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# FOOD INSECURITY UNDER CLIMATE CHANGE AND ADAPTATION OF FARM HOUSEHOLDS IN SUMEDANG DISTRICT, WEST JAVA PROVINCE, INDONESIA

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## ABSTRACT

Ensuring food security for farm households in the face of climate change is considered to be a major challenge for most developing countries, including Indonesia. The study aims to assess the impact of climate change on household food insecurity and the adequacy of current adaptation in addressing the large range of climate change impact under 17 General Circulation Models (GCMs). The result confirmed that farm households in the study area have already lived with changing climate and are likely to face higher degree of climate change in the future. The simulated rainfall has been decreasing, while the minimum and maximum temperature showed an increasing trend, to the extent highly variable across the 17 GCMs. Climate condition affected the Household Rice Sufficiency Level (HRSL), as it decreased from 61.35-64.80% under baseline to 59.75-62.09% and 59.43-61.63% under near-future and far-future, respectively, relatively lower than the observed HRSL (62.89%). Adaptations provided better HRSL, where the adapted households have 5.65%, 8.45%, and 9.29% higher HRSL than the non-adapted, under on-farm, off-farm and the combination of on- and off-farm adaptation, respectively. The current adaptations have also been proved to be relatively effective to lessen the climate change impact on HRSL under near- and far-future climate. The current adaptations, however, have not been adequate yet to ensure rice sufficiency at household level, suggesting the necessity to enhance household rice availability through various types of adaptations.

**KEYWORDS**: Climate change, Household rice sufficiency level, Adaptation

## INTRODUCTION

Ensuring food security for farm households in the face of climate change is considered to be a major challenge for most developing countries [19]; [24], including Indonesia [47]. Even before the impact of climate change was considered, enormous number of households was already vulnerable to food insecurity [17], and climate change is likely to make the situation worse. People in developing countries are more susceptible to climate change due to their low adaptive capacity and growing dependence on agriculture, which is highly sensitive to climate change[30]. [27] estimated that around 70% of the food-insecure in the world reside in rural areas, and directly or indirectly depend on agriculture for income as well as food.

The food insecurity implications of climate change, to date, have been explored by previous studies, largely in relation to climate change-induced yield reduction of food crops and hence, reduction in food production [10]; [41]). While food production has been identified as the main determinant of food availability [25], to single it out as the only indicator is not adequate to provide sufficient indication on the extent to which climate change has affected food security. To date, studies using indicators that better represent the food insecurity impact of climate change have been evolving, at macro and meso, but not micro level. For example, [9] measured the national level food insecurity implication of climate change in Mali using Risk of Hunger (ROH), which indicated the percentage of the population whose daily calorie intake falls below requirements for a healthy life. Other examples are [49] used daily calorie availability as an overall indicator of climate change impact on national level food security in China and [44] used food ballance to indicate the national food security impact of climate change in Indonesia.

Adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to climate change and variability, moderating potential damages, and helping them cope with adverse consequences [28]. According to [25], adaptation of food system to climate change may occur in relation to agronomic aspects regarding food production, government-set price and income concerning access to food, and changes in societal values concerning food utilization. Sophisticated approach has been growing to simulate the efficacy of adaptation options in addressing the impact of changing climate, by integrating the GCM models and various crop growth simulations, such as APSIM ([38]; [33]; DSSAT [22]; [6], and CROPWAT [4]; [35]. This integrated approach has been applied at macro and meso level studies to simulate the extent to which current adaptations have been effective in addressing the impact of climate change on Risk of Hunger in Mali [9], daily calorie intake in China [49], and food ballance in Indonesia [44]. However, study that applied the approach at micro (households) level is, if not at al, barely available.

This study provides an analysis of climate change impact on food insecurity at household level and the adequacy of the locally-specific on- and off- farm level adaptation measures autonomously developed by farm households to cope with the large range of climate change impact under 17 GCMs. In specific, the study aims to analyze (i) the range of changes in climate, specific for the study area under 17 GCMs, (ii) the extent to which the changes in climate affect farm households' food insecurity, as represented by HRSL, and (iii) the adequacy of farm households' current adaptation practices in addressing the food insecurity-impact of current and future climate.

