents interviewed at each district in the study area.

This study applies both purposive and random sampling methods. Extension officers were purposively selected, but other respondents, including farmers and water managers, were randomly selected. The extension officers were pest analysts (POPT-*Pengamat Organisme Pengganggu Tanaman*) and the head of agricultural branch offices at the sub-district level (KKCD–*Kepala Kantor Cabang Dinas*). These extension

Table 2
Overview of study participants. Table 2 corresponds to Fig. 2.

	Karawang	Subang	Bekasi	Indramayu	Total
Farmers	13	29	3	7	52
Water Managers	2	5	1	–	9
Extension officers	7	16	1	1	24
Total	22	50	5	8	85

officers directly interact with farmers, water managers, and village leaders on their daily routine. Huts where farmers usually gather were visited, and one of the farmers was asked as a representative for the interview. The interviews may be conducted on a one-on-one or as a group. In many occasions, the interviews are performed as a group. Usually, farmers appointed a person who is considered knowledgeable about the areas as their representative. Other farmers are free to join the discussion and to share their opinion during the interview process directly. The water management offices, including the sub-division level (SDPA–*Sub-Divisi Pengelolaan Air*), division level (*DPA*), and Ir. Djuanda reservoir, were also visited. Except for the DPA and Ir. Djuanda offices, the same procedures as those applied to farmers were conducted for gaining information from stakeholders at the sub-division level of the water management offices. It is worth mentioning that during the period of the study, the provincial disaster management office (BPBD–*Badan Penanggulangan Bencana Daerah*) was non-existent in the study area. The tasks of disaster risk reduction and management are delegated to governmental agencies, according to the responsibilities of the departments. For example, the damage assessment from flooding or water-deficit events in irrigated rice fields is executed under the duty of the ministry of agriculture, performed by extension officers. Furthermore, the present study also includes examples of locations and time-series EVI profiles for reasons of disruptions. Reasons for irregularities in cropping schedules and their approximate locations (e.g., villages or sub-districts) were obtained during interviews. Then, the locations were visited, specific reasons were confirmed with farmers living in the surrounding areas, and coordinates were noted.

2.3. Qualitative content and Bow-Tie analyses

This study used a conventional qualitative content analysis to scrutinize 85 responses from semi-structured in-depth interviews [9,13,46]. The text data were qualitatively evaluated using an inductive approach due to lack of established frameworks for guiding what factors should be included or excluded in the study area [24]. The analysis was started using a coding strategy. The coding strategy means to use certain labels to categorize the responses. The process involves two-step procedures, including open coding and selective coding. In the former, the texts are labeled into abstract groups, while in the latter, the labels are categorized into themes and used to summarize the data [14]. These categories represent reasons for disruptions in cropping schedules perceived by the stakeholders.

Next, a Bow-Tie analysis is used to visualize relationships from potential causes to consequences of disruptions in cropping schedules (Fig. 4). The Bow-Tie analysis is a risk evaluation method used for demonstrating causal and consequence relationships in risk scenarios [26]. The components of the Bow-Tie include hazards, causes, preventive barriers, top events, recovery barriers, consequences, escalation factors, and escalation factor barriers [19]. A hazard is an activity or process that potentially causes harm. Hazards are normal farming activities that can turn into a disaster if control over them is lost. Causes are possible reasons for a top event. For example, cropping schedules can be delayed because of a flooding event. Preventive barriers are measures that can be performed to stop causes escalating into a top event. A top event is a point in time when a control over a hazard is lost, for example when cropping schedules are disrupted. A top event indicates the analysis focus (e.g., disruptions in cropping schedules). A top event is a common ground to facilitate communication between researchers and stakeholders. During a top event, there is no damage involved, and recovery barriers can be performed to stop a top event turning into consequences. Consequences are undesirable events caused by a top event. Escalation factors are conditions that inhibit the effectiveness of barriers. Escalation factor barriers are measures that can be performed to manage escalation factors. It is worth mentioning that the present study does not particularly define thresholds for particular elements of the Bow-Tie analysis, such as when potential causes may manifest into a top event or preventive barriers are considered effective. The Bow-Tie analysis is generated from the interview results. Thus, the progression from potential causes, a top event, to consequences purely relies on the authors' interpretation of respondents' perceptions.

3. Results

3.1. Deviation of cropping schedules

Stakeholders, including farmers, extension officers, and water managers, reported that planting dates in the majority of irrigated rice fields deviate from the official cropping calendar during both wet and dry planting seasons:

> *… in reality, there are delays in planting dates, and most planting dates agglomerate in the periods of rice fields with classes III and IV.*

This finding was corroborated by the *t*-test result that found significant differences between the estimated and reference SOSs for each rice field class during wet and dry planting seasons, as shown in Table 3. Thus, the null hypothesis (H_0) was rejected. Furthermore, observing the column of mean differences of the *t*-test, it is apparent that the deviation of ongoing cropping schedules from the official cropping calendar in wet planting seasons is smaller than that of dry planting seasons for each rice class. The reason is partly related to lower access to irrigation water during dry planting seasons compared to that during wet planting seasons. Additionally, the delay in wet season planting dates may contribute to the delay in dry season planting dates. Table 3 also shows that the mean differences between the estimated and reference SOSs in rice field classes IV and V are higher than those in rice field classes I, II, and III. A plausible reason may be related to the

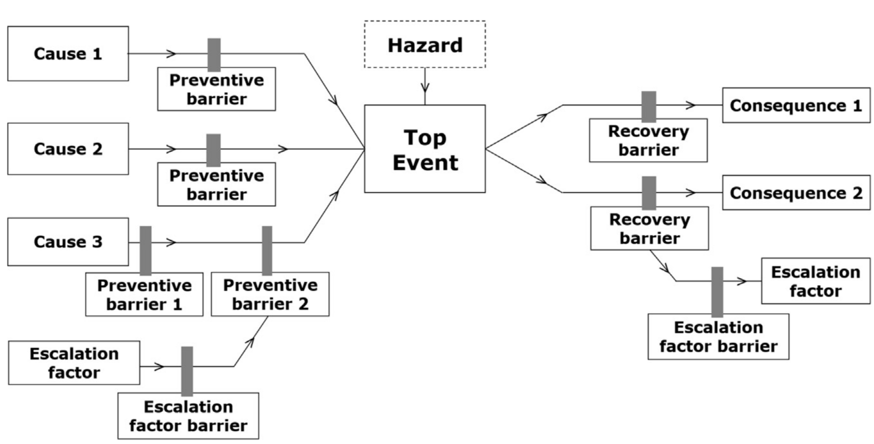

Fig. 4. Bow-Tie analysis diagram. Elements include hazards, causes, preventive barriers, top events, recovery barriers, consequences, escalation factors, and escalation factor barriers.

Table 3
Independent samples *t*-test between the estimated and reference SOSs.

Rice Field Class	Planting Season	*N*	*M* ± *SD* (DOY ± days)	*t*	*df*	Mean Difference (days)	
						DPS	WPS
I	DPS[a]	105	115 ± 25***	9.69	104	24	
	WPS[b]	105	319 ± 25***	5.84	104		14
II	DPS	105	134 ± 21***	13.52	104	28	
	WPS	105	332 ± 21***	6.16	104		12
III	DPS	120	154 ± 30***	12.01	119	33	
	WPS	120	353 ± 27***	7.25	119		18
IV	DPS	105	186 ± 25***	20.73	104	50	
	WPS	105	16 ± 27***	11.98	104		31
V	DPS	75	200 ± 24***	17.73	74	49	
	WPS	75	33 ± 28***	9.80	74		32

[a] DPS = Dry Planting Season.
[b] WPS = Wet Planting Season; *N* = number of samples; *M* ± *SD* = Mean ± 1 Standard Deviation; *t* = *t*-test; *df* = degree of freedom.
*** significant at $p < 0.001$.

accumulation of delays in planting dates from rice fields located closer to primary irrigation channels to rice fields located at the tail end of irrigation channels.

