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Smallholder Farm Households' Vulnerability and Adaptation to Climate-induced Food Insecurity

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Authors' contributions

This work was carried out in collaboration between all authors. Author AC designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Smallholder farm households seem to have no alternative in addressing climate-induced food insecurity, but to adapt their livelihood systems to the changing climate condition.

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The study aimed to explore the link between climate-induced rice-insufficiency and vulnerability level of smallholder farm households, which determined their household-level adaptation responses, in Sumedang District, West Java Province, Indonesia. The Climate Change Impact, Adaptation, and Vulnerability (CCIAV) approach, developed by the Intergovernmental Panel on Climate Change (IPCC), was applied. The result suggested that under current climate condition, most smallholder farm households in the study area were already insufficient in their rice availability, as indicated by their low rice sufficiency level (HRSL). With no adaptation, climate condition was likely to worsen the smallholders' rice sufficiency status, by shifting the currently rice-sufficient household to be rice-insufficient, or forced those who were already insufficient to be severely insufficient. Further analysis indicated a link between household rice sufficiency status and the composite household vulnerability level (HVI), where rice-severely-insufficient households typically had the highest composite-HVI (0.54), relative to rice-insufficient (0.46) and rice-sufficient households (0.39). Meanwhile, the application of the IPCC-vulnerability framework approach suggested a link between smallholders' adaptation and vulnerability level. The adapted households typically had smaller overall IPCC-HVI than the non-adapted did, where the IPCC-HVI of the on-farm, off-farm, and the combined on-and off-adapted households was recorded, respectively at -0.11, -0.03, and -0.12, substantially lower than the non-adapted (+0.11). The study also recognized five major areas for adaptation-strengthening interventions in the study area, which involved in sequence according to its level of priority: (1) food condition, (2) irrigation, (3) livelihood, (4) knowledge, and (5) finance.

Keywords: Climate change; food insecurity; vulnerability; adaptation.

1. INTRODUCTION

Smallholder farm households in developing countries are typically vulnerable to climate-induced food insecurity, due to their limited capacity to adapt [1,2]. Though there is no unanimously agreed estimate on the portion of smallholders in the world's farms, most likely due to the lack of standardized definitions of the terms [3], all estimates worldwide suggested a huge portion, which ranged from 50% [4] to 85% [5]. In Indonesia, the smallholders constitute equally substantial portion, where the latest Farm Household Census reported a figure of around 55.95%, defined as those whose farmland size is less that 0.5 ha [6]. Taking the problem of huge portion into account, the impact of changing climate condition on smallholder farmers has been a focus of attention worldwide.

Climate change is expected to further exacerbate the current numerous risks that smallholder farmers have already faced to their agricultural production, which often undermine their household food security condition [7]. Since farming is often the only livelihood on which most smallholders rely, any small reduction in agricultural yields is likely to worsen the already limited access of the smallholders to sufficient food [8]. Furthermore, the smallholders' limited resources and capacity to cope with the shocks made them highly vulnerable, and accordingly forced most of them to shift in and out of a state of undernourishment [9].

The smallholders seem to have no alternative to address the adverse impact of climate change on their food condition but to adapt their livelihood systems to the changing climate conditions [10]. Previous studies indicated that smallholder farmers have assumed autonomously some adaptation measures in their farming management practices, which range from simple adjustment on planting calendar to investment on input and infrastructure [11]. Referring back to their highly limited resources and hence capacity, the autonomous adaptation measures of the smallholders have yet to be optimal and still leave substantial residual impacts untapped [12]. This has been a key challenge for decision makers, policy makers, and development partners to understand the current adaptation measures of the smallholders in their efforts to address the adverse food insecurity implication of climate change.

In order to feed into the decisions on the design and implementation of adaptation strategies for responding to the adverse impact of climate change on food insecurity, researches have been growing in addressing the issue. In this connection, various research approaches, methods, and tools have been developed. The first approach was introduced by IPCC [13] known as Climate Change Impact, Adaptation, and Vulnerability (CCIAV). The development of this approach, as well as its methods and tools, has been surprisingly fast, but tends to be partial. Impact study, on the one side, culminated in "top-down" approach [14] or "scenario-based" approach [15]. On the other side, vulnerability study led to bottom-up approach [14]. Meanwhile, in its recent development, adaptation has been incorporated into the top-down approach to assess its efficacy in addressing the biophysical impact of climate change [16,17] and into the bottom-up approach to address the vulnerability of a system to climate change [18,19]. Important critics pertinent to this approach have been dealing with integration of the top-down and bottom-up. Though at conceptual level, it has been adequately addressed by the fast development of integrated approach [20], at methodological level, however, the progress has been very limited.