## MATERIALS AND METHODS

### Study area

The study was conducted in Ujungjaya Sub district, Sumedang Regency, West Java Province, Indonesia. The study area covered all the nine villages available in Ujung Jaya, 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. The Sub-district covers a landmass of 8,056 ha, where agriculture occupies 2,637 ha (32.73%). According to its water supply, farming is divided into rain-fed, whose water supply is exclusively derived from rainfall, occupying 1,946.5 ha or 73.81%; and the remaining 26.19% are irrigated, whose water supply is supplemented and/or regulated by irrigation infrastructure. The main commodity planted is rice, with most popular variety is Ciherang whose growing period is around 120 days. The average annual productivity of irrigated rice was recorded at 6.28 ton/ha and that of the rainfed was 4.20 quintal/ha [7].

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.

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 (March or April). The second planting is highly critical in relation to rainfall pattern, where the risk of failure resulting from limited water supply is critically high.

In irrigated areas, planting time is relatively more flexible due to supplementary water supply from irrigation. Planting occurs at almost every month, though the general pattern follows that of the rainfall. 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 (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.

### Sampling

Sample households were calculated using the following formula:

$$n = \frac{Z^2_{1-\alpha/2}\,p(1-p)N}{d^2(N-1) + Z^2_{1-\alpha/2}\,p(1-p)} \text{.................. } \textit{(equation 1)}$$

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 data [3], the proportion was 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 [48].

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.

### Data collection

Observed climate data of precipitation and minimum and maximum temperature was collected for 30 years (1981 – 2010) from local climate station located closest to the study area, that is Jatiwangi Climate Station. Based on which, the projected changes in average monthly rainfall and minimum and maximum temperature was generated for two time slices, i.e. near-future (2011 – 2040) and far-future (2041 – 2070). The 30 year period was chosen condering that this is the minimum period needed to define a climate.

Sample household survey combined with field observation was also made to generate data on: (i) household's rice production system that involve current farm management practices, current yield, and current allocation of its production; and (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.

### Data analysis: Assessment of Food Insecurity and Adaptation under Current Climate

HRSL was used to represent household food insecurity, which is calculated 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 [51], the minimum requirement 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:

$$HRR = p \; x \; 2400 \; x \; c \; x \; h \; x \; 365 \quad \textit{(Kg Rice/Household/Year)} \text{ .......................... } \textit{(equation 2)}$$

*Where:*
*p = Portion of the total household calorie requirement derived from rice*
*c = Calorie-to-rice conversion factor, where 100 gram rice contains 360 kcal* [13]
*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)................................. (equation 3)*

*Where:*

*y* = *Harvesting Yield x Post Harvest Handling Losses (13.35% for irrigated and 10.39% for rainfed* [37] *x Harvesting Yield-to-Unhusked Rice Conversion (86.02%) x Unhusked Rice-to-Rice Conversion (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 as the ratio of HRA to HRR, which indicated the extent to which a household is able to attain its rice sufficiency level. The HRSL was calculated individually for each sample household using individual household data generated from household survey. Afterward, the average HRSL of the whole sample was calculated to represent the magnitude of the current household food insecurity. The average HRSL was also calculated for splitted groups of sample households based on the types of their current adaptation:

1. On-farm adapted group covers those households who had made on-farm adjustments that involve (i) shifting planting time and (ii) improving irrigation scheduling.
2. Off-farm adapted group covers those households who had better access to rice from external sources, in this case access to government-subsidized rice (Rice for the poor/Raskin program). Off-farm adapted households are those who manage to access at least 10 kg raskin, out of the total 15 kg allocated for each poor household per month.
3. Combined on- and off- farm adapted group covers those households who had made both on- and off adaptations.
4. Non-adapted group covers those households who had made neither on- nor off-adaptations.

A comparison was then made accordingly between the adapted and non-adapted group to provide an indication on the efficacy of current adaptation in addressing the current climate impact.