Fig. 5 shows the maps of deviations of long-term average (LTA) planting dates (2000–2015) from the official cropping calendar during wet and dry planting seasons. The planting dates in the majority of rice fields tend to deviate from the stipulated planting dates. Areas that deviate more than 15 days during wet and dry planting seasons are around 60% and 80%, respectively. The delay in planting dates tends to increase as rice fields located further from the primary irrigation channels. Furthermore, around 5.6% rice fields located at the tail end of irrigation channels cannot pursue rice cultivations during dry planting seasons. One of the reasons is likely related to lack of access to irrigation water during dry planting seasons.

Fig. 6 shows deviations (days) of long-term average (2000–2015) planting dates from the official cropping calendar at the sub-district level in four districts in the study area. The difference in deviations between wet and dry planting seasons varies per sub-district. Several sub-districts can perform wet planting seasons earlier than the stipulated schedules, such as Cibitung in Bekasi district or Pabuaran and Pagaden in Subang district. These sub-districts have high access to irrigation water, allowing farmers to adjust planting dates. Some sub-districts, for example in Indramayu district, show that delays during dry planting seasons are shorter than those of wet planting seasons. Farmers cope with difficulties in irrigation distribution during dry planting seasons by performing quick dry season planting dates, taking advantages of occasional rainfall that still occur at the end of wet seasons. Furthermore, it can be seen that the deviation in dry planting seasons is longer than that of wet planting seasons in the majority of sub-districts in each district. Delays in dry planting seasons are the highest in Muaragembong, Pedes, Pamanukan, and Sukra sub-districts for Bekasi, Karawang, Subang, and Indramayu districts, respectively. These sub-districts are located at the tail end of irrigation channels, having low access to irrigation water during dry planting seasons.

3.2. Reasons for disruptions in cropping schedules

Six categories emerge from the qualitative content analysis as reasons for disruptions in cropping schedules in the study area, including economic motives, weather variabilities, geographic locations, coping strategies, farmers' interactions, and agricultural infrastructures. These reasons are not watertight, but interrelated to some extent with others. It is worth mentioning that this study does not aim to take side to any group. Some reasons may benefit a particular farmer group and at the same time cause harmful effects to other rice fields. Instead, this paper reveals the progression how potential causes may turn into disruptions in cropping schedules and result in adverse events to provide information for reducing vulnerability in the study area.

3.2.1. Economic motives

As expected, economic motives are identified as one of the prominent reasons that influences disruptions in cropping schedules. Two forms of non-compliance associated with economic motives were identified, including the intentional delay in planting dates and the irregularities in cropping patterns. Farmers in both categories are likely to own rice fields with good access to irrigation water and are thus able to rely less on rainfall during wet and dry planting seasons. It seems that the abolition of regulation for the annual complete drying of irrigation channels in September provides time independence for farmers to tailor their cropping schedules.

The first category is farmers who deliberately delay their planting dates. It is found that some farmers in the rice field class I decide to delay land preparation and rice transplanting activities from October-November to November-December. Farmers and extension officers in Compreng and Binong sub-districts, Subang district, and Anjatan sub-district, Indramayu district (n = 5) mentioned that one of the reasons for delaying planting dates is to avoid difficulties of harvesting and post-harvesting activities during the peak of wet seasons in January and February (see Table 4A, Fig. 7A):

> *… farmers are afraid; if the harvesting period is in February, the (heavy) rain is still present. Farmers want to harvest in drier months to avoid the difficulties in harvesting and drying harvested yields. When rice yields are not of high quality (e.g., damaged by rainfall), the (market) price gets lower. Intermediaries also have more difficulties in visiting and taking rice paddies from rice fields; consequently, rice paddies will not be easy to sell;*

Farmers (n = 9) also deliberately adjust the period of harvesting in their rice fields so that it does not coincide with great harvest periods in other sub-districts. This strategy maximizes the selling price of harvested yields.

> *… if farmers follow the (official) cropping calendar of the PJT II, the price of rice yields is lower. If rice paddies are planted in January and harvested in April, the price is higher, because rice fields in Pagaden, Rancasari, Binong sub-districts have already been harvested.*

The second category is farmers who adopt irregular cropping patterns. Cropping schedules become inconsistent as farmers who have good access to irrigation water adopt intensive cropping patterns, including the alternating double- and triple-rice cropping cycle and the continuous triple-rice cropping cycle. For example, farmers in Pabuaran sub-district (rice field class I), Subang district continuously practice the triple-rice cropping cycle without fallow periods (n = 13). Farmers in Binong sub-district (rice field class I), Subang district who perform the alternating double- and triple-rice cropping cycle (n = 3) (see Table 4B, Fig. 7B) mentioned:

> *… farmers in this area (Binong) cultivate rice fields without a specific fallow period. There is no term for a delay from the official cropping calendar. We (farmers) count it per year. There used to be fallow periods after harvesting. Now, farmers choose to plant again after harvesting … in one year we harvest two times, and in two years we can harvest five times. It used to be four harvests in two years …*

It seems that the intensive cropping pattern is one of the strategies for profit maximization. This strategy may be related to the tenure of rice fields. Farmers reported that rice fields are commonly rented with an annual payment. Tenant farmers *(guntai)* thus make efforts to maximize profit from each planting season:

> *… farmers used not to rent their rice fields. Even though the area is more than ten bouw or bahu (± 70,000 m²), the owners themselves do or*