The study integrates the concept of impact, vulnerability, and adaptation to assess the smallholders' climate-induced rice-insufficiency condition under current vulnerability and adaptation practices. In specific, the study aims to assess: (i) the smallholders' current climate-induced rice sufficiency status, as determined by HRSL, under various types of the smallholders' current adaptation practices, (ii) the smallholders' current vulnerability level, as represented by the composite- and IPCC-HVI, and (iii) the extent to which the smallholders' current HVI linked to the smallholders' current rice sufficiency status and adaptation practices, based on which set of adaptation-strengthening recommendations could be formulated, accordingly.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Ujungjaya Sub district, the District of Sumedang, West Java Province, Indonesia. The study area covered all the nine villages available in Ujungjaya, namely Cibuluh, Cipelang, Keboncau, Kudangwangi, Palabuan, Palasari, Sakurjaya, Sukamulya, and Ujungjaya. The location lies approximately between longitudes 107°84' - 108°82' E and latitude 6°84' - 7°84' S, with the altitude of 50 m above sea level, indicating the lowest area of Sumedang District. Ujungjaya Sub-district covers a landmass of 8,122 ha, where agriculture occupies 2,637 ha or around 32.47%. According to its water supply, farming is divided into rain-fed, whose water supply is exclusively derived from rainfall, occupying 828 ha or 31.40%; and the remaining 68.60% are irrigated, whose water supply is supplemented and/or regulated by irrigation infrastructure, which ranges from very simple to well-constructed cannal. The main commodity planted by farmers is rice, with most popular variety is Ciherang whose growing period is around 120 days. The average annual productivity of rice in the district was recorded at 6.28 ton/ha [21].

In the study area, irrigation infrastructure mostly, if not all, has no sufficient capacity to maintain stable water supply for farming all year around. This is because irrigation infrastructure is not equipped with well-constructed water storage facilities to accumulate water from rainfall during rainy season and release it during the dry season. The average annual rainfall of the area is around 2,597 mm during the last 5 years, the lowest in comparison to that in other sub-districts of Sumedang.

Ujung Jaya Sub-district has average population growth of 0.17% and total households of around 9,726 [22], where around 37.44% fall into poor household category based on indicators developed by Social Protection Programs [23]. Majority of the people (72.68%) are farmers.

Farming calendar generally follows the pattern of rainfall. In the rain-fed areas, planting is generally made 2 times a year. The first planting links to the onset of rainy season (usually in November or December), while the second starts immediately after the first harvesting. The second planting time is highly critical in relation to the pattern of rainfall, where the risk of failure resulting from limited water supply is critically high. Farmers are fully aware of the risks but for most of them little they can do due to their limited resources. They just rely on their fortune, hoping that enough rain will still occur until harvesting.

In irrigated areas, planting time is relatively more flexible, made possible by supplementary water supply from irrigation. Planting occurs at almost every month, though the general pattern still follows that of the rainfall Fig. 1. Delay in planting time is relatively common in the study area, in relation to the onset of rainy season. There are at least two main reasons for the delay in planting. The first is limited labor. The phenomenon of decreasing interest of the youth on farming is already observed in the study area. The youths generally move to urban areas for off-farm employments, leaving the old to grapple with farming. The second links to water availability at farm plots level, determined mainly by access to water reservoir. Land preparation for planting requires large amount of water. For those farmers whose farm plots are close to reservoir or those who own enough resources to make better access to water supply, land preparation can be done immediately at the onset of rainy season. Meanwhile, farmers with limited resources or those whose farm plots are far off the reservoir should wait until the level of reservoir high enough to flow, or until water from rainfall is sufficiently accumulated in their farm plots.

According to the local practices, planting rice generally starts with raising the seedlings in a nursery and later transplanting them in the main field. Small numbers of farmers also do direct planting, where seeds are drilled directly to zero tilled land, but this practice is only limited to dry-season planting. The main motivations of farmers to do zero-tilled direct planting are to save water and at the same time shorten the growing period, so that they can gain early harvest, giving them more flexibility for the next planting.