**Data analysis: Assessment of Food Insecurity and Adaptation under Future Climate Projection**

The study applied multiple GCMs to address the uncertainty that entails to climate projections [32]. In this case, 17 GCMs under climate change scenarios of RCP8.5 and RCP4.5 were used to generate simulated climate (precipitation and minimum and maximum temperature) for baseline, near-future and far-future periods. The GCMs used include BCC-CSM1, CCSM4, CESMI-CAM5, CSIRO-Mk3-6-0, FIO-ESM, NOAA GFDLCM3, NOAA GFDL ESM2G/2M, GISS-E2-R1-3, HadGEM2-ES, IPSL-CM5A-LR, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MRI-CGCM3.

The output of the GCMs were then used as input for CROPWAT model [11]; [15] to generate estimates of climate change-induced rice yield reduction. Prior to its application, the CROPWAT was adjusted by local data to represent the local farming condition. The adjustments made include planting time, irrigation scheduling, and crop and soil characteristic. The irrigation schedule options of CROPWAT was set for "rain-fed" and "irrigate at fixed interval per stage". Based on data collected through interview with local farmers and field observation, the interval of irrigation for different stages of rice development was defined according to different planting times at fixed application depth of 20 mm as presented on Table 1. Adjustment was also made for crop and soil data to match the local specific condition of the study area.

Based on the output of CROPWAT model, the average annual rice yield for individual sample household was calculated for baseline, near-future and far-future. The average annual rice yield then enter into equation 2 to generate individual HRSL for the three periods. A comparison was then made among those periods for both adapted and non adapted households to assess the adequacy of the current adaptation practices.

***Table 1. Irrigation interval under different planting time***

| Planting Time | Irrigation Interval (days) for Each Development Stage |
|---|---|

| (Month) | Initial (I) | Development (II) | Mid Season (III) | Late Season (IV) |
|---|---|---|---|---|
| Oct,Nov,Dec,Jan | 3 | 3 | 7 | 7 |
| Feb,Mar,Apr,May | 7 | 10 | 14 | 14 |
| Jun,Jul,Aug,Sep | 7 | 14 | 14 | 14 |

Source: Interview and Field Observation

## RESULTS AND DISCUSSION

### Household food insecurity and adaptation under current climate

The result of the study shows that all the sample households are food-insecure, as indicated by their HRSL that falls below 100%, with an average of 62.89% ± 8.93%. The HRSL was calculated according to the minimum calorie availability of 2,400 kcal/capita/day recomended by [51], to ensure a per capita daily calorie intake of 2,150 kcal. This standard is far above the national average calorie intake which is 1.842 kcal/ capita/day [7]. Substituting the WNPG standard with the national average calorie intake makes 10.90% of the sample household graduated from rice-insufficient group and the average HRSL increase to 83.64% ± 11.88%. The contribution of rice to the daily calorie intake of the sample households ranges from 74.95% to 87.36%, with an average of 79.28 ± 2.64%, much higher than that at the national level which is 49.00% [18], suggesting the sample households' heavy reliance on rice, a typical characteristic of poor households in most developing countries [19]. This finding is consistent with the fact that the population from which the sample households were selected, is all farm households in the study area whose welfare fell within the lowest fourth deciles.

In order to assist the food-insecure households in the study area, government has introduced "Subsidized Rice for the Poor" program, well-known as Raskin. Under Raskin Program, a total of 15 kg rice is allocated per household per month at subsidized price, and households are charged Rp1,600/kg to cover the cost of distribution. Though the price has been much cheaper than the market price (around Rp6,400/kg at the time of data collection), only 21.79% of the sample househods can take full benefit of the program. The ramaining 18.59% and 59.62% can only afford 10 kg and 5 kg subsidized rice per month, respectively. This finding represents the limited economic access of the poor to adequate rice.