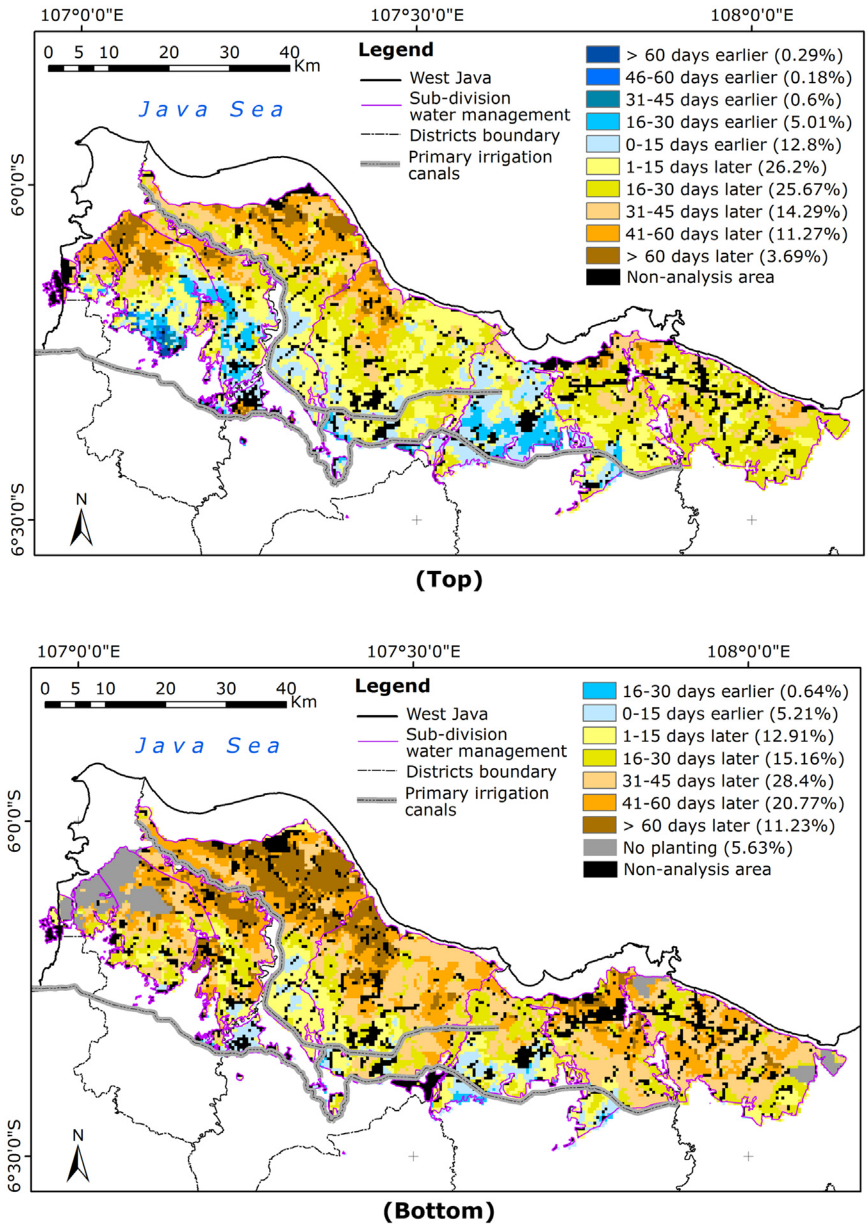

Fig. 5. Deviation (days) of long-term average (2000–2015) planting dates from the official cropping calendar in irrigated rice fields served by Ir. Djuanda reservoir during (top) wet and (bottom) dry planting seasons.

employ other farmers the entire cropping practices. Now, rice fields are mostly rented (guntai). The rent price per bahu is ± Rp. 15–22 million (± € 1000–1500) per year. The payment should be in cash because many people want to rent rice fields …

Furthermore, it is likely that the irregularity in cropping patterns, in part, causes massive water demand during dry planting seasons in irrigated rice fields located further down the irrigation system. Respondents (n = 51) reported insufficient irrigation water for cultivating rice fields during dry planting seasons. Rice field classes IV and V risk of suffering from water shortages the most as the start of dry planting seasons in these rice field classes is often shifted into the peak of dry seasons in July and August (see Table 4C, Fig. 7C). For example, some farmers who own rice fields belong to class V, such as in Bobos, Karangmulya, Patimban, and Rancadaka villages, Subang district, and Sukra and Patrol villages, Indramayu district, reported that they are unable to pursue dry planting seasons because of lack of access to irrigation water. The persistent irrigation water shortages during dry planting seasons in water-deficit prone rice fields may also be partly related to the 'urbanization' along irrigation networks. Respondents (n = 26) mentioned that the decrease in access to irrigation water might be related to the increase of water users. Previous studies have mentioned that population growth and urban development have influences on access to irrigation water [8,56]. One of the farmers mentioned:

…water deficits happen during dry months because water is used by upper rice fields and other users (southern regions). Only they who have access to water can cultivate rice fields during dry planting seasons.

3.2.2. Weather variabilities

Weather variabilities are intuitively one of the critical reasons that influences cropping schedules. Weather variabilities can be categorized into non-extreme and extreme events. The former refers to regular seasonal weather changes and the latter refers to events that likely result in flooding and water deficits in rice fields. Firstly, non-extreme weather events play a role in supporting land preparation. Farmers do

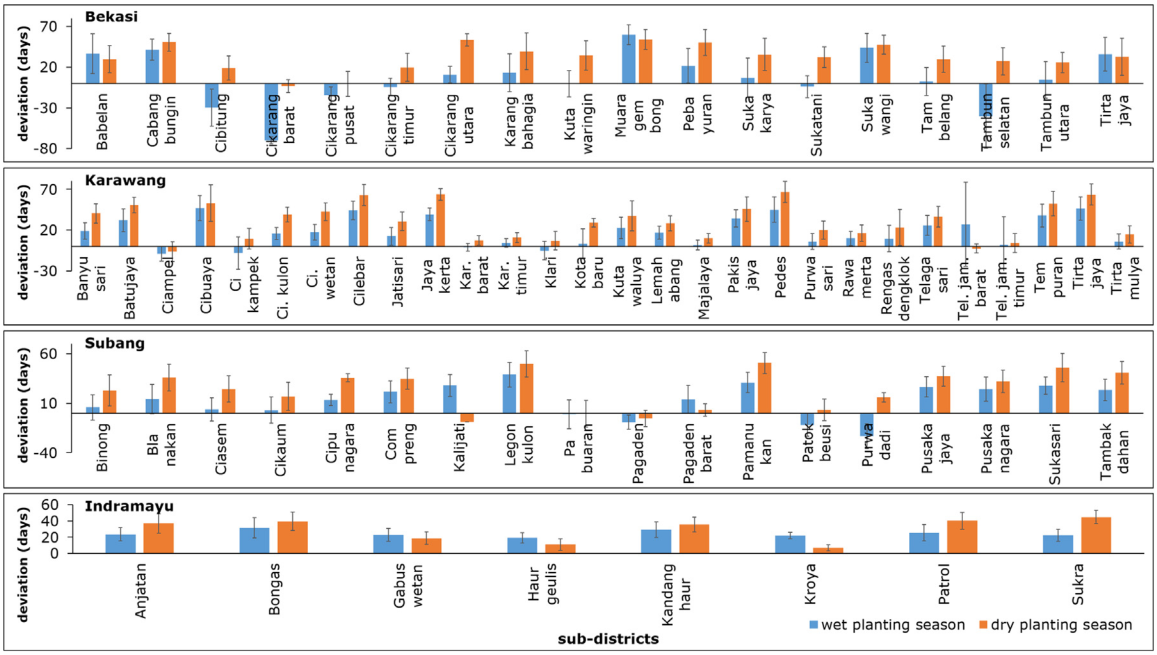

Fig. 6. Deviations (days) of long-term average planting dates (2000–2015) from the official cropping calendar in irrigated rice fields served by Ir. Djuanda reservoir in four rice-producing districts of West Java.

not start the tillage until irrigation water to sustain wet planting seasons is perceived sufficient. Farmers (n = 12) mentioned that a sufficient amount of rainfall is needed to complement irrigation water to support synchronous tillage or quick planting during wet planting seasons:

> *Water discharge from irrigation channels is small. To start wet planting seasons, farmers need a significant amount of water for tillage. After fallow, cracks in dry soil is wide. If irrigation water discharge is low, it might require one week to fill cracks in 1–2 Ha rice fields. If rainfall is present, tillage can be performed together and faster.*

The concerted planting is likely associated with strategies to reduce or spread the risk of crop damages resulting from rat, pest, disease, or bird attacks during growing periods. This finding is coherent with that of previous studies mentioning that farmers adjust planting dates to avoid crop damages from bird and rat attacks [10]. This finding also adds insights to the conclusion of Sawano et al. [53] who mentioned that the cropping calendar was well expressed as a function of cumulative precipitation from the onset of wet seasons. Additionally, extension officers mentioned that delays in planting dates might also be connected to the habit of farmers that exorbitantly pond rice fields with irrigation water before tillage and rice transplanting. This particular practice is partly related to the weed control mechanism [6,34].