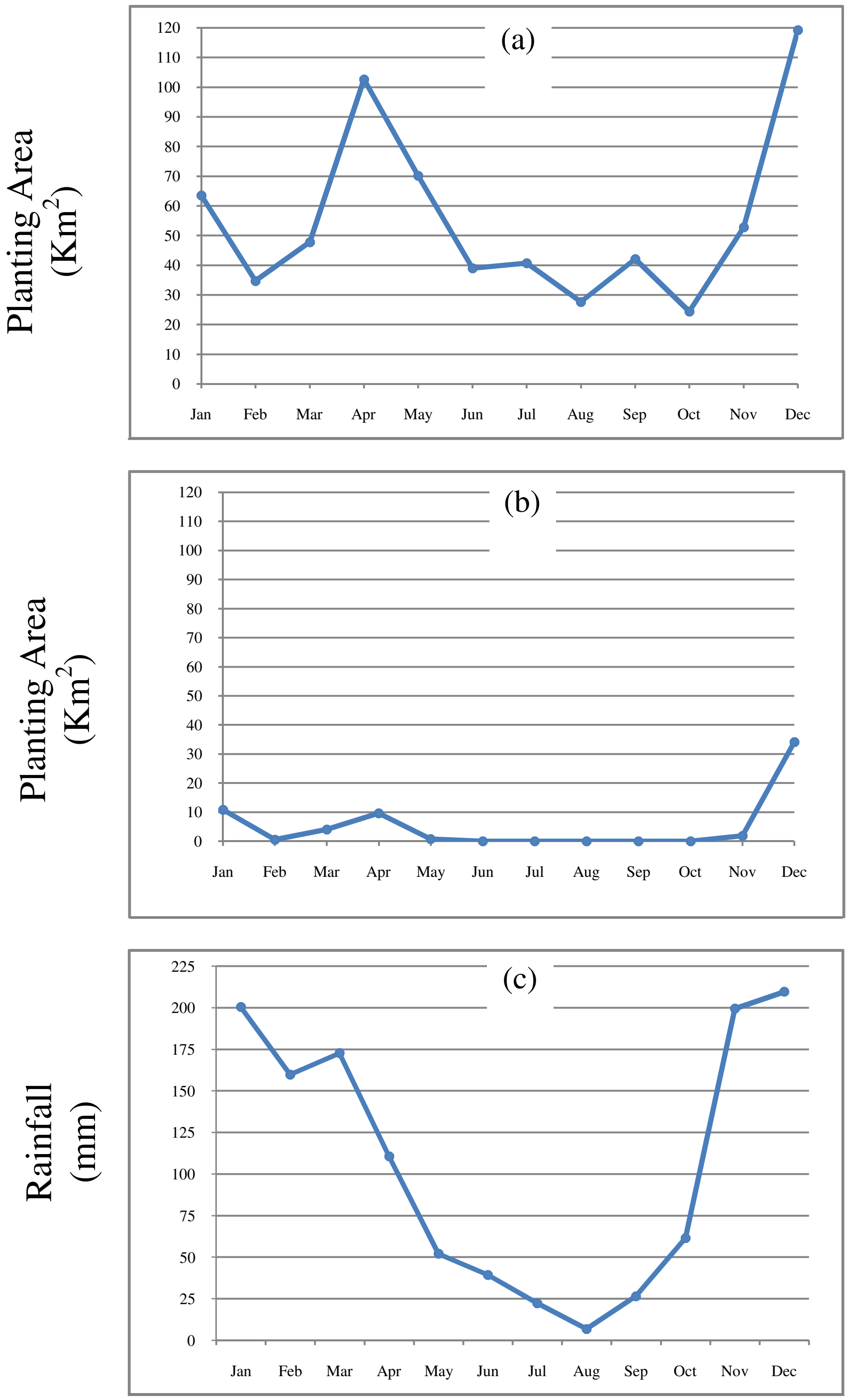

Fig. 1. Planting calendar of irrigated (a) and rain-fed farm (b), in relation to rainfall pattern (c)
Source: Annual report of planting area for 2012 [24]

Irrigation is generally applied on a rotational-based, with an application interval of 3 days during the earlier stages of rice growth and 7 days during the later stages. However, when water is not adequately available (usually during dry season), the application interval was prolonged until 7 or 10 days during the earlier stages and often until 14 days during the later stages. The depth of water irrigation in each application is set relatively constant, generally at a level of no more than 20 mm. The frequency of irrigation application varies for different locations of farm plots, depending on their access to water reservoir. For those farmers whose farm plot has limited access to water reservoir (e.g. rain-fed or farm plots with irrigation canals but located far-off the reservoir), irrigation might be supplemented with water pumps. But, this is only possible for famers who own adequate resources, while those who cannot afford the pumps just rely exclusively on rainfall. These variations in the onset of planting time and irrigation schedule among farmers reflect their autonomous responses to changes in local climate, which is highly determined by their capital.

2.2 Sampling

Sample households were calculated using the following formula:

$$n = \frac{Z^2_{1-\alpha/_2} p(1-p)N}{d^2(N-1)+Z^2_{1-\alpha/_2} p(1-p)} \quad (1)$$

Where:

n = Number of minimum sample required
α = Confidence interval (95%)

$$Z_{1-\alpha/_2} = 1{,}96$$

p = Proportion of climate change-induced food-insecure households (estimated based on the percentage of farm plots suffering from planting/harvesting failure to the total farm plots affected by drought, flood, and pest/diseases infestation. Using the Sumedang District Agricultural Office (ADO) data, the proportion was estimated at 0.32)
d = Limit error or absolute precision (0,05)
N = Total Population, i.e. all households in the study area whose welfare fall within the lowest fourth deciles, which according to the 2011 Data Collection for Social Protection Programs (PPLS) conducted by Statistics Indonesia (BPS), the total number was around 3.641 households [23].

Based the above formula, it is found out that the required number of sample for this study was 156 households. The sample was selected randomly from the "by-name and by-address" data of the 3.641 households, which has been released officially by PPLS.

2.3 Data Collection

Data collection was conducted from November to December 2013. It was just after planting for some households and during planting or land preparation for some others. Data was collected using questionnaire through interview with the housewife together with the head of sample households. Interview was made at the house of sample households, upon a prior appointment for most convenient time to the respondents. Two couples of experienced interviewers were recruited and short training to familiarize the questionnaire was made prior to the data collection. In order to verify the data generated from the interview, a triangulation was made through Focus Group Discussion (FGD) and interview with key informants, field observation, and secondary data collected from related local offices.