For poor households to be food secure, a better access to sufficient supplies of food should be guaranteed all year-round, through either its own subsistence farm production or its purchase. The household's overall access to food will deteriorate when its farm productivity suffers or when its off-farm income falls, or when food prices rise. When at least one of the three occurs, households generally make necessary adjustments, i.e. on-farm to secure its production and stabilize prices, or off-farm to secure its income, or both. Studies in nine countries vulnerable to adverse impact of climate change (Bangladesh, Bhutan, Burkina Faso, Ethiopia, the Gambia, Kenya, Micronesia, Mozambique and Nepal) indicated that out of the 3.269 households surveyed, 88% has already adopted coping or adaptation measures to counter the adverse effect of climate change [50]. Other studies suggested that subsistence livelihoods have evolved a number of coping mechanisms to manage weather variability, including drought years and low crop yield [46]; [34]. Consistent with this finding, the result of the study showed that more than half of the sample households (54.49%) have adopted either on-farm or off-farm adaptation or the combination of the two.

Further analysis, as presented on Figure 1 indicates that on-farm adaptation has made the adapted households to have 5.65% higher HRSL than the non-adapted. This suggests that the current local farmers' on-farm adjustments that involve shifting planting time to better match the changing in rainfall pattern and improving irrigation scheduling, have been effective to lessen the impact of changing climate on rice yield, and subsequently increase the HRSL. This finding is consistent with previous study as changing planting date and improving irrigation have been the most common on-farm adjustment made by poor households in Africa [23].

Similar result was observed for off-farm adaptation, where the HRSL of off-farm adapted households was 8.45% higher than that of the non-adapted. This finding confirmed that those farm households who have a better access to external sources will be better able to compensate climate change-induced reduction in rice yield and subsequently ensure better HRSL. The result of the study also suggested that the combination of the on-farm and off-farm adaptation lead to 9.29% higher HRSL for adapted households in comparison to that of the non-adapted. It is also higher than the increase under either on-farm or off-farm adaptation.

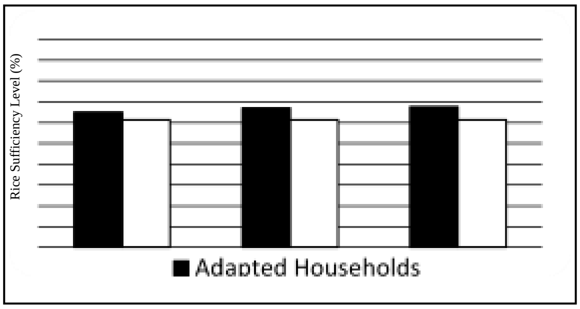

**Figure 1. The current Rice Sufficiency Level of sample households under different types of adaptation practices.**

### Household food insecurity and adaptation under future climate condition

The result of future climate analysis, as presented on Table 2 and Table 3, confirmed that climate change has been occurring in the study area. Under far-future projection, annual rainfall was recorded to range from 884.33 mm to 1,313.96 mm as assessed by MIROC5 and GISSE2R1, respectively. This figure is lower than the simulated annual rainfall for near-future and baseline, which range respectively from 963.30 mm to 1,327.52 mm and from 1,084.42 mm to 1,933.47 mm. The annual maximum temperature was projected to increase from 27.10-30.82$^{o}$C under baseline to 27.62-31.53$^{o}$C and 28.37-33.09$^{o}$C under near- and far-future, respectively. Similarly, the projection of the annual minimum temperature also showed an increasing trend, where it increased from 22.95-27.71$^{o}$C under baseline to 23.86-28.22$^{o}$C and 24.64-28.81$^{o}$C under near- and far-future, respectively. In average, the 17 GCMs suggested a decrease of -8.89% and -9.36% in annual rainfall under near- and far-future projection, respectively. Meanwhile, the minimum temperature decreased by -0.65$^{o}$C and -1.23$^{o}$C, and the maximum by -0.69$^{o}$C and -1.28$^{o}$C under near and far-future, respectively. The projected changes in climate for the study area is considered to be relatively moderate for temperature and low for rainfall, in comparison to the regional climatic projection for Java Island, where the projected increase in temperature ranged from 1.30$^{o}$C in the west part of Java to 1.36$^{o}$C in the east [43], and the projected decrease in rainfall was around -30% until 2080 [26].