Secondly, extreme weather variabilities, resulting in flooding and water-deficit events, cause severe impacts to rice fields [45,59]. During a strong La-Niña year, rice field areas affected by flooding are likely larger than those of non-extreme year. Higher river discharge during extreme weather years may cause dike failures in main rivers or their tributaries. For example, farmers reported that the dike of Cipunagara river failed in January 2014, and a flood event occurred in rice fields that were at the time of a fallow period (see Table 4C, Fig. 7C). According to farmers, the flood event in January 2014 was the most extreme since the 1980s. Farmers, water managers, and extension officers (n = 17) in Subang district reported:

> *Flooding often occurs in January and February. Usually, there is no flood in March; flood occurs only until the end of February. Flooding in 2014 was the worst;*
>
> *Flooding happened due to the dike breach in January 2014;*

Farmers mentioned that noticeable impacts of flooding and water-deficit events are economic damages and time losses [29,44,60]. Damages or losses can be discriminated into either direct or indirect effects. Direct economic damages are closely associated with growing stages of rice fields during disasters. The more mature rice plants affected by disaster events, the higher potential financial losses experienced by farmers. An example of indirect economic damages is related to the inability of farmers to pursue dry cropping seasons because of the insufficient growing time, lack of financial capital, or lack of economic feasibility. Farmers often need to expend additional costs for continuing rice cultivation after disruptions in cropping schedules. Furthermore, respondents (n = 67) agree that flooding events result in delays in wet planting seasons, and cause losses in available planting time. It is likely that the longer the duration of flooding events, the longer the delay in wet season planting dates, which subsequently results in late dry season planting dates, and partly contributes to the insufficient planting time for pursuing dry planting seasons. Interestingly, farmers in the rice field

Table 4
Examples of locations of and reasons for deviations in cropping schedules from the official cropping calendar in irrigated rice fields served by Ir. Djuanda reservoir in West Java. Table 4 corresponds to Figs. 2 and 7.

ID	Latitude	Longitude	Reasons	Likely reasons
A	−6.4125	107.8623	Delay in wet season planting dates	Economic motives
B	−6.4000	107.6123	Alternating double- and triple-cropped irrigated rice fields	Economic motives
C	−6.2458	107.8401	(a) Delay in wet season planting dates because of severe flooding events. (b) Planting failure due to lack access to irrigation water during dry planting seasons.	Coping strategy, Weather variability, Geographic location, Agriculture infrastructure
D	−6.2458	107.4461	Change of control from the central government on cropping schedules	Farmers' interaction

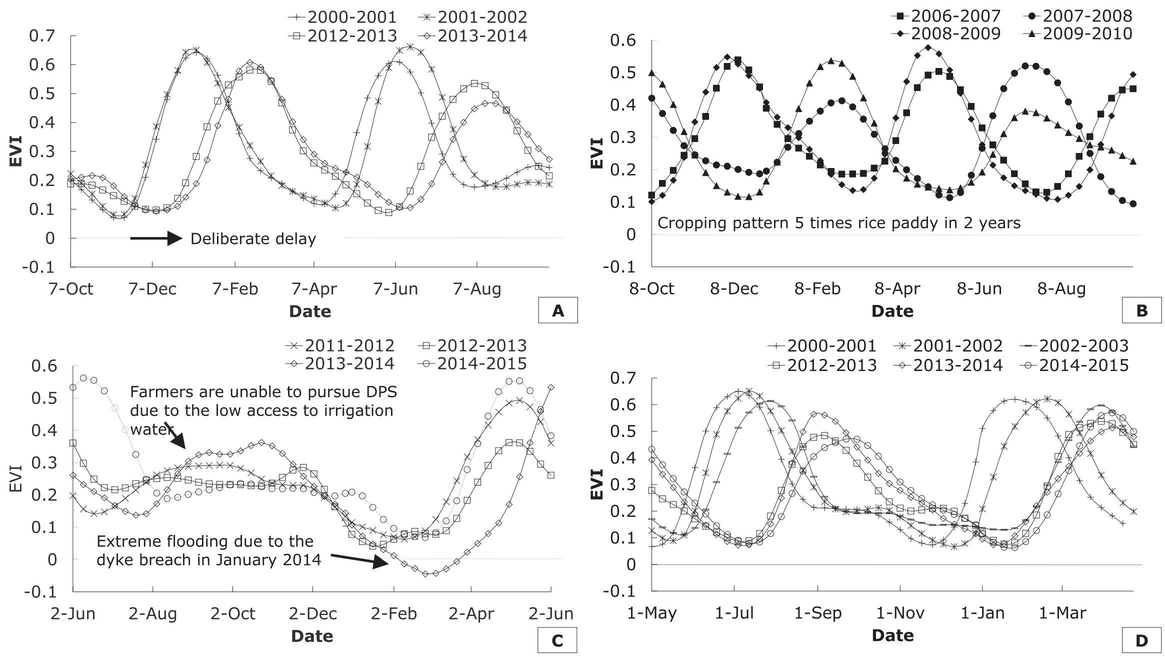

Fig. 7. Examples of reasons for disruptions in cropping schedules derived from the time-series Enhanced Vegetation Index (EVI) dataset (average 5 × 5 pixels). (A) Delay in planting dates until the middle of December (e.g. 2012/13) to avoid harvesting difficulties during wet seasons; (B) Alternating double- (e.g. 2006/07) and triple- (e.g., 2009/10) rice cropping cycle; (C) Farmers resort to delaying wet season planting dates due to flooding events; (D) Shift in cropping schedules due to a change in government control on farming practices since the wet planting season in 2003. Start of Season is when the EVI value is 0.1 during a growing phase. Reasons and locations were obtained through in-depth interviews. Fig. 7 corresponds to Fig. 2 and Table 4.

class V mentioned that smaller flooding events tend to cause a greater asynchronous planting date compared to that of larger flood events. This pattern is plausible because a large number of farmers simultaneously cannot practice rice cultivation when rice fields are affected by an extensive flood event:

> *… after small flooding events, the similarity in planting dates among rice fields is lesser. However, after a large flood event, the similarity in planting dates are greater.*

Another example of indirect losses is related to social unrest. Water competitions frequently arise when rice fields located in different classes need a massive amount of water at the same time during dry planting seasons. The competition frequently happens among farmers who own rice fields in the same irrigation channels. However, it seems that the water competition is fiercer among farmers with different rice field classes or sub-districts.

3.2.3. Geographic locations

Geographic locations emerge as one of the issues that potentially disrupts cropping schedules. This factor is associated with the spatial characteristics of rice fields and access to irrigation water. Respondents (n = 15) mentioned that the rice agroecosystem in the study area could be distinguished into two categories: normal *(sawah darat)* and swampland (deep and semi-deep) rice fields *(sawah lebak)*. *Sawah darat* has good access to irrigation water during both wet and dry planting seasons compared to that of *sawah lebak*. Swampland rice fields mostly are located near coastal areas, at relatively low elevation, far from primary irrigation channels, have poor drainage and irrigation infrastructures, and scheduled last to receive irrigation water. Swampland rice fields are often, but not always, associated with the rice field class V. These characteristics, partly, make these rice fields prone to flooding and water-deficit events during wet and dry planting seasons, respectively. Surface runoff accumulates in low-lying rice fields and is frequently difficult to drain during wet planting seasons partly because of inadequate drainage systems. Respondents (n = 21) described that farmers resort to exercising late wet season planting dates, waiting accumulated water to subside or evaporate:

> *… when farmers plant in December or January, seedling beds are often destroyed by flooding. Thus, the planting time is usually delayed until the end of February.*