Data collected included: (i) household's rice production system that involved current farm management practices, current yield, and current allocation of its production; (ii) household's consumption pattern assessed by weekly-based household food consumption through interview with the housewife to generate data on the portion of total household calorie requirement derived from rice; and (iii) household's socio-economic characteristics to explore factors determining the household vulnerability and adaptation practices. In addition, observed climate data of precipitation and minimum and maximum temperature was also collected for 30 years (1981 – 2010) from local climate station located closest to the study area, which is Jatiwangi Climate Station. The climate data was used to simulate the extent to which the current local climate has affected the local rice yield, and subsequently the HRSL.

2.4 Data Analysis

Data analysis was made based on the new IPCC concept of impact, adaptation, and vulnerability assessment [12]. The new IPCC concept used the term "impact" primarily to refer to the effects on natural and human systems of climate change. In the context of this study, impact referred to the climate-induced HRSL. Meanwhile, the term "vulnerability" referred to the propensity or predisposition to be adversely affected. In this study, vulnerability was quantified as composite- and IPCC-vulnerability index. Finally, the term "adaptation" referred to the process of adjustment in natural and human systems in response to actual or expected climate and its effect, which moderated harm or exploited beneficial opportunities [25]. Here, three types of smallholders' current adaptation were identified and their link to the smallholders' vulnerability level and rice sufficiency status was assessed.

2.4.1 Calculation of household rice sufficiency level under current local climate

The influence of the current local climate condition on HRSL was assessed through its impact on rice yield using CROPWAT simulation model [26]. Based on which, the HRSL was calculated, accordingly, as the ratio of the actual availability to the minimum requirement of rice at household level to meet the whole members' minimum calorie requirement. With reference to the 2012 National Workshop for Food and Nutrition [27], the minimum requirement at availability level was set at 2.400 kcal/capita/day. Based on which, the annual household minimum requirement of rice (HRR) was calculated using the following formula:

$$HRR = p \; x \; 2400 \; x \; c \; x \; h \; x \; 365$$

(Kg Rice/Household/Year) (2)

Where:

- p = Portion of the total household calorie requirement derived from rice (assessed by weekly-based household food consumption through interview with housewife)
- c = Calorie-to-rice conversion factor, where 100 gram rice contained 360 kcal [28]
- h = Number of household members

On the other side, the annual actual availability of rice at household level (HRA) was assessed using the following formula:

$$HRA = \sum_{i=1}^{n} (y_i \, x \, l_i) - (c + s) + np$$

(Kg Rice/Household/Year) (3)

Where:

y = Output of CROPWAT for baseline period x Conversion Factor from Harvesting Yield to Ready-to-Husk Grain (86.02%) x Conversion Factor from Ready-to-Husk Grain to Rice (62.74%)
l = Harvesting area (ha)
n = Times of planting (n=2 for rain-fed farm plots and n=3 for irrigated farm-plots)
c = Portion of harvest allocated to cover cost of production (wage, seed, rent, etc.)
s = Portion of harvest sold for purposes other than cost of production
np = Food from sources other than households' own farm production (external sources)

The HRSL was calculated individually for each sample household using individual household data generated from the household survey. Afterward, the food insecurity status of each sample household was determined, accordingly, as follows [29]:

1. Rice-sufficient group covers those households whose RSL is equal to or more than 90%,
2. Rice-insufficient group cover those households whose RSL range from 70% to 89.99%, and
3. Rice-severely insufficient group covers those households whose RSL is less than 70%.

In order to assess the link between the smallholders' rice sufficiency status and their current adaptation practices, a cross-tabulation [30] was made between these two variables. The smallholders' current adaptation practices were categorized into the following three groups:

1. On-farm adapted group covered those households who made on-farm adjustments that involved (i) shifting planting time to better match with the rainfall pattern and (ii) improving irrigation scheduling.
2. Off-farm adapted group covers those households who diversified their livelihoods to off-farm employments, which guarantee more stable income and better access to external sources of rice (particularly the government-subsidized rice through rice-for-the poor or known as *Raskin* program).
3. Combined on- and off- farm adapted group covered those households who had made both on- and off adaptations.
4. Non-adapted group covered those households who had made neither on- nor off-adaptations.

2.4.2 Calculation of household vulnerability index

The study applied two different approaches, which involved composite index approach and IPCC-framework approach [18,31,32]. The composite index was calculated using balanced weighted average of the following five major vulnerability components, which involved (1) Irrigation water, (2) Knowledge, (3) Food, (4) Finance, and (5) Livelihood. Each vulnerability component consisted of several indicators (or sub components) representing the current household vulnerability, as presented on Table 1.