***Table 2. Projection of annual climatic condition (rainfall and minimum & maximum temperature) and its impact on regional rice yield (rain-fed and irrigated) with and without adaptation for baseline, near-future, and far-future periods, under RCP4.5, generated by 17 GCMs (minimum, median, and maximum)***

| **Variables** | **Baseline** | | | **Near-Future** | | | **Far-Future** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Minimum** | **Median** | **Maximum** | **Minimum** | **Median** | **Maximum** | **Minimum** | **Median** | **Maximum** |
| Rainfall (mm) | 1,084.42 | 1,267.25 | 1,933.47 | 963.30 | 1,250.28 | 1,327.52 | 884.33 | 1,238.88 | 1,313.96 |
| Minimum Temperature ($^{o}$C) | 22.95 | 25.05 | 27.71 | 23.86 | 25.76 | 28.22 | 24.64 | 26.26 | 28.81 |
| Maximum Temperature ($^{o}$C) | 27.10 | 28.56 | 30.82 | 27.62 | 29.23 | 31.53 | 28.37 | 29.79 | 33.09 |
| Rain-fed Yield (quintals/ha): | | | | | | | | | |
| - Adapted | 41.01 | 41.56 | 41.65 | 41.01 | 41.43 | 41.47 | 40.88 | 41.43 | 41.43 |
| - Non-Adapted | 23.85 | 25.87 | 30.62 | 20.82 | 23.05 | 25.19 | 18.76 | 22.29 | 23.22 |
| Irrigated Yield (quintals/ha): | | | | | | | | | |
| - Adapted | 60.10 | 60.10 | 60.10 | 60.04 | 60.04 | 60.10 | 59.98 | 60.04 | 60.04 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| - Non Adapted | 34.43 | 40.53 | 50.98 | 32.92 | 35.27 | 43.67 | 31.05 | 34.07 | 41.13 |

*Table 3. Projection of annual climatic condition (rainfall and minimum & maximum temperature) and its impact on regional rice yield (rain-fed and irrigated) with and without adaptation for baseline, near-future, and far-future periods, under RCP8.5, generated by 17 GCMs (minimum, median, and maximum)*

| **Variables** | **Baseline** | | | **Near-Future** | | | **Far-Future** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Minimum** | **Median** | **Maximum** | **Minimum** | **Median** | **Maximum** | **Minimum** | **Median** | **Maximum** |
| Rainfall (mm) | 958.79 | 1,239.62 | 1,912.48 | 1,085.89 | 1,238.78 | 1,384.08 | 917.84 | 1,243.91 | 1,384.95 |
| Minimum Temperature (°C) | 22.92 | 25.06 | 27.73 | 23.99 | 25.84 | 28.27 | 25.43 | 26.68 | 29.39 |
| Maximum Temperature (°C) | 27.06 | 28.55 | 30.92 | 27.73 | 29.33 | 31.92 | 28.98 | 30.45 | 33.53 |
| Rain-fed Yield (quintals/ha): | | | | | | | | | |
| - Adapted | 41.39 | 41.56 | 41.64 | 41.39 | 41.43 | 41.47 | 41.30 | 41.39 | 41.43 |
| - Non-Adapted | 23.22 | 25.36 | 31.12 | 20.53 | 23.26 | 25.87 | 20.40 | 23.01 | 24.77 |
| Irrigated Yield (quintals/ha): | | | | | | | | | |
| - Adapted | 60.10 | 60.10 | 60.10 | 60.04 | 60.04 | 60.04 | 60.04 | 60.04 | 60.04 |
| - Non Adapted | 34.85 | 41.01 | 50.49 | 31.89 | 34.79 | 37.63 | 22.55 | 33.58 | 37.39 |