Interestingly, the perception of farmers about access to irrigation water seems to influence planting dates. Frequently suffered from water-deficit events during dry planting seasons, farmers decide to neglect or completely abandon the cropping calendar. For example, farmers in Babelan sub-district, Bekasi cultivate rice fields based on water availability either from irrigation or river channels, especially during dry planting seasons. An extension officer of Babelan mentioned that the irrigation water schedule is irregular, and farmers completely do not follow the cropping calendar:

> *Farmers in Babelan cultivate rice fields according to water availability; farmers do not follow the cropping calendar… Planting dates depend on water availability … Farmers in Pantai Hurip, Hurip Jaya, and Muara Bakti villages plant whenever water is available and not saline … irrigation water for Bekasi is inadequate …*

3.2.4. Coping strategies

Coping strategies emerge as a reason that potentially disrupts cropping schedules. Coping strategies are the ability of farmers to face and manage adverse conditions that afflict their farming practices [64]. Coping strategies are connected with the weather variability factor. Table 5 lists coping strategies employed by farmers to reduce potential impacts of flooding and water-deficit events in irrigated rice fields during wet and dry planting seasons, respectively. It is worth mentioning that the list is not exhaustive and only includes coping strategies that directly affect planting dates. In reality, farmers exercise a broad range of coping strategies at the household or community level to reduce potential impacts of disaster events on their livelihoods. For example, farmers may work as farm labors in other villages, migrate temporarily to bigger cities (e.g., Jakarta) and work in non-farming sectors, or ask more remittances from relatives abroad.

Table 5
Example of coping strategies to flood and water-deficit events that influence cropping schedules.

Flooding (wet planting season)	Water deficit (dry planting season)
- Collective decision to pursue normal planting and face the risk of being affected by flood events (n = 4) - Delaying wet season planting dates (n =16) - Having a longer vegetative phase in seedling beds, approximately 30–40 days (n = 4) - Making seedling beds in a higher elevation fields (n = 5) - Pumping water out from flooded rice fields (n = 15) - Strengthening river dikes with soils, sand sacks, and bamboo (n = 14) - Fixing the dike failures and rice field embankments (n = 13) - Seed re-sowing and rice plants re-transplanting (n = 22) - Looking for wild rice plants or buying extra rice plants for re-planting (n = 12) - Planting earlier than normal cropping schedules (n = 5)	- Starting early dry planting seasons to take advantage of water availability and remaining soil moisture (n = 6) - Pursuing normal planting and face the risk of being affected by water-deficit events (n = 4) - Pumping water from river or irrigation channels (n = 31) - Exercising *giring gilir* (overseeing the water flow until it reaches the designated rice fields) (n = 7) - Damming a river or diverting and reusing irrigation water from upper stream rice fields (n = 5) - Seeking assistance from local government, asking for aids (n = 7) - Not pursuing dry planting season[a] (n = 4)

[a] farmers may decide not to pursue dry planting season if available planting time and resources are perceived inadequate, or estimated cost for continuing rice cultivation will surpass the acceptable potential income.

It seems that the decision for pursuing particular measures to reduce disaster impacts on rice cultivation result from the perception of farmers about natural hazards and availability of resources. For example, farmers in Kebondanas, Subang district use hydro pumps to obtain water directly from irrigation channels or rivers as a reaction to water-deficit events during dry planting seasons. The possible measures may also be inspired by individual experiences or discussions among stakeholders *(musyawarah)*. The collective stakeholders' actions seem to enhance the outcomes of the selected strategies. For instance, farmers in Pangarengan village, Subang district may dam a river or divert used irrigation water to water-deficit rice fields. Depending on water availability, stakeholders (e.g., water managers, extension officers, and farmers) may tailor water distribution and strictly employ continuous supervisions until irrigation water reaches the designated rice fields to cope with emergency situations during dry planting seasons *(giring gilir)*.

It is worth noting that farmers may not be able to perform any corrective strategies if natural hazard impacts surpass the coping capacity of farmers. For example, farmers could not perform any coping strategies to initiate rice cultivation according to regular cropping schedules during the dike failure event in Pamanukan sub-district, Subang district in January 2014:

> *In January 2014, it was impossible for farmers to do any measures due to extreme flooding;*
>
> *Planting dates were delayed in flooded rice fields. Farmers can only wait for flooding to subside…*

3.2.5. Farmers' interactions

Farmers' interactions are also found to play a role in determining cropping schedules. In this context, farmers' interactions refer to daily interplay between farmers and rice agricultural stakeholders that potentially influences cropping schedules. The scope of the interactions can range from the local to national level, both formally and informally. Items that belong to farmers' interactions include stakeholders' meetings, community events, perceptions of risk of rat attacks, local belief systems, and government controls.

Stakeholder meetings or community events may influence rice planting dates. Respondents (n = 10) mentioned that stakeholders in every sub-districts conduct a two-weekly meeting *(rapat minggon)* to exchange ideas or discuss issues related to farming conditions in their respective sub-districts. The participants consist of, but not limited to, village officers, water managers, farmer group representatives, and extension officers. The issues conversed may comprise the cultivation planning, coping strategies to flooding and water deficit events, or condition of agricultural infrastructures. Community events such as Islamic holidays or the election of village leader may also influence planting dates (n = 4).

The perception of the risk of rat attacks among farmers influences planting dates during wet and dry planting seasons. Respondents (n = 11) explained that both smallholder and large holder farmers are aware of the threat of rat attacks (e.g., *Rattus argentiventer*) that potentially damage their rice cultivation. The problem of rat attacks in West Java has been discussed in previous studies [31,35,62]. It is found that smallholder and large holder farmers are reluctant to initiate rice cultivation because of the risk of being damaged by rat attacks, and tend to wait until other farmers start cropping seasons. Smallholder farmers mentioned that they prefer to wait for synchronous planting to minimize the risk of being attacked by rats, pests, or diseases during growing periods:

> *… there was a commando for rice cultivation, now the influence of farmer groups or extension officers on farmers' decisions is weaker. Farmers tend to work individually for self-profit. In fact, farmers seem to wish rats, pests, or diseases afflict rice plants of other farmers who planted first. If the latter is not attacked by rats, pests, or diseases, then the former will follow to cultivate rice fields. If the contrary occurs, then farmers wait a little while for cultivating rice fields.*

In this regard, 'local champions' (e.g., respected leaders or large holder farmers) play a role in determining planting dates. It is found that social cohesion, directed by local leaders, among smallholder farmers tend to play a major role in guiding cropping schedules in some villages; while in other villages large holder farmers are the one who tends to navigate planting dates. This finding is coherent with that of previous studies mentioning the influence of social capital [2] and key persons in directing the community efforts to cope with disaster impacts [39].