Since each of the vulnerability sub components was measured in a different scale, there was a necessity to standardize the score of each sub component as an index (I_{SC}) by using the following formula:

$$I_{SC} = \frac{S_{SC} - S_{SCmin}}{S_{SCmax} - S_{SCmin}}$$

=Where:

I_{SC} = Standardized score of sub component
S_{SC} = Actual score of sub component,
S_{SCmin} = Minimum score of sub component
S_{SCmax} = Maximum score of sub component

The standardized score of each sub component (I_{SC}) were then averaged to generate the score of vulnerability component (I_C). Afterward, the composite-HVI was calculated as the balance-weighted average of the standardized score of vulnerability components by using the following formula:

$$Composite\ HVI = \frac{(I_I + I_W + I_K + I_{Fo} + I_{Fi})}{5}$$

Where:

I_I = Standardized score of “Irrigation” component
I_W = Standardized score of “Water” component,
I_K = Standardized score of “Knowledge” component
I_{Fo} = Standardized score of “Food” component
I_{Fo} = Standardized score of “Finance” component

Under the IPCC framework, the vulnerability sub components were re-grouped into the IPCC three major components of vulnerability, which involved exposure, sensitivity, and adaptive capacity [33]. The re-categorization of vulnerability sub components into the three IPCC vulnerability factors is presented on Table 2. The first step in calculating the IPCC-vulnerability index is to calculate the standardized score for each of the IPCC-vulnerability factors (exposure, sensitivity, and adaptive capacity) by balanced weighted averaging the standardized score of its component indicators. The IPCC-vulnerability index was then calculated using the following formula:

$$IPCC - Vulnerability\ Index = (I_e - I_{ac}) * I_s$$

Table 1. The components of household composite-vulnerability

Vulnerability components	Sub-components	Elaboration and scoring of the sub-components
Irrigation water	Distance of households' farm plot to irrigation reservoir	The shorter the distance, the lower the score, and the better the irrigation. Scoring: (1) < 0.5 km; (2) 0.5 s/d 1.0 km; (3) > 1.0 km
	Method(s) to access irrigation reservoir	The better the method(s), the lower the score, and the better the irrigation. Scoring: (1) canal, piping, and water pumping, (2) canal and piping, (3) canal, (4) rely on rainfall
Knowledge	Education of household head	The higher the education, the lower the score, and the better the knowledge. Scoring: (1) More than High School; (2) High School; (3) Junior School; and (4) Elementary School or less
	Involvement in farmer group activities	Those who involved will get lower score, and be better in knowledge. Scoring: (1) Involved; and (2) Not involved
Food	Percentage of food from own-farm production	The lower the percentage, the lower the score, and the better the food condition. Scoring: (1) < 50%; (2) 50-60%; (3) > 60%
	Number of months a household having difficulty to access food	The less the numbers, the lower the score, and the better the food condition. Scoring: 3) < 3 months; (2) 3-4 months; and (1) > 4 months
Finance	Ownership of livestock	Those who owned will get lower score, and be better in finance. Scoring: (1) Owned; and (2) Not Owned
	Access to credit	Those who have access will get lower score, and be better in finance. Scoring: (1) Received credit at least once and (2) Never received credit (during the last 5 years)
Livelihoods	Diversification in livelihoods	Those who diversified their livelihood will get lower score. Scoring: (1) Farming, farm labor, and off-farm labor; and (2) Farming and farm labor.

Where I_e, I_{ac}, and I_s are standardized score of exposure, adaptive capacity, and sensitivity, respectively. In this study, the HVI (both composite and IPCC) was scaled from -1 (least vulnerable) to 1 (most vulnerable).

The HVI (both composite and IPCC) was calculated individually for each sample household using individual household data generated from the household survey. The average standardized score of each composite-HVI component was also calculated according to the three categories of the smallholders' current rice sufficiency status. The scores were then presented on spider diagram in order to visualize the link between the smallholders' current composite-HVI and their current rice-sufficiency status. Afterward, a triangle diagram was also drawn to visualize the link between the smallholders' current IPCC-HVI and their current adaptation practices.

Table 2. The scoring of IPCC-vulnerability components

IPCC-vulnerability factors	Component indicators
Exposure	Distance from households' farm plot to irrigation reservoir Method(s) to access irrigation reservoir
Sensitivity	Percentage of food from own-farm production Number of months a household having difficulty to access food
Adaptive capacity	Education of household head Ownership of livestock Involvement in farmer group activities Access to credit Diversification in livelihoods

3. RESULTS AND DISCUSSION

3.1 Smallholders' Rice Sufficiency Status and Adaptations under Current Climate

Climate condition affected rice-sufficiency status through its direct impact on rice-yield reduction. In order to get an insight into the extent to which the current climate condition affected the smallholders' rice-sufficiency status in the study area, a 30-year time series data of precipitation and the minimum and maximum temperature was collected and their impact on rice-yield reduction was simulated using CROPWAT. The result indicated that the changes in the climatic condition during the last 30 years resulted in an average annual rice-yield reduction of 15.63% and 18.79% for irrigated and rain-fed farm plot, respectively.

Afterward, the current climate-induced rice-yield-reduction implication on the smallholders' HRSL was calculated subsequently to assess the impact of current climate on the smallholders' rice-sufficiency status. The result indicated that out of the 156 sample households, only 7.05% was sufficient in rice, while the remaining 61.54% and 31.41% had been insufficient and severely-insufficient, respectively. The study also suggested, as indicated on Fig. 2, that a household's rice sufficiency status was linked to the different types of current adaptations it had developed to cope with the climate-induced yield reduction of rice. Three types of adaptations were identified, which involved on-farm adaptation, off-farm adaptation, and the combination of the on- and off-farm adapatation.