The most direct and obvious impact of climate change is that on food production [16]. Changes in precipitation and temperature will bring changes in crop yield [42]. The result of the study suggested that rice yield reduction has been occuring to the extent substantially different between irrigated and rainfed farm, as well as between adapted and non-adapted farm. Under baseline, the non-adapted irrigated rice yield was recorded to range from 36.06 to 44.64 kwintal/ha. The yield then decreased to a lower level of 33.28-38.41 kwintal/ha and 32.13-36.12 kwintal/ha under near- and far-future, respectively. Similar reduction in rice yield was also recorded for non-adapted rain-fed rice, where the yield decreased from 23.85-30.62 kwintal/ha under baseline to 20.82-25.19 kwintal/ha and 18.76-23.22 kwintal/ha, under near- and far-future, respectively. Meanwhile, contrary to that of the non-adapted, the yield of adapted rice field is projected to be relatively stable at around 60.00 kwintal/ha for irrigated and 41.50 kwintal/ha for rain-fed rice field. In average, the 17 GCMs indicated rice yield reduction to occur at a level of -14.22% for irrigated and -16.27% for rain-fed rice field. This level of yield reduction is considered to be relatively low in comparison to the range of projected yield reduction at the Indonesian national level, as recorded by previous studies to range from 15% to 25% [2]; [40]; [36]. Other study also suggested that a combination of 2°C increase in temperature and 246 mm decrease in rainfall in Indonesia has resulted in a decrease of rice yield by -38% [44].

Food insecurity implication of the climate change is presented on Figure 2. The figure showed that changes in climate condition have exacerbated the food insecurity challenge among poor farm households in the study area. Regardless that the uncertainty in projection of future climate has been a limitation to impact studies, the average HRSL was projected to decrease to the extent variable across the 17 GCMs for near and far-future under RCP8.5 and RCP4.5. The average HRSL was projected to range from 59.75% to 62.09% in the near future, slightly lower than that in baseline, which range from 62.35% to 64.80%, as projected by GISSE2R1 and MIROC5, respectively. It then further decreases in the far-future, to range from 59.43% to 61.63%. A similar trend of reduction in the average HRSL is shared between RCP8.5 and RCP4.5, where the degree of change under RCP8.5 is slightly higher. This finding is consistent with similar study in Africa, which confirms a worsening food insecurity condition to occur under future climate [14]. Studies in some other countries like China, India, and USA, also confirm that climate change threaten food security beyond 2050, though the studies claimed that agriculture in those countries is still relatively resilience under current climate ([45];[49];[31]).

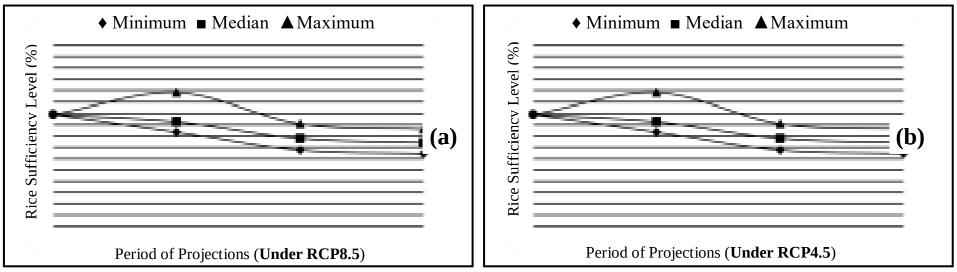

**Figure 2. Rice Sufficiency Level (RSL) of Farm Household under Regional Climate Change Projections Generated by 17 GCM Models for Near-Future and Far-Future Periods under RCP8.5(a) and RCP4.5(b) Climate Scenarios in Comparison to the Observed and Baseline data.**

The above result, however, was obtained without considering the current local farmers' adaptations. Ignoring such adaptations can lead to an overestimate of the climate change impact [9]. It is therefore, an analysis was made to assess the impact of climate change under three types of adaptations, and the results are presented on Figure 3. The figure suggested that on-farm adaptation reduced the impact of climate change, as the on-farm adapted households have higher HRSL than that of the non-adapted. Under the GCMs with climate change scenario of RCP4.5, the average HRSL of the on-farm adapted households range from 64.82% to 65.42% under the baseline. The figure is higher than that of the non-adapted, which range from of 57.30% to 62.99%, as estimated by MRI-CGCM3 and CCSM4, respectively. Furthermore, on-farm adaptation has been effective to maintain the average simulated HRSL of adapted households relatively more stable than that of the non-adapted under near-future and far-future climate. While the simulated HRSL of the non-adapted households have dropped substantially to a lower range of 54.37%-58.17% and 53.78%-57.11% in the near- and far- future, the simulated HRSL of the adapted households has been relatively stable at a level close to baseline. On-farm adaptation practices also reduced the variability in projected HRSL of the adapted households across the 17 GCMs.