Also, the local belief system is found to influence cropping schedules. This finding is not surprising as local beliefs or local wisdom is prevalent and exercised as guidelines for managing rice cultivation in many rice-producing regions in Southeast Asia [38]. Respondents (n = 14) described that farmers in several villages (e.g., Compreng sub-district) choose not to perform rice transplanting in the first three weeks of May *(kemeian)*. The farmers believe that the growth of rice plants will not be optimal if planting dates are set within the period. A polarized belief was identified in the study area about *kemeian:*

> *… Farmers in this area (Blanakan sub-district) believe in kemeian. Farmers do not make seedling beds until the middle of May. Much crop diseases emerge in May, causing rice plants in seedling beds stay small…;*
>
> *… farmers in swampland rice fields affected by flooding (also Blanakan sub-district) do not follow kemeian;*
>
> *… farmers in Legonkulon sub-district do not agree with kemeian …*

Furthermore, cropping schedules may also be influenced by the change in the rice agricultural control from the central government (n = 14). Before 1998 (new order era), the rice agricultural system was strictly regulated by a top-down approach [41]. Farming practices and inputs, such as planting dates or crop varieties, were tightly controlled by the central government. After 2000 (regional autonomy era), the strict regulation of farming practices from the central government loosened. It seems that farmers perceive that they gain greater independence in managing their farming practices. One of the respondents mentioned that the years from 1998 to 2001 marked the change in cropping schedules. However, analyzing the time-series remotely-sensed data in Telagasari village, Karawang district, it is found that the shift of planting dates was started in the wet planting season in 2003 (see Table 4D, Fig. 7D). It seems that this opportunity was also used by farmers to adjust planting and harvesting dates to more favorable conditions. On the other side, nonetheless, farmers in the rice field class V frequently associate the change of government control as one of the reasons for the water shortage events during dry planting seasons:

> *… during the new order era, flood duration in swampland rice fields (sawah lebak) might reach two months; however, farmers could still plant during the two planting seasons. Irrigation water was available during dry planting seasons, but now irrigation water does not reach this area (rice field class V).*

3.2.6. Agricultural infrastructures

It is found that agricultural infrastructures potentially influence cropping schedules. Agricultural infrastructures encompass physical resources for supporting rice cultivation, including the conditions of irrigation, drainage networks and river channels, rice varieties, and farming labors, among others.

Respondents (n = 28) mentioned that many drainage and river channels located close to coastal areas suffer from narrowing and shallowing. The sediment transported from upper stream areas may have a role in the narrowing and shallowing processes of drainage or river channels. Farmers and extension officers also mentioned that the disappearance of irrigation, river, and drainage channels is partly due to the conversion of these networks into rice fields, fish ponds, or settlements. The deteriorating conditions of irrigation and drainage networks partly contribute to disruptions in irrigation water distribution, leading to irregularities in planting dates. Also, poorly maintained drainage and river channels may prolong flood depth and duration in rice fields, causing a longer delay in wet season planting dates. Respondents (n = 53) frequently reported spilled water due to the inadequate capacity of irrigation channels to convey irrigation water to rice fields:

> *… water shortages happen in Tanjung Tiga village (Blanakan sub-district, Subang district) … the capacity of irrigation channels is not adequate for water flow, the embankment of irrigation channels is low, drainage channels are shallow and narrow …water spills along the channels. Irrigation water cannot reach the designated rice fields.*

Furthermore, rice varieties also influence cropping schedules (n = 13). Large holder and tenant farmers prefer to plant rice varieties with longer growing duration (135–150 days), such as *Oriyza sativa Glutinosa (beras ketan)*, while smallholder farmers prefer to plant shorter growing duration rice varieties (115–125 days), such as *Oryza sativa Poaceae* (*Ciherang*). Rice plants harvested by the former is mainly for sale while crop yields produced by the latter is aimed for self-consumption. Farmers who prefer rice paddies with longer growth periods tend to practice early transplanting to ensure synchronous harvesting with those planting shorter growth period rice varieties. It seems that the selection of rice varieties is also, in part, influenced by the rice field tenure and market price. One of the farmers mentioned that the market price of longer growth duration rice varieties is higher than that of shorter growth duration rice varieties:

> *… the cost of renting rice fields is expensive and is mostly based on the market price of beras ketan (Oriyza sativa Glutinosa). So, farmers who rent rice fields prefer to plant the beras ketan variety …*

Farmers (n = 3) mentioned that the availability of labor farmers influence cropping schedules. A shortage of labor farmers for rice transplanting frequently occurs because of the concurrence between great harvesting and transplanting periods. Labor farmers prefer harvesting to transplanting jobs because of the higher income of the former than the latter. Furthermore, it is found that farmers commonly make an informal contract with labor farmers (mediated by middleman) to secure workers for tillage, transplanting and harvesting activities. However, it seems that the ‘ownership’ of specific working areas by labor farmers may increase the risk of delays in planting dates. A tillage labor may perform land preparation activities for a vast area of rice fields. Additionally, farmers often must adjust the tillage and transplanting dates to the tight schedule of labor farmers. Studies mentioned that the problem of labor shortages in rural areas are associated with the increase of off-farm employment and improvement of rural transports to urban areas, enabling the annual or monthly basis migration [20].

3.3. Bow Tie analysis

Fig. 8 shows the result of the Bow-Tie analysis with the disruption in cropping schedules as the top event. The content of the Bow-Tie analysis were obtained from the in-depth interview and qualitative content analysis. The Bow-Tie analysis connects and visualizes the relationship between potential causes and consequences of the top event. The potential causes are reasons for disruptions in cropping schedules, comprising economic motives, weather variabilities, geographic locations, farmers’ interactions, and coping strategies. Coping strategies, efforts to reduce damages and losses, appear as one of the potential causes for disruptions in cropping schedules. Some farmers may wait for flooding to subside and report the event to the local government, while other farmers with access to resources may drain water from their submerged rice fields using hydro pumps. The consequences are potential impacts if the disruption in cropping schedules materializes into disaster events, including harvest failures, yield quality and quantity reductions, and livelihood disruptions, among others.

The Bow-Tie analysis provides foundation for identifying potential prevention or corrective barriers to reduce potential disaster impacts in irrigated rice fields. For example, as a preventive barrier, investment in the rehabilitation of river or irrigation channels may minimize the spillover and loss of water during irrigation distribution, reducing the risk of cropping schedule disruptions. Furthermore, Fig. 8 adds an element of intermediate events to the Bow-Tie analysis. This study particularly interested in the loss of control over the implementation of cropping schedules. The loss of control over other activities that are connected to the top event, such as farming labor availability or irrigation infrastructure conditions, is termed as intermediate events. These intermediate events may result from the ineffective implementation of preventive or corrective barriers, which may lead to the top event and consequences. It is worth noticing that Fig. 8 does not include the escalation factor and escalation factor barrier. The inclusion of these categories may obscure the aim of the Bow-Tie analysis, which is to understand the progression from potential causes, top event, to consequences and the identification of unsafe conditions. As an example, an individual smallholder farmer may not able to afford the cost of pumping water from the closest river to rice fields (escalation factor); however, cost sharing among smallholder farmers may enable such an attempt and reduce the risk of crop damages (escalation factor barrier).

The Bow-Tie analysis exposes several insights that need to be considered to reduce potential damages from adverse events in irrigated rice fields. Firstly, multiple potential causes exist, and they may manifest in a single or multiple consequences. This finding suggests that