Fig. 2 indicated that the non-adapted group assumed the largest portion of rice-insufficient households, relative to the adapted did, implying that with no adaptation, climate condition was likely to worsen the smallholders' rice sufficiency status, by shifting the currently rice-sufficient household to be rice-insufficient, or forced those who were already insufficient to be severely insufficient. Further, the figure showed that on-farm adaptation brought about smaller portion of households who were severely insufficient in rice than the off-farm adaptation did (25.00% vs. 27.27%). However, the portion of rice-sufficient households was larger among the off-farm than that among the on-farm adapted (9.09% vs. 5.00%). The combination of the on-farm and off-farm adaptation resulted in larger portion of rice-sufficient (11.63%) and smaller portion of rice-severely insufficient households (23.26%) than either the on-farm or off-farm adaptation did. In general, the study generated an impression that adaptations have shifted some portion of households from rice-severely insufficient to rice-insufficient group and further from rice-insufficient to rice-sufficient group. However, the portion of those who shifted from insufficient to sufficient group is substantially smaller than those shifted from the severely insufficient to insufficient group.

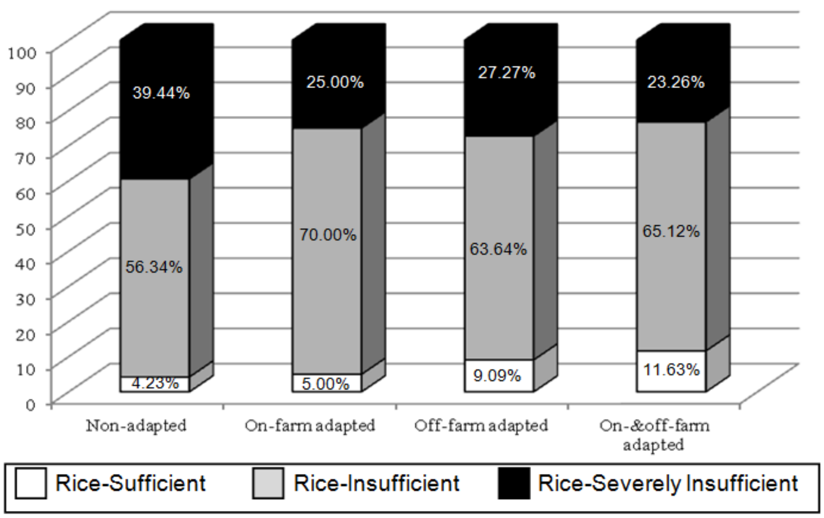

Fig. 2. The proportion of sample households (%) according to different rice sufficiency status, under different types of adaptation

One plausible argument to justify the above findings was the limmited contribution of on-farm adaptation to the smallholders' improved HRSL because the minimized rice-yield-reduction impact of the on-farm adaptation to increased rice production was confined to the yield potencies of the rice variety grown and the extremely limited size of land per household, which ranged from only 0.03 ha to 0.06 hectar. Therefore, this type of adaptation seemed to be only sufficient to shift substantial portion of households from "severely-insufficient" to "insufficient", but not from "insufficient" to "sufficient" group. Another argument would be the fact that off-farm adaptation provided additional cash income to farm household, which resulted in increased household's economic access to sources of rice other than household's own farm production. When it was combined with improved physical access to rice, made possible by government subsidized rice program (Raskin), the off-farm adaptation would be effective to shift larger portion of households who are already in "rice-insufficient group" further to "rice-sufficient group". Those arguments were in line with the results of previous studies [34,35,36], which suggested that one single adaptation was likely to be inadequate, and hence diversity of adaptation measures are required to address the impact of changing climate adequately. Furthermore, it was confirmed by previous study that a substantial increase in food production was not sufficient to ensure food security, unless it was accompanied by increased access to adequate and nutritious food and capacities to cope with climate-induced food insecurity [37].

3.2 Smallholders' Vulnerability Level and Rice Sufficiency Status

The study defined five major components of composite-vulnerability that represented conditions underlying the smallholders' current vulnerability to climate-induced rice yield reduction in the study area, which threaten the smallholders' rice sufficiency status. The five vulnerability components being analyzed involved food, irrigation, livelihood, knowledge, and finance. The study indicated a link between the smallholders' composite-HVI and their household rice sufficiency status, where rice-sufficient households had lower HVI (0.39) than the insufficient (0.46) and severely-insufficient households (0.54). The finding sugested that the higher the HVI of a smallholder household, the more likely the household to be rice-insufficient or even rice severely insufficient. Further analysis was also made to assess the extent to which each of the five composite-vulnerability components has determined the smallholders' current rice sufficiency status and the result is presented on Fig. 3.