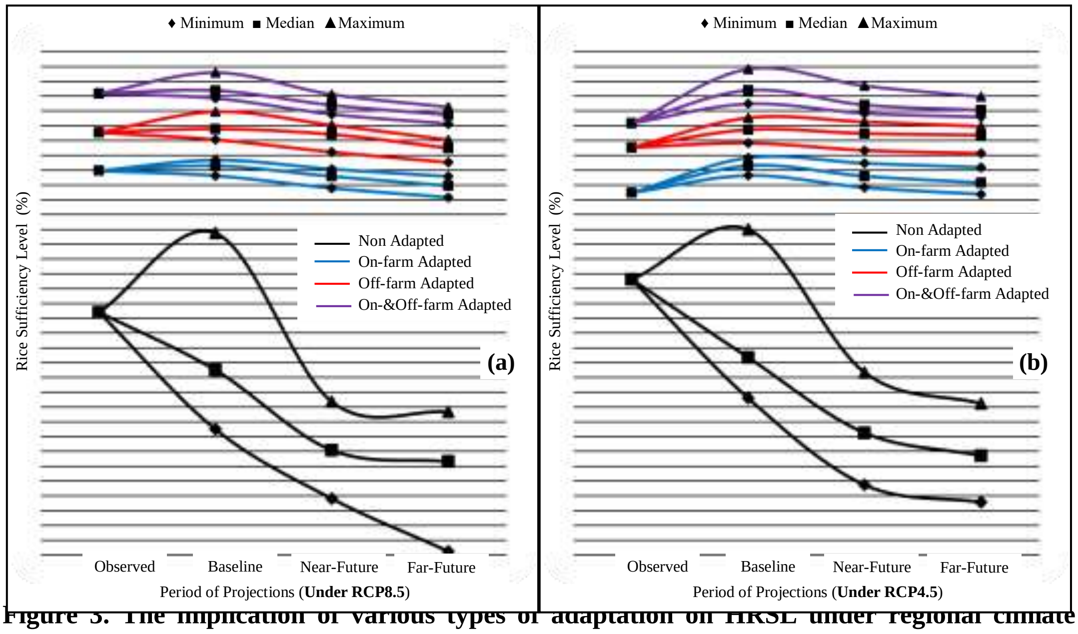

**Figure 3. The implication of various types of adaptation on HRSL under regional climate change projections generated by 17 GCM models for near-future and far-future periods under RCP8.5(a) and RCP4.5(b) climate scenarios.**

On-farm adaptation lessened the food insecurity implication of climate change through its effective role in reducing the climate change-induced reduction in rice yield. This finding is supported by previous study, which suggested that on-farm adapted households consistently produced more food than that of the non-adapted, which results from a decreased risk of crop failure ([20]; [21]. Moreover, the two main on-farm adaptations widely assumed by the local farmers (*i.e.* shifting planting time and improving irrigation), have been among the most effective adaptations reported by previous studies [23]; [8]; [46].

However, looking only at on-farm adaptation is inadequate to derive conclusion on the overall households' adaptations to counter the food insecurity implication of the changing climate. Previous study argues that diversification of adaptation strategies are crucial to ensuring households' resilience to climate change [29]. Hence, the role of the off-farm adaptation has also been taken into account in this study. Figure 3 suggested that off-farm adaptation through diversified livelihoods has been effective to shift the HRSL of adapted household upward to relatively higher level than that of the non-adapted. Under baseline condition, the HRSL of the off-farm adapted households was recorded to range from 65.92% to 66.77%, relatively higher than that of the non-adapted, as estimated under climate model of MIROC5 and GFDLCM3, respectively. Consistent with previous study [5], this finding suggests that diversification into off-farm income generating activities have formed an important supplementary source of income for households and accordingly, improved their food access. The off-farm adaptation has also been effective to maintain the HRSL of adapted households relatively more stable than that of the non-adapted, under both near- and far-future projections. In addition, this type of adaptation was also observed to reduce the variability across the GCMs in simulating the future HRSL.