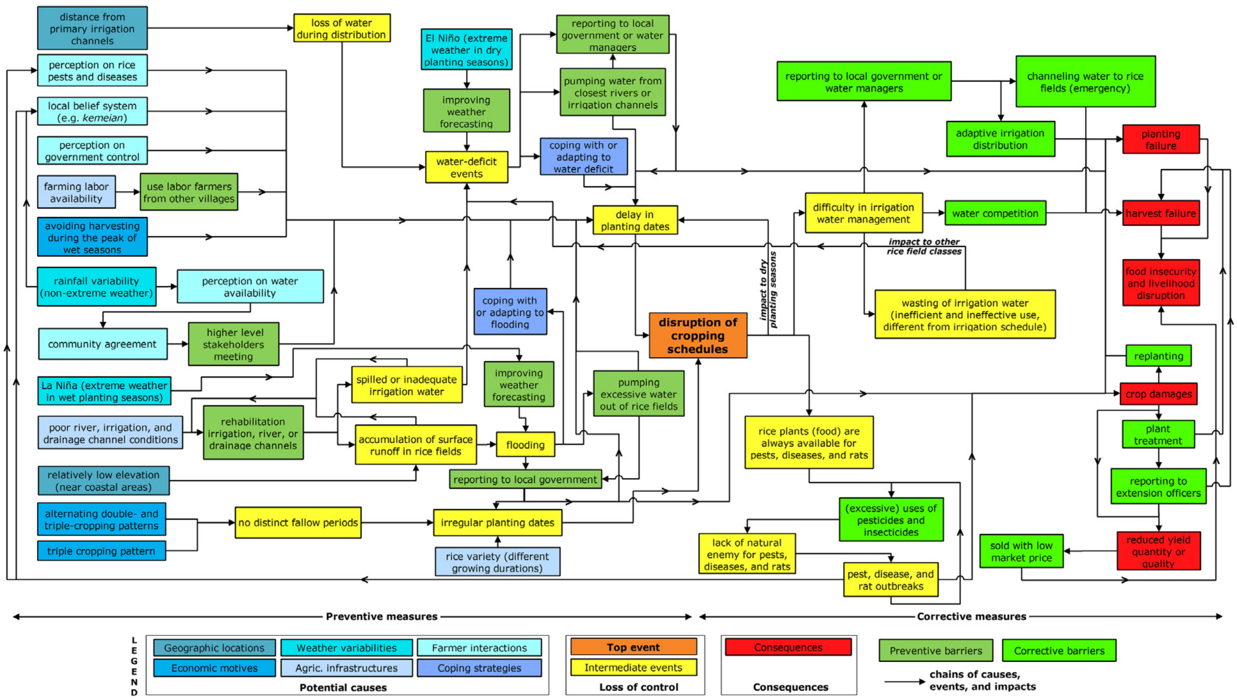

Fig. 8. Bow-Tie analysis of reasons for disruptions in cropping schedules in irrigated rice fields served by Ir. Djuanda reservoir in West Java. Reasons comprise economic motives, weather variabilities, geographic locations, coping strategies, farmers' interactions, and agricultural infrastructures.

partial intervention on potential causes of disruption in cropping schedules may not directly result in a decrease in potential damages. However, comprehensive and continuous efforts to interrupt the progression from potential causes to the top event are likely reduce vulnerability. Additionally, the progression indicates that potential causes may generate intermediate events before the actual top event occurs and materializes into consequences. This finding implies that stakeholders have opportunities to mobilize resources to perform preventive or corrective barriers before potential causes turn into disaster impacts. This result also advocates that lack of capacity to perform preventive and corrective barriers from rice stakeholders may exacerbate potential disaster impacts. For example, flooding accumulating in low-lying rice fields may be prolonged because of poor drainage channel conditions and lack of access to hydro pumps to drain ponding water.

Secondly, the mismanagement of farming practices in rice fields may influence the outcomes of other rice fields. In other words, vulnerability may increase because of the irregularity in cropping schedules performed by other farmers. For example, intensive triple-rice cropping cycle or irregular planting dates may generate habitat and food for rice pest and disease reproduction, jeopardizing rice cultivation in the next season or other rice areas. Another example is that farming groups may adjust their planting dates for benefits of their groups, which inevitably create water-deficit problems in other rice field classes located at the tail end of irrigation channels. Finally, the Bow-Tie analysis exposes incorrect procedures performed to address unsafe conditions in irrigated rice fields. For example, farmers use chemical pesticides or insecticides to eradicate threats of rice pest and diseases. This negative coping strategy may result in pest outbreaks due to lack of natural enemies of rice pest and diseases. Later, farmers tend to use pesticides with higher chemical substance to suppress the increasing threats of rice pests and diseases, repeating the same loop of negative coping mechanisms.

Furthermore, the elements of the Bow-Tie analysis are categorized into natural hazards, vulnerability, and disaster impacts, as shown in Table 6. The Bow-Ties analysis demonstrates that the interaction between natural hazards and vulnerability potentially materializes in a range of disaster impacts. Unsafe conditions that contribute to the increase of vulnerability of farmers to natural hazards in the study area have also been exposed. Unsafe conditions take tangible and intangible forms and may occur from the farm to national level, comprising dangerous locations, unsustainable farming activities, unsuitable coping strategies, fragile infrastructures, and inaccurate perceptions. The result clarifies the multi-dimension and multi-level nature of vulnerability [1]. Water managers, extension officers, or risk reduction officers are likely able to reduce the vulnerability of farmers to natural hazards in the study area by addressing the unsafe conditions.

3.4. Reducing vulnerability of farmers to natural hazards

This study has demonstrated that unsafe conditions play an essential role in increasing the vulnerability of farmers to natural hazards. Since reducing vulnerability may also contribute to the decrease of the risk of natural hazards, addressing unsafe conditions is one of the means to reduce potential disaster impacts in irrigated rice fields. The following recommends ways to reduce the vulnerability of farmers to natural hazards by specifically addressing unsafe conditions in irrigated rice fields.

Addressing unsafe conditions related to economic motives can reduce the vulnerability and increasing resilience of farmers to natural hazards. Farmers with good access to irrigation water realistically attempt to improve their livelihoods by adopting an intensive rice cropping pattern. In this respect, local government officers should improve awareness that farmers, including those who are poor and vulnerable, can progress their economic conditions through livelihood diversification, which is also likely to increase the resilience of farmers to unexpected disaster impacts [58,66]. Also, extension officers should encourage farmers to focus on sustainable rice production that does not neglect the ecological aspect, social cohesion, or compromise the ability of other farmers for cultivating rice fields [16,25]. For example, instead of focusing solely on intensive rice monoculture, farmers are encouraged to adopt balanced cropping practices. One of the forms of balanced cropping practices is the adoption of a double-rice cropping cycle with fallow periods in between planting seasons. Farmers may optimize the use of rice fields for planting cash crops (e.g., onions,

Table 6
Hazard, vulnerability (unsafe conditions), and disaster impacts in irrigated rice fields served by Ir. Djuanda (Jatiluhur) reservoir in West Java.

Hazard	Vulnerability	Disaster Impacts

- Non-extreme weather variabilities
 	
- Extreme weather variabilities
  - La-Niña, resulting in flooding events
  - El-Niño, resulting in water-deficit events
- Hazards of biological origin (e.g., rats, brown planthoppers, and birds)
	Unsafe conditions
	
	Dangerous locations:
	- Relatively low elevation compared to neighboring rice fields
	- Near coastal areas
	Unsustainable farming activities:
	- Alternating double- and triple-rice cropping cycles
	- Triple-cropping cycle
	Unsuitable coping strategies:
	- Pumping water directly from main irrigation channels
	- Water competition
	- Excessive uses of chemical pesticides
	Fragile infrastructures:
	- Inadequate and deteriorating conditions of irrigation, river, and drainage channels
	- Lack of labor farmers
	Inaccurate perception on:
	- Rats, pests, or diseases
	- Government control of agriculture system
	- Local belief system
		- Crop damages resulting in yield quality and quantity reductions
		- Planting failures
		- Harvest failures
		- Livelihood disruptions and food insecurity

tomatoes, long beans) or adopting a rice-fish system. Studies have demonstrated that balanced cropping practices provide long-term benefits through ecosystem services to rice farmers in terms of pest control, nutrient cycling, and rice-fish culture, compared to intensive cropping practices (triple-rice cropping cycle) [61]. An intensive cropping practice adds one more planting season; however, it has evidently deteriorated environmental conditions surrounding rice fields and does not contribute to economic improvements of farmers [61].