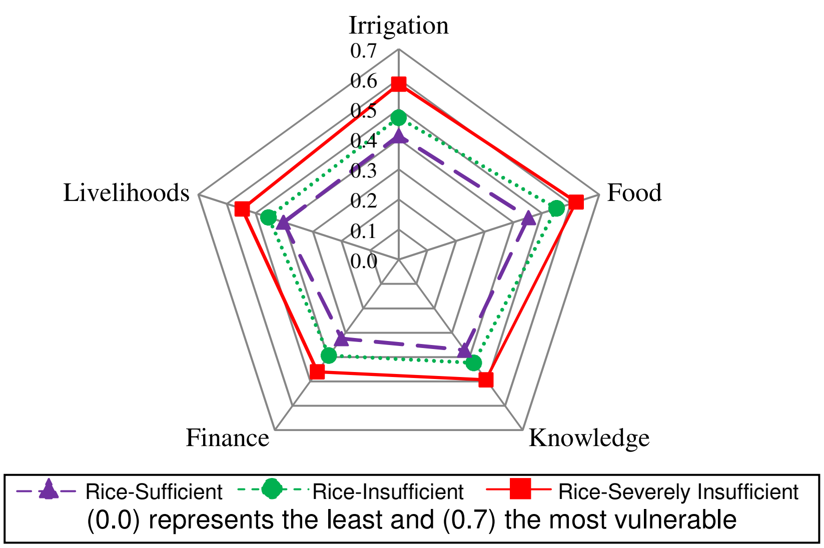

Fig. 3. Spider diagram indicating the link between the five major components of composite-vulnerability and the household rice sufficiency

Fig. 3 showed that rice-severely insufficient households were typically those most vulnerable to climate-induced rice yield reduction, in terms of all the five vulnerability components. Any integrated interventions that reduced simultaneously the score of the five components were likely to shift a household from rice-severely insufficient to rice-insufficient, and further to rice-sufficient group. The figure also indicated the level of significance of one vulnerability component relative to another in determining the overall composite-vulnerability level of a household. The higher the score of a component, the more significance was its contribution to the overall composite-vulnerability.

The study revealed that "food" component had the highest score (0.53) and followed consecutively by irrigation (0.47), livelihood (0.45), knowledge (0.42), and finance (0.38).

This indicated that rice sufficiency status of a household in the study area was most sensitive to changes in the condition of the food component. Therefore, any intervention that improved the smallholders' food condition was most likely to reduce the overall composite-vulnerability level of the household, to the extent relatively higher than that addressing any of the other vulnerability components did. The study recognized at least two critical areas for intervention to improve the smallholders' food condition, i.e. their dependence on own-farm rice production and incidence of household's facing difficulties to access food (in this case, access included both economic and physical access). Interventions that addressed those two areas are most likely to reduce the score of food component, and hence the household's composite-vulnerability level.

The second most influencing vulnerability component was irrigation, which represented condition underlying the smallholders' access to irrigation water for their farm plot. There were at least two main factors that determined farm households' access to irrigation water for their farm plot, i.e. distance to water irrigation reservoir from households' farm plot and the method(s) to access the reservoir. Building-up simple water harvesting facilities around the smallholders' farm plot or improving water access facilities (such as irrigation canals, piping or water pumping) was most likely to result in a smaller score of irrigation component, and hence a lower composite-vulnerability level.

The remaining three major components (knowledge, finance, and livelihood) seemed to have a strong link one to another. The knowledge component determined a smallholder's access to innovation and technology, and when combined with the household's better financial resources and more diversified livelihoods, were most likely to result in the smallholder's better capacity to adapt by ensuring better adoption of innovation and technology. This, in turn, would ensure a minimized climate induced reduction in rice yield, leading to increased rice production and hence reduced the overall household's vulnerability to climate-induced rice yield reduction.

Overall, it was also justified to infer that the score of a vulnerability component represented its priority level for intervention relative to the others. In this case, the study suggested that the first priority area for any intervention to address the smallholders' composite-vulnerability in the study area was the food condition, and followed by irrigation, livelihoods, knowledge, and finance.

3.3 Smallholders' Vulnerability Level and Adaptation Practices

The study applied the IPCC-vulnerability framework approach to assess the extent to which the smallholders' current vulnerability linked to the different types of their current adaptation practices. Literature suggested [38] that adaptations were manifestations of adaptive capacity and they represented ways of reducing vulnerability. The result of the study indicated that adapted households typically had smaller IPCC-HVI than the non-adapted did. The IPCC-HVI of the on-farm adapted households was recorded at -0.11, substantially lower than either the non-adapted (+0.11) or the off-farm adapted (-0.03). The combination of the on- and off- adaptation had brought about the lowest IPCC-HVI, which was recorded at -0.12. In this regards, it could be inferred that the more vulnerable a smallholder was, or in this case the higher the smallholder's IPCC-HVI, the less likely was the smallholder to adapt. This finding is consistent with previous study, which confirmed that at macro level, the high income nations are most likely to adapt, and the most vulnerable are least likely to adapt [39].

Further analysis, as presented on Fig. 4, suggested that the non-adapted households were typically those with highest score in exposure (0.62) and sensitivity (0.64), but the lowest score in adaptive capacity (0.44). On-farm adaptation reduced the score of exposure to a level relatively lower (0.40) than the off-farm adaptation did (0.48). In the context of this study, on-farm adaptation reduced the smallholders' likelihood of being exposed to climate-induced rice-yield reduction through improved access to water irrigation and shifting planting time to better match the rainfal pattern. Meanwhile, the lower contribution of off-farm adaptation was justified by its typical nature of indirect contribution in that, as already elaborated above, increased financial resources from off-farm adaptation only contributed to better adoption of innovation and technology, when it was accompanied by smallholders' better access to knowledge and information.