The diversity of adaptation measures reported by previous studies [20]; [21]; [29], and grouped under this study into on-farm, off-farm and the combination of on- and off-farm adaptation, could be a reflection that one single adaptation strategy may not be sufficient for subsistence farm households to address the impact of changing climate adequately. The complementarities attached to the diverse set of adaptation strategies are thus a crucial concern for adaptation assessment. Within this concern, an assessment of the efficacy of the combined on- and off-farm adaptation was also made in this study. Figure 3 showed that the combined on- and off-farm adaptations have shifted the HRSL of the adapted households upward to a level higher than the non-adapted. Under baseline period, the simulated HRSL of adapted households was recorded to range from 67.24% to 68.41%, higher than that of the non-adapted. The simulated HRSL under the combined on- and off-farm adaptation was also slightly higher than that under either on-farm or off-farm adaptation. In terms of its stability to the near- and far- future period, the simulated HRSL under the combined on- and off-farm adaptation has been more stable than that under off-farm adaptation, but less than that under the on-farm. This finding reflected the heavy reliance of the sample households on their subsistence farming, where on average 86.69% their rice availability was derived from their subsistence farm. This makes the HRSL of the sample households highly sensitive to changes in farm yield. Thus, on-farm adaptation that reduces the climate change-induced yield reduction will lead to more stable HRSL. Meanwhile, off-farm adaptation through diversified livelihoods to off-farm income generating activities increased the economic access to rice that provided supplementary supply of rice to subsistence farm households. Therefore, it contributed more to the increased HRSL rather than to its stability. In line with this finding, previous studies [12]; [39]) confirmed the complementary relation between off- and on-farm adaptation by suggesting that livelihood diversification to off-farm activities improve the market access when subsistence crops are not plentiful enough to provide food security.

## CONCLUSION

Farm households in the study area have already lived with changing climate and are likely to face higher degree of climate change in the future. The simulated rainfall has been decreasing, while the minimum and maximum temperature showed an increasing trend, to the extent highly variable across the 17 GCMs. Annual rainfall was recorded to range from 1,084.42 to 1,933.47 mm under baseline. Afterward, it decreased to 963.30 - 1,327.52 mm and 884.33 - 1,313.96 mm under near- and far-future projections, respectively. The annual maximum temperature was projected to increase, from 27.10-30.82ºC under baseline to 27.62-31.53ºC and 28.37-33.09ºC under near- and far-future, respectively. Similarly, the projection of the annual minimum temperature also showed an increasing trend, where it increased from 22.95-27.71ºC under baseline to 23.86-28.22ºC and 24.64-28.81ºC under near- and far-future projection, respectively. Climate condition affects HRSL through its influence on rice yield. Under current climate, the observed average HRSL was recorded at 62.89%, while the simulated baseline was 61.35-64.80%. Afterward, the HRSL was projected to decrease to 59.75-62.09% and 59.43-61.63% under near- and far-future, respectively. This suggested that the sample households have already been rice-insufficient and the changing climate is likely to make it worse in the future.

Adaptation practices provided better HRSL to the adapted households. On-farm adaptation increased the average observed HRSL of adapted households by 5.65% and the off-farm increased it by 8.45%. The combined practices of on- and off-farm adaptations resulted in higher increase of average HRSL (9.29%) than the increase under either on- or off-farm adaptation. This finding confirmed the complementary relation between off- and on-farm adaptations by suggesting that livelihood diversification to off-farm activities improve the market access when subsistence crops are not plentiful enough to provide food security. The current adaptations have also been proved to be relatively effective to curb the increasing impact of climate change on HRSL under near- and far-future climate. While the simulated HRSL of the non-adapted households have dropped substantially under near-future and far-future climate condition, the simulated HRSL of the adapted households has been relatively stable at a level close to the baseline.

Though they have been proved to be effective to lessen the impact of climate change under current and future climate, the current adaptation practices have not been adequate yet to provide rice sufficiency for farm households in the study area. This finding suggested the necessity to enhance rice availability at household level through various types of on- and off-farm adaptations. On-farm adjustments improved the ability of farm households to be rice self-sufficient, while the off-farm adaptations improved farm households' access to external sources of food and increase their ability to purchase food.

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