Addressing unsafe conditions associated with fragile infrastructures may improve the productivity of irrigated rice fields. For example, efforts to improve poor infrastructure conditions can secure water availability and reduce the risk of crop damages from flooding and water-deficit events during wet and dry planting seasons, respectively. Previous studies have provided evidence that improvements in irrigation performance by enhancing land and water productivity are useful for alleviating poverty in rural areas [33,43]. Such efforts may be performed using a range of structural measures, namely the construction of reservoirs or rehabilitation of irrigation channels, among others.

Furthermore, farmers often cope with disaster impacts using their limited resources. However, it seems that strategies focusing on building the resilience and reducing the vulnerability of farmers to natural hazards are likely to be more effective for decreasing potential damages and losses in the long-term [22]. These efforts can also be performed using a range of non-structural measures, such as awareness programs on adverse impacts of unsuitable coping strategies, training and education on best farming practices, or livelihood diversification. Also, the adoption of insurance mechanisms can be useful for transferring the remaining risk of natural hazards [50].

The present study finds that farmers' interactions may contribute to unsafe conditions and lead to disruptions in cropping schedules. The coordination among stakeholders may be beneficial for addressing constraints limiting rice production and succeeding the implementation of stipulated cropping schedules for the common good. However, evidence shows that disruptions in official cropping schedules can be partly attributed to decisions of farmer groups, indicating the downside of social capital. In this respect, farmers are recognized as members of an extensive irrigation system regulated by an official cropping calendar. It seems that social capital is used as a tool to achieve objectives of a particular group while compromising the right of other farmers to have equal opportunities to irrigation water at the broader irrigation system level [48]. Extension officers, together with local government officers, should design strategies to increase the awareness of farmers of the benefits of a regulated irrigation distribution and cropping calendar. Additionally, instead of leaving the system to work under a free market system, it seems that policy interventions are required for untangling disruptions in cropping schedules. Further studies to stimulate the compliance of farmers to the official cropping calendar are suggested.

Finally, this study emphasizes that addressing unsafe conditions requires creativity that goes beyond on-the-farm and community decisions. Reducing vulnerability requires local stakeholders to continuously collaborate with external stakeholders. For example, information about the probability of El Niño–Southern Oscillation (ENSO) provided by the national meteorological office (BMKG–Badan Meteorologi dan Geofisika) is indispensable for supporting farmers in designing well-informed cropping plans. Given the importance of weather and farming information, the national government officials should focus on supporting access to such data, for example, by improving tools and methods for obtaining and sharing updated critical information among stakeholders. Also, extension officers or water managers may need to proactively learn from rice farming and water management practices that have been proven to be successful in other rice-producing regions. The officers need to be connected with research institutes, such as the International Rice Research Institute (IRRI), to obtain updated information on challenges in rice farming. At the same time, studies for improving flood- and drought-tolerant rice varieties and devising environmentally-friendly cropping practices must be continuously encouraged [28,52,69]. Furthermore, the availability of farming information should be supported by the ability of farmers in quantifying changes (e.g., rainfall, rice disease symptoms) and interpreting available data [27,67,71]. For example, farmers can be trained to collect and interpret rainfall data through Farmer Field Schools (FFS).

4. Discussion and conclusion

This paper has successfully investigated disruptions in cropping schedules in irrigated rice fields served by Ir. Djuanda (Jatiluhur) reservoir in West Java using different analysis tools to improve understanding of the vulnerability of farmers to natural hazards. Firstly, using the time-series remotely-sensed dataset, the present study has revealed that ongoing cropping schedules are significantly different from the cropping calendar stipulated by the provincial government of West Java and PJT II during wet and dry planting seasons. In the same vein, Sianturi et al [55] has successfully mapped cropping patterns in northern districts of West Java and found that for the last fourteen years (2000–2014), wet and dry season planting dates in the study area may range from the first week of November to the third week of March and from the end of March to the second week of August, respectively. Thus, there have been more than five classes of planting dates performed by farmers in the last decade (see Table 1). The finding may also indicate that different references for planting dates exist among rice farmers. Both farmers who use the official calendar as their reference for planting dates and farmers who perform planting dates according to their habits and perceptions of socioeconomic and environmental conditions are common in the study area. On the one hand, farming practices and the efficiency in irrigation water uses need to be improved so that farmers can adapt to changing conditions and improve rice productivity. On the other hand, these results raise a question whether the official cropping calendar and irrigation distribution schedules need to be adjusted to suit changing environmental and socio-economic settings. Secondly, using responses from farmers, extension officers, and water managers, the present study has shown that disruptions in cropping schedules can be attributed to several reasons, including economic motives, weather variabilities, geographic locations, coping strategies, farmers' interactions, and agricultural infrastructures. Thirdly, this study has demonstrated using the Bow-Tie analysis that vulnerability can be partly traced back to daily farming activities and socioeconomic and environmental processes. Finally, the present study has pinpointed tangible and intangible unsafe conditions that are likely to increase the vulnerability of farmers to natural hazards, including dangerous locations, unsustainable farming activities, unsuitable coping strategies, fragile infrastructures, and inaccurate perceptions. Results from this study can be used as inputs by extension officers, water managers, and disaster risk reduction officers for designing pathways for reducing the vulnerability of farmers to natural hazards. Also, it is worth mentioning that findings from this study can be used by disciplines related to rural and agricultural development in less developed and developing countries. For example, vulnerability to natural hazards is closely related to vulnerability to poverty. In fact, poverty is one of the consequences and drivers of disaster events [63]. Disaster events may cause loss of lives, assets, and livelihoods, increasing the vulnerability of affected people to poverty. Poor people may resort to live in dangerous locations due to their inability to afford safe and legal living space, increasing their vulnerability to natural hazards. In this respect, efforts to address unsafe conditions are likely beneficial for confronting both issues to secure lives and livelihoods of the poor and the vulnerable [63].

The present study is not without limitations. Firstly, this research used the Start of Season (SOS) as the indicator to investigate disruptions in cropping schedules. The SOS is relatively easy to recognize in the time-series profiles of EVI and precedes other phenology metrics during growing seasons. Other phenology metrics, such as the heading stage or end of season, exist and may be useful as indicators to understand disruptions in cropping schedules. Secondly, reasons for disruptions in cropping schedules and accompanying time-series EVI profiles were obtained through in-depth interviews and field visits. At the same time, the use of the Bow-Tie analysis requires investigators to carefully choose a top event that serves as a common ground and allows discussions among stakeholders. These procedures are labor intensive and time-consuming. Investigators may need to spend time staying in the study location (e.g., one cropping season), observe applied farming practices, and visit same areas several times to clarify respondents' statements. Thirdly, this research primarily utilized the responses of farmers, water managers, and extension officers for understanding unsafe conditions and suggesting ways for reducing the vulnerability of farmers to natural hazards. It is possible that other latent factors that are not revealed by this study exist considering the intricate, multifaceted, and multi-dimensional nature of vulnerability. Thus, findings from this study should be regarded as exploratory, a guide, and a background for further in-depth studies. Despite the limitations, the present study has provided information for water managers, disaster risk reduction officers, and extension officers for devising strategies and policies for regulating cropping schedules, reducing the vulnerability to natural hazards, and building resilient rice agriculture. Further studies are recommended. Studies that probe unsafe conditions in irrigated rice fields should also incorporate the perspectives of other stakeholders, such as academics or business people. Additionally, quantitative studies to monitor changes in the vulnerability of farmers to natural hazards are suggested.

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Author Contributions

Riswan Sianturi processed the data and wrote the paper. V.G. Jetten contributed important considerations, discussions and research ideas.

Conflicts of Interest

The authors declare no conflict of interest.

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