Off-farm adapted households had relatively lower score in sensitivity (0.39) than the on-farm adapted did (0.55). Lower sensitivity score, in this context, represented lower dependence on rice from own farm production and lower incidence of having difficulties to access food. Off-farm adaptation suggested more diversified livelihoods that led to increased off-farm income, and hence ensured the smallholder's better economic access to various sources of rice other than their own farm production. This subsequently resulted in reduced dependence on subsistence rice or ensure more stable access to external sources of rice, and hence ensure lower sensitivity score for off-farm adapted households.

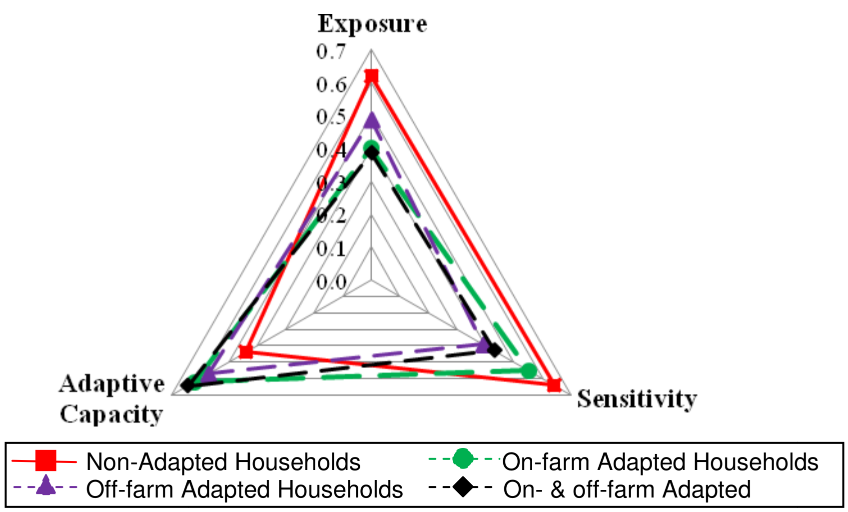

Fig. 4. Triangle diagram indicating the link between the three components of IPCC-vulnerability (exposure, sensitivity, and adaptive capacity) and different types of adaptation practices

The combined on- and off-farm adapted households typically had higher score of adaptive capacity (0.64), relative to either the on-farm or off-farm adaptation did (0.44 and 0.57, respectively). According to current literature, adaptive capacity was manifested into adaptation when a system was exposed to constraints [38]. This suggested, as confirmed by the result of the study, that the higher the adaptive capacity score of a household, the more likely was the household to pursue various types of adaptations. The study identified at least five major factors determining the adaptive capacity score of a household in the study area. Those involved livelihood diversification, access to credit, ownership of livestock, education of household head, and involvement in farmer group activities. The first three determining factors ensured a household's better financial capital, when combined with better acccess to innovation and technology, as represented by the remaining two factors, ensured the household's better capacity to adapt.

4. CONCLUSION

Under current climate condition, most smallholder farm households in the study area were already insufficient in their rice availability. With no adaptation, climate condition was likely to worsen the smallholders' rice sufficiency status, by shifting the currently rice-sufficient household to be rice-insufficient, or forced those who were already insufficient to be severely insufficient. Further analysis indicated a link between smallholder' rice sufficiency status and the different types of the smallholders' current adaptation practices, where the combined on- and off-farm adaptation link to highest portion of rice-sufficient households, relative to either the on- or off-farm adaptation.

The assessment of smallholders' composite-vulnerability level revealed that rice-severely-insufficient households typically had the highest composite-HVI (0.54), relative to rice-insufficient (0.46) and rice-sufficient households (0.39). This suggested that the more vulnerable a household was, or in this case the higher the composite HVI of a household, the more likely the household to be rice-insufficient or even rice-severely-insufficient. Meanwhile, the application of the IPCC-vulnerability framework approach suggested a link between smallholders' adaptation and vulnerability level. The adapted households typically had smaller overall IPCC-HVI than the non-adapted did, where the IPCC-HVI of the on-farm, off-farm, and the combined on-and off- adapted households was recorded, respectively at -0.11, -0.03, and -0.12, substantially lower than the non-adapted (+0.11).

Overall, the study suggested that smallholders' improved rice sufficiency status could be ensured through strengthening the smallholders' current adaptation practices, which covered on-farm, off-farm, or the combined on- and off-farm adaptations. Considering that adaptation was the manifestation of adaptive capacity, and impact was determined by interaction between exposure and sensitivity, adaptation-strengthening intervention to ensure improved rice sufficiency status of a smallholder should focus on strengthening the smallholder's adaptive capacity on the one side, and reducing the smallholder's sensitivity and exposure on the other side. Further, the study recognized five major areas for adaptation-strengthening intervention in the study area, which involved in sequence according to its level of priority: (1) food condition, (2) irrigation, (3) livelihood, (4) knowledge, and (5) finance.

COMPETING INTERESTS

Authors declare that there are no competing interests.